Probability of Making A Successful Mine Escape While Wearing A Self-Contained Self-Rescuer

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Abstract

A computer simulation has been developed to estimate the chances of a miner making a successful escape while wearing a SCSR. The model takes into account: (1) training in the use of SCSRs, (2) apparatus integrity, and (3) the oxygen cost of a mine escape. This Bureau of Mines report examines survival odds for a prototypical escape, and illustrates how these odds change when SCSR training is improved.

Introduction

When a mine disaster occurs, the basic survival technique for a miner is to escape from the mine. After a mine fire or explosion, the atmosphere inside the mine may become oxygen deficient or filled with smoke and toxic gasses. Under these circumstances, escape is virtually impossible unless a miner is equipped with a self-rescue device that supplies oxygen while isolating his or her lungs from the ambient atmosphere.

Federal regulations require that every person who goes into an underground coal mine in the United States be supplied with a Self-Contained Self-Rescuer (SCSR) and trained in its use (U.S. CFR Title 30, 1988). A SCSR is a closed-circuit breathing apparatus designed for the purpose of mine escape. It must be capable of providing at least a 60-minute supply of oxygen, regardless of the condition of the mine atmosphere.

The chances of a miner making a successful escape while wearing a SCSR depend on three issues:

1. Training—Did the miner don the SCSR properly?
2. SCSR integrity—Did the SCSR function, or did the miner decide to abandon it?
3. Oxygen cost—Did the SCSR provide enough oxygen?

A computer simulation that takes these issues into account has been developed to estimate survival odds for a prototypical escape. This report examines how these odds change when SCSR training is improved.

Mine Escape Model

Although mine disasters seem to occur with great regularity, they are still rare events. Since SCSRs are a relatively new technology, there are very few case studies of escape attempts involving miners wearing the apparatus. As a consequence, there is not enough historical data to allow us to assess the impact of the device. Unfortunately, experiments in this area are impractical, if not impossible. It would be very costly to reconstruct a mine disaster or escape situation as a controlled experiment. Moreover, it would be unethical to expose human subjects to risk just for the sake of collecting experimental data validating SCSR technology or training. Yet, there are compelling reasons for wishing to evaluate an individual's chances of escaping an unbreathable mine atmosphere. We therefore decided to develop a model of a mine escape in order to estimate survival odds under certain conditions.

Models may actually offer some advantages over real-world scenarios. The first is parsimony. Our model provides a theoretical framework for explaining or predicting the outcome of an escape attempt in terms of training, SCSR integrity and oxygen consumption issues. The underlying logic and formulas are visible, and the issues are clearly focused and segregated. A second advantage is that, because our model is computer generated, a user can make choices or decisions on initial conditions or parameter sets. This means that the mine escape model can be used to make what-if calculations to explore alternatives, or to test the affects of marginal changes in parameters on survival odds.

In essence, for the present task, the probability of a successful mine escape is arrived at through simulation. The model can be considered a programmed structure, because it is a logical progression of if/then/else decisions. In particular, it is a worksheet template written in Lotus 1-2-3 with the @Risk add-on (Palisade Corp, 1988). The model has an empirical basis because it uses the experimental results of training studies, SCSR field audits, and oxygen cost experiments to calculate survival odds.

Prototypical Escape

Prototypical escape means a hypothetical situation in which a disaster has occurred, and, in order to survive, a miner must evacuate to safety. Certain conditions are stipulated as follows:

1. The miner is still in fresh air, but his only escape route is a straight-line path through a fatally hostile environment.
2. At the start of his escape, the miner tries to don a SCSR. If he can actually don and activate the device, and if the apparatus is functional, the worker begins moving along the escape route.
3. Once the miner starts along the escape route, he is always trying to make forward progress, never stopping to rest. He continues moving until all of the oxygen supplied by the SCSR is consumed.
4. At the end of the escape route, there is fresh air and safety.

Training

Attrition occurs at the start of a prototypical escape because some miners cannot don their SCSRs. The first component of the mine escape model, therefore, is training. Training involves two related factors:

1. **Proficiency**—At any given mine, each worker can be classified according to how well he is able to don and activate the SCSR. For the purposes of this model, donning proficiency is defined by a five-level classification scheme (Failing, Poor, Marginal, Adequate and Perfect).
2. **Outcome**—The second factor, donning outcome, focuses on the actual results when SCSR donning is attempted. A miner either completes the donning sequence perfectly, or he falls short. The chance that any particular miner can don his apparatus correctly is influenced by the general level of SCSR donning skill at his mine site.

The two training factors, then, are related by the assumption that the higher the general skill level at a mine, the greater the odds are that a representative miner will be able to don a SCSR in an emergency.

Donning proficiency is modeled as a discrete function. It is represented as a five-state look-up table presented below. Some preliminary definitions are needed:

Skill Level = i; i	=	1,2,3,4,5
Pr(Skill Level = i)	=	Probability that a miner drawn from the workforce at a given mine can don a SCSR at that skill level.
	=	Fraction of workforce at that skill level.

Donning Proficiency

Skill Level	Fraction of Workforce at that Skill Level
Failing = 1	F1
Poor = 2	F2
Marginal = 3	F3
Adequate = 4	F4
Perfect = 5	F5

Because the skill levels are exclusive and exhaustive, the following relationship always holds:

$$F1 + F2 + F3 + F4 + F5 = 1$$

This relationship also guarantees that the skill level probabilities are normalized.

The second factor that the training model accounts for is SCSR donning outcome. SCSR donning outcome depends on skill level, and it is represented as a two-state discrete function, defined below:

Values (F1, F2, F3, F4, F5) for this model have been obtained from four mines that were part of an empirical assessment of SCSR donning proficiency at sites in the eastern United States. At every mine, 30 volunteers were selected for testing in the workplace. Each worker was instructed to don the SCSR just as he would if it were necessary to escape the mine, and to do the entire procedure. While one researcher videotaped the miner's performance, another evaluated and timed the trial. The results have been closely scrutinized, and are an accurate representation of the proficiency levels found at the four mines. The aggregate data are presented in the form of pie charts in Figure 1.

In the final analysis, whether a miner fails or succeeds in the real world would be determined by the ability to use his SCSR well enough to survive an attempt to evacuate through an unbreathable atmosphere. Individual actions that characterize each category in the classification scheme, taken from selected donning evaluations, are profiled below.

Failing

- The mouthpiece flange was outside the miner's lips and he did not adjust straps.
- The miner put the SCSR on backwards. The mouthpiece and noseclips pulled out—he put the mouthpiece back in but forgot the noseclips. He did not adjust the waist or neck straps.
- The miner failed to activate the oxygen and forgot to put on the noseclips.

Skill Level = i; i	=	1,2,3,4,5	
Pr(Success,i)	=	Probability that a miner will successfully don his SCSR, given his donning proficiency.	
Pr(Failure,i)	=	1 – Pr(Success,i).	
		State	**Probability**
Outcome(i)	=	Successfully dons SCSR = True	Pr(Success,i)
		Miner fails to don SCSR = False	Pr(Failure,i)

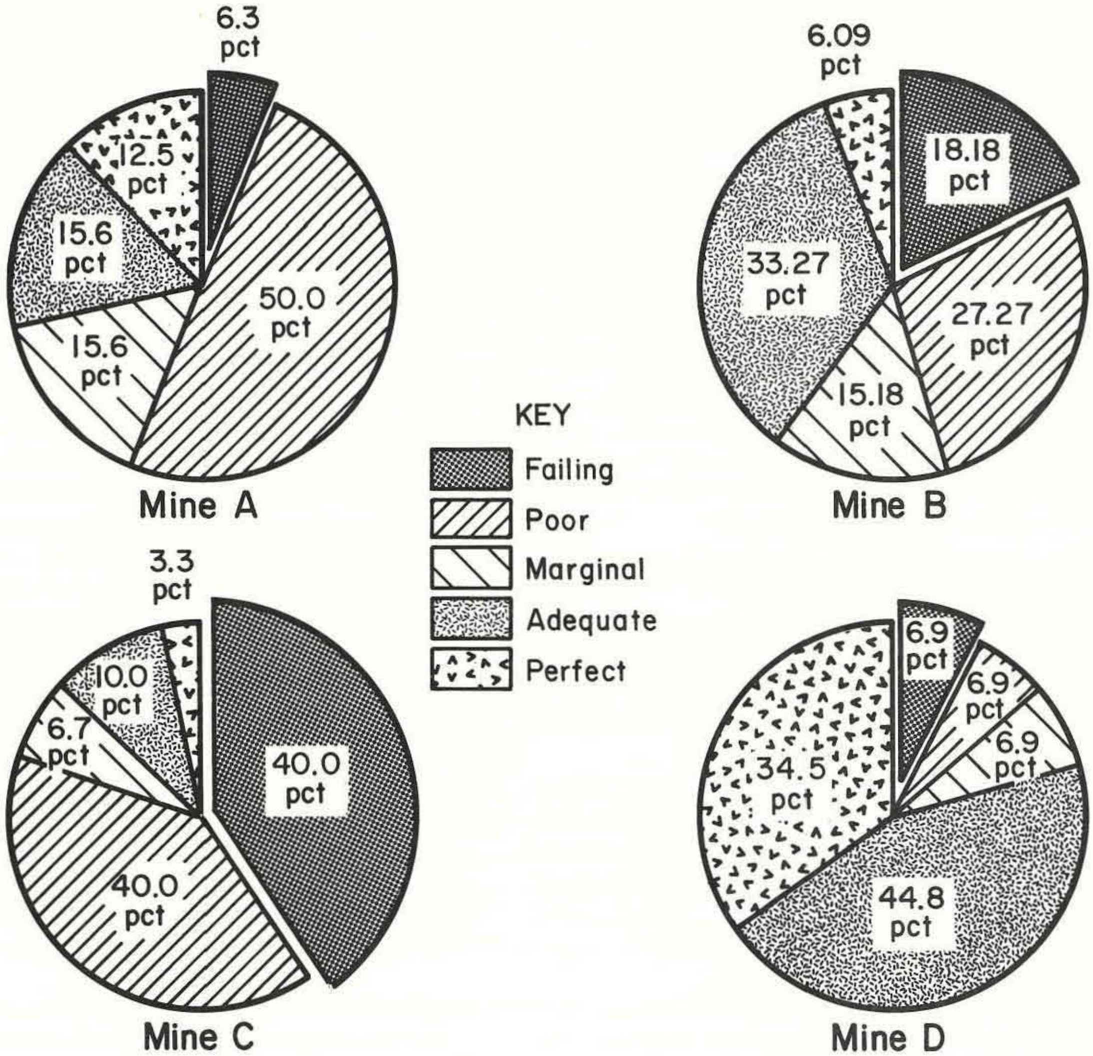

Figure 1. Donning proficiency profiles.

Poor

- The miner stood up to put the SCSR on. The mouthpiece and noseclips pulled out because the trainee failed to adjust his neckstrap. He appeared to be very confused during the entire donning sequence.
- The miner didn't loop the neckstrap. Instead, he put the waist strap around his neck. He also put the goggles on over his glasses and forgot to put his hardhat back on.
- The miner failed to adjust the neck strap; as a result, there was noticeable tension on the breathing hose.

Marginal

- The miner twisted the neckstrap around the breathing hose.
- The miner didn't put on the goggles and failed to fasten his waist strap. The noseclips slipped off, but he put them back on.
- The miner adjusted the neckstrap after looping, but he never secured the waist strap. He took the mouthpiece out to look for noseclips, and put it back in once he found them. He initially hung the goggles around his neck. He had to remove the mouthpiece and noseclips to put the

goggles on. After donning the goggles, he replaced the mouthpiece and noseclips.

Adequate

- The miner adjusted the neckstrap before activating the oxygen.

- The miner adjusted the neckstrap before donning the goggles. After he put his hat on, he fastened and snugged the waist strap.

- The miner looped the neckstrap over his hat and lamp cord.

Perfect

- The miner performed a perfect 3+3 sequence.

- The miner did a perfect sequence. The waist strap should have been slightly tighter.

As can be seen, "failing" here merely applies to an individual's omission of one or another of the steps necessary to isolate the lungs. In point of fact, miners in both the "failing" and "poor" categories would be considered less than proficient with the apparatus. Individuals in the "adequate" and "perfect" categories, on the other hand, would be considered proficient.

In order to arrive at a conservative but fair interpretation of what performance at a particular skill level might mean in the real world, researchers analyzed evaluations of 1264 donning trials. To illustrate use of this analysis, consider how failures were treated. It was found that 32.8% of all critical steps (those necessary to isolate one's lungs) omitted initially were subsequently corrected during the trials. While a miner's inability to get his lungs isolated would result in death, there are three chances in ten that he might convert his failure into a partial success. For this reason, "failing" was not assigned a zero chance of survival, but set instead at 30%. The same reasoning was used to apportion weights to the other categories. Estimates of successful donning probabilities for all skill levels are given in Tables 1 and 2.

Table 1. SCSR donning trial performance (in 1264 trials).

	Missed steps	Corrected steps	Missed steps subsequently corrected
Critical	525	172	32.8
Secondary	780	336	43.1

Table 2. SCSR donning probabilities.

Skill Level	Probability (%)
Failing	30
Poor	50
Marginal	70
Adequate	90
Perfect	100

SCSR Integrity

SCSR integrity is the second component of the mine escape model. This issue was defined by asking what the chances are that a miner will abandon his SCSR after donning it. The Bureau of Mines and Mine Safety and Health Administration (MSHA) have conducted field audits of SCSRs, and both agencies have investigated actual mine escapes involving the apparatus. The results of this research have yielded a 10% use-failure rate for the devices and suggest two reasons why a SCSR might be abandoned. First, the apparatus fails to provide life support due to a manufacturing defect, or because of damage caused by the in-mine environment. A second reason the device might be abandoned is that the miner is unfamiliar with how a SCSR works, and decides that the apparatus is not functioning properly.

SCSR integrity is modeled as a discrete distribution. It can also be represented by the two state look-up table presented here:

		State	Probability
SCSR integrity	=	Miner keeps SCSR = True Miner abandons SCSR = False	Pr(Keeps SCSR) Pr(Abandons SCSR) = 1 – Pr(Keeps SCSR)

Oxygen Consumption

The third component in the mine escape model is oxygen consumption. Attrition occurs if a miner is not supplied with enough oxygen to make a successful escape. The amount of oxygen that a miner consumes while making an escape depends on three factors:

1. The miner's body weight, which simply refers to how much the escaping miner weighs, and is modeled as a normal distribution.
2. Escape distance (that is, the length of the escape route).
3. The oxygen cost of a mine escape.

Oxygen cost, given in terms of standard temperature and pressure with dry bulb (STPD), is a parameter that depends on travel mode: walking upright, walking in a bent posture (duck walking), or crawling. The oxygen cost values for each of the three modes of travel during escape are as follows:

Walking upright = 0.3 mL O_2 (STPD)/kg-m

Bent posture = 0.5 mL O_2 (STPD)/kg-m

Crawling = 0.7 mL O_2 (STPD)/kg-m

In other words, a miner consumes twice as much oxygen while crawling during his attempt to escape as he would use if he could walk upright. The formula for oxygen consumption would be: Oxygen_Consumption = Oxygen cost * Body_weight * Escape_distance.

The linear model makes three assumptions. First, oxygen consumption at rest is insignificant when compared with consumption while moving. Second, once a miner starts along the escape route, he is always trying to make forward progress and never stops to rest. Third, in the computer simulation, the miner walks in a bent posture the entire length of the escape route.

Another feature of the linear oxygen consumption model is that by keeping oxygen cost and body weight fixed, oxygen consumption is a homogeneous function of degree 1 in escape distance. In other words, when the escape distance is doubled, oxygen consumption is doubled.

A miner who must escape a fatal hostile environment has two survival strategies available. If he cannot don his SCSR, or the apparatus fails to function, there is a "worst-case" strategy—the miner can simply hold his breath, consuming the residual oxygen in his lungs, and make a short-distance escape attempt. The best course of action, and the only one that would be tenable over a long distance, however, is to use the SCSR while escaping.

Oxygen consumption for both survival strategies can be measured in terms of ratios. For a miner who holds his breath and attempts to reach fresh air within a short-distance, the oxygen consumption ratio (or Holds_Breath_Ratio) equals Oxygen_Consumption/Residual_Oxygen available in the lungs. For a miner using his SCSR, the oxygen consumption ratio (or SCSR Ratio) is equal to the Oxygen_Consumption/Oxygen_Supplied by the SCSR.

In both of the survival scenarios mentioned above, the oxygen consumption ratios will always be positive. If a calculated ratio is less than one, then that particular escape strategy supplied the miner with enough oxygen to permit a successful escape. If the ratio calculated was greater than one, however, a successful escape from the hostile mine atmosphere would be considered impossible, since the miner would not have enough oxygen available under that escape strategy. Our choices for oxygen consumption parameters are given in Table 3.

Table 3. Oxygen consumption parameters.

	Oxygen (STPD)[a]	
Body weight	**SCSR**	**Residual**
87 kg[b]	100 L	0.5 L

[a]STPD = Standard temperature and pressure with dry bulb
[b]Standard deviation, 10 kg

Calculating Survival Odds

When all the models are put together, the computer simulation calculates survival odds for a specified escape scenario using a generate-and-test algorithm. Before the odds can be calculated, however, the user must provide some initial values for parameters in the simulation. The parameter set defines a particular prototypical escape. The user must also specify the escape distance, which is the independent variable.

Once all user input is specified and the simulation activated, it will generate randomly a combination of Training, SCSR Integrity and Oxygen Consumption. This combination describes:

1. Whether or not the miner was able to don his SCSR successfully;

2. Whether the miner possesses a functional SCSR, or an apparatus that he will abandon immediately after donning; and

3. How much oxygen the miner must consume in order to complete the escape.

The simulation then tests whether the combination results in a successful escape for the miner.

In other words, the simulation checks which of the two survival strategies, if either, lets the miner travel the escape distance. The simulation is then repeated a large number of times to accumulate statistics on the number of successful escapes, using the following logic:

Pr(Escape) = Probability of a successful mine escape.
= Number of successful escapes/Number of trials.

Mathematically, escape probability is calculated by introducing a special function called Is_A_Success that tests for a successful escape.

Is_A_Success has the following properties:

Is_A_Success = 1, if the miner made a successful escape.
= 0, if the escape attempt fails.

The Is_A_Success function takes two logical variables as arguments: Uses_SCSR and Holds_Breath.

Uses_SCSR = True, if [(Outcome=True) and (SCSR Integrity=True) and (SCSR Ratio ≤ i)].
= False, otherwise.

Holds_Breath = True, if (Holds Breath Ratio ≤ 1)
= False, otherwise.

The variables are logical analogues of the two survival strategies. In terms of the logical variables, Is_A_Success can be rewritten as:

Is_A_Success = 1, if [(Uses_SCSR) or (Holds_Breath) = True].
= 0, otherwise.

Let's look at what happens if we evaluate Is_A_Success for a large number of trials, and accumulate the results according to the following program:

Step 1: Let j be an index, representing each trial: j = 1 to N_Trials. Pick N_Trials = 1000 for a valid simulation.

Step 2: Randomly generate values for Holds_Breath(j) and Uses_SCSR(j) for the jth trial, and evaluate Is_A_Success.

Is_A_Success(j) = 1, if the *j*th trial was a success.
= 0, otherwise.

Step 3: Calculate an expected value for Is_A_Success, E(Is A Success). The expected value is the successful escape probability:

Sum(Is_A_Success) = Number of successful escapes in N trials.
E(Is_A_Success) = Sum(Is_A_Success)/N_trials.
= Number of successful escapes/N_trials.
Pr(Escape) = E(Is_A_Success).

By varying the escape distance, and repeating the probability calculation, the user can map out the functional dependence of survival odds based on escape distance and parameter choices. A complete listing of computer pseudo-code for the simulation algorithm is listed in the Appendix 1. Because the mine escape model was written in Lotus 1-2-3, Appendix 2 is an example of a worksheet template, and Appendix 3 is a cell-by-cell listing of the worksheet.

Results

The computer simulation was applied to the four mines that were part of the SCSR donning proficiency field study. In each case survival probability was plotted as a function of escape distance, and the resulting family of curves is shown in Figure 2. To make a fair comparison, it was assumed that all of the miners faced the same prototypical escape, but each mine had the distribution of SCSR donning skills shown by the pie charts in Figure 1. In other words, the family of survival probability curves was generated by changing SCSR donning outcomes according to empirical data derived from field studies.

Overall, workers at Mine D have the best chances of making a successful mine escape, while those at Mine C have the lowest survival odds. The difference amounts to nearly 30%, and is due to relative SCSR donning proficiency. The lesson seems clear: survival odds change for the better when SCSR training improves. The dispersion of ability levels may be quite different between two sites without affecting 20 overall outcomes. For instance, the survival probability curves for mines A and B almost overlap, although the pie charts are not divided the same way. This is because the expected number of workers at each mine who would actually succeed in using SCSRs proficiently is nearly equal. So, at least for a prototypical escape, the actual details of donning skill distribution are not so important. What does matter is that the average level of donning proficiency is as high as it can be.

The survival probability curve can be divided into three regions along the escape distance axis, according to which survival strategy, if any, dominates. This is shown in Figure 3. Region 1 covers short distances, from 0 to approximately 20 m. Over this range, the miner can simply hold his breath, consuming the residual oxygen in his lungs, and make a quick escape. For short distances, the "worst-case" strategy dominates, because a miner avoids the risk of attrition due to improper donning or SCSR integrity failure. If we look at escape distances in Region 2, from about 20

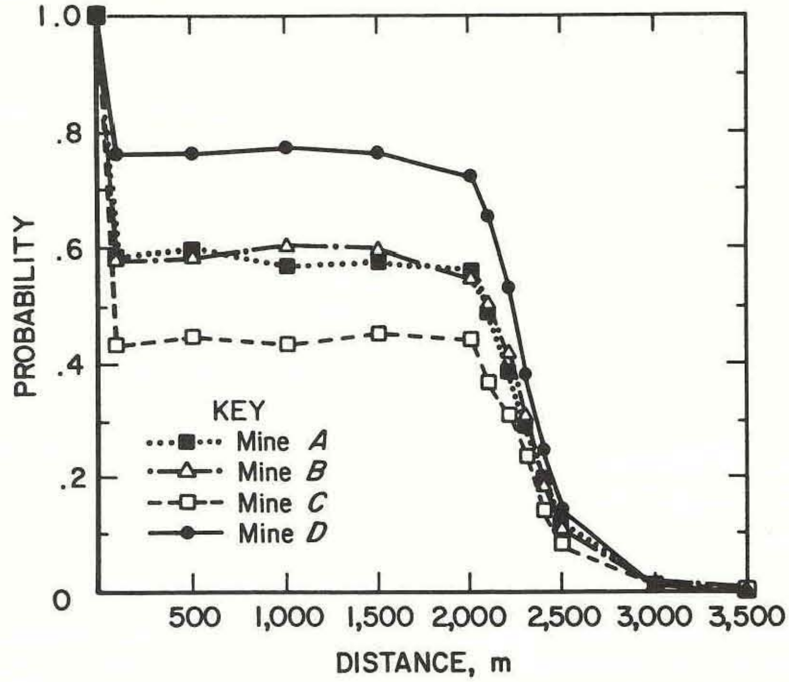

Figure 2. Probability of successfully escaping an unbreathable atmosphere while wearing an SCBA.

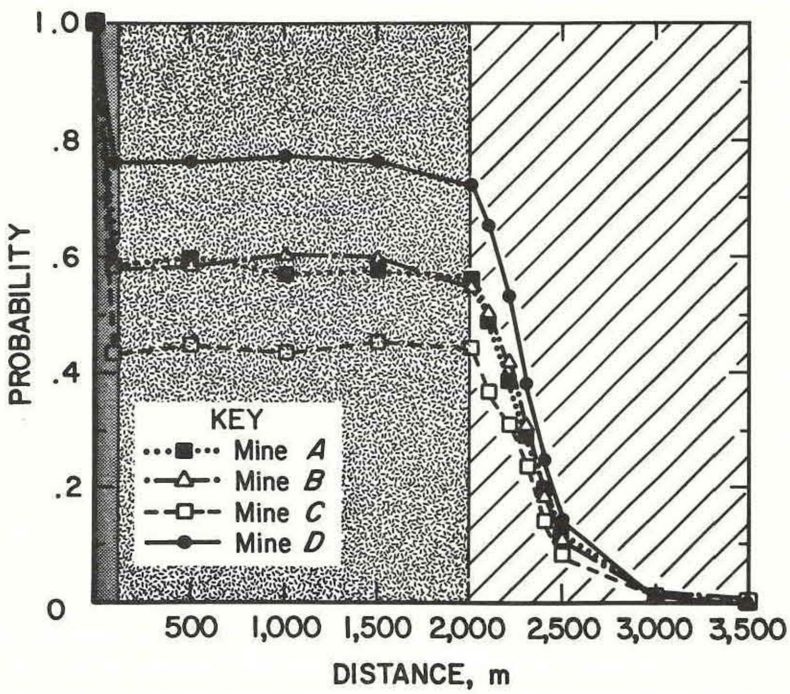

Figure 3. Survival strategy regions. (Patterns from left to right indicate regions 1, 2, and 3, as described in the text.)

to nearly 2000 m, using the SCSR while escaping is the best course of action. Finally, no survival strategy dominates when escape distance greatly exceeds 2000 m, which is the case in Region 3, because a miner would not have enough oxygen available under either strategy.

Discussion

The chances of a miner making a successful escape while wearing a SCSR depend on three issues:

1. **Training**—Did the miner don the SCSR properly?

2. **SCSR Integrity**—Did the SCSR function, or did the miner decide to abandon it?

3. **Oxygen Cost**—Did the SCSR provide enough oxygen?

A computer simulation that takes these issues into account was developed to estimate survival odds for a prototypical escape, and used to show these odds change when SCSR training improves. The computer simulation was applied to four mines that were part of a SCSR donning proficiency field study. The results show that relative survival odds for different mines can vary by as much as 30%, and that this difference is due to SCSR donning proficiency. The results also confirm the common sense view that using a SCSR is the best survival strategy, and the only one that is tenable over long distances. The real limitation on escape distance is that SCSRs make available only a finite quantity of useable oxygen. This must be taken into account in planning for mine emergencies.

Because theoretical issues are clearly segregated and the mathematical structure of the model is open to modification, it seems likely that the computer simulation can be extended naturally to cover other factors affecting survival odds:

1. The location of SCSR caches along escape routes;

2. Decision making under uncertainty, with regards to choice of escape routes; and

3. Group dynamics in mine emergencies.

These will be topics for future research.

References

Palisade Corp., At Risk: Risk Analysis and Modeling for the P.C. Computer software, (Newfield, NY) 1988.

U.S. Code of Federal Regulations, Title 30—Mineral Resources; Chapter I—Mine Safety and Health Administration, Department of Labor; Subchapter O—Coal Mine Safety and Health; Part 75—Mandatory Safety Standard—Underground Coal Mines, sec. 75.1714; July 1, 1988.

Appendix 1

Simulation Algorithm—Computer pseudo-code for the mine escape model is listed below. Variable names in the program are concatenated for the sake of clarity. Commands or reserved words in the pseudo-language are shown in bold type.

```
REMARK  Stipulate parameter set

REMARK  Donning Skill Level
      ENTER F1,F2,F3,F4,F5

REMARK  Donning Probability
      ENTER P1,P2,P3,P4,P5

REMARK  Create Look Up-Table
      LET LOOK_UP_TABLE(1) :=P1
      LET LOOK_UP_TABLE(2) :=P2
      LET LOOK_UP_TABLE(3) :=P3
      LET LOOK_UP_TABLE(4) :=P4
      LET LOOK_UP_TABLE(5) :=P5

REMARK SCSR Integrity
      ENTER Pr(Abandons SCSR)
      Pr(Keeps SCSR) := 1 - Pr(Abandons SCSR)

REMARK Oxygen Consumption
      ENTER Mean, Std Dev
      ENTER SCSR Oxygen
      ENTER Residual Oxygen

REMARK Choose a value for escape distance
      ENTER Escape Distance

REMARK Choose a value for the number of trials
      ENTER N_trials

REMARK Initialize variables used as counters or accumulators
      LET j := 0
      LET Sum (Is_A_Success) := 0

REMARK Begin while loop

WHILE j <= N_trials

REMARK Training
REMARK Randomly assign a skill level to an escaping miner
GENERATE Donning-Proficiency := DISCRETE(1,FI;2,F2; 3,F3;4,F4;5,F5)

REMARK Randomly assign a training outcome (Failure = FALSE, Success = TRUE)
REMARK Use Look_Up_Table to get successful donning probabilities

      Pr(Success) := LOOK_UP_TABLE(Donning-Proficiency)
      Pr(Failure) := 1 - Pr(Success)

      GENERATE Outcome :=DISCRETE(FALSE, Pr(Failure); TRUE, Pr(Success))

REMARK: Generate SCSR Integrity

      GENERATE SCSR Integrity := DISCRETE(FALSE, Pr(Abandons SCSR); TRUE,
Pr(Keeps SCSR))

REMARK: Calculate Oxygen Consumption

      GENERATE Body_Weight := NORMAL(Mean, Std_Dev)

      Oxygen_Consumption := Oxygen_Cost * Body_Weight * Escape_Distance

      SCSR_Ratio := Oxygen_Consumption/SCSR_Oxygen

      Holds_Breath_Ratio := Oxygen_Consumption/Residual_Oxygen
```

```
REMARK Calculate Uses_SCSR and Holds_Breath

     Uses_SCSR    :=     IF [(Outcome = TRUE) AND (SCSR
                         Integrity = TRUE) AND
                         (SCSR Ratio <=1)] THEN TRUE,
                         ELSE FALSE

     Holds_Breath:=      IF (Holds_Breath_Ratio <=1) THEN TRUE ELSE FALSE

REMARK      Calculate Is_A_Success

     Is_A_Success := IF (Uses_SCSR OR Holds_Breath = TRUE) THEN 1, ELSE 0

REMARK Accumulate Statistics

     Sum(Is_A_Success) := Sum(Is_A_Success) + Is_A_Success

END WHILE

REMARK      Calculate Survival Odds

     Pr(Escape) := Sum(Is_A_Success)/N_Trials
```

Appendix 2

Worksheet Representation—An example of a worksheet template for the mine escape model, written in Lotus 1-2-3 with the @Risk add-on, is listed below.

```
Probability of Mine Escape

Independent Variable
--------------------
Distance     1000 m

Survival Strategies
-------------------
02 Available SCSR 100 L
Residual 02 lungs 0.5 L

Physiological Parameters
------------------------
02 Cost      0.5 mL/Kg-m

Body Weight Avg    87 Kg
      Std Dev      8 Kg

Site Specific Training Results
------------------------------
      Rating        Percentage

Fail              6.9%
Poor              6.9%
Marginal          6.9%
Adequate         44.8%
Perfect          34.5%

Total 100%
```

```
Look-up Table for Training Outcome

Rating      Grade Outcome
Fail        0     0

Poor        1     0
Marginal    2     1
Adequate    3     1
Perfect     4     1

Outcome (0 = fail, 1 = success)
Integrity (0 = fail, 1 = success)
     Body Weight          02 Used
-------------------------------------
     87                   43.50
-------------------------------------
SCSR Ratio                Holds Breath Ratio
-------------------------------------
     0.44                      87.00
Training          Outcome            Integrity
-------------------------------------
     3                    1            1
Is-A-Success
-------------------------------------
     1
```

Appendix 3

Cell-by-cell Worksheet Listing—A cell-by-cell listing, showing how to reconstruct the worksheet template is presented below.

```
AI:   (FO)  'Probability of Mine Escape
A3:   (FO)  'Independent Variable
A4:   (FO)  \-
B4:   (FO)  \-
A5:   (FO)  'Distance
B5:   (FO)  1000
C5:   (FO)  'm
A7:   (FO)  'Survival Strategies
A8:   (FO)  \-
B8:   (FO)  \-
A9: (FO) '02 Available SCSR
C9: (FO) 100
D9: 'L
AIO:  (FO) 'Residual 02 lungs @
CIO:  (FI) 0.5
DIO:  'L
A12:  'Physiological Parameters
A13:  \-
B13:  \-
C13:  \-
A14:  '02 Cost
B14:  (FI) 0.5
C14:  'mL/Kg-m
A16:  'Body Weight
C16:  'Avg
D16:  (FO) 87
E16:  'Kg
C17:  'Std Dev
D17:  (FO) 8
E17:  'Kg
A19:  'Site Specific Training Results
A20:  \-
B20:  \-
C20:  \-
D20:  \-
A21-  "Rating
C21:  'Percentage
A22:  'Fail
C22:  (PI) 0.069
A23:  'Poor
C23:  (PI) 0.069
A24:  'Marginal
C24:  (PI) 0.069
A25: 'Adequate
C25:  (PI) 0.448
A26:  'Perfect
C26:  (PI) 0.345
C27:  \=
A28:  'Total
C28:  (PO) @SUM(C22..C26)
A31:  'Look-up Table for Training Outcome
A32:  \-
B32:  \-
C32:  \-
D32:  \-
A33:  'Rating
C33:  "Grade
D33:  "Outcome
A34:  'Fail
C34:  (FO) 0
D34:  (FO) @DISCRETE(0,0.7,1,0.3,2)
A35:  'Poor
C35:  (FO) 1
D35:  (FO) @DISCRETE(0,0.5,1,0.5,2)
A36:  'Marginal
C36:  (FO) 2 @
D36:  (FO) @DISCRETE(0,0.3,1,0.7,2)
A37:  'Adequate
C37:  (FO) 3
D37:  (FO) @DISCRETE(0,0.1,1,0.9,2)
A38:  'Perfect
C38:  (FO) 4
D38:  (FO) 1
A40:  'Outcome (0 = fail, 1 = success)
A41:  'Integrity (0 = fail, 1 = success)
A44:  'Body Weight
C44:  '02 Used
E44:  'SCSR Ratio
G44:  'Holds Breath Ratio
A45:  \-
B45:  \-
C45:  \-
D45:  \-
E45:  \-
F45:  \-
G45:  \-
H45:  \-
A46:  (FO)  @NORMAL(D16,D17)
C46:  (F2)  +B14*A46*B5/1000
E46:  (F2)  +C46/C9
G46:  (F2)  +C46/C10
A48:  'Training
C48:  'Outcome
E48:  'Integrity
A49:  \-
B49:  \-
C49:  \-
D49:  \-
E49:  \-
A50:  0) laDISCRETE(0, C22 , 1 , C23 , 2 ,C24, 3 , C25, 4, C26, 5)
C50:  (FO) @VLOOKUP(A50,C34..D38,1)
E50:  (FO)  @DISCRETE(0,0.1,1,0.9,2)
A52:  (FO)  'Is-A-Success
A53:  (FO)  \-
B53:  (FO)  \-
A54:  (FO)

@I F((G46<=1)#0 R# ((E46<=1) #AND#(C5 0=1) #AND#(E50=1)), 1, 0)
```