Information Circular 9178

# A Catastrophe-Theory Model for Simulating Behavioral Accidents

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## CONTENTS



## ILLUSTRATIONS



## TABLES

# A CATASTROPHE-THEORY MODEL FOR SIMULATING BEHAVIORAL ACCIDENTS

**By William E. Souder** [1]

## ABSTRACT

Behavioral accidents are a particular type of accident. They are caused by inappropriate individual behaviors and faulty reactions. Catastrophe theory is a means for mathematically modeling the dynamic processes that underlie behavioral accidents. Based on a comprehensive data base of mining accidents, a computerized catastrophe model has been developed by the Bureau of Mines. This model systematically links individual psychological, group behavioral, and mine environmental variables with other accident causing factors. It answers several longstanding questions about why some normally safe behaving persons may spontaneously engage in unsafe acts that have high risks of serious injury. Field tests with the model indicate that it has three important uses: It can be used as an effective training aid for increasing employee safety consciousness; it can be used as a management laboratory for testing decision alternatives and policies; and it can be used to help design the most effective work teams.

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## INTRODUCTION

The following are four examples of normally safe-behaving persons who suddenly stepped out of character and knowingly committed unsafe acts. Their acts had disastrous consequences for them.

1. Three experienced divers and life-saving instructors ignored normal safety procedures to go on a night dive, incompletely equipped, in an unexplored underwater cave. All three drowned.
2. An experienced 45-yr-old supervisor assisting a work crew suddenly turned and walked into the path of the crew's bulldozer and was crushed before anyone could stop him.
3. A 40-yr-old senior electrician who was completing his work shift suddenly swung an iron wrecking bar over his shoulder and abruptly turned to return it to the toolcrib. The end of the bar struck the 400,000-V overhead cable he had just installed, killing him instantly.
4. An experienced mine employee knowingly walked under a bad roof, pointing out various roof flaws to his companion. He was crushed by a sudden fall of that roof.

What caused these reckless behaviors? These were not rational acts: there were few rewards and enormous personal risks in these acts. These were not inexperienced and untrained personnel. They were mature, intelligent, and responsible individuals. They behaved safely all their lives, espoused safe behaviors, and served as role models for their peers. The puzzling, unanswered question remains: why did they do these things?

These are examples of a particular type of accident: the behavioral accident. In a behavioral accident, the primary cause is an inappropriate reaction or maladjustive behavior of the individual to external stimuli. Behavioral accidents involve complex interactions among individual perceptions, attitudes, personalities, values, tolerances, prior experiences, and work environments. As the four cases suggest, individual and group phenomena may contribute to behavioral accidents. Elements of carelessness, inattention, thoughtlessness, poor habits, machoism, bandwagon effects, and thrill seeking are suggested within these cases. Because of their many causal factors, the diagnosis and prevention of behavioral accidents is often elusive and difficult.

This Bureau of Mines report describes research to define, empirically measure, and model behavioral accidents. Perhaps a greater degree of understanding of the phenomenon can lead to its prevention.

## BACKGROUND

Human error often results from a mismatch between individual capacities and workloads. Overloading employees beyond their capacities can set up stresses that cause them to make errors. Conversely, underloading employees may not arouse them sufficiently, causing them to make errors as a result of boredom and inattention.

However, real-life situations are much more complex than these simple statements might imply. Everyone's capacity for work differs. Moreover, people's capacities may change as a result of their most recent experiences, daily variations, and other factors. One of these factors is the individual's perception of an overload. For example, it may not matter what the ergonomic standards say: if a person perceives he or she is overloaded then these perceptions will guide his or her behavior. Since individual perceptions can be highly variable, the capacity-workload equilibrium is likely to be correspondingly variable. To further complicate matters, some persons can adjust to work overloads while others cannot. For example, some experienced automobile drivers automatically adjust to fatigue and adverse road conditions by increasing their intensity of concentration and alertness. But not everyone can so easily adjust their behaviors in this fashion. Thus, the capacity-workload equilibrium is a complex, dynamic, individual phenomenon (*14, 18*).[2]

Figure 1 depicts the system of factors that have been found to relate to human errors (*14, 18*). If the capacity-workload equilibrium is disturbed by some combination of the factors shown in figure 1, a human error may occur. Whether or not an error does in fact occur is a function of the individual's adjustive behaviors. Individuals who accordingly adjust their behaviors to changes in supervision, work groups, external stimuli, and the other factors shown in figure 1 may moderate the effects of these changes, thereby avoiding a human error.

Note that even if a human error does occur it will not necessarily lead to an accident, as illustrated in figure 1. The external conditions may not be right for an accident to happen. For example, adjustive behaviors may enable a driver to compensate for a slick spot on the highway, thus avoiding skidding into an oncoming automobile. But if there is no oncoming automobile, then conditions are not right for a collision and adjustive behaviors are relatively less important.

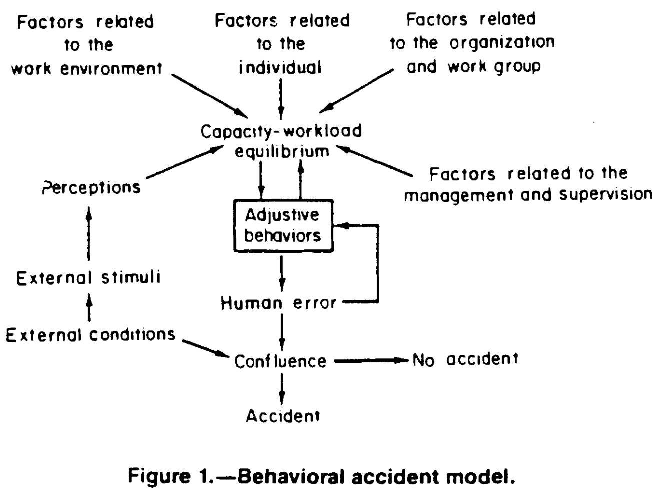


**Figure 1.—Behavioral accident model.**

[2] Italic numbers in parentheses refer to items in the list of references at the end of this report.

# FOCUS AND SCOPE OF THIS STUDY

The focus of this study was on individual adjustive behaviors and their relationships with the variables system shown in figure 1. Why, how, and when individuals successfully adjust and the consequences of failures to adjust were the topics of this research.

The adjustive behaviors of underground miners were studied by analyzing a sample of fatal-accident reports. Based on these analyses, and the use of catastrophe theory concepts (*20, 22*), a computer model was constructed that simulates behavioral accident systems. The model was tested and evaluated by a sample of mine employees. Recommendations were made for routinely using the model within mine operating firms.

# METHODOLOGY

## ACCIDENT SAMPLE

Mine Safety and Health Administration (MSHA) reports of fatal underground bituminous coal mine accidents from April 1979 to March 1985 were selected as the target population for the study of behavioral accidents. The choice of this target population was a compromise. Accident reports for earlier periods frequently lacked the necessary detailed information. On the other hand, a long enough time span was needed to cover a range of economic conditions. And it was desirable to include the most recent time periods in order to capture the latest conditions within the industry.

This target population was refined by selectively removing various reports. Reports with inadequate writeups or incomplete information were removed. Since the focus was on individual psychological and behavioral phenomena, reports involving multiple fatalities, equipment failures, and inadequate training or inexperience of the victim were removed. Reports from mines with injury rates over 50 pct above the industry average were also removed. The objective was to obtain a population where many of the traditional accident causes were absent, yet fatalities still occurred because of inappropriate individual adjustive behaviors.

These procedures resulted in a population of 358 fatal accident cases. Since this population was too large to be thoroughly studied within the available staffing and time constraints, sampling was used. The population was stratified by accident type, victim skill class, geographic location of the mine, and mine size. Accident reports were then randomly sampled from each stratum in numerical proportion to their occurrence in the 358 accident case population.

These procedures resulted in 60 fatal-accident cases for study. The stratification and random sampling insured that a range of important phenomena were present within a representative sample of 60 cases. As noted later in this report, these careful sampling procedures permitted the behavioral accident phenomena to be distinguished from the multitude of other confounding causes and factors. Behavioral accident phenomena are likely to be an important component of most accidents. However, their presence may remain undected because they are obscured by a multitude of other causes.

## VARIABLES AND RATING SCALES

Based on an in-depth analysis of selected literature (*5, 12, 14, 18*), the 20 variables listed in table 1 were chosen for this study. Each of these variables relates to accident phenomena with individuals, and each is reported to be empirically measurable (*5, 12, 14, 18, 21*).

Some of the variables in table 1 are objectively measurable; examples are age, experience, and size. Others are highly subjective, such as carefulness, alertness, and confidence. Many of these variables can be measured by observation, supervisor's ratings, peer ratings, or personnel records. Others require carefully standardized rating scales, for example, field dependency. The so-called field-dependent individual is unable to extract salient information from a complex background (*12, 21*). For example, an individual who is unable to distinguish a zebra that is standing in front of a striped background evidences field dependency. Standard tests have been developed for measuring degrees of field dependency (*21*).

Rating scales were devised for measuring each variable, as illustrated in table 2. In pilot tests of interrater reliability, a panel of 10 qualified judges applied these scales in nine different exercises. After a brief training and learning period, the judges ratings showed no statistically significant differences (using Cochran Q, binomial, and kappa statistical tests of agreement (*11, 17*)). Moreover, in various trials of the scales, the author correctly repeated the results with 94 pct accuracy. Thus, it appears that the rating scales are highly reliable and repeatable (*11, 17–18*).

## CONTENT ANALYSES MEASUREMENTS

Each of the 60 MSHA reports was carefully read and summarized to highlight its contents. In following established procedures (*1, 8*), each report was then reread and rated by the author on each of the variables listed in table 1, using scales like the one illustrated in table 2. While this approach of reading and rating text based on the reader's impressions may be open to some arbitrariness, it is a seriously accepted methodology. Two other readers who were trained in content analyses methods reproduced the author's ratings with 90- to 96-pct accuracy, using random

**Table 1.—Summary list of variables**

| Name | Definition | Number [1] |
|---|---|---|
| | INDIVIDUAL FACTORS | |
| Age | Victim's age | 3 |
| Safety | Percentage of safe behaviors demonstrated by victim | 5 |
| Carefulness | Extent to which victim showed carefulness in task behaviors | 6 |
| Initiative | Extent to which victim demonstrated safety initiatives | 7 |
| Alertness | Extent to which victim correctly observed danger signals that preceded accident. | 8 |
| Evasiveness | Extent to which victim acted to avoid or evade a potential accident situation | 9 |
| Training | Recentness of training received by victim | 12 |
| Field dependency | Extent to which victim was psychologically field dependent for perceptual information processing. | 14 |
| Self-control | Extent to which victim maintained restraint over emotions | 15 |
| Impulsivity | Extent to which victim demonstrated impulsive behaviors | 16 |
| Experience | Victim's level of experience | 19 |
| | WORK ENVIRONMENT | |
| Commitment | Extent to which firm demonstrated commitment to safety | 10 |
| Size | Size of firm | 13 |
| Rate | Injury rate at firm | 20 |
| Policy | Number of safety policies promulgated by firm | 17 |
| | ORGANIZATION AND WORK GROUP | |
| Integration | Degree to which victim was integrated with work group | 4 |
| Confidence | Degree of confidence in crew members shown by supervisor | 18 |
| | MANAGEMENT AND SUPERVISION | |
| Attitude | Top management attitude toward safety | 1 |
| Norm | Safety norm of immediate supervisor | 2 |
| Enforcement | Extent to which safety policies were enforced | 11 |

[1]Identification number assigned for subsequent discussion and analysis.

**Table 2.—Example of a rating scale for the norm [1] variable**

| *Indicators* | *Rating* |
|---|---|
| Supervisor cautioned crew members to be aware of poor roof | High safety norm or +. |
| Supervisor admonished crew to constantly check to see that cables were neatly stowed. | Do. |
| Supervisor frequently held informal safety meetings | Do. |
| Supervisor stopped the work to remove a possible hazard | Do. |
| Supervisor did not hold any regular safety meetings | Low safety norm or −. |
| Supervisor seldom stressed carefulness and safety | Do. |
| Supervisor often took chances and behaved carelessly | Do. |
| Supervisor permitted crew to take shortcuts | Do. |
| Inadequate information provided about supervisor's safety norm. | Inadequate data or 0. |

[1]See table 1 for definition.

samplings of text from the reports. This is a relatively high interrater statistic that lends more confidence to the results presented here. Additional standard precautions were also taken to increase the validity of the results (*1, 8, 19*).

In addition to the content rating data, various contributing factors, such as failure to comply with safe operating procedures and failure of management, were often cited in the MSHA reports by the investigating teams. These items were carefully noted and recorded for further analyses.

# CONTENT ANALYSES RESULTS

## DATA REDUCTION

The content analyses produced a string of 60 +, −, or 0 scores (one for each accident case) for each variable listed in table 1. Five of the twenty variables were then eliminated from further consideration because their degree of causal involvement (DCI) was too low. The *ith* variable was eliminated when $DCI_i$, defined as

$$[60 - N_i(0)]/60 \qquad (1)$$

was less than or equal to 0.60. Here, $N_i(0)$ is the number of times the *ith* variable was rated 0 for inadequate data in the content analyses (see table 2). Equation 1 effectively eliminates any variables that could not clearly be scored either + or − in at least 60 pct of the accident cases in the content analyses. Although this was a rather intuitive approach to data reduction, it was effective. The five variables thus eliminated were variables 1, 4, 5, 17, and 18 from table 1.

## UNIVARIATE ANALYSES

Of the 15 variables that survived the degree of causal involvement test, 9 occurred often enough among the 60 accident cases to be statistically significant. These results are summarized in table 3. Thus, the accident cases examined were characterized by some problem or some deficiency in these nine aspects. That is, low supervisor safety norms, carelessness, low safety initiatives, lack of alertness, poor evasiveness, poor enforcement, high field dependency, poor self-control, and impulsivity characterized the cases. These results are consistent with the conventional wisdoms about accident causation (*14*, *18*).

On the other hand, table 4 presents results that are not consistent with the conventional wisdoms. The conventional wisdoms hold that youthful employees, weak safety commitments by the firm, lack of employee training, lack of employee experience, large firm size, and an environment of high injury rates are primary causes of fatalities (*14*, *18*). As the results in table 4 show, the sample of fatal accidents examined was not characterized by these attributes. The sample was purposely selected in such a way that these attributes were removed from it (see "Accident Sample" section). The victims were not young, inexperienced, and deficient in training. Over half of the firms were large, accident rates at the firms were not above average, and management commitments to safety were strong. Nevertheless, fatal accidents occurred. Clearly some other factors must have caused the accidents studied.

These results thus support the central thesis of this study: the victim's own inadequate adjustive behaviors can be the primary cause of an accident. Such behavioral accidents can occur in spite of the fact that other variables and factors all point to a generally safe, potentially accident-free environment.

## CONTRIBUTING FACTORS

Table 5 shows the incidence, $I_j$, and statistical significance of the *jth* contributing factors cited in the reports by the investigating teams. The incidence is given by

$$I_j = (NC_j/60), \tag{2}$$

where $NC_j$ is the number of times the *jth* contributing factor was cited. As with equation 1, this is a rather intuitive approach to reducing the data.

As table 5 shows, the incidence of failures of management (failure to enforce safety commitments made by the firm, failure to eliminate known hazards, etc.) and failures to comply with approved safe operating procedures were statistically significant. That is, the investigators cited these factors a significant number of times. Similarly, as table 5 shows, the investigating teams cited faulty employee judgments and lax supervisors, who permitted unsafe practices, as significant contributing factors. These results are consistent with the conventional wisdoms. These are precisely the factors that research has repeat-

**Table 3.—Statistically significant variables [1]**

| Name | Comments | Number [2] |
|---|---|---|
| Norm | In 76 pct of fatalities, immediate supervisor evidenced a low safety norm. | 2 |
| Carefulness | In 80 pct of fatalities, victims did not show careful behaviors in performing various tasks. | 6 |
| Initiative | Safety initiatives were absent in 80 pct of fatalities | 7 |
| Alertness | In 86 pct of fatalities, victims apparently failed to correctly observe pertinent danger signals that preceded the accident. | 8 |
| Evasiveness | In 98 pct of fatalities, victims failed to act to avoid or evade pending danger. | 9 |
| Enforcement | In 81 pct of fatalities, supervisor did not enforce established safety rules and practices. | 11 |
| Field dependency | In 95 pct of fatalities, victims appeared unable to extract salient information from a complex background (high field dependency) | 14 |
| Self-control | In 89 pct of fatalities, victims evidenced low self-control | 15 |
| Impulsivity | In 79 pct of fatalities, victims demonstrated impulsive behaviors, with little foresight into consequences and little regard for personal safety. | 16 |

[1]Binomial statistical test, with level of significance for rejection set at 0.10. See reference 17 (pp. 36–42) for binomial test used. Note that in this test, $N = N_i(+) + N_i(-)$, where $N_i(+)$ and $N_i(-)$ are the number of times the *ith* variable was scored + and −, respectively.

[2]Identification number assigned for subsequent discussion and analysis.

**Table 4.—Nonsignificant variables [1]**

| Name | Comments | Number [2] |
|---|---|---|
| Age | About half (45 pct) of victims were over 35 yr old, thus youthfulness was not a significant factor in the fatalities studied. | 3 |
| Commitment | Over half (52 pct) of cases were characterized by a strong safety commitment by firm. | 10 |
| Training | In over half (51 pct) of the fatalities, victims had received formal training for job within prior 3 months. Thus, recentness of training did not deter the fatalities studied. | 12 |
| Size | Over half (52 pct) of firms studied were large size (annual outputs above industry mean). | 13 |
| Experience | Over half (59 pct) of victims had more than 10 yr experience | 19 |
| Rate | Over half (53 pct) of sites had injury rates below industry mean | 20 |

[1]Binomial statistical test, with level of significance for rejection set at 0.10. See reference 17 (pp. 36–42) for binomial test used. Note that in this test, $N = N_i(+) + N_i(-)$, where $N_i(+)$ and $N_i(-)$ are the number of times the *ith* variable was scored + and −, respectively.

[2]Identification number assigned for subsequent discussion and analysis.