Mathematical Evaluation for Controlling Hazards

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Two significant needs have been recognized in order to facilitate efficient control of hazards for the purpose of accident prevention. One is the need for a method to determine the relative seriousness of all hazards for guidance in assigning priorities to preventive effort. The second need is for a method to measure the justification of the estimated cost of the contemplated corrective action.

To fulfill these needs, the author gives a formula that "calculates the risk" of a hazardous situation and gives 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 and gives a quantitative estimate of the justification of the cost.

A problem that frequently faces many safety personnel is to determine how serious each known hazard is, and to decide to what extent he should concentrate his resources to correct the situation. Normal safety routines such as inspections and investigations usually produce a varying list of hazards that are too numerous to be corrected all at once. Decisions must be made as to which are the most urgent.

On costly projects, higher management often asks whether the particular risk justifies the cost of the work required to eliminate it. Since all budgets are limited, it is necessary to decide whether costly projects to eliminate hazards are really worthwhile. The question of whether an expensive engineering project is justified is usually answered by a general opinion that 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. Because of 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 personnel, elaborate engineering or construction jobs may be approved when the risks involved really do not justify them.

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This article presents a formula for "calculating the risk" due to a hazard. It quantitatively evaluates the potential severity of a hazardous situation. Use of the formula will provide a logical system for safety personnel and management to set priorities for attention to hazardous situations.

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, one must approach accident prevention with reason and good judgment. The maximum possible benefit 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," this does not mean that the hazard is not serious and may be ignored.

It does mean that, based on an evaluation of the controlling factors, the return on the investment or the amount of accident prevention benefit is below the standards established. The amount of money involved will provide greater safety benefit if used to alleviate other higher-risk hazards that this system will identify. As for the hazard in question, less costly preventive measures should be sought.

CALCULATING RELATIVE RISK SCORES

For the purpose of this presentation, three important definitions are:

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:* the combination of a hazard with some person or activity that could start an accident sequence. Examples of hazard-events are: a person walking through a field that contains an unguarded well opening; a person not wearing eye protection in an area especially hazardous to eyes; a person driving a vehicle that has defective brakes; a man climbing up a defective ladder; a person driving a vehicle on a slippery road.

c. *Accident sequence:* the chain of occurrences that begins with a "hazard-event" and ends with the consequences of an accident.

The expression "a calculated risk" is often used for situations where work is to be done without proper safety precautions. Usually such work is done without any mathematical measurement of hazards. Using the formula below, the risk is actually calculated and, thus, more meaningfully quantified. Such quantification is achieved by considering the potential *consequences* of an accident, the *exposure* factor, and the *probability* factor. The formula is:

$$R = C \times E \times P$$

where R represents the risk score
C represents the consequences
E represents the exposure factor
P represents the probability factor

Consequences refer to the most probable results of a potential accident, including injuries and property damage. The rating selected depends on an appraisal of the entire situation surrounding the hazard and accident experience. Factor 1 in Table 1 gives degrees of consequence ranging from minor to catastrophic. A numerical rating associated with each level appears in the column at the right. If an identified hazard has the potential of producing a catastrophe involving numerous fatalities or over $1,000,000 damage, its numerical value in the formula will be 100. If, as is more common, an identified hazard can produce a disabling injury or damage up to $1,000, it will have a rating of 5. The rest of the values may be read directly from the remaining items under Factor 1.

Exposure refers to the frequency of occurrence of the hazard-event (a combination of a hazard with a person or activity that can start an accident sequence). Factor 2 in Table 1 gives the various levels of exposure and the numerical rating associated with each level. Selection of the appropriate exposure level is based on observation, past experience, and knowledge of the activity concerned. Events that occur continuously or many times daily receive a rating of 10 while events that are only remotely possible receive a rating of 0.5.

Probability refers to the likelihood that, once the hazard-event occurs, the complete accident sequence 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. Factor 3 in Table 1 gives the various probability levels and the related ratings. Factors 4 and 5 will be discussed later.

EXAMPLES OF RISK SCORES

Use of the above formula can be demonstrated using four real, but widely different, examples. The diversity is intended to illustrate the broad applicability of the method.

Example no. 1 involves a quarter-mile stretch of two-lane road used by both vehicles

TABLE 1
RATINGS FOR RISK CALCULATION AND COST JUSTIFICATION

FACTOR	CLASSIFICATION	RATING
1. Consequences (Most probable result of the potential accident)	Catastrophe; numerous fatalities; damage over $1,000,000; major disruption of activities	100
	Multiple fatalities; damage $400,000 to $1,000,000	50
	Fatality, damage $100,000 to $500,000	25
	Extremely serious injury (amputation, permanent disability); damage $1,000 to $100,000	15
	Disabling injury; damage up to $1,000	5
	Minor cuts, bruises, bumps; minor damage	1
2. Exposure (The frequency of occurrence of the hazard-event)	Hazard-event occurs:	
	Continuously (or many times daily)	10
	Frequently (approximately once daily)	6
	Occasionally (from once per week to once per month)	3
	Unusually (from once per month to once per year)	2
	Rarely (it has been known to occur)	1
	Remotely possible (not known to have occurred)	0.5
3. Probability (Likelihood that accident sequence will follow to completion)	Complete accident sequence:	
	Is the most likely and expected result if the hazard-event takes place	10
	Is quite possible, not unusual, has an even 50/50 chance	6
	Would be an unusual sequence or coincidence	3
	Would be a remotely possible coincidence	1
	Has never happened after many years of exposure, but is conceivably possible	0.5
	Practically impossible sequence (has never happened)	0.1
4. Cost factor (Estimated dollar cost of proposed corrective action)	Over $50,000	10
	$25,000 to $50,000	6
	$10,000 to $25,000	4
	$1,000 to $10,000	3
	$100 to $1,000	2
	$25.00 to $100	1
	Under $25.00	0.5
5. Degree of correction (Degree to which hazard will be reduced)	Hazard positively eliminated, 100%	1
	Hazard reduced at least 75%	2
	Hazard reduced by 50% to 75%	3
	Hazard reduced by 25% to 50%	4
	Slight effect on hazard (less than 25%)	6

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. The hazard occurs, however, 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. 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.

Three steps are required to determine a risk score for this situation. One must list the accident sequence of events that could result in the undesired consequences, select the value for each element in the formula, and perform the actual calculation.

The accident sequence might involve the following seven events.

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 is oblivious to the traffic. (The hazard-event.)
4. Although traffic is "one way" out at this time, one vehicle comes from the opposite 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. The pedestrian is killed.

Given the above series of events, the components of the formula are supplied below. The consequence is a fatality; therefore, $C=25$ (See Table 1). In relation to exposure, the hazard-event is the pedestrian remaining in the road and having an attitude of disregard. This type of person appears occasionally. Therefore, $E=3$. Factor 2 in Table 1 gives the approximate frequency of occurrence.

The probability of all events of the accident sequence following the hazard-event is: "conceivably possible, although it has never happened in many years." The 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 in the real situation. In view of the above, the probability (P) is equal to 0.5.

The third step involves substitution of values into the formula and the performing of the simple arithmetic.

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

The reader is cautioned that the risk score of one case alone is meaningless. Additional hazardous situations must also be calculated for comparative purposes and to develop a definite pattern.

Example no. 2 deals with an actual situation that occurred several years ago. Fifty (50) compressed air hoses were in use for general cleaning purposes in a machine shop. They were being used without proper pressure-reduction nozzles at various pressures, some up to 90 pounds per square inch. This caused potential eye hazards, although eye protection was worn by most men. The most probable consequence of this hazard was a serious eye injury.

Applying the same three steps as in the first example, the accident sequence is:

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. (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.

Given these circumstances, the consequence is a disabling eye injury, so $C=5$. The exposure is directly observable. The hazard-event, an employee removing his eye protection while still in an eye hazardous area, occurs many times daily. $E=10$. The probability of the total accident sequence is judged to be "quite possible," so $P=6$. The calculation then is:

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

After deriving the above two risk scores, plus two more, perspective will be gained by relating the scores to a larger context of risk scores calculated independently.

Example no. 3 involves a more complex situation. A 12,000 gallon propane storage tank is subject to two hazards. One hazard is the fact that the tank is located beside a well travelled road. The road slopes and is occasionally slippery due to rain, snow, or ice. It is possible that a vehicle (particularly a truck) could lose control, leave the road, strike, and rupture the tank, causing a propane gas explosion and fire that could destroy several buildings. The consequences might amount to \$200,000 damage 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 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 the runaway vehicle.

In this case, there are two hazards; the evaluation is done in two parts, one for each of the hazards, and the total scores are added. Considering just the situation involving the runaway vehicle, the sequence might be as follows:

1. Many vehicles are driven down the hill beside 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 descends the hill. (The hazard-event.)
4. The driver loses his steering control at a point when he is uphill from the tank and moving toward it.
5. The vehicle's brakes fail to stop it from sliding.
6. The vehicle heads directly toward the tank.
7. The vehicle strikes the tank with enough force to rupture it and permit the propane gas to begin to leak.
8. A spark or flame, perhaps from a vehicle fire, ignites the propane.
9. An explosion and conflagration occur.
10. Building and equipment damage is $200,000 and one man is killed.

Here, the consequences involve one fatality and a loss of $200,000. Therefore, $C=25$.

The hazard-event that would start the accident sequence is the truck starting to slide on the road. This has happened "rarely." Therefore, the exposure factor (E) is equal to 1. To decide on the likelihood that the complete accident sequence will follow the occurrence of the hazard-event, consider the probability of each event:

Event 4: The loss of steering control at the precise point in the road approaching the tank is possible but would be unusual.

Event 5: 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.

Event 6: The vehicle heading directly toward the tank is highly unlikely. Momentum would cause the vehicle to continue straight down the road.

Event 7: The likelihood of the vehicle striking the tank with great force, and squarely, is 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 slowly. 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 of it. However, events 8, 9, and 10 are likely to follow if event 7 takes place.

In summary, the highly unlikely nature of most of the events from 4 through 7 gives a net probability of almost "one in a million." It has never happened, but it *is* conceivable. Therefore, $P=0.5$. The calculation for the first risk is:

$$R_1 = 25 \times 1 \times 0.5 = 12.5$$

The second hazard is treated similarly. The list of events is:

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. (The hazard-event.)
3. The pipeline bursts.
4. Metal debris is thrown in all directions by the blast and several pieces strike the propane tank with sufficient force to rupture the tank.
5. Propane starts to leak from 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.

The pipeline hazard would rate a $C=25$. In regard to the hazard-event, high pressure air lines have occasionally been neglected or damaged. The frequency of such occurrences is considered "unusual." Therefore, $E=2$.

An estimate is made of the probability that a damaged pipeline will explode and that the explosion will occur close enough and with enough blast for flying debris to strike the propane tank with great force. Several bursts have occurred in the past years, but none has 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 $P=0.5$. The score for the second risk is then determined.

$$R_2 = 25 \times 2 \times 0.5 = 25$$

Finally, the two risk scores are added:

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

Example no. 4 deals with a less severe but probably more common type of situation. 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 non-sparkproof refrigerators could leak, vaporize, contact electrical sparks, and result in an explosion or fire. The most likely results would be minor injuries and possible damage estimated at $200. The event sequence might be:

1. Various kinds of chemicals are placed and stored in approximately 100 refrigerators. (This is normal practice.)
2. Occasionally flammable volatile solvents are placed in a non-sparkproof refrigerator. (This is a violation of safe practice; the hazard-event.)
3. A solvent container leaks or the cover is not adequately tightened.
4. Fumes reach an electrical spark.
5. Fumes explode and cause $200 damage.

For this situation the consequence rating is set at 5. Since the safety procedure is frequently violated the exposure rating is set at 6. The probability of the accident sequence following the violation and resulting in the accident is considered "remotely possible." Therefore, $P=1$.

This produces the following calculation:

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

Using the above procedures, the risk scores for an additional 22 hazardous situations were calculated. In Table 2, these 26 cases appear in order according to the magnitude of their risk score. This is, in essence, a ranking of hazards in the order of the relative seriousness of their risks. The risk scores are divided into three groups according to the urgency of action required. The positioning of these "action" categories depends on the sound judgment of persons who are knowledgeable about local conditions. Such a locally developed "Risk Score Summary and Action Sheet" is a most useful device. When necessary and advisable, the list can be presented to management for top level awareness and approval of the action column. The beneficial uses of this listing also include the following:

1. It establishes priorities for attention by both safety and management personnel. Hazardous situations appear in the order of their importance. The position on the list for any item may be lowered by corrective action. The corrective action may be directed toward the possible consequences, the exposure, or the probability factor.
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 category in which its risk score falls. In particular, the list would serve as guidance for stopping a job when a highly hazardous situation is noted in an essential operation. If the risk score is above the upper critical line, the job must be stopped until some corrective action can be taken to lower at least one of the three factors to get the score into a less urgent category.
3. The list provides a means of setting goals and objectives for the safety program, other than or in addition to, those based on accident statistics. For example, a safety program can be rated or safety accomplishment demonstrated by the number of cases for which corrective action has been taken, resulting in the cases being 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 given time.

With reference to Table 2, and all of the examples used, 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 originated. Most of the severe cases were selected for expediency from previous

TABLE 2

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 non-sparkproof 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	

years' experience, were hypothetical, or combined experience and hypothesis. It is recommended that potential users of this system compile workable lists as soon as possible from their past experience. It is helpful to generate hypothetical (but reasonable) situations to be used as guidance for comparative evaluation of new hazards as they occur.

COST JUSTIFICATION

Once a hazard has been recognized, appropriate corrective action must be tentatively planned and its cost estimated. A slight expansion of the formula used to determine risk scores can be used to measure "justification"; i.e., to determine if the estimated cost is justified. The formula is:

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

C, E, and P refer to consequences, exposure, and probability as before; CF and DC refer to *cost factor* and *degree of correction*. The cost factor is a measure of the estimated dollar cost of the proposed corrective action. Factor 4 in Table 1 gives the values and their respective ratings. The degree of correction is 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. The estimate will be based on experience and knowledge of the activity concerned. The classification and the associated ratings appear in Table 1 as Factor 5. They range from slight effect on the hazard to total elimination (100%).

When the required values are obtained, they are placed in the formula to determine the numerical value of a countermeasure's justification score. For any justification score of 10 or *more*, the expenditure will be considered justified. For a score *less* than 10, the cost of the contemplated corrective action is not justified. This "critical justification score" has been arbitrarily set at 10, but is based on experience, judgment, and the current budgetary situation. Extended experience at a particular organization may dictate elevation or lowering of the critical score. Accident experience, local budgetary situations, and a general appraisal of the organization's safety status would enter into such a change.

EXAMPLES OF JUSTIFICATION SCORES

The same examples used to illustrate the calculation of risk scores can serve here as well.

Example no. 1 involved the hazard of pedestrians and vehicles using the same roadway. A possible corrective action to reduce this risk would be the construction of a sidewalk alongside the road. The estimated cost is $1,500. The J formula is then used to determine whether this expenditure is justified. The C, E, and P components are given in the earlier discussion as 25, 3, and 0.5, respectively. Since the estimated cost is $1,500, $CF=3$. The degree of correction accomplished by building a parallel sidewalk is judged to be at least 75% but not 100%; therefore, $DC=2$. (See Table 1, Factor 5.) The calculations then are:

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

Since J is less than 10, the conclusion is that the cost is *not* justified. It is important to note that the lack of sufficient justification evaluates the situation from the safety viewpoint *only*. Management might feel that there is added justification for morale or other purposes. Additionally, since the risk score is still a substantial 37.5, other less costly corrective measures should be sought. This might include 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.

Example no. 2 involved 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. To determine justification for the expenditure, values for each element in the formula are required. The values of C, E, and P as discussed before are 5, 10, and 6 respectively. The cost of the corrective action is $400, so $CF=2$. The corrective action will reduce the hazard by at least 50%, so $DC=3$. Substituting in the formula:

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

Since J is well above 10, the cost of installing pressure reduction nozzles is strongly justified.

Example no. 3 was concerned with the doubly 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. The values of C, E, and P are set at 25, 1, and 1.5 respectively, with the two hazards combined. Since the cost of relocation is $16,000, $CF=4$. In even the best location available, there remained a remote

TABLE 3

WORKSHEET FOR RISK AND COST JUSTIFICATION CALCULATION

A. Problem: Hazard #________

B. Location: Remedy #________

C. Sequence of events or factors necessary for accident:

1.
2.
3.
4.
5.
6.
7.

D. Formula Factors: Rating

		Rating
C Consequence	________	____
E Exposure	________	____
P Probability	________	____
CF Cost Factor	________	____
DC Degree of Correction	________	____

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

E. Circle one: The estimated cost of corrective action:

is justified is not justified

F. Name________ Date________

possibility of damage to the tank, so $DC = 2$. The *J* formula would then read:

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

Based on the established criteria, the cost of relocation is not justified. It is emphasized that the conclusion reached 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 another less costly corrective action. In this case, 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 risk score and the probability of serious damage to the tank would be considerably lessened at nominal cost.

Example no. 4 related to the hazard of non-sparkproof refrigerators being used for the storage of chemicals. The proposed correction is to place warning signs on all such refrigerators cautioning against their use for storing volatile solvents. The application of such decals along with administrative controls would probably reduce violations by 50 to 75%. Since the cost of warning decals for 100 boxes would be \$87, the following calculation is appropriate:

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

According to the criteria, the cost of the signs is justified. The case requires further review since the effectiveness of the corrective action is set at only 50 to 75%. Before installation of the warning signs, the risk score was 5 x 6 x 1 = 30. After installation, the exposure factor is reduced considerably so that the new risk score (5 x 2 x 1) is equal to 10. This is a relatively low risk, not of an emergency nature, but also not to be completely ignored. Longer range solutions should be considered, such as insuring that only sparkproof refrigerators are purchased in the future and that when repairs are made on a box, it is altered to become sparkproof.

For convenience in undertaking a hazard analysis to determine risk and justification scores, a worksheet appears as Table 3.

In summary, one must state the problem briefly and consider the most likely consequences of an accident related to a specific hazard. Then one must review all factors carefully, preferably on the scene. After listing the actual step-by-step sequence of events that will most likely produce the consequences chosen, a decision must be made as to the most appropriate corrective action. Given this, an estimate of the cost of implementation and a judgment about the degree of correction that will be accomplished are made. When alternative countermeasures are possible, the cost factor and degree of hazard reduction steps are repeated.

The hazard-event, as defined earlier, is specified and its frequency of occurrence is noted. If there is doubt because a value falls between two ratings, select a proportional value in between; i.e., interpolate. To determine the probability rating, consider the likelihood of *each* event in the accident sequence. For example, if two unusual coincidences are required, this could be judged as "remotely possible." Two remotely possible occurrences might be regarded as "conceivably possible." Endeavor to be consistent. Consider *only* the consequences chosen above. If lesser or greater consequences are studied, additional computations must be made since both the consequences and probability ratings will be different. Given all the required values, the risk scores and justification scores can be generated.

When there are alternative corrective measures that have acceptable justification scores, the one that is most desirable from the safety viewpoint is the one that produces the greatest reduction in the risk score. Thus, for each alternative, it is useful to assume that the corrective measures are in effect and then recompute the risk score. Selection of corrective actions may, of course, be influenced by nonsafety considerations such as the size of the investment required, the relative effects on morale, aesthetics, efficiency, convenience, and ease of implementation.

One should not be a slave to the justification formula. A highly hazardous situation may exist for which no corrective action gives an acceptable justification score. In such a case, whatever corrective action is necessary to reduce the risk should be taken, regardless of the justification score. The formula is for *guidance* only, and it pertains *only* to safety justification. Use of the formula should result in significant improvement in some of the methods used by the safety engineering profession, plus substantial monetary savings.