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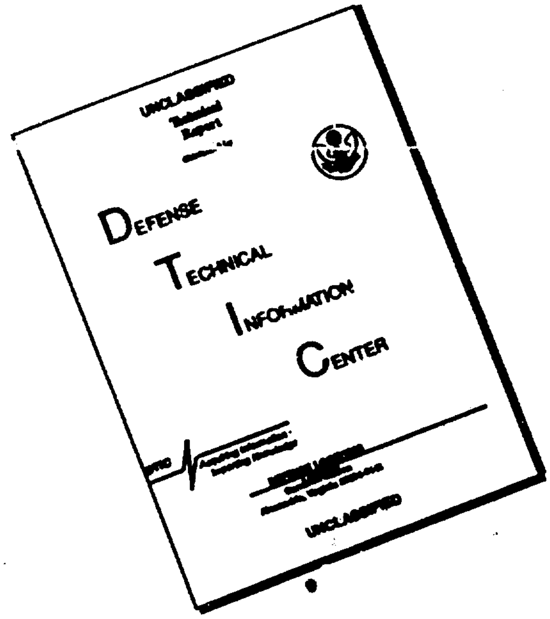

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MATHEMATICAL EVALUATIONS FOR CONTROLLING HAZARDS

By:
William T. Fine

ABSTRACT: To facilitate expeditious control of hazards for accident prevention purposes, two great needs have been recognized. These are for (1) a method to determine the relative seriousness of all hazards for guidance in assigning priorities for preventive effort; and (2) a method to give a definite determination as to whether the estimated cost of the contemplated corrective action to eliminate a hazard is justified.

To supply these needs, a formula has been devised which weighs the controlling factors and "calculates the risk" of a hazardous situation, giving a numerical evaluation to the urgency for remedial attention to the hazard. Calculated Risk Scores are then used to establish priorities for corrective effort. An additional formula weighs the estimated cost and effectiveness of any contemplated corrective action against the Risk Score and gives a determination as to whether the cost is justified.

PUBLISHED 8 MARCH 1971

NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

UNCLASSIFIED

NOLTR 71-31

MATHEMATICAL EVALUATIONS FOR CONTROLLING HAZARDS

The methods described in this report were conceived and developed by the author in recognition of needs for a method of determining relative urgencies for attention to hazards, and for a simple system to give guidance as to whether the estimated cost of an engineering project to eliminate a hazard is justified. These needs are satisfied by the use of formulae which weigh the varying degrees of the controlling factors.

In a few months of actual use at the Naval Ordnance Laboratory, these formulae have furnished solid foundation for safety recommendations for engineering action; they have saved many thousands of dollars by cancelling costly projects which the risks did not justify; and they have given better direction to the entire safety program by indicating the relative potential seriousness of all hazards.

Since weights or values assigned to the various factors of the formulae are empirical, extended experience may indicate advisability of raising or lowering some of the criteria. However since results are primarily for comparative purposes, relative evaluations will be valid within any organization as long as standards of judgment are consistent.

These methods are promulgated for information and for any use desired by addressees. It is believed they have universal application and should provide advancement in the state of the art of the safety engineering profession.

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Captain, USN
Commander

ROBERT ENNIS
By direction

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Chapter 1

INTRODUCTION

GENERAL. The purpose of this chapter is to illustrate the need for quantitative evaluations to aid in the control of hazards and to explain the general plan of this report.

A problem frequently facing the head of any (field type) safety organization is to determine just how serious each known hazard is, and to decide to what extent he should concentrate his resources and strive to get each situation corrected. Normal safety routines such as inspections and investigations usually produce varying list of hazards which cannot all be corrected at once. Decisions must be made as to which ones are the most urgent. On costly projects, management often asks whether the risk due to the hazard justifies the cost of the work required to eliminate it. Since budgets are limited, there is necessity to assign priorities for costly projects to eliminate hazards.

The question of whether a costly engineering project is justified is usually answered by a general opinion which may be little better than guesswork. Unfortunately in many cases, the decision to undertake any costly correction of a hazard depends to a great extent on the salesmanship of safety personnel. As a result, due to insufficient information, the cost of correcting a very serious hazard may be considered prohibitive by management, and the project postponed; or due to excellent selling jobs by Safety, highly expensive engineering or construction jobs may be approved when the risks involved really do not justify them.

In Chapter 2 of this report, a formula is presented to "calculate the risk" due to a hazard, or to quantitatively evaluate the potential severity of a hazardous situation. Use of this formula will provide a logical system for safety and management to determine priorities for attention to hazardous situations, and guidance for safety personnel in determining the areas where their efforts should be concentrated.

In Chapter 3 of this report, a formula is presented for determining whether or not the cost of eliminating a hazard is justified. Use of the formula will provide a solid foundation upon which safety personnel may base their recommendations for engineering-type corrective action. It will assure that projects which are not justified will not be recommended.

This report deals with justification of costs to eliminate hazards. This does not imply in any way that a cost, no matter how great, is not worthwhile if it will prevent an accident and save a human life. However we must also consider accident prevention with reason and judgment. Budgets are not unlimited. Therefore the maximum possible benefit for safety must be derived from any expenditure for safety. When an analysis results in a decision that the cost of certain measures to eliminate a hazard "is not justified," we do not say or suggest that the hazard is not serious and may be ignored. We do say that, based on evaluation of the controlling factors, the return on the investment, or in other words, the amount of accident prevention benefit, is below the standards we have established. The amount of money involved will no doubt provide greater safety benefit if used to alleviate other higher-risk hazards which this system will identify. As for the hazard in question, less costly preventive measures should be sought.

DEFINITIONS. For the purpose of this presentation, three factors are defined as follows.

a. HAZARD: Any unsafe condition or potential source of an accident. Examples are: an unguarded hole in the ground; defective brakes on a vehicle; a deteriorated wood ladder; a slippery road.

b. HAZARD-EVENT: An undesirable occurrence; the combination of a hazard with some activity or person which could start a sequence of events to end in an accident. Examples of hazard-events are: a person walking through a field which contains a hazard such as an unguarded well opening; a person not wearing eye protection while in an eye hazardous area; a person driving a vehicle that has defective brakes; a man climbing up a defective ladder; a vehicle being driven on a slippery road.

c. ACCIDENT SEQUENCE: The chain of events or occurrences which take place starting with a "hazard-event" and ending with the consequences of an accident.

d. Additional definitions will be provided in later pages as needed.

Chapter 2

FORMULA FOR EVALUATING THE SERIOUSNESS OF THE RISK DUE TO A HAZARD

GENERAL. The purpose of this chapter is to present a complete explanation of the method for quantitatively evaluating the seriousness of hazards, and some of the benefits that may be derived from such analyses.

The expression "a calculated risk" is often used as a catch-all for any case when work is to be done without proper safety measures being taken. But usually such work is done without any actual calculation. By means of this formula, the risk is calculated. The seriousness of the risk due to a hazard is evaluated by considering the potential consequences of an accident, the exposure or frequency of occurrence of the hazard-event that could lead to the accident, and the probability that the hazard-event will result in the accident and consequences.

THE FORMULA is as follows:

Risk Score = Consequences x Exposure x Probability

Abbreviated: R = C x E x P

Definitions of the elements of the formula and numerical ratings for the varying degrees of the elements are given below.

a. CONSEQUENCES C: The most probable results of a potential accident, including injuries and property damage. This is based upon an appraisal of the entire situation surrounding the hazard, and accident experience. Classifications and ratings are:

Description	Rating
(1) Catastrophe: numerous fatalities; extensive damage (over $1,000,000); major disruption of activities of national significance................................	100
(2) Multiple fatalities; damage $500,000 to $1,000,000..	50

Description	Rating
(3) Fatality, damage $100,000 to $500.000......	25
(4) Extremely serious injury (amputation, permanent disability); damage $1000 to $100,000.........	15
(5) Disabling injuries; damage up to $1000.....	5
(6) Minor cuts, bruises, bumps; minor damage...	1

b. EXPOSURE E: Frequency of occurrence of the hazard-event (the undesired event which could start the accident-sequence). Classifications are below. Selection is based on observation, experience and knowledge of the activity concerned.

Description	Rating
The hazard-event occurs:	
(1) Continuously (or many times daily).........	10
(2) Frequently (approximately once daily)......	6
(3) Occasionally (from once per week to once per month)..	3
(4) Unusually (from once per month to once per year)...	2
(5) Rarely (it has been known to occur)........	1
(6) Very rarely (not known to have occurred, but considered remotely possible)......................	0.5

c. PROBABILITY P: This is the likelihood that, once the hazard-event occurs, the complete accident-sequence of events will follow with the necessary timing and coincidence to result in the accident and consequences. This is determined by careful consideration of each step in the accident sequence all the way to the consequences, and based upon experience and knowledge of the activity, plus personal observation. Classifications and ratings are:

DESCRIPTION	Rating
The accident-sequence, including the consequences:	
(1) Is the most likely and expected result if the hazard-event takes place...........................	10
(2) Is quite possible, would not be unusual, has an even 50/50 chance................................	6
(3) Would be an unusual sequence or coincidence	3
(4) Would be a remotely possible coincidence. (It has happened here.)................................	1
(5) Extremely remote but conceivably possible. (Has never happened after many years of exposure.).....	0.5
(6) Practically impossible sequence or coincidence; a "one in a million" possibility. (Has never happened in spite of exposure over many years.)..	0.1

EXAMPLES. The use of this formula is demonstrated by actual examples. Six widely different types of situations have been selected to illustrate the broad applicability of the formula and method of computation.

a. Example No. 1 (Actual case)

(1) Problem. There is a quarter-mile stretch of two-lane road used frequently by both vehicles and pedestrians departing or entering the grounds. There is no sidewalk, so pedestrians frequently walk in the road, especially when the grass is wet or snow covered. There is little hazard to pedestrians when all the traffic is going in one direction only; but when vehicles are going in both directions and passing by each other, the vehicles require the entire width of the road, and pedestrians must then walk on the grass alongside the road. It is considered that an accidental fatality could occur if a pedestrian steps into the road, or remains in the road at a point where two vehicles are passing.

(2) Steps to Use the Risk Score Formula:

(a) Step 1. List the accident-sequence of events that could result in the undesired consequences.

1 It is a wet or snowy day, making the grass along the road wet and uninviting to walk on.

2 At quitting time, a line of vehicles, and some pedestrians are leaving the grounds, using this road.

3 One pedestrian walks on the right side of this road, and he has an attitude which makes him oblivious to the traffic. (This is the hazard-event.)

4 Although traffic is "one way" out at this time, one vehicle comes from the opposing direction causing the outgoing traffic line to move to the right edge of the road.

5 The pedestrian on the right side of the road fails to observe the vehicles, and he remains in the road.

6 The driver of one vehicle fails to notice the pedestrian and strikes him from the rear.

7 Pedestrian is killed.

(b) Step 2. Determine values for elements of formula:

1 Consequences: A fatality. Therefore C = 25.

2 Exposure: The hazard-event is event 3 above, the pedestrian remaining in road and refusing to notice the line of traffic. It is considered that this type individual appears or is "created" by conditions occasionally. Therefore E = 3.

3 Probability of all events of the accident-sequence following the hazard-event is: "conceivably possible, although it has never happened in many years." Reasoning is as follows: events 4, 5, 6 and 7 are individually unlikely, so the combination of their occurring simultaneously is extremely remote. Event 4 is unlikely because traffic is "one way" at quitting time. Event 5 is unlikely because a number of drivers would undoubtedly sound their horns and force the pedestrian's attention. Event 6 is unlikely because most drivers are not deliberately reckless. Event 7, a fatality, is unlikely because vehicle speeds are not great on the road, and the most likely case would be a glancing blow and minor injury. Not even a minor injury has ever been reported here. In view of the above Probability P = 0.5.

(c) Step 3. Substitute into formula and determine the Risk Score.

$$R = C \times E \times P = 25 \times 3 \times 0.5 = \underline{37.5}$$

(NOTE: The Risk Score of one case alone is meaningless. additional hazardous situations must also be calculated for comparative purposes and a definite pattern. Five additional cases are similarly calculated below.)

b. Example No. 2 (Actual situation several years ago. Hypothetical case now.)

(1) Problem. Fifty (50) compressed air hoses are in use for general cleaning purposes in a machine shop, being used without proper pressure-reduction nozzles at various pressures some up to 90 pounds per square inch. This causes potential eye hazards, although eye protection is worn by most men. The most probable consequence of this hazard is a serious eye injury.

(2) Using the Risk Score Formula:

(a) Step 1. List the sequence of events to cause an eye injury accident:

1 Many machine operators use compressed air streams to blow metal chips from work.

2 Most employees occasionally remove their safety glasses while still in the hazardous area. (This is the hazard-event.)

3 One employee who is not wearing eye protection walks past a machine while an air hose is being used.

4 A metal chip blows into the employee's eye.

5 A serious eye injury results.

(b) Step 2.

1 Consequence: A disabling eye injury. C = 5.

2 Exposure: The hazard-event (an employee removing his eye protection while still in an eye hazardous area) is considered to occur many times daily. E = 10.

3 Probability: The total accident-sequence is considered "quite possible." P = 6.

(c) Step 3. Substitute into formula and determine the Risk Score.

$$R = C \times E \times P = 5 \times 10 \times 6 = \underline{300}$$

c. Example No. 3 (Actual case)

(1) Problem. A 12,000 gallon propane storage tank is subject to two hazards. One hazard is the fact that the tank is located alongside a well-traveled road. The road slopes, and is occasionally slippery due to rain, snow or ice. It is considered possible that a vehicle (particularly a truck) could go out of control, leave the road, strike and rupture the tank, and cause a propane gas explosion and fire that could destroy several buildings, with consequences amounting to damage costing $200,000, plus a fatality. The second hazard is the tank's location close to ultra-highly compressed air lines and equipment. A high pressure pipeline explosion could result from a malfunctioning safety valve, a human error in operating the equipment, damage to a pipeline, or from other causes. Blast or flying debris could conceivably strike the propane storage tank, rupture it and cause it to explode with the same consequences as for a runaway vehicle.

(2) Using the Risk Score formula: (NOTE: In this case there are two hazards, so the evaluation is done in two parts, one for each of the hazards, and the total scores are added.)

(a) Step 1. Consider just the first hazard, that due to a vehicle. List the sequence of events that would result in an accident:

1 Many vehicles are driven down the hill alongside the storage tank.

2 The road has suddenly become slippery due to an unexpected freezing rain.

3 One truck starts to slide on the slippery road as it goes down this hill. (NOTE: This is the "hazard-event" that starts the accident sequence.)

4 The driver loses his steering control at a point when he is uphill from and approaching the tank.

5 Brakes fail to stop the vehicle from sliding.

6 Vehicle heads out of control toward the tank.

7 Vehicle strikes the tank with enough force to rupture it and permit the propane gas to leak out.

8 A spark ignites the propane.

9 Explosion and conflagration occur.

10 Building and equipment damage is $200,000, and one man is killed.

(b) Step 2. Substitute numerical values into formula:

1 Consequences: One fatality and Damage loss of $200,000. Therefore C = 25.

2 Exposure: The hazard-event that would start the accident sequence is event No. 3, the truck starting to slide on this road. This has happened "rarely." Therefoe E = 1.

3 Probability: To decide on the likelihood that the complete accident-sequence will follow the occurrence of the hazard-event, we consider the probability of each event:

a Consider event 4: Loss of steering control to occur at the precise point in the road approaching the tank is possible but would be a coincidence.

b Consider event 5: failure of brakes. Once the vehicle started to slide, if the road were ice covered, it would be expected that the brakes would fail to stop the slide.

c Consider event 6: the vehicle heading toward the tank. This is highly unlikely. Momentum would cause the vehicle to continue straight down the road.

d Consider event 7, the vehicle striking the tank with great force, and squarely. Extremely unlikely.

If a vehicle were sliding on an ice covered surface toward the tank, it would be easily diverted from its direction of travel by a number of obstructions between the road and the tank. When roads are slippery, travel is curtailed and drivers are cautioned to drive slow. A slow rate of speed would be unlikely to produce enough force to damage the tank. The shape and position of the tank are such that a vehicle would tend to glance off it.

e Events 8 through 10 are likely to follow if event 7 took place.

f In summary, the highly unlikely nature of most of the events from 4 through 7 gives a net Probability of almost a "one in a million" possibility. It has never happened, but it is conceivable. Therefore P = 0.5.

4 R = 25 x 1 x 0.5 = 12.5

(c) Step 3. Repeat the entire above process for the second hazard (location near the high pressure air lines and equipment): List the sequence of events:

1 Normal daily activities involve operation of equipment and pressurizing of pipelines some of which are in the vicinity of the propane storage tank.

2 A pipeline containing air compressed to 3000 pounds per square inch, approximately 50 feet away from the storage tank, has become deteriorated or damaged. (This is the hazard-event.)

3 The pipeline bursts.

4 Metal debris is thrown by the blast in all directions, several pieces flying and striking the propane tank with such force that the tank is ruptured.

5 Propane starts to leak out of the tank.

6 A spark ignites the propane fumes.

7 The propane and air mixture explodes.

8 Building damage is $200,000, and one man is killed.

(d) Step 4. Determine values and substitute in formula.

1 Consequences: One fatality and damage loss of $200,000. C = 25.

2 Exposure: High pressure air lines have been known to have been neglected or damaged. Frequency of such occurrences is considered "unusual." Therefore E = 2.

3 Probability: Now we estimate the likelihood that a damaged pipeline will explode and the explosion will occur close enough and with enough blast to throw debris and strike the propane tank with such force as to complete the accident sequence. Several bursts have occurred in past years, but none have damaged the propane tank. Few of the pipelines are close enough to endanger the tank. After careful observation, the accident sequence is considered very remotely possible. The classification is placed at P = 0.5.

4 Substituting into the formula:

$$R = 25 \times 2 \times 0.5 = 25$$

$$\text{Total } R = 12.5 + 25 = 37.5$$

d. Example No. 4

(1) Problem. Building 303 contains a number of ovens which are used for environmental testing (heating) of explosives, in quantities up to five pounds of explosive material per oven at one time. One side of the building is made of "blowout panels" so that in case of an accidental detonation of explosives, most of the blast will be expended out the blowout wall with less demolishment of the entire building. This type of oven has been known to "run away" or heat excessively due to faulty heat control devices, and thereby cause the explosives in the oven to detonate. The potential hazard considered here is the endangering of persons who occasionally walk past the building on its blowout side. Such persons could be severely injured if an explosion occurred while they were passing by.

(2) Potential sequence of events:

(a) Several ovens are in use, each containing five pounds of explosives undergoing test.

(b) Persons are usually present in the area outside the building on the blowout side. This is a normal and accepted condition.

(c) The thermostatic controls of one oven in use become defective and the oven temperature rises above safe operating range (the hazard event).

(d) The secondary emergency shutoff control fails to function.

(e) The oven overheats.

(f) The explosive content of the oven explodes.

(g) A passerby near the building is fatally injured by the blast and flying debris.

(3) Formula use:

(a) Consequence: A fatality. C = 25.

(b) Exposure: The hazard-event, the malfunctioning of the oven heat controls, has happened before, but very "rarely." E = 1.

(c) Probability of the complete accident sequence following the hazard event: all ovens have been equipped with secondary emergency shutoff controls. Monthly maintenance procedures have now been established to ensure their proper functioning. Failure of the secondary shutoff if it should be needed is considered highly unlikely. It would be a remotely possible coincidence if the secondary failure occurred at the same time and on the same oven on which a thermostatic control failed. Therefore the Probability rating P = 1.

(d) Substituting in the formula:

$$R = 25 \times 1 \times 1 = 25$$

e. Example No. 5 (Actual case)

(1) Problem. There are approximately 100 household-type refrigerators in use in which various kinds of chemicals are stored. Many of these refrigerators are not sparkproof Flammable volatile solvents stored in nonsparkproof refrigerators could leak, vaporize, contact electrical sparks and result in an explosion or fire. Most likely results would be minor injuries and possible damage estimated at $200.00.

(2) Necessary sequence of events for an accident:

(a) Various kinds of chemicals are placed and stored in approximately 100 refrigerators (normal practice).

(b) Occasionally flammable volatile solvents are placed in a nonsparkproof refrigerator (a violation of safe practice. This is the hazard-event).

(c) A solvent container leaks (or the cover is not on tight).

(d) Fumes reach an electric spark.

(e) Fumes explode and cause $200.00 damage.

(3) Formula use:

(a) Consequence: Damage is $200.00. C = 5.

(b) Exposure: The hazard-event, the violation in event (b) above, is believed to occur frequently. E = 6.

(c) Probability: The probability of the accident sequence following the violation and resulting in the accident is considered "remotely possible." Therefore P = 1.

(d) Substituting in the formula:

$$R = 5 \times 6 \times 1 = 30$$

f. Example No. 6 (Actual case)

(1) Problem. The hallways of Shop Building 25 are subjected to considerable traffic by pedestrians and shop-carts or wagons. A hazardous traffic situation at one blind corner could result in collisions between persons walking and materials on carts, and cause minor injuries.

(2) Necessary sequence of events:

(a) One employee walking and one employee pushing a cart approach the blind corner from different directions at exactly the same time. (This is the hazard-event.)

(b) Both employees approaching the intersection are unwary and somewhat in a hurry.

(c) One or both employees on the collision course fail to react and stop in time to avoid a collision.

(d) A minor injury results.

(3) Formula use:

(a) Consequence: Minor injury. C = 1.

(b) Exposure: The hazard-event occurs many times daily. E = 10.

(c) Probability: The complete accident-sequence is quite possible, not unusual. P = 6.

(d) Risk Score R = 1 x 10 x 6 = 60

SUMMARIZING RISK SCORES. As demonstrated above, the Risk Scores for 20 additional hazardous situations have been calculated. These 26 cases are now listed in order of the magnitude of their Risk Scores, or we can say - in order of the relative seriousness of their risks. See Table 1: Risk Score Summary and Action Sheet. The critical (dotted) lines are drawn where best judgment dictates to signify urgency for corrective action in accordance with the Risk Scores.

Table 1

RISK SCORE SUMMARY AND ACTION SHEET

HAZARD DESCRIPTION	RISK SCORE	ACTION
Window washer on third floor, without safety belt, hangs on with one hand and leans out	1500	Immediate correction required. Activity should be discontinued until hazard is reduced.
Men working in ditch six feet deep, ditch not shored, dirt is soft, subject to sliding	750	
Painters on scaffold without handrail, 30 feet high, not using safety belts	750	
Benzene used for cleaning floor of shop, a busy area, men smoke, other spark sources nearby	450	
Compressed flammable gas cylinders standing unsecured on pallet, along busy aisle, caps on	375	
Uncontrolled compressed air used in machine shop, up to 90 psi, for general cleaning	300	
Men smoking in flammable storage warehouse, no sprinkler system, highly flammable material	270	
Portable electric drill in use without ground wire, getting rough usage by several people	200	Urgent. Requires attention as soon as possible.
Compressed air receiver without safety relief valve, automatic shut-off at 200 psi, old equipment	180	
People walking past deep unguarded ditch, considerable traffic, poor lighting	150	
Heavy instruments unstable on seven foot high shelf case, subject to bumping by employees	150	
Trucks rounding blind corner without stopping, opposing traffic and pedestrians, 10 MPH limit	135	
Steps of main building slippery whenever wet, no handrail, many pedestrians daily	90	
Compressed oxygen cylinder standing unsecured near wall, little traffic or movement	85	Hazard should be eliminated without delay, but situation is not an emergency.
Pedestrian and hand-cart traffic at blind corner in hallway of shop building	60	
Oxygen and acetylene cylinders stored together, caps on, good ventilation, fireproof surroundings	45	
Inadequate handrailing along outside stairway, occasional use every day	40	
Large propane storage tank in busy area: vehicle traffic, and high pressure air operations	37.5	
Both pedestrians and vehicles using same road. Road not always wide enough for both	37.5	
Chemicals stored in nonsparkproof refrigerators, occasionally including flammable volatile liquids.	30	
Broken sidewalk, occasional pedestrian traffic, holes and loose concrete	30	
Persons near explosives building, within range of possible missiles; safe procedures in building	25	
Portable vacuum pump lacking belt guard. Pump moved around occasionally by several employees	18	
Machinist using heavy file without file handle, in daily use	18	
Workman using hammer with loose head, in use daily for odd jobs	18	

RESULTS AND USES OF SUMMARY OF RISK SCORES.

a. The Risk Score Summary and Action Sheet on Table 1 is now a very useful device. If necessary or advisable, the list should be presented to management for top level concurrence and approval of the ACTION column.

b. Beneficial uses of this list are as follows:

(1) Establishes priorities for attention by both Safety and Management. Hazardous situations are listed in the order of their importance. The position on the list of any item can be lowered by corrective action which will decrease its possible Consequences, Exposure, or Probability.

(2) It provides guidance to indicate urgency of newly discovered hazards. For each new hazardous situation, compute the Risk Score. Its urgency is indicated by the ACTION area in which its Risk Score falls. In particular, it would serve as guidance as to whether a job must be stopped when a highly hazardous situation is noted in a highly essential operation. If the Risk Score is above the upper critical line, job must be stopped until some corrective action can be taken to, at the least, lower any one of the three factors to get the Score into a less urgent category.

(3) It would provide a means of setting goals and objectives for the Safety Program, other than or in addition to the use of accident statistics. For example, a safety program can be rated, or safety accomplishment can be demonstrated by the number of cases for which corrective action has been taken and caused the cases to be placed in less urgent categories. A goal could be to have no hazardous situations above the lowest category. The safety status of an organization can be indicated by the number of items in each category at any time.

NOTE: With reference to Table 1, the author hastens to point out that very few of the listed hazardous situations presently exist at the Naval Ordnance Laboratory, the locale where this program originates. Most of the severe cases were selected for expediency from previous years' experience, are hypothetical, or combine experience and hypothesis. It is recommended to potential users of this system, that they also compile workable lists as soon as possible from their past experience and hypotheses, to be used as guidance for comparative evaluation of hazardous situations as they occur or are discovered.

Chapter 3

FORMULA TO DETERMINE JUSTIFICATION FOR RECOMMENDED CORRECTIVE ACTION

GENERAL. The purpose of this chapter is to describe the method of determining whether the cost of corrective action to alleviate a hazard is justified. Once a hazard has been recognized, appropriate corrective action must be tentatively decided upon and its cost estimated. Now the "Justification" formula can be used to determine whether the estimated cost is justified.

THE FORMULA is as follows:

$$\text{Justification} = \frac{\text{Consequences x Exposure x Probability}}{\text{Cost Factor x Degree of Correction}}$$

Elements are abbreviated:

$$J = \frac{C \times E \times P}{CF \times DC}$$

It should be noted that the elements of the numerator of this formula are the same as in the Risk Score formula described in Chapter 2. We have simply added a denominator made up of two additional elements which are as follows:

a. COST FACTOR CF: A measure of the estimated dollar cost of the proposed corrective action. Classifications and ratings are:

	Cost	Rating
(1)	Over $50,000	10
(2)	$25,000 to $50,000	6

	Cost	Rating
(3)	$10,000 to $25,000..............	4
(4)	$1,000 to $10,000...............	3
(5)	$100 to $1,000..................	2
(6)	$25.00 to $100..................	1
(7)	Under $25.00....................	0.5

b. DEGREE OF CORRECTION DC: An estimate of the degree to which the proposed corrective action will eliminate or alleviate the hazard, forestall the hazard-event, or interrupt the accident sequence. This will be an opinion based on experience and knowledge of the activity concerned. Classifications and ratings are:

	Description	Rating
(1)	Hazard positively eliminated, 100%	1
(2)	Hazard reduced at least 75%, but not completely.................................	2
(3)	Hazard reduced by 50 to 75%.......	3
(4)	Hazard reduced by 25 to 50%.......	4
(5)	Slight effect on hazard (less than 25%......................................	6

CRITERIA FOR JUSTIFICATION. Values are substituted into the formula to determine the numerical value for <u>Justification</u>. The Critical Justification Rating is <u>10</u>. For any rating over 10, the expenditure will be considered justified. For a score less than 10, the cost of the contemplated corrective action is not justified.

NOTE: The critical Justification Rating has been arbitrarily set at 10, based on experience, judgment and the current budgetary situation. After extended experience at any individual organization, based on accident experience, budgetary situations, and appraisals of the safety status, it may be found desirable to raise or lower the critical score.

EXAMPLES. The use of the Justification formula will be illustrated by the use of the same six examples discussed in Chapter 2.

a. Example No. 1: The hazard of pedestrians and vehicles using the same road. To reduce this risk, the corrective action being considered is to construct a sidewalk alongside the road, at an estimated cost of $1500.00. The "J" formula is now used to determine whether this contemplated expenditure is justified.

(1) Substitute values in the "J" formula"

$$J = \frac{C \times E \times P}{CF \times DC}$$

(a) C, E, and P, for this situation were discussed as Example No. 1 in Chapter 2 of this report and determined to be 25, 3 and 0.5, respectively.

(b) Cost Factor. The estimated cost is $1500.00. Therefore CF = 3.

(c) Degree of Correction. The probability of the hazard-event occurring is considered to be reduced at least 75 percent, but not 100 percent, by the construction of a sidewalk. Therefore DC = 2.

(d) Justification Rating.

$$J = \frac{25 \times 3 \times 0.5}{3 \times 2} = \frac{37.5}{6} = 6.25$$

(2) Conclusion. "J" is less than 10. Therefore the cost of construction of the sidewalk is not justified.

NOTE: This lack of sufficient justification evaluates the situation from the safety viewpoint only. Management could feel there is added justification for morale or other purposes.

(3) Additional consideration. Since the Risk Score is still a substantial 37.5, other (less costly) corrective measures should be sought. This includes improved administrative

controls to enforce one-way traffic measures, reduce speed, and encourage pedestrians to use another exit gate. This will reduce the Risk Score by reducing both Exposure and Probability.

b. Example No. 2: The hazard due to compressed air being used in a shop without proper pressure reduction nozzles. The proposed corrective action is installation of proper pressure reducing nozzles on the 50 air hoses, at a cost of $8.00 each, or $400.00. To determine justification for the expenditure:

(1) Determine values for the elements of the "J" formula:

(a) C, E, and P, were discussed in Example No. 2 of Chapter 2 and evaluated at 5, 10 and 6 respectively.

(b) Cost Factor. The cost of the corrective action is $400,00, so CF = 2.

(c) Degree of Correction. The corrective action will reduce the hazard by at least 50 percent, so DC = 3.

(d) Substituting in the formula:

$$J = \frac{5 \times 10 \times 6}{2 \times 3} = \frac{300}{6} = 50$$

(2) Conclusion. "J" is well above 10. The cost of installing pressure reduction nozzles is strongly justified.

c. Example No. 3: The hazardous location of the 12,000 gallon propane storage tank. The proposed corrective action is to relocate the tank to a place where it will be less likely to be damaged by any external source, at an estimated cost of $16,000.

(1) Determine values for elements of the formula:

(a) C, E, and P, were determined in Example No. 3 of Chapter 2, to be 25, 1 and 1.5 (the two hazards combined).

(b) Cost Factor. Cost of relocation is $16,000. CF = 4.

(c) Degree of Correction. In the very best location available, there still remains a remote possibility of damage to the tank, so DC = 2.

(d) Substituting in the formula:

$$J = \frac{25 \times 1 \times 1.5}{4 \times 2} = \frac{37.5}{8} = 4.7$$

(2) Conclusion. Based on the established criteria, the cost of relocation of the tank is not justified.

(3) It is emphasized that the conclusion in this case that the proposed corrective action is not justified, does not mean that the hazard is of little or no significance. The Risk Score is still 37.5, and this remains of appreciable concern. Since the potential consequences of an accident are quite severe, effort should be expended to reduce the risk, by reducing either the Exposure or the Probability, or devising other less costly corrective action. In this case it is considered that an additional steel plate barrier could be erected to protect the tank from the compressed air activities, and one or two strong posts in the ground could minimize danger from the road. Thus the Probability of serious damage to the truck, and the Risk Score, would be considerably lessened at a very nominal cost.

d. Example No. 4: The hazard to persons near a building in which explosives are processed. The proposed corrective action is the construction of a barricade along the outside of the building to protect passersby in event of an explosion within, at an estimated cost of $5000.00. Using the "J" formula:

(1) Determine values for elements of the formula:

(a) C, E, and P, as discussed in Example No. 4 of Chapter 2 were evaluated at 25, 1, and 1, respectively.

(b) Cost Factor. Estimated cost is $5000.00. CF = 3.

(c) Degree of Correction (to protect passersby) is considered over 75 percent. DC = 2.

(2) Substituting values in the formula:

$$J = \frac{25 \times 1 \times 1}{3 \times 2} = \frac{25}{6} = 4.20$$

(3) Conclusion. The expenditure of $5000.00 to construct a barricade to protect passersby is not justified.

(4) Further consideration. Review of this problem revealed that although the Probability of the complete accident sequence occurring was adjudged to be remote, it could be made much more remote (and the Risk Score halved) by administrative controls such as portable barriers and warning signs, to reduce or eliminate the presence of passersby in the danger zone. Further, the type of solution that was proposed for this problem (extensive barricading) does not get at the source of the problem. It would fail to protect property and persons inside the barricade. It is considered preferable to concentrate on more extensive measures to prevent an explosion such as by installation of additional fail-safe mechanisms on the ovens.

e. Example No. 5: The hazard of household type refrigerators (nonsparkproof) being used to store chemicals. The proposed corrective action is to place warning signs (decals) on all nonsparkproof refrigerators, cautioning against their use for volatile solvents, plus administrative controls. Cost of signs for the 100 boxes is $87.00.

(1) Determine values for elements of the formula:

(a) C, E, and P, as discussed in Example No. 5 of Chapter 2 were evaluated at 5, 6 and 3, respectively.

(b) Cost Factor. Cost is $87.00 CF = 1.

(c) Degree of Correction. The proposed action of placing warning signs is considered to have an effect of reducing the violation by 50 percent to 75 percent. Therefore DC = 3.

(2) Substituting values in the formula:

$$J = \frac{5 \times 6 \times 1}{1 \times 3} = \frac{30}{3} = 10$$

(3) Conclusion. The cost of the decal warning signs is justified.

(4) In this case a review is indicated since the Degree of Correction of this corrective action is considered only 50 percent to 75 percent. Prior to installation of the warning signs, the Risk Score was 5 x 6 x 1, or 30. With the signs, plus administrative action, the Exposure is considered to be reduced considerably, so that the Risk Score R will equal 5 x 2 x 1 = 10. This is a relatively low risk, not of any emergency nature, but also not to be completely ignored. Longer range solutions should be considered such as insuring that only sparkproof refrigerators will be purchased in the future, and that when maintenance or repairs are done on any of the refrigerators, they be altered and made sparkproof.

f. Example No. 6: The hazard of the blind corner in the shop building hallway. The proposed corrective action is to install a mirror so that persons approaching the blind intersection can easily see traffic approaching from the other direction. Estimated cost is $85.00.

(1) Determine values for elements of the formula:

(a) C, E, and P, as discussed in Example No. 6 of Chapter 2 were evaluated at 1, 10 and 6, respectively.

(b) Cost Factor. Estimated cost is $85.00 CF = 1.

(c) Degree of Correction is considered 25 percent to 50 percent. DC = 4.

(2) Using the formula:

$$J = \frac{1 \times 10 \times 6}{1 \times 4} = \frac{60}{4} = 15$$

(3) Conclusion. The cost to alleviate the hazardous blind intersection by installing a mirror is justified.

(4) Review. It is considered that this corrective action will reduce Exposure and Probability to six and three respectively, making the Risk Score 18. For this now relatively low priority hazard, providing a warning sign and/or marking of traffic lanes could be considered, for added safety.

RECOMMENDED PROCEDURE FOR USING THE "J' FORMULA. A convenient "J" Formula Worksheet (Appendix A) and a Rating Summary Sheet (Appendix B) are furnished for convenience in undertaking a hazard analysis to determine the Justification Rating. Once a hazard has been recognized, the following procedure is recommended:

a. State the problem briefly.

b. Decide on the most likely consequences of an accident due to the hazard.

c. Review all factors carefully, on the scene. List the actual step-by-step sequence of events that is most likely to result in the consequences chosen. You must be specific.

d. Decide on the most appropriate corrective action and obtain or make a rough estimate of its cost.

e. Consider carefully the effect of the proposed corrective action on the hazard, and estimate roughly the degree to which the dangerous situation will be alleviated.

f. If alternative corrective measures are possible, repeat steps (d) and (e) for them.

g. Select the hazard-event (the first undesirable occurrence that could start the accident sequence.

h. Consider the existing situation carefully to determine the frequency of the occurrence of the hazard-event, by on the scene observation and then decide on the Exposure Rating. If in doubt between two ratings, interpolate.

i. For the Probability Rating, consider the likelihood of the occurrence of each event of the accident sequence, including the resulting injury and/or damage, and form an opinion based on the descriptive words. For example, if two "unusual" coincidences are required, this could be considered "remotely possible"; two "remotely possible" occurrences could be "conceivably possible"; etc. If in doubt between two ratings, interpolate. Endeavor to be consistent. Consider the occurrence of only the same consequences which were decided on in step (b) above. For example if you decided on consequences of a fatality, then in this step you may only consider the probability of a fatality. If you also wish to consider lesser injuries, a separate and additional computation must be made, since both the Consequences and Probability evaluations would be different. Scores should be added.

j. You have now obtained ratings for all the elements of the "J" formula. Substitute in the formula and compute the Justification Score.

k. If alternative corrective measures are being considered to alleviate the hazard, compute their Justification Scores also.

l. If there are alternative corrective measures which have acceptable Justification Scores, the most desirable from the Safety standpoint is the one which would make the greatest reduction in the Risk Score. Therefore, for each alternative, assume that the corrective measures are in effect and recompute the Risk Score. Of course this selection may also be affected by external (nonsafety) considerations such as the size of investment required, the relative effects on morale, esthetics, efficiency, convenience, ease of implementation, etc.

EXCEPTION TO RELIANCE ON THE "J" FORMULA. A highly hazardous situation may exist for which no corrective action which will give an acceptable Justification Score can be devised. Obviously in such a case, whatever corrective action is necessary to reduce the Risk Score should be taken regardless of the Justification Score.

Appendix A

"J" FORMULA WORKSHEET

PROBLEM:

Sequence of events or factors necessary for accident:

1.

2.

3.

4.

5.

6.

7.

Formula Factors:		Rating
C Consequence:	______________________	__________
E Exposure:	______________________	__________
P Probability:	______________________	__________
CF Cost Factor:	______________________	__________
DC Degree of Correction:	______________________	__________

J Justification: $J = \frac{C \times E \times P}{CF \times DC} = \frac{\quad x \quad x \quad}{x} =$

The estimated cost of corrective action is/is not justified.

Appendix B

RATING SUMMARY SHEET FOR "J" FORMULA

Factor		Classification	Rating
1. <u>Consequences</u>.	a.	Catastrophe; numerous fatalities; damage over $1,000,000; major disruption of activities...	100
	b.	Multiple fatalities; damage $500,000 to $1,000,000..................................	50
Most probable result of the potential accident.	c.	Fatality, damage $100,000 to $500,000........	25
	d.	Extremely serious injury (amputation, permanent disability); damage $1000 to $100,000........	15
	e.	Disabling injury; damage up to $1000.........	5
	f.	Minor cuts, bruises, bumps; minor damage.....	1
2. <u>Exposure</u>.		<u>Hazard-event occurs</u>:	
	a.	Continuously, (or many times daily)..........	10
	b.	Frequently (approximately once daily)........	6
The frequency of occurrence of the hazard event.	c.	Occasionally (from one per week to once per month)......................................	3
	d.	Unusually (from once per month to once per year).......................................	2
	e.	Rarely (it has been known to occur)..........	1
	f.	Remotely possible (not known to have occurred)	0.5
3. <u>Probability</u>.		<u>Complete accident sequence</u>:	
	a.	Is the <u>most likely</u> and expected result if the hazard-event takes place.....................	10
Likelihood that accident sequence will follow to completion.	b.	Is <u>quite possible</u>, not unusual, has an even 50/50 chance................................	6
	c.	Would be an <u>unusual</u> sequence or coincidence..	3
	d.	Would be a <u>remotely possible</u> coincidence.....	1
	e.	<u>Has never happened</u> after many years of exposure, but is conceivably possible.................	0.5
	f.	<u>Practically impossible</u> sequence (has never happened)..................................	0.1
4. <u>Cost Factor</u>	a.	Over $50,000...............................	10
	b.	$25,000 to $50,000.........................	6
Estimated dollar cost of proposed corrective action.	c.	$10,000 to $25,000.........................	4
	d.	$1,000 to $10,000..........................	3
	e.	$100 to $1,000.............................	2
	f.	$25.00 to $100.............................	1
	g.	Under $25.00...............................	0.5
5. <u>Degree of Correction</u>.	a.	Hazard positively eliminated, 100%..........	1
	b.	Hazard reduced at least 75%.................	2
Degree to which hazard will be reduced.	c.	Hazard reduced by 50% to 75%................	3
	d.	Hazard reduced by 25% to 50%................	4
	e.	Slight effect on hazard (less than 25%).....	6

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) Naval Ordnance Laboratory White Oak, Silver Spring, Maryland 20910	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP N/A

3. REPORT TITLE

MATHEMATICAL EVALUATIONS FOR CONTROLLING HAZARDS

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

5. AUTHOR(S) (First name, middle initial, last name)

William T. Fine

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
8 March 1971	45	0

8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NOLTR 71-31 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

This document has been approved for public realease and sale, its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

To facilitate expeditious control of hazards for accident prevention purposes, two great needs have been recognized. These are for (1) a method to determine the relative seriousness of all hazards for guidance in assigning priorities for preventive effort; and (2) a method to give a definite determination as to whether the estimated cost of the contemplated corrective action to eliminate a hazard is justified.

To supply these needs, a formula has been devised which weighs the controlling factors and "calculates the risk" of a hazardous situation, giving a numerical evaluation to the urgency for remedial attention to the hazard. Calculated Risk Scores are then used to establish priorities for corrective effort. An additional formula weighs the estimated cost and effectiveness of any contemplated corrective action against the Risk Score and gives a determination as to whether the cost is justified.

UNCLASSIFIED
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
J Formula						
Risk Score Formula						
Accident sequence						
Calculated risk						
Hazard-event						
Consequences						
Exposure						
Probability						
Cost Factor						
Degree of Correction						
Justification						
Risk Score						

UNCLASSIFIED
Security Classification