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METHODOLOGICAL FRAMEWORK FOR CONDUCTING A RISK ASSESSMENT STUDY

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ABSTRACT

Scope: This two-phase study presents both a method for recording the potential incident scenarios and the danger sources they originate from as well as a model for calculating the incident scenarios likelihood coefficient L, thus limiting the assessor's subjectivity influence on the results.

Method: In the first part, the associated risk assessment terminology is clarified. Tables of potential hazards, their associated dangers and the resulting potential incident scenarios are presented. All scenarios were linked to three categories of managerial negligence root causes in terms of: (a) health and safety system, (b) communication and (c) enforcement. In the second part, the tools are used to acquire incident field data from actual facilities. The recorded total potential incident scenarios are linked to the immediate, basic and managerial root causes responsible for triggering the incident (cause-event) chain mechanism. Statistical data processing revealed a strong linear relationship between the managerial causes present, the remaining (active) potential incident scenarios and the likelihood of their occurrence, which allows the calculation of both the likelihood coefficient L used in the quantitative risk assessment models as well as the residual risk.

Results: The potential incident scenario table and the questionnaire provided can be used to obtain field data results and an accurate identification of the total number of potential incidents in the great majority of operations. Equations are provided allowing assessors to calculate rather than speculate on the incident likelihood of occurrence directly from the number of total and active incident scenarios identified by the assessor, as well as an estimate on the minimum (non-zero) residual risk.

1. INTRODUCTION

Risk Assessment is the basic tool for calculating the workplace incident probability or risk index R, the analysis of which facilitates the operations safety strategy development. Most of the quantitative risk assessment models used by safety professionals calculate R as a measure of the risk level. This index is usually represented by the simplified probabilistic equation R = F x S x L (Arvanitogeorgos, 1999), where R is the total risk index of a potential incident, S the coefficient expressing the severity of the incident on the human health, F the coefficient expressing the frequency of exposure to the danger and L the coefficient expressing the likelihood of the incident to occur. The values assigned to the likelihood coefficient L widely, if not only, rely on the risk assessor's experience. The proposed model presents a calculation method of the value L based on the total incident scenarios and their respective managerial root cause identification thus limiting the assessor's subjectivity influence on the results (Knox, 2002, Kumamoto, 1996).

Since L represents a probability of an incident or a group of incidents to occur, the risk assessors must be able to identify all the possible incident scenarios to begin with, therefore an effective risk assessment methodology was also developed in order to achieve this goal.

On the other hand, the main focus was kept on the intention to keep this approach simple, practical and useable by most of the risk assessors.

2. INTRODUCTION OF THE TERM UNSAFE MENTALITY BONDING IN THE ROOT CAUSE–EVENT CHAIN MECHANISM

Nobody wants to be involved in an accident; yet accidents happen. Researchers have proven that an accident is the result of a sequence of events that is triggered by an *initiating event*, often linked to poor management practices (Bedford, 2001, Kumamoto et al., 1996, Vose, 2000). Specifically, the root cause-event chain mechanism is: Managerial Causes→Basic Causes→Immediate Causes→Unpleasant Event→Consequences (Bird et al., 1985). Immediate Causes are technically oriented hence first-line-worker sensitive. Basic Causes are less technically oriented; they include management issues as well and are therefore more supervisory-personnel oriented. By applying effective preventive measures at any of the links, the chain is broken and the event does not happen.

However, this mechanism is not a straight line flow chart; actually, the Managerial Causes affect a broader range of Basic Causes which in turn induce a bigger number of Immediate Causes thus creating an environment in which a variety of unpleasant events (incidents) is possible. Therefore, one managerial cause initiates not one, but a number of chain-event mechanisms that may result in more than one incidents (Fig.1).

On the other hand, if managerial measures are fully and effectively implemented no chain-event mechanism can be initiated. The closer to the potential incident the recommended measures (squares in Fig.1) are implemented, the less number of events they affect. However, there is always the probability that, in spite of the fact that the specified safety measures exist, an incident may still occur because of human misbehavior. This is a result of the fact that (a) the human brain perceives its surroundings collectively and holistically and acts accordingly; (b) there is always an uncertainty in the human behavior, which depends on non-measurable factors (Renn, 1998).

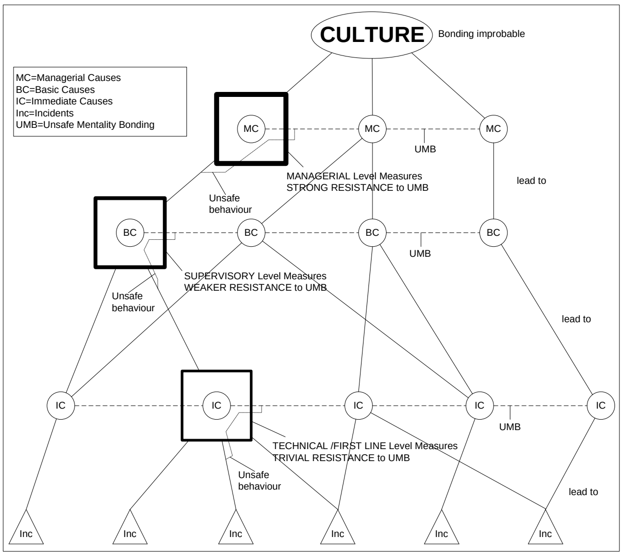

Figure 1: The root cause-event chain mechanism and the effect of Unsafe Mentality Bonding (UMB) depicted by the horizontal dotted lines

The workforce adopts unsafe practices that penetrate the adopted measures thus rebuilding the chain links that may re-initiate the cause-event mechanism making an incident finally occur (dotted lines in Fig.1). The problem for the business is that this phenomenon is not readily identifiable because the cause-event sequence follows an "unexpected" path i.e. the incident but not for reasons that would normally be expected: the research showed that workers, in spite of the fact they could identify the hazards and were capable of applying the necessary safety measures, they tended to adopt an *overall* unsafe behavior by defying safety practices because other workplace conditions were not as safe as they should be; so a worker would not put back a machine guard after repair or maintenance not because he did not know this is the standard practice, but because the working area had no air conditioning, or a supervisor would not enforce wearing safety shoes because of the workload of a demanding working environment. The authors propose the term *Unsafe Mentality Bonding, UMB,* (horizontal dashed lines in Fig.1) to describe the behavior of a worker who may ignore the measures because of his total perception of the management's general attitude or of the working environment safety and not because he was is not aware of danger, an issue which is raised by researchers (Dekker, 2002, Howe, 2000, Miller et al., 1987, Vrendenburgh, 2002). This phenomenon is easily identifiable in comments of employees of the type "Keeping machine guards in place is the least of my problems; don't you see there is no air conditioning here?", or, "We work under extreme stress, I cannot demand from my workers to wear safety shoes." These comments were very frequent during the research.

Also, an incident probability is time dependent. Measures reduce the accident probability but only temporarily, since UMB builds up immediately after their initial application, reinstating the risk to higher levels. Since mentality is involved in the process, managerial measures are more effective in the sense they are more time-resistant. Measures related to immediate and basic causes are mainly technical and less managerial, therefore less time effective. Managerial measures resist UMB more effectively (bolder rectangle lines in Fig.1).

3. INCIDENT PROBABILITY

Thus far, the calculation of the event probability has been mainly limited to calculating the probability of a specific accident. In practice however, the vast majority of businesses are interested in preventing *all* accidents *at all times*. Anyway, the legal framework demands just that. It is of no real value to a business to focus only on applying a specific top priority group of measures i.e. in their chemical processes and experience a fatality in the warehouse or a serious injury in the offices.

In the following, a method is presented for the calculation of the likelihood of any incident due to the inevitable presence of managerial causes namely mistakes and omissions at managerial level since researchers agree that managerial measures is the only way to effectively reduce incidents (Laios et al., 2003, Smith et al., 1987, Topf, 1987, Vrendenburgh, 2002).

The risk index R is directly proportional to the incident likelihood L. Values can be easily assigned to the coefficients F and S as they depend on measurable process-dependent parameters, whereas, L expresses the probability of worst case consequence event i.e. when no measures are present hence depending solely on behavior as mentioned in standard EN 1050:1997. In any case, in order to assign values to these coefficients, an effective Risk Assessment Study is of imperative importance.

4. THE RISK ASSESSMENT PROCESS

The objective of a Risk Assessment Study is to propose effective preventive measures to break the cause-event chain mechanism before an incident occurs. In order to achieve this, the risk assessor must work on the chain in reverse, which means forecast the event, identify the causes and propose related measures.

There is no universal approach for conducting a Risk Assessment Study. On the contrary, there are several models used by professionals and scientists that largely depend on the assessors' experience, perception or opinion. The models are either too simple or too complicated to be applied in most of the operations.

For the past 20 years, the following Risk Assessment methodological framework has been applied to hundreds of business operations with excellent results; it succeeded in either preventing or investigating numerous incidents by identifying managerial incident causes and recommending appropriate managerial measures.

4.1 Analysis of the incident mechanism

When a business activity is developed, the workforce operates within a working environment transforming the raw materials into the product as shown in Figure 2.

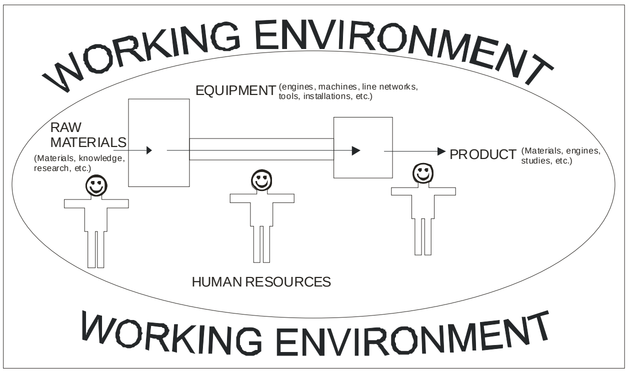

Figure 2: Interaction of Working Environment-Raw Materials-Hardware with the Workforce

In the broad sense of all business activities, Raw Materials and Products may be abstract concepts like knowledge, ideas or studies, which cover research or service operations, Hardware may include machinery, equipment, transport lines, tools etc. while the Human Resources include employees, visitors, contractors and any other person that could be affected by the operations.

A business operation is sustained through the interaction of all its constituents that must function under specific requirements in the form of specifications, rules, procedures, guidelines etc. Violation of the above may initiate an event sequence that usually has unpleasant consequences on the human resources as shown in the flowchart of the Fig.3.

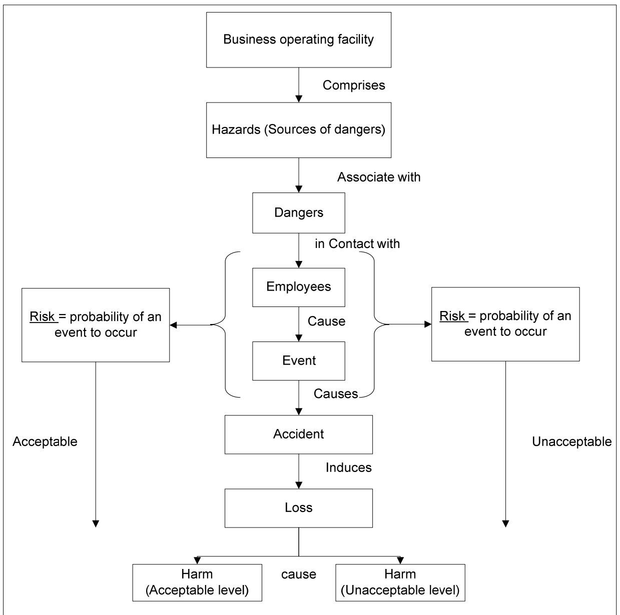

Figure 3: Event-sequence flowchart resulting in an unpleasant incident

A combination of the above concepts of Figures 2 & 3 is presented in Figure 4 in which it is depicted how the workforce may come to contact with the activity's operational hazards if the protective measures, represented by the dotted line, are violated. In order for an unpleasant incident to occur, uncontrolled energy has to be released; the danger entailed in the hazard sources of a working environment is actually their property that allows energy release; protective measures are used to direct the released energy in a controlled manner; failure to do so results in uncontrolled energy release which, if it contacts the workforce, may result in an accident with health consequences of varying degree.

For example, *death (consequence)* may be the result of an electrocution *(unpleasant event)*, as a result of the contact of a worker's body part *(protection failure)* with metallic elements *(hazard)* that were under voltage *(danger)*, while a *scorched skin (different consequence)* may be the result of a burn *(different unpleasant*

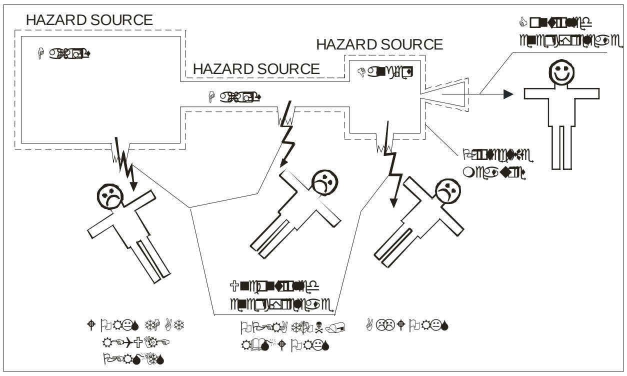

Figure 4: Adverse Interaction among Working Environment-Raw Materials-Hardware with the Workforce during a business operation

event), as a result of the contact of a worker's body part *(same protection failure)* with metallic elements *(same hazard)* that were under high temperature *(different danger).*

Of course, such an event may or may not take place depending on the measures taken and the effectiveness of their implementation.

4.2 Clarifications on the risk assessment terminology

For most of the risk assessors the risk assessment terminology poses a huge burden as bibliography lacks consistency in the interpretation of the various terms. The terms *hazard, danger, risk, accident, consequence* as well as the *causes* are often confused and misused. The problem is mainly an issue of agreeing on the terms interpretation. To avoid this confusion, the following terminology should be adopted:

Hazard (or) Danger source: Any hardware in a workplace environment i.e. raw material, hardware, working environment conditions and human behavior.

Danger: The hazardous property associated with the hazard

Risk: The probability of an incident to happen

Incident: An unpleasant event as a result of the business operations

Incident scenario: A foreseen unpleasant event

Potential incident scenario: An incident scenario that can happen in the operation under study and can be recognized by the risk assessor

Active incident scenario: A potential incident scenario that will definitely happen in due course because the recommended by the risk assessment study measures are not fully or consistently implemented

Latent incident scenario: A potential incident scenario that is not expected to happen because all the measures recommended by the risk assessment study are fully and consistently implemented

Consequence=Loss: The psychosomatic health degradation of any human being potentially present at the workplace or property damage

Therefore, the workplace hazards and the associated dangers cannot be eliminated, but only contained by effectively applying measures, resulting in risk minimization which asymptotically tends to zero.

4.3 Necessary data requirements to conduct an effective risk assessment study

The above line of thinking leads to the conclusion that the following elements are necessary in order to conduct an effective risk assessment study:

- Hazard identification
- Danger identification per hazard
- Possible incident scenario identification per danger
- Recommended measures per scenario i.e. per hazard

4.4 Identification of Hazards, Dangers, Incident Scenarios and their association

After 17 years during which hundreds of workplace risk assessment studies were conducted by the author, the following comprehensive lists of hazards, dangers and possible incident scenarios were produced as shown in the first three columns of Table 1, while in the fourth column is presented the hazard–danger–potential incident scenario association which yielded as a direct outcome of incident investigations, employee interviews and the author's experience.

Table 1: Workplace hazards – danger – potential incident scenarios lists and their association

Hazards	Dangers	Possible Incident Scenarios	Association of Hazards – Dangers – Potential Incident Scenarios
1. Floor	i. Slipperines	A. Slipping	1. i, iii, vii – A, A+B, A+C, A+E
2. Objects on floors	ii.Obstruction of movement	B. Falling at (the same level)	2. ii,iii,vii – D, D+B, D+C, D+E
3. Hot/ frozen objects	iii.Temperature extremes	C. Bumping, knocking into, hitting against	3. iii – E
4. Floor elevations/ openings	iv. Height difference	D. Tripping	4. iv – B, F, L
	v. Reactivity	E. Contacting/ touching	
5.Chemical substances	vi.Motion/inertia	F. Falling from/ to (a different level)	5. v–E, G, H, I, J, M, N
6. Fixed equipment	vii. Sharpness (point or edge)	G. Inhalation	6. ii, iii, vi, vii, viii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xxiv – C, E, J, K, L, M, N, Q
		H. Swallowing/ digestion	
7. Portable equipment	viii. Particle release	I. Fire	7. ii, iii, vi, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xxiv – C, E, J, K, L, M, N, Q
	ix. Tension	J. Explosion	
8. Transport lines	x. Weight	K. Entrapment	8. ii, iii, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi – C, E, J, L, M, N
	xi. Pressure	L. Hit/ struck by	
9. Structural elements	xii. Vacuum	M.Infection/ contamination by	9. ii, iii, vi, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xxiv – C, E, J, K, L, M, N
	xiii. Noise		
10. Vehicles	xiv. Invisibility	N.Exposure to	10. ii, vi, vii, viii, ix, x, xi, xii,

	xv.Radiation	O. Overexertion	xiii, xiv, xv, xvi, xxiii, xxiv – C, E, J, K, L, N, Q
11. Loads (moving and stationary)	xvi.Voltage difference	P. Working under/ with	11. ii, iii, vii, x, xiv, xxix, xxx – C, E, K, L, N, O, Q
12. Confined spaces	xvii.Asphyxiating atmosphere	Q. Crushed by/ under/ between	12. i, ii, iii, v, vi, vii, xi, xii, xiii, xv, xvi, xvii, xviii, xix, xx, xxi, xxii – C, E, K, L, M, N
13.Fine-grain materials	xviii. Humidity		13. xxii, I
14. Live stock/ pests	xix.Insufficient ventilation/ odors		14. xx – E, M
15. Micro-organisms	xx. Infectiousness		15. xx – E, M
16. Air quality & conditioning	xxi.Insufficient lighting		16. iii, v, xxiii, xv, xviii, xix, xx, xxi, xxiii, xxiv - N
17.Working environment ergonomics	xxii. Low density		17. ii – C, E, K, L, P
18. Work type	xxiii. Air draught		18. xxv, xxvi, xxvii, xxviii – O, P
19. Heat source/ combustibles combination	xxiv. Vibration		19. iii, v – I, J
20. Behavior	xxv.Lack of movement		20. Not applicable – All cases A-Q
	xvi. Repetition		
	xvii.Stressfulness/ workload		
	xviii. Work relations		
	xix. Storage/ transport height		
	xxx. Center of gravity position		

4.5 Identification of the Incident Causal Factors, the Protective Measures and their association

Managerial, Basic and Immediate Causes are explicitly listed in the ANSI Z16.2 standard. This tool was used in hundreds of incident investigations and a more comprehensive version is presented in Table 2. This list is nevertheless not complete in the sense that for specific operations very special root causes can be added in the immediate cause list.

Table 2: Immediate, Basic and Managerial cause list

A. Immediate Causes

UA. Unsafe Acts	UC. Unsafe Conditions
UA1. Acting without authorization	UC1. Guards out of place
UA2. Acting without personnel warning	UC2. Insufficient guarding
UA3. Guard bypassing	UC3.Insufficient working space
UA4. Lockout Tagout violation	UC4. Insufficient access
UA5. Improper material handling	UC5. Heat/ ignition sources
UA6. Non-use of equipment	UC6. Unexpected movement
UA7. Use of defective equipment	UC7. Protruding parts
UA8. Misuse of equipment	UC8. Unstable material storage
UA9. Non-use of Personal Protective Equipment	UC9. Insufficient equipment
UA10. Use of defective Personal Protective Equipment	UC10. Defective equipment
UA11. Misuse of Personal Protective Equipment	UC11. Insufficient work area demarcation
UA12. Improper manual handling	UC12. Insufficient equipment/ installation demarcation
UA13.Maintenance of machinery/ equipment in motion	UC13. Insufficient material labelling
UA14. Maintenance of electrical machinery/ equipment under voltage	UC14. Insufficient Lockout - Tagout
UA15. Rules violation	UC15. Improper working outfit/ jewellery
UA16. Bantering	UC16. Improper-insufficient PPE
UA17. Working under influence	UC17. Insufficient lighting
UA18. Repetitive motion	UC18. Insufficient air conditioning
UA19. Improper working posture	UC19. Vibration
UA20. Overexertion	UC20. Insufficient housekeeping

B. Basic Causes

WM. Wrong Motive	PF. Personal Factors	OF. Occupational Factors
WM1. Saving time (hastiness)	PF1. Lack of knowledge-skills	OF1. Insufficient job specifications
WM2. Saving effort	PF2. Lack of attention - focus	OF2. Insufficient design
WM3. Seeking ease, comfort	PF3. Familiarization with danger	OF3. Insufficient maintenance
WM4. Attract attention		OF4. Normal wear
WM5. Display independence		OF5. Abnormal wear
WM6. Seeking approval		OF6. Insufficient equipment
WM7. Express hostility		
WM8. Seek financial rewards		

C. Managerial Causes

M1. Insufficient programming
M2. Lack of programming
M3. Insufficient specifications - programming - procedures

M4. Lack of specifications-programming-procedures
M5. Insufficient training
M6. Lack of training
M7. Insufficient enforcement
M8. Lack of enforcement
M9. Insufficient know-how
M10. Lack of know-how

In order for an incident to take place the chain must be initiated, which in turn means that all incidents are due to at least one managerial cause from the list. The interesting fact is that any of the managerial causes may initiate any of the potential incident scenarios. However, not all immediate or basic causes lead to all types of incidents. Using the incident investigations conducted as well as the incident recall method, Table 1 was expanded to include the association among the Hazards – Dangers and Potential Incident Scenarios to include the Causal Factors. The result is depicted in Table 3.

Table 3: Workplace Hazards – Potential Incident Scenarios – Causal Factors association

Hazards	**Association of Hazards with the Dangers and Potential Incident Scenarios**	**Associated Immediate Causes (Table 2)**	**Associated Basic Causes (Table 2)**	**Associated Managerial Causes (Table 2)**
1. Floor	i, iii, vii – A, A+B, A+C, A+E	UC11,12,13,16,19,20 UA1,25,6,7,8,9,10,11,15, 16,17,18,20	WM1,2 PF1,2,3 OF1,2,3,4,5,6	
2. Objects on floors	ii,iii,vii – D, D+B, D+C, D+E	UC3,4,6,7,8,11,12,13,15, 16,17,20 UA1,12,15,16,17	WM1,2,3 PF1,2,3 OF1,2	
3. Hot/ frozen objects	iii – E	UC1,2,3,4,5,6,7,9,10,11, 12,13,14,16,17,18,20 UA1,2,3,4,5,9,10,11,15	WM1,2,3,4 PF1,2,3 OF1,2,3,4,5,6	
4. Floor elevations/ openings	iv – B, F, L	UC3,4,6,7,8,10,11,15,16, 17,19,20 UA1,2,3,6,7,8,9,10,11,14, 15,16,17,19,20	WM1,2,3,4,5, 6 PF1,2,3 OF1,2,3,4,5,6	
5. Chemical substances	v – E, G, H, I, J, M, N	UC1,2,3,4,6,8,9,10,11,12, 13,14,15,16,17,20 UA1,2,5,6,7,8,9,10,11,15, 16,17	WM1,2 PF1,2,3 OF1,2,6	
6. Fixed equipment	ii, iii, vi, vii, viii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xxiv – C, E, J, K, L, M, N, Q	UC1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17,19,20 UA1,2,3,4,13,14,15,16, 17	WM1,2,3,4,5, 6,7,8 PF1,2,3 OF1,2,3,4,5,6	All cases M1-M10

7. Portable equipment	ii, iii, vi, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xxiv – C, E, J, K, L, M, N, Q	UC1,2,3,4,5,6,7,8,9,10, 11,12,14,15,16,17,19,20 UA1,2,3,4,6,7,8,9,10,11 15,16,17	WM1,2,3,4,5, 6,7,8 PF1,2,3 OF1,2,3,4,5,6
8. Transport lines	ii, iii, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi – C, E, J, L, M, N	UC1,2,3,4,5,7,9,10,11,12, 13,14,15,16,17,18,19,20 UA1,2,3,4,6,7,8,9,10,11, 14,16,17	WM1,2,3,4,5, 6,7,8 PF1,2,3 OF1,2,3,4,5,6
9. Structural elements	ii, iii, vi, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xxiv – C, E, J, K, L, M, N	UC1,2,3,4,5,6,7,9,10,11, 12,14,15,16,17,19,20 UA1,2,3,4,6,7,8,9,10,11, 13,14,15,16,17	WM1,2,3,4,5, 6,7,8 PF1,2,3 OF1,2,3,4,5,6
10. Vehicles	ii, vi, vii, viii, ix, x, xi, xii, xiii, xiv, xv, xvi, xxiii, xxiv – C, E, J, K, L, N, Q	UC1,2,3,4,5,6,7,8,9,10, 12,13,14,15,16,17,18,19, 20 UA1,2,7,8,9,11,12,16,7	WM1,2,3,4,5, 6,7 PF1,2,3 OF1,3,4,5
11. Loads (moving and stationary)	ii, iii, vii, x, xiv, xxix, xxx – C, E, K, L, N, O, Q	UC3,4,5,6,7,8,9,10,11,12 13,14,15,16,17,19,20 UA1,2,5,6,7,8,9,10,11,12, 15,19,20	WM1,2,3,4,5, 6,7 PF1,2,3 OF1,2,3,4,5,6
12. Confined spaces	i, ii, iii, v, vi, vii, xi, xii, xiii, xv, xvi, xvii, xviii, xix, xx, xxi, xxii – C, E, K, L, M, N	UC3,4,5,6,7,9,10,11,12, 13,15,16,17,18,19 UA1,2,4,6,7,8,9,10,11,15 17	WM1,2,3,4,5, 6,7,8 PF1,2,3 OF1,2,3,4,5,6
13. Fine-grain materials	xxii, I	UC1,2,3,4,6,9,10,11,12, 13,16,17 UA1,2,4,5,6,7,8,9,10,11, 15,16,17,19	WM1,2,3 PF1,2,3 OF1,2,3,4,5,6
14. Live stock/ pests	xx – E, M	UC9,10,12,13,16,20 UA15,16	WM4,6,7 PF1,2 OF1
15. Micro-organisms	xx – E, M	UC1,2,9,10,11,12,13,16, 18,20 UA1,2,5,6,7,8,9,10,11,151 6,17	WM1,2 PF1,2,3 OF1,2,6
16. Air quality & conditioning	iii, v, xxiii, xv, xviii, xix, xx, xxi, xxiii, xxiv - N	UC3,4,5,6,7,8,9,10,11,121 5,17,18,19,20 UA6,7,8,12,15,18,19,20	WM1,2,3,4,5, 6,7,8 PF1,2,3 OF1,2,3,4,5,6
17. Working environment ergonomics	ii – C, E, K, L, P	UC3,4,5,6,7,8,12,20 UA12,15,18,19,20	WM1,2,3,4,5, 6,7,8 PF1,2,3 OF1,2,3,4,5,6

18. Work type	xxv, xxvi, xxvii, xxviii – O, P	UC3,4,9,10,11,12,13,15, 17,18,19,20 UA6,7,8,12,15,18,19,20	WM1,2,3,4,5, 6,7,8 PF1,2,3 OF1,2,3,4,5,6
19. Heat source/ combustibles combination	iii, v – I, J	UC5,8,9,10,11,12,13,20 UA1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16,17,18,19,20	WM1,2,3,4,5, 6,7,8 PF1,2,3 OF1,2,3,4,5,6
20. Behavior	Not applicable – All cases A-Q	UC1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15 UA1,2,3,4,5,6,7,8,9,10, 11,12,13,14,15,16,17,18,19,20	WM1,2,3,4,5, 6,7,8 PF1,2,3 OF1,2,3,4,5,6

Managerial Causes were then classified into three major categories and corresponding recommended measures were linked to each category as shown in Table 4, namely:

- Partial or total lack of health & safety system
- Partial or total lack of internal communication techniques
- Partial or total lack of managerial enforcement

Table 4: Incident Managerial Causes and corresponding recommended measures

Managerial Causes Classification	**Corresponding measures**
M1. Partial or total lack of a Health & Safety System	1S. Written policies, procedures, guidelines, rules, safe methods of work and action planning for continual improvement
M2. Partial or total lack of internal Communications	2C. Training, meetings, verbal & non-verbal internal communication techniques
M3. Partial or total lack of a managerial enforcement	3E. Continuous safety supervision, auditing, & follow-up on the implementation of the above

5. INCIDENT LIKELIHOOD COEFFICIENT CALCULATION METHODOLOGY

Following the reasoning of the previous sections, the likelihood of an incident can be expressed as:

$P_{i,incident}=(P_{active\ incident\ scenarios}/P_{max\ potential\ incident\ scenarios})_{i,}$

where i represents different risk level. It was chosen to classify business operations into 6 risk level categories, i=1-6, as follows:

1=very low risk (offices and their support areas)

2=low risk (production support areas)

3=medium risk (production areas)

4=high risk (production areas)

5=medium risk (warehouse areas)

6=medium to high risk (technical areas

5.1 Data collection specimen and the incident recall method

The data was collected from 10 major industrial facilities that included operations from all 6 categories. The specimen included the examination of 6,044 potential incident scenarios as a result of 12,039 managerial, 28,568 basic and 37,341 immediate causes.

With the aid of the Tables 1&3, interviews were conducted with 539 employees of all hierarchy levels. During the interviews the incident recall method was extensively applied. (Bird, 1985) The author's experience as well as incident records were also taken into account to identify per category and to the best extent possible, all potential incident scenarios PS_i which were then associated to the seven possible combinations of the three categories of managerial factors $M_{s,i}$, $M_{c,i}$, $M_{e,i}$, $M_{s,i}/M_{c,i}$, $M_{s,i}/M_{e,i}$, $M_{s,i}/M_{e,i}$ and $M_{s,i}/M_{c,i}/M_{e,i}$, where $M_{s,i}$ was the number of managerial causes related to lack of a health & safety system, $M_{c,i}$ the number of managerial causes related to lack of communications and $M_{e,i}$ the number of managerial causes related to lack of managerial enforcement. If M_i is the total number of managerial causes for category i, then: $M_i=M_{s,i}+M_{c,i}+M_{e,i}$

A table was produced that depicted the distribution of the number potential incident scenarios PS_i with respect to the possible managerial causes combination that could induce the scenarios.

The results were statistically analyzed per risk category to establish the correlation between the number of managerial causes present in each of the three categories with the number of active incident scenarios that they could induce AS_i.

5.2 Managerial Cause statistical analysis

The statistical analysis performed showed that, for each risk category i=1-6, there is a strong linear relationship between the number of active incident scenarios AS_i and the number of managerial causes of each category, given by a linear equation. Hence:

$AS_i=f\{M_{s,i}, M_{c,i}, M_{e,i}\} \rightarrow AS_i = C_i + D_i* M_{s,i} + E_i* M_{c,i} + F_i* M_{e,i}$

While the statistical analysis of the data collected produced the following equations:

$AS_1= 2.43-0.021*M_{s,1}+0.212*M_{c,1}+0.976*M_{e,1}$

$AS_2= 0.91-0.327*M_{s,2}+1.558*M_{c,2}+0.852*M_{e,2}$

$AS_3= -3.35+2.390*M_{s,3}+1.376*M_{c,3}+0.308*M_{e,3}$

$AS_4= 5.38+1.270*M_{s,4}+0.043*M_{c,4}+0.041*M_{e,4}$

$AS_5= 1.92+0.735*M_{s,5}-0.250*M_{c,5}+0.552*M_{e,5}$

$AS_6= -2.38+0.729*M_{s,6}+0.038*M_{c,6}+0.577*M_{e,6}$

The probability of any incident occurring in a business operation, if managerial measures are not fully and consistently implemented is then calculated as the ratio:

$P_i = AS_i / PS_i$ or

$P_i = [C_i + D_i * M_{s,i} + E_i * M_{c,i} + F_i * M_{e,i}] / PS_i$

while the coefficient L_i of a risk assessment model can be calculated as $L_i = P_i * L_{max}$ where L_{max} is the maximum value assigned to L by the selected model.

An assessor is expected to identify all the PS_i's, by ignoring the measures being taken, attributed to a combination of all possible managerial causes whether the respective managerial measures are implemented or not. Then, the distribution of managerial causes can be fed into the equations to yield the AS's this distribution yields; the ratio (incident probability which expresses the probability of any of the AS_i's to happen) $P_i = AS_i/PS_i$ should then be close to 1 implying an 100% probability of all potential scenarios to be active thus to happen in the future; in time and while the managerial causes are fully and efficiently implemented, the number of AS_i's drops and therefore the ratio AS_i/PS_i becomes less than 1. In an initial risk assessment all PS_i's must be identified and checked against the number of AS_i's; if in this initial risk assessment there is a deviation between the two numbers then this implies that either the identified PS_i's were not linked to a sufficient number of managerial causes to begin with or the a lot of the scenarios are of extremely low probability. At a later stage, if some of the managerial measures are implemented then the numbers $M_{s,i}$,$M_{c,i}$ and $M_{e,i}$ drop, therefore the AS_i's the equations yield drops thus reducing the AS_i/PS_i ratio; in this case a low probability implies that a large number of managerial measures were effectively implemented.

5.3 Examples

A risk assessor conducts a risk assessment at a category 6 facility; he identifies PS_6=40 potential incident scenarios that can be attributed, according to the assessor, to M_6=65 managerial causes analyzed as follows: $M_{s,i}$=20 attributed to lack of safe methods of work and procedures including action planning, $M_{c,i}$=15 attributed to lack of training and safety meetings and $M_{e,i}$=30 attributed to lack of enforcement methods like auditing, management review, safe behaviour observations etc. By applying these numbers to the corresponding for i=6 equations in 4.2, the number of active incident scenarios is calculated to be AS_6=30,8 meaning that out of the 40 potential incident scenarios the 31 are active and may result in an incident. In this case, the probability of any incident is 31/40=77% while the rest are latent.

If another risk assessor conducts a risk assessment at a category 6 facility and identifies PS_6=200 potential incident scenarios attributed to again M_6=65 managerial causes with the same distribution, then AS_6 remains =30,8 whence the probability of an incident drops to 15,5%, implying that either the identification of managerial causes is insufficient or several measures have been implemented thus reducing the incident probability.

If another risk assessor conducts a risk assessment at a category 5 facility that has taken absolutely no measures and identifies PS_5=41 potential incident scenarios attributed to M_5=76 managerial causes distributed to $M_{s,5}$=27, $M_{c,5}$=12 and $M_{e,5}$=37 causes, the corresponding equation will yield $AS_{5=}$39 active incident scenarios, which means that 2 of the identified scenarios are not likely to happen and could be omitted based on the available data.

6. RESULTS

6.1 Application field

The statistical analysis yielded that the probability P_i varies between 2-5 and 100% for all risk categories i=1-6.

Also, the equations are accurate within a specific value range of the three categories of managerial causes $M_{s,i}$,$M_{c,i}$,$M_{e,i}$. However, this range varies from 101-2289 (maximum values), which means that the specimen was large enough to cover most business operations.

6.2 Immediate causes

The contribution of the number of unsafe acts with respect to the number of unsafe conditions is 3:2.

The most contributing to accidents unsafe condition is the lack of housekeeping (34%).
The most contributing to accidents unsafe act is the employee non-conformance to safety rules (57%).

6.3 Basic causes

The contribution of the number of wrong motives with respect to the number of personal factors and operational factors is 3:4:3.

The most contributing to accidents wrong motivation factor is hastiness (48%).
The most contributing to accidents personal factor is the employee familiarization with danger (79%).
The most contributing to accidents operational factor is the lack of safe methods of work (66%).

6.4 Effectiveness of managerial measures

Implementation of isolated managerial measures has minimal contribution to incident prevention (health & safety system 10%, training 8%, enforcement 16%).

The most effective combination of managerial measures is the implementation of a health & safety system along with its enforcement contributing to incident prevention from 45-66%.

7. CONCLUSIONS

The proposed methodology provides all the required data for the execution of an effective Risk Assessment Study. The tools provided are simple, practical and easy to familiarize with; they do not require software support and can be used in a wide range of business operations.

If the tools provided are used by an experienced assessor in combination with employee involvement and incident recall, the incident likelihood coefficient can be easily calculated.

The probability of an incident can never be zero, the residual risk varying from 2-5% mainly because of the involvement of the unsafe mentality bonding.

The contribution to accidents of the unsafe acts with respect to unsafe conditions presented in similar studies appears overrated in relation to the results of this study.

Housekeeping is a top priority issue that all business operations must address. The implementation of a 5S system would definitely facilitate this effort

The development of safe work methods is imperative especially for non-everyday jobs. A job safety analysis must be conducted in these cases.

The probability of an incident is directly related to managerial causes. To establish this relation the risk assessor must be able identify the maximum potential incident scenarios and to associate them with the corresponding managerial causes.

The tools provided do not eliminate the need for the assessor’s experience, but they restrict it to a smaller degree thus enhancing objectivity.

Training acts only as a catalyst; it is only effective in combination with other managerial measures.

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