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Probability of Making a Successful Mine Escape While Wearing a Self-Contained Self-Rescuer—A Computer Simulation

By John G. Kovac, Charles Vaught, and Michael J. Brnich, Jr.

1910 ★ 80 YEARS ★ 1990

BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

kg	kilogram	m	meter
kg · m	kilogram meter	min	minute
L	liter	mL	milliliter

PROBABILITY OF MAKING A SUCCESSFUL MINE ESCAPE WHILE WEARING A SELF-CONTAINED SELF-RESCUER–A COMPUTER SIMULATION

By John G. Kovac,[1] Charles Vaught, [2] and Michael J. Brnich, Jr.[3]

ABSTRACT

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

[1]Supervisory physical scientist.
[2]Research sociologist.
[3]Mining engineer.
Pittsburgh Research Center, U.S. Bureau of Mines, Pittsburgh, PA.

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 gases. 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 an SCSR and trained in its use.[4] An SCSR is a closed-circuit breathing apparatus designed for the purpose of mine escape. The SCSR must be capable of providing at least a 60-min supply of oxygen, regardless of the condition of the mine atmosphere.

The chances of a miner making a successful escape while wearing an 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 consumption.*–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. This work is in support of the U.S. Bureau of Mines mission to increase the chances of all miners surviving a mine disaster.

MINE ESCAPE MODEL

Although mine disasters seem to occur with great regularity, they are still rare events. Since SCSR's 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 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 evaluating an individual's chances of escaping an unbreathable mine atmosphere. The researchers 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 advantage is parsimony. The Bureau's 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 the 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 effects 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 using the Lotus 1-2-3[5] computer software with the @Risk add-on.[6] 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 that in a hypothetical situation in which a disaster has occurred, 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 the only escape route is a straight-line path through a fatally hostile environment.
2. At the start of the escape, the miner tries to don an SCSR. If the miner 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 or she is always trying to make forward progress, never stopping to rest. The miner 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.

[4]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 Standards–Underground Coal Mines, sec. 75.1714; July 1, 1988.

[5]Reference to specific products does not imply endorsement by the U.S. Bureau of Mines.

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

TRAINING

Attrition occurs at the start of a prototypical escape because some miners cannot don their SCSR's. 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 or she 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 or she falls short. The chance that any particular miner can don the apparatus correctly is influenced by the general level of SCSR donning skill at the worker's minesite.

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 an 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 work force at a given mine can don an SCSR at that skill level.
= Fraction of work force at that skill level.

Skill level	*Fraction of work force at that skill level*
Donning proficiency:	
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.

SCSR donning outcome depends on skill level, and it is represented as a two-state discrete function, defined below:

Skill Level = i; i = 1,2,3,4,5.

Pr(Success,i) = Probability that a miner will successfully don the SCSR, given his or her 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)

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 or she would if it were necessary to escape the mine and to do the entire procedure. While one researcher videotaped the miner's performance, another researcher 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 figure 1.

In the final analysis, whether a miner fails or succeeds in the real world would be determined by the miner's ability to use the 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 the straps were not adjusted.

- The miner put the SCSR on backwards. The mouthpiece and nose clips were pulled out. The mouthpiece was put back in, but the miner forgot the nose clips. The waist or neck straps were not adjusted.

- The miner failed to activate the oxygen and forgot to put on the nose clips.

Poor:

- The miner stood up to put the SCSR on. The mouthpiece and nose clips were pulled out because the trainee failed to adjust the neck strap. The miner appeared to be very confused during the entire donning sequence.

- The miner didn't loop the neck strap. Instead, the waist strap was put around the neck. The miner also put the goggles on over the glasses and forgot to put the 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 neck strap around the breathing hose.

- The miner didn't put on the goggles and failed to fasten the waist strap. The nose clips slipped off, but the miner put them back on.

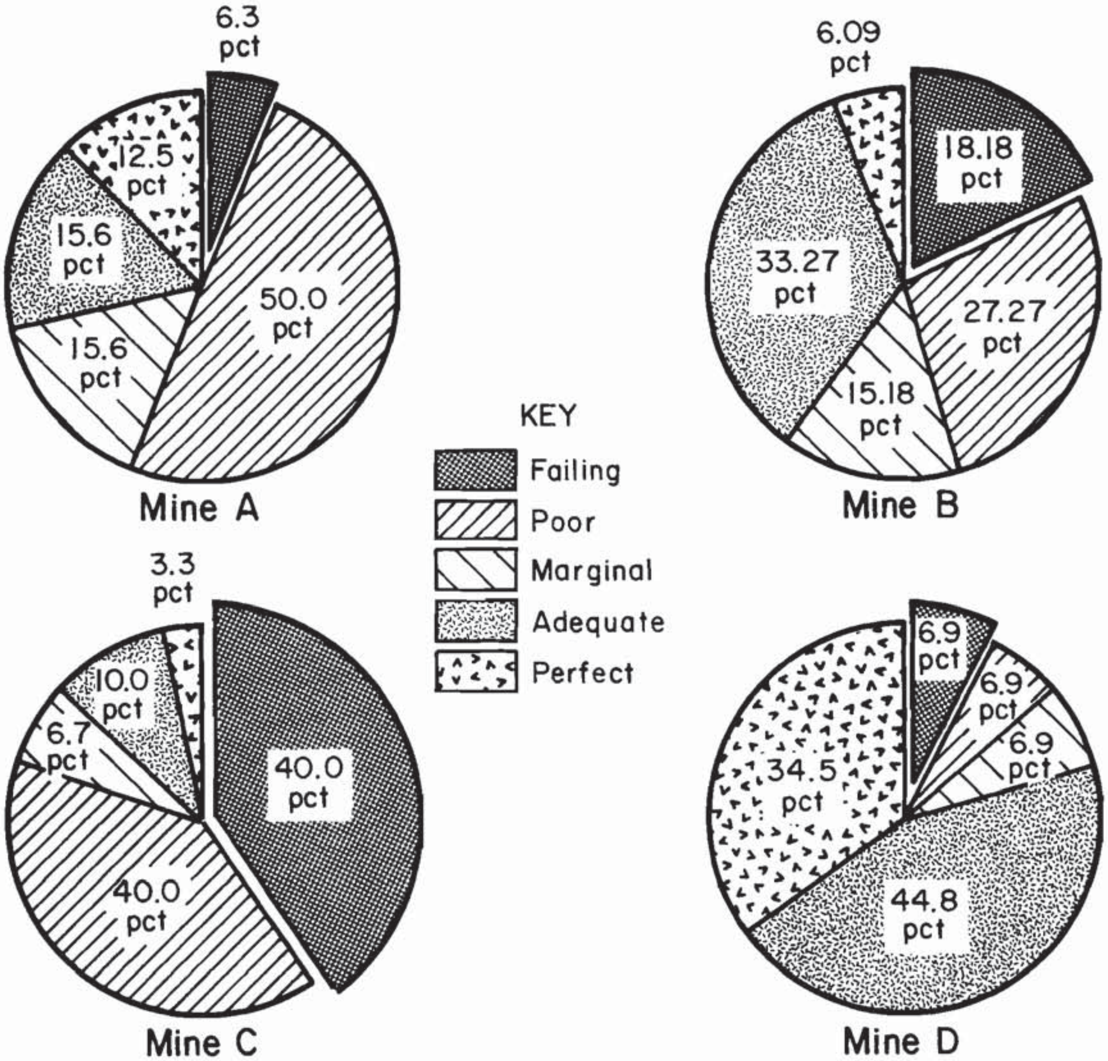

Figure 1.–Donning proficiency profiles.

• The miner adjusted the neck strap after looping, but never secured the waist strap. The mouthpiece was taken out to look for nose clips and put back in once the nose clips were found. Initially, the goggles were hung around the neck. The mouthpiece and nose clips had to be removed to put the goggles on. After donning the goggles, the mouthpiece and nose clips were replaced.

Adequate:

• The miner adjusted the neck strap before activating the oxygen.

• The miner adjusted the neck strap before donning the goggles. After the hat was put on, the waist strap was fastened and snugged.

• The miner looped the neck strap over the hat and lamp cord.

Perfect:

• The miner performed a perfect 3+3 sequence.[7]

• The miner did a perfect 3+3 sequence, except that 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.

[7]Vaught, C., M. J. Brnich, and H. J. Kellner. Instructional Mode and Its Effect on Initial Self-Contained Self-Rescuer Donning Attempts During Training. BuMines RI 9208, 1988, 11 pp.

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 1,264 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 the lungs isolated would result in death, there are 3 chances in 10 that the miner might convert the 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[1]

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

[1]1,264 trials.

Table 2.-SCSR donning probabilities

Skill level	*Probability, %*
Failing	30
Poor	50
Marginal	70
Adequate	90
Perfect	100

SELF-CONTAINED SELF-RESCUER 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 the SCSR after donning it. The Bureau and the U.S. Mine Safety and Health Administration have conducted field audits of SCSR's, and both agencies have investigated actual mine escapes involving the apparatus.[8] The results of this research have yielded a 10% use-failure rate for the devices and suggest two reasons why an SCSR might be abandoned. First, the apparatus fails to provide life support because of a manufacturing defect or because of damage caused by the in-mine environment. Second, the device might be abandoned because the miner is unfamiliar with how an 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	Pr (Keeps SCSR)
		Miner abandons SCSR = false	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) body weight, which simply refers to how much the escaping miner weighs, modeled as a normal distribution, (2) escape distance, that is, the length of the escape route, and (3) 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:

	O_2 *(STPD), mL/kg·m*
Walking upright	0.3
Bent posture	.5
Crawling	.7

In other words, a miner consumes twice as much oxygen while crawling during the attempt to escape as would be consumed if he or she could walk upright. The formula for oxygen consumption would be *Oxygen_Consumption* = *Oxygen_cost* * *Body_weight* * *Escape_distance*.[9]

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 or she 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 the miner cannot don the SCSR, or the apparatus fails to function, the miner can simply hold his or her breath, consuming the residual oxygen in his or her lungs, and make a short-distance escape attempt. This is a worst-case strategy. 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 or her breath and attempts to reach fresh air within a

[8]Kyriazi, N., J. G. Kovac, J. Shubilla, W. Duerr, and J. Kravitz. Self-Contained Self-Rescuer Field Evaluation: First-Year Results of 5-Year Study. BuMines RI 9051, 1986, 12 pp.

[9]Italic print indicates mathematical variables used in appendix A.

short distance, the oxygen consumption ratio (or *Holds_Breath_Ratio*) = *Oxygen_Consumption/Residual_Oxygen* available in the lungs. For a miner using the SCSR, the oxygen consumption ratio (or *SCSR-Ratio*) = *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 1, then that particular escape strategy supplied the miner with enough oxygen to permit a successful escape. If the ratio calculated is greater than 1, 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. The choices for oxygen consumption parameters are given in table 3.

Table 3.–Oxygen consumption parameters

	Mean
Body weight ...... kg ..	[1]87
Oxygen, L (STPD):	
SCSR	100
Residual	0.5

[1]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 is activated, the computer simulation will randomly generate a combination of training, SCSR integrity, and oxygen consumption. This combination describes (1) whether or not the miner was able to don the SCSR successfully, (2) whether the miner possesses a functional SCSR, or an apparatus that he or she 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 divided by 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: *Uses_SCSR* and *Holds_Breath* as arguments.

Uses_SCSR = True, if [(outcome = true) and (SCSR_integrity = true) and (*SCSR_Ratio* ≦1)].
= 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 *Is_A_Success* is evaluated for a large number of trials and the results are accumulated according to the following program:

Step 1: Let j be an index, representing each trial: j = 1 to *N_Trials*. *Pick N_Trials* = 1,000 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 jth 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)* divided by *N_Trials*.
= Number of successful escapes divided by *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 pseudocode for the simulation algorithm is in appendix A. Because the mine escape model was written in Lotus 1-2-3, appendix B is an example of a worksheet template and appendix C 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. 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 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 overall outcomes. For instance, the survival probability curves for mines A and B almost overlap, although the pie charts in figure 1 are not divided the same way. This is because the expected number of workers at each mine who would actually succeed in using SCSR's 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 (shown in figure 3). Region 1 covers short distances, from 0 to approximately 20 m. Over this range, the miner can simply hold his or her breath, consuming the residual oxygen in his or her 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 to nearly 2,000 m, using the SCSR while escaping is the best course of action. Finally, no survival strategy dominates when escape distance greatly exceeds 2,000 m, which is the case in region 3, because a miner would not have enough oxygen available under either strategy.

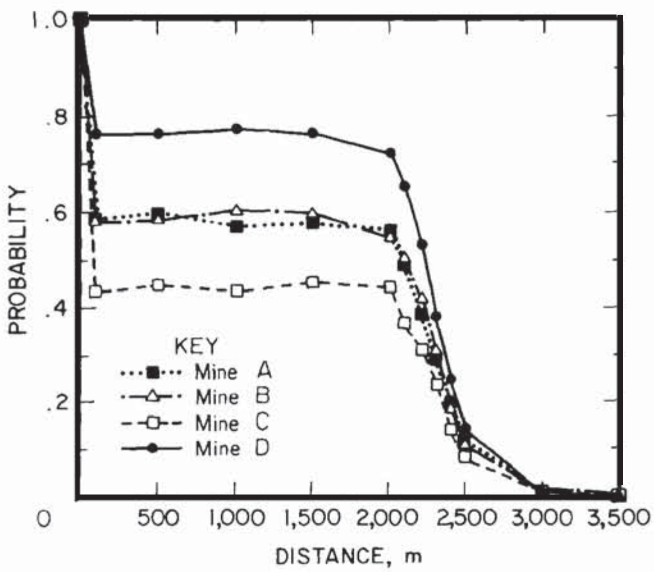

Figure 2.-Probability of successfully escaping unbreathable atmosphere using SCSR.

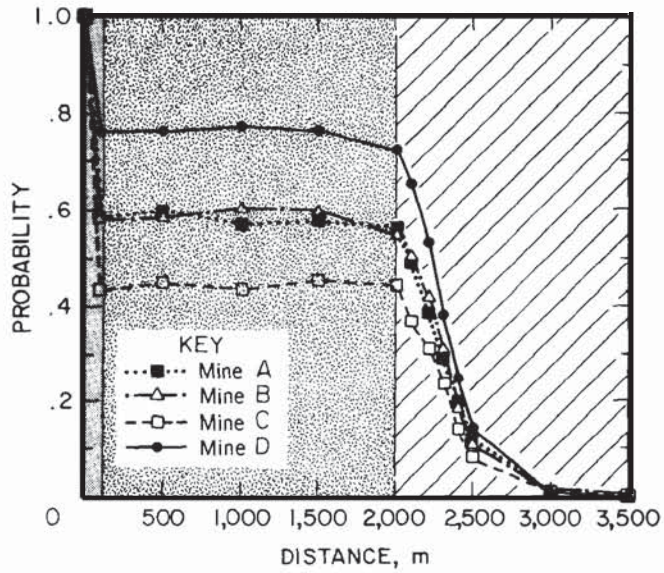

Figure 3.-Survival strategy regions. (Patterns from left to right indicate regions 1, 2, and 3 as described in text.)

DISCUSSION

The chances of a miner making a successful escape while wearing an 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 consumption*.–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 was used to show that these odds change when SCSR training improves. The computer simulation was applied to four mines that were part of an 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 an SCSR is the best survival strategy and the only one that is tenable over long distances. The real limitation on escape distance is that SCSR's make available only a finite quantity of usable 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 naturally extended to cover other factors affecting survival odds: (1) the location of SCSR caches along escape routes, (2) decisionmaking under uncertainty, with regard to choice of escape routes, and (3) group dynamics in mine emergencies. These will be topics for future research.

APPENDIX A.–SIMULATION ALGORITHM

Computer pseudocode 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 pseudolanguage 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,F1;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 B.–WORKSHEET REPRESENTATION

An example of a worksheet template for the mine escape model, using the Lotus 1-2-3 computer software with the @Risk add-on, is listed below.

Probability of Mine Escape
Independent Variable

Distance	1000 m

Survival Strategies

O2 Available SCSR	100 L
Residual O2 lungs	0.5 L

Physiological Parameters

O2 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	O2 Used
87	43.50

SCSR Ratio	Holds Breath Ratio
0.44	87.00

Training	Outcome	Integrity
3	1	1

Is-A-Success
1

APPENDIX C.–CELL-BY-CELL WORKSHEET LISTING

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

A1: (F0) 'Probability of Mine Escape
A3: (F0) 'Independent Variable
A4: (F0) \-
B4: (F0) \-
A5: (F0) 'Distance
B5: (F0) 1000
C5: (F0) 'm
A7: (F0) 'Survival Strategies
A8: (F0) \-
B8: (F0) \-
A9: (F0) 'O2 Available SCSR
C9: (F0) 100
D9: 'L
A10: (F0) 'Residual O2 lungs
C10: (F1) 0.5
D10: 'L
A12: 'Physiological Parameters
A13: \-
B13: \-
C13: \-
A14: 'O2 Cost
B14: (F1) 0.5
C14: 'mL/Kg-m
A16: 'Body Weight
C16: 'Avg
D16: (F0) 87
E16: 'Kg
C17: 'Std Dev
D17: (F0) 8
E17: 'Kg
A19: 'Site Specific Training Results
A20: \-
B20: \-
C20: \-
D20: \-
A21: ^Rating
C21: 'Percentage
A22: 'Fail
C22: (P1) 0.069
A23: 'Poor
C23: (P1) 0.069
A24: 'Marginal
C24: (P1) 0.069
A25: 'Adequate
C25: (P1) 0.448
A26: 'Perfect
C26: (P1) 0.345
C27: \=
A28: 'Total
C28: (P0) @SUM(C22..C26)
A31: 'Look-up Table for Training Outcome
A32: \-
B32: \-
C32: \-
D32: \-
A33: 'Rating
C33: ^Grade
D33: ^Outcome
A34: 'Fail
C34: (F0) 0
D34: (F0) @DISCRETE(0,0.7,1,0.3,2)
A35: 'Poor
C35: (F0) 1
D35: (F0) @DISCRETE(0,0.5,1,0.5,2)
A36: 'Marginal
C36: (F0) 2
D36: (F0) @DISCRETE(0,0.3,1,0.7,2)
A37: 'Adequate
C37: (F0) 3
D37: (F0) @DISCRETE(0,0.1,1,0.9,2)
A38: 'Perfect
C38: (F0) 4
D38: (F0) 1
A40: 'Outcome (0 = fail, 1 = success)
A41: 'Integrity (0 = fail, 1 = success)
A44: 'Body Weight
C44: 'O2 Used
E44: 'SCSR Ratio
G44: 'Holds Breath Ratio
A45: \-
B45: \-
C45: \-
D45: \-
E45: \-
F45: \-
G45: \-
H45: \-
A46: (F0) @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: (F0) @DISCRETE(0,C22,1,C23,2,C24,3,C25,4,C26,5)
C50: (F0) @VLOOKUP(A50,C34..D38,1)
E50: (F0) @DISCRETE(0,0.1,1,0.9,2)
A52: (F0) 'Is-A-Success
A53: (F0) \-
B53: (F0) \-
A54: (F0) @IF((G46< =1)#OR#((E46< =1)#AND#(C50=1) #AND#(E50=1)),1,0)

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