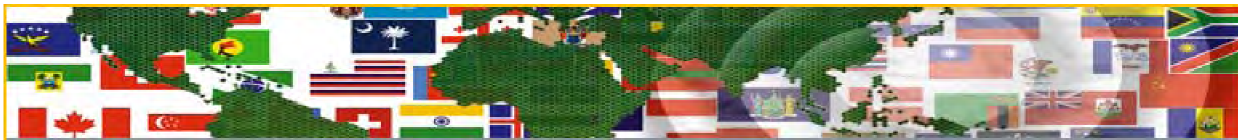

International System Safety Regional Conference 2008

ISSRC 2008

23 – 25 April 2008
Singapore

From Qualitative towards Quantitative Assessment in Risk Management

N. Krishnamurthy
Safety Consultant and Trainer, Singapore

ABSTRACT

Occupational risk is commonly assessed by a qualitative risk matrix wherein a qualitative estimate of risk is derived from three or more levels of likelihood of occurrence and severity of consequence of various hazards charted in tabular form, with the levels designated according to word descriptions of probability and impact for each level. This leads to vagueness and ambiguity of classification of real-life hazards, and limits the effective use of qualitative risk assessment in decision-making by the management.

Author contends that with most qualitative definitions of levels some quantification is already implied and/or is invoked to decide the level, and that this quantification — now thrown away after qualitative classification — can be retained in subsequent analysis increasing the usefulness of the risk assessment.

Specifically, he demonstrates how qualitative judgements on likelihood and severity can be converted into quantitative assessments and subsequently used to quantify risk. The 10-point scales proposed in the paper can have wide global applications, paving the way for developing a uniform standard for risk assessment in various enterprises around the world.

Keywords: Risk assessment, risk management, risk matrix, qualitative, quantitative, likelihood and severity scales.

Paper presented at Session 12 : Mishap Risk Assessment/Management (2), 24 April 2008, 14.50-15.30

From Qualitative towards Quantitative Assessment in Risk Management

N. Krishnamurthy, Ph.D.; Safety Consultant and Trainer; Singapore

Abstract

Occupational risk is commonly assessed by a qualitative risk matrix wherein a qualitative estimate of risk is derived from three or more levels of likelihood of occurrence and severity of consequence of various hazards charted in tabular form, with the levels designated according to word descriptions of probability and impact for each level. This leads to vagueness and ambiguity of classification of real-life hazards, and limits the effective use of qualitative risk assessment in decision-making by the management.

Author contends that with most qualitative definitions of levels some quantification is already implied and/or is invoked to decide the level, and that this quantification – now thrown away after qualitative classification – can be retained in subsequent analysis increasing the usefulness of the risk assessment.

Specifically, he demonstrates how qualitative judgements on likelihood and severity can be converted into quantitative assessments and subsequently used to quantify risk. The 10-point scales proposed in the paper can have wide global applications, paving the way for developing a uniform standard for risk assessment in various enterprises around the world.

Keywords: Risk assessment, risk management, risk matrix, qualitative, quantitative, likelihood and severity scales

Introduction

With no consensus or global standards on risk assessment formats in different enterprises in various countries, there is no common yardstick or benchmark to evaluate the safety performance in hazardous activities. Equally important is the lack of precision of the terminology and definitions of safety parameters for assessors, which results in very subjective and widely variable risk assessments.

The present paper proposes a technique to enable risk assessors to develop definitive and universally recognisable measures of likelihood and severity of mishaps and losses, and hence to better evaluate risks and implement controls. In due course the database from this method will hopefully enable smooth and seamless integration of worldwide statistics and thus improve occupational safety on a global scale.

Risk Matrix

Risk assessment deals with the identification of hazards and the evaluation of the magnitude of the risks associated with such hazards. Typically most risk assessment methodologies consider risk (R) to be a function of a number of independent parameters, mainly likelihood (L) (or 'Probability' or 'Frequency') of occurrence of a mishap, and severity (S) (or 'Impact') of its consequence. The general practice in risk assessment is to tabulate the job steps and associated hazards, and assign qualitative or numerical levels, or quantitative values to L and S, which are then combined into risk levels R, and then categorised.

To aid in evaluation and decision-making, the L, S, and R levels or values may be marked on a "risk matrix" (i.e. a table of risk values) with L and S levels along the horizontal and vertical axes (or vice versa), as in figure 1. Then, any combination of L and S may be located in the table as the intersection of appropriate row and column.

Likeli-hood↓	Severity		
	Low	Medium	High
High	Medium	High	High
Medium	Low	Medium	High
Low	Low	Low	Medium

Figure 1 – 3×3 Risk Matrix

Commonly, m likelihood levels and n severity levels are

978-981-08-0446-6/08/© 2008 RPS

defined qualitatively by generic descriptions or quantitatively by actual (or relative) values. The (m.n) combinations of L and S define the status of all possible risks in the defined domain. The risk matrix provides a visual representation of the risk level within the spectra of the three variables from their lowest to highest levels. It is a common technique which facilitates management policy for risk categorisation and control implementation.
There should be a minimum number of three levels but the maximum is quite variable, from 3 to 10 or more depending on the distinctive number of component levels that can be uniquely defined and the resources available. Five levels seem to be widely accepted. American Petroleum Institute (ref. 1) and American Society of Mechanical Engineers, among many other authorities, recommend the 5×5 matrix.

It would be best for universal use to set the lowest likelihood or severity levels at the left end of rows and bottom end of columns. Then risk increases from the origin, namely the bottom left corner of the risk matrix towards the opposite, namely the top right, corner as marked on figure 1.

The risk matrix cells may then be grouped into different categories of risk, to be controlled according to some conventional hierarchy of safeguards, to constitute risk management.

Current Risk Matrix Methodologies

Techniques for combining the effect of L and S by a risk matrix can be broadly classified as follows:

(a) Qualitative Assessment: In the risk matrix, risk for any hazard may be designated as the intersection of its likelihood and severity levels. Graded qualitative descriptions are then assigned to groups of cells as 'risk categories' in the risk matrix, known as 'Qualitative Risk Matrix', as shown in figure 1. (Ref. 2.)

(b) Numerical Assessment: In this extension of the qualitative method, numbers (often referred to as 'ranks') 1, 2, ..., m and n are assigned to likelihood and severity levels. It is natural and conventional to start with 1 for the least risk. Currently there is a minority of organisations which start with the worst risk value – combination of worst likelihood and worst severity – as 1, leaving open the potential for disastrous misunderstanding outside such organisations.

Numerical ranks are generally preferred over qualitative terms due to the former's ease of communication with and use by the lower echelons of organisations, especially for site use and reporting. It also often simplifies decision-making.

The numbers generally do not confer actual value to the variables: A likelihood of '3' may not mean 3 times a year. They may not even indicate relative values: For example, the severity of a bruise may be assigned a rank of '1', and the next level of injury such as a fracture may be assigned the rank '2'; but the latter will be many times more painful and costly than just twice the former. The numbers indicate only an ordering of component levels, higher numbers simply implying worse likelihood or severity. For this reason, it is inappropriate to refer to this risk matrix as 'quantitative' as some do. Further, there is actually a truly 'quantitative' risk matrix as will be described later. Thus, the type of assessment described in this sub-section is simply qualitative evaluation expressed numerically.

The likelihood and severity ranks may be combined to give the rank of the resulting risk – referred to as the 'risk index' – in one of various ways. But the most common is simple multiplication of likelihood and severity ranks, i.e. R = L.S, as shown in figure 2 (ref. 3), which is the most common practice, and the only combination method considered hereinafter.

The resulting products representing risk indices in the (m.n) cells are grouped into different categories in logical fashion for further processing, as indicated at bottom of the table in figure 2.

Numerical grouping also has the advantage over qualitative grouping in that numbers separate a single category into separate sub-groups of graded risk. Thus, although in figure 2, 1-3 is marked 'Low risk', it is evident that '3' is worse than '2' which is worse than '1'.

(c) Semi-Quantitative Assessment: Where quantitative data is available for one (or a few, but not all) parameters of risk, or when relative values of various parameters are available (e.g. 'medium' frequency of a mishap being three times as frequent as 'low' frequency), the resulting risk matrix is referred to as 'Semi-Quantitative'. This may involve some mathematical manipulations, and management decisions may be related to the quantitative portion of the data and results.

(d) Quantitative Assessment: Where quantitative data is available for both (or all) parameters of risk, probabilistic and other mathematical techniques are used to determine consequential risk in a quantitative fashion. The resulting risk matrix is known as 'Quantitative Risk Matrix'. Examples of quantitative data may be parts of million of a toxic component in drinking water, dollars cost per accident, etc. Academicians, scientists, practitioners, and administrators in chemical and other quality-controlled industries have extensively dealt with quantitative risk assessment and management.

This then has been the practice with risk matrix for the last few decades, and continues to hold sway with minor refinements and increasing detail, with facilitating computerisation, and enabling legislation. Qualitative, semi-quantitative, and quantitative risk matrices are discussed by Barringer (ref. 4).

Risk Management Considerations

In qualitative and numerical risk assessment, categories are classified based on experience and resources available. It is common practice to assume that the combination of likelihood 'a' and severity 'b', and the combination of likelihood 'b' and severity 'a' will have (nearly) the same overall loss and hence same risk. However, management may find reasons to treat the two in a pair differently. In semi-quantitative and quantitative risk assessments, some mathematical logic is invoked to facilitate categorisation.

Most beginners and many small and medium enterprises generally do qualitative or numerical risk assessment, with likelihood and severity levels being described in generic terms involving little or no quantification. The rest of the paper will deal exclusively with qualitative and numerical risk matrices.

Language Problems with Qualitative Assessment

Assessors use very colourful but confusing terminology for the likelihood and severity levels and for risk categories – too many to list here. As there are no accepted uniform standards or conventions, the variations in terminology have the potential to diminish the effectiveness of findings and recommendations at best, and to cause confusion and misinterpretation and hence lead to adverse consequences at worst.

Impact ➔ / Likeli-Hood ➔	Insignificant (1)	Minor (2)	Moderate (3)	Major (4)	Catastrophic (5)
Almost certain (5)	5	10	15	20	25
Likely (4)	4	8	12	16	20
Possible (3)	3	6	9	12	15
Unlikely (2)	2	4	6	8	10
Rare (1)	1	2	3	4	5
Risk–1-3: Low, 4-6: Moderate, 8-12: High, 15-25: Extreme					

Figure 2 – 5×5 Risk Matrix (AS/NZS 4360: 1999)

The dominance of risk terminology is so pervasive that risk assessors treat the terms as sacred mantra-s (slogans), each group using them religiously without knowing what exactly they mean or how precisely they must be applied in real life. The problems with language in qualitative assessment may be discussed under the two heads: (1) Confusion in terminology, and (2) vagueness of the descriptions of terms.

Table 1 – Summary of Terms Used for Various Levels in Published Literature

	Lowest level	Intermediate levels	Highest level
Likelihood	Barely credible, Extremely unlikely, Highly unlikely, Improbable, Incredible, Minimal, Rare, Remote, Very low, Virtually impossible	Frequent, Infrequent, Improbable, Likely, Moderate, Occasional, Possible, Probable, Quite likely, Quite unlikely, Rare, Remote, Small, Unlikely, Very likely, Very unlikely ▪ 'Likely' appears in 3rd, 4th and 5th positions on a scale of 1 to 6.	Almost certain, Certainty, Frequent, Highly likely, Highly probable, Very frequent, Very likely, Virtually certain
Severity	Insignificant, Limited, Low, Minor, Negligible, None, Notable, Unimportant	Acceptable, Critical, Disaster, Extremely serious, Highly significant, Limited, Major, Marginal, Minimal, Minor, Moderate, Serious, Severe, Significant, Substantial, Very serious ▪ 'Severe' appears in 2nd, 3rd, 4th, and 6th positions on a scale of 1 to 6.	Catastrophic, Critical, Major, Severe, Unsurvivable
Risk	Acceptable, Effectively zero, Low, Negligible, Normal, Trivial, Very low	Acceptable, Acceptable with controls, Critical, Heavy, High, Low, Low-Medium, Medium, Moderate, Serious, Significant, Substantial, Tolerable, Undesirable ▪ 'Moderate' appears in 2nd and 3rd positions on a scale of 1 to 6.	Catastrophic, Critical, Extreme, High, Intolerable, Unacceptable, Very high

<u>(1) Confusion in Terminology</u>

Table 1 shows (in alphabetical order) a sampling of terms ('linguistic ratings') used in 15-20 selected publications from around the world for 3 to 6 levels of likelihood, severity, and risk in published literature. In the table entries, apart from obvious lack of consistency in the nomenclature, it is quite worrisome that certain words appear at different (relative) levels in assessments from various sources

Figure 3 shows the results of a survey with 507 respondents by Hillson (ref. 7) on the interpretation of commonly used likelihood-related terms. Not only does the spread of interpretations average about 20%, but also do a number of different words cover almost the same range of interpretation. The variations and the overlaps are so wide that the conclusions there from could be rendered completely meaningless. For instance in figure 3, 'Quite likely' is a sub-set of 'Likely', and 'Highly unlikely' overlaps 'Unlikely' by about 80%!

Researchers behind figure 3 examined only 15 terms. 'Rather likely' is missing. Others like 'Remote' are used in some assessment forms to describe (low) likelihood, with sometimes funny results: An otherwise smart foreman wanted to know where he – male nouns and pronouns hereinafter also referring to females unless specifically defined – could find the 'remote control' for measuring likelihood of fall from height!

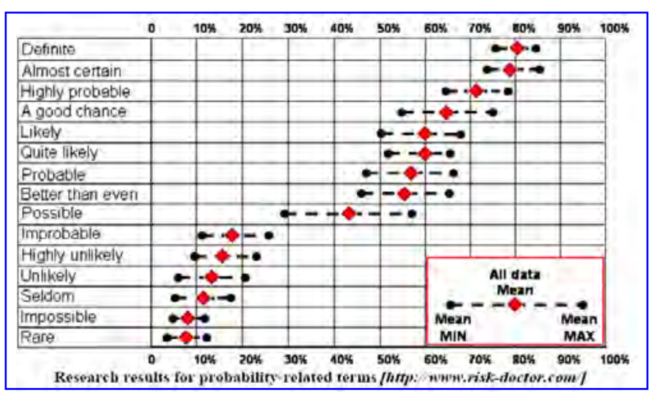

Figure 3 – Problem of Language in Qualitative Definition

Table 1 and figure 3 indicate that when technical words are not carefully and clearly defined, their use in making decisions will be of dubious value. One may easily conclude that use of simple words in common usage to describe terms for assessment and management may even be counter-productive.

In a similar vein, the grade of severity at which one assesses a particular loss or harm is also quite variable, again expressed as a matter of personal experience and risk perception, and used as a matter of imposed routine. One group the author counselled during a risk assessment workshop rated all personal injuries at a construction worksite as 'High' because all (or most) of them hated the sight of blood!

When human safety, property damage, and other vital consequences hang in the balance of such decisions, it is all the more critical that either common words used as classification terms be clearly defined on a industry-wide basis, or special terms and definitions be developed for universal application. Although jargon reigns supreme in all 'modern' human endeavour, it is too risky – pun intended! – to play with words in safety matters. An already difficult decision is unnecessarily compounded by using cliché terms, just because somebody used one in a specific context and it stuck.

A Simple Solution for Confusing Terminology: There is a quick fix for the tyranny of terminology: Assessors, companies, Societies, Ministries, and Governments should immediately swear off unnecessarily long, or complex, or exotic words, and resolve to use only the simplest of words, if only because complicated, nice-sounding words with no clear definitions only serve to confuse the issue. Why say 'Catastrophic' when 'Most (severity)' would do? 'Trivial' when 'Very Low (risk)' would do?
To counter these effects, author advocates the use of the simplest of words, such as 'Low', 'Medium', and 'High' as adjectives to the variables involved. He has dealt with this topic in his book (ref. 5) and in greater detail in his other paper in the same proceedings as this paper (ref. 6). The author has been pleading (ref. 5) for the use of the simplest of simple adjectives such as 'Low', 'Medium', and 'High' for all mishap variables, likelihood, severity, or risk. They have a near-universal appeal at least in a relative sense, and can be understood by almost all around the world.

Figure 4 depicts how 'Least' (or 'Lowest') and 'Most' (or 'Highest') will define the span for any of the variables, and how with the simple addition of words 'Low' and 'High' and the adjective 'Very' the span can go from 3 to 5 to 7 levels. For even numbers, 'Medium' may be omitted as a convention, retaining symmetry of wording.

3 Levels			Least	Medium	Most		
5 Levels		Least	Low	Medium	High	Most	
7 Levels	Least	Very Low	Low	Medium	High	Very High	Most

Figure 4 – Recommended Terms as Adjectives to Likelihood, Severity, and Risk for 3 to 7 Levels

Author does not worry about terminology beyond seven levels. By then, the problem would have been lobbed into the 'Large Enterprise' domain of the risk management ivy-league, in which assessors and users alike would have sufficient high-powered expertise (or get high-priced help) to handle any additional sophisticated terminology.

(2) Vagueness of Description

Apart from the terms themselves, descriptions of probabilities and severities for the same levels not only are too generic, but also vary widely around the world, from industry to industry, and even within the same industry.

Typical are the definitions listed in tables 2 and 3 for likelihood and consequences for a 3×3 matrix as given by Garlick in his recent book (ref. 8).

Table 2 –Three Likelihood Level Descriptions

Descriptor	Definition
Probable	Can be expected to occur
Possible	Not expected to occur
Improbable	Conceivable, but highly unlikely to occur

Table 3 – Three Consequence Level Descriptions

Descriptor	Definition
Major	Some important objectives cannot be achieved
Moderate	Some objectives affected
Minor	Minor effects that are easily remedied

Without the benefit of the author's subsequent explanations and examples of application of these definitions, one would be hard put to use them with any confidence. The usage problem gets exponentially worse as the number of levels of the component parameters increase beyond three.

Table 5 – Singapore MOM Injury Severity Descriptions

Severity	Description
Minor	No injury, injury or ill-health requiring first aid treatment only (includes minor cuts and bruises, irritation, ill-health with temporary discomfort)
Moderate	Injury requiring medical treatment or ill-health leading to disability (includes lacerations, burns, sprains, minor fractures, dermatitis, deafness, work-related upper limb disorders)
Major	Fatal, serious injury or life-threatening occupational disease (includes amputations, major fractures, multiple injuries, occupational cancer, acute poisoning and fatal diseases)

Likelihood versus Severity

It is interesting but hardly surprising that qualitative likelihood definitions are much vaguer than severity definitions, as may be seen from tables 4 and 5 sourced from Singapore Ministry of Manpower (ref. 2).

Severity, being a measure of the consequences of a mishap, is based mostly on considerable individual and shared experience. Almost every one can remember or visualise, and estimate the difference between a scratch and a fracture, between the loss of a pencil and a Picasso painting. Description of human injuries is often quite specific, as in table 5. Thus, to a certain extent, most people can categorise the severity of a hazard into one of three or more categories reasonably well.

Likelihood on the other hand, is a prediction of whether and how often an event will happen or a situation will develop – which at best will be an educated guess. In his 2005 paper Hillson (ref. 7) also comments against the "limitations of natural language" to describe likelihood. Other aspects of communication about risk management may be found in author's paper, reference 6.

Subconscious Quantification

Author whole-heartedly endorses the view (ref. 9): "All qualitative risk assessment has an either explicit or implicit quantitative basis." When an assessor or a respondent picks one of the common terms to designate the level, he presumably bases it on some kind of mental logic. In other words, his estimate is not arbitrary or random, but a judgement call founded on his knowledge and/or experience.

For likelihood, he would have asked himself: "How often does this happen, or has this happened?" Even if the answer to this is 'few' or 'many', it still reflects a numerical or otherwise quantitative evaluation, in absolute terms 'five times a month', or at least in relative terms like 'double that of last year'. Author adopts the crude but effective trick of asking himself (or others) how many times out of ten times of the activity did (or could) the mishap occur (ref. 10). The analysis may not be explicit or formal, but it would be still implicit and subconscious. For severity, as already explained, quantitative data is easily accessible.

Table 4 – Singapore MOM Likelihood Descriptions

Likelihood	Description
Remote	Not likely to occur
Occasional	Possible or known to occur
Frequent	Common or repeating occurrence

In any case, if and when one has no personal experience of the task under investigation, and statistics on it do not exist, he would still think of – even act out – scenarios in his mind. Or he might check with his colleagues or neighbours. If still at a loss, he will (and must) check around for published literature or browse the internet. So again, his final choice of level should be bounded by available data or experience.

Human beings are measurers and quantifiers, unlike most animals. Unfortunately, this mental exercise is nullified and the fruits of its labours thrown away after the assessor settles on a single magic chant-word, and that word gets embedded in all subsequent developments from it.

On the other hand, qualitative assessors also need to be cautious about dependence on short-term memory or sensational media reportage to fix their likelihood or severity levels. Recently a South-East Asian country had many air crashes within a few weeks, and author's students invariably assessed likelihood of an air accident 'High' after that. The same respondents did not know that within their own city, about 200 people died in traffic accidents during the year past, or that there was one suicide a day on an average.

Risk perception variations would confuse the issue also, as the author has discussed in his recent paper, reference 6. Further, one cannot completely do away with qualitative analysis either. Monthly income of $1000 sounds perfectly quantitative, but will mean different qualities of life in Africa and in U.S.A.

When the author asks of his class: "What is the likelihood of a worker falling off a scaffold?" the respondents invariably answer, 'High'. They are of course confusing severity with likelihood: The consequences of falling from height are so horrible, and the images the accident dredges up into their mental screen so gory, that these impacts overshadow the distinction between likelihood and severity. Actually, if 25 people fall off scaffolds in a particular year, and there are 5000 worksites, then the rate of fall per site that year for any worksite was 25/5000 or 1 in 200. In other words, for a particular worksite, the frequency of fatal fall would be once in 200 years – a very, very low likelihood!

Subconscious quantification is thus a double-edged sword! We need a more rational method to decide. The ultimate escape from the tyranny of loose terminology is to do away with verbal designations altogether for levels and go to numerical scales instead. That is exactly what the author will be proposing. It is in this context of proliferating confusion of loaded words that the author offers an alternative, more definitive mode of thinking and deciding about qualitative measures of risk parameters.

Author's 'Deca-Scale' Proposal

Needless to say, attempts have been made in the past to integrate and bring some order into the chaos of risk assessment, a recent notable effort being the formalisation of a 5×5 risk matrix by Moore (ref. 11). However, most efforts have been for specific projects or domains, in very limited contexts.

In this paper the author proposes two broad concepts to develop a basic universal scale for likelihood and severity variations of occupational hazards, on a very natural scale of 1 to 10 – which he will designate 'Deca-Scale' – covering most of possibilities of credible hazards under normal circumstances:

(1) Global 'range' and local 'span' of credible hazards; and,
(2) Definitions of generic bounds for the likelihood and severity levels in the global range.

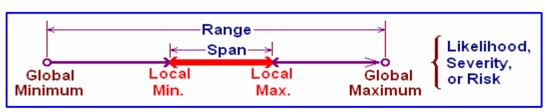

Figure 5 – Range and Span Defined

Range and Span: In what follows, the author will use the term 'range' to denote the entire spectrum of possibilities cited for any variable, from global minimum to maximum. He will use the term 'span' for any subset of the range, to define the local minimum to maximum domain which is applicable to his particular job or project. (See figure 5.)

For instance, if the hospital stay and treatment for a particular injury varies from 1 day to 1 year, but an assessor wishes to cover only stays between 3 days to 3 months, then the range is 1 to 365, and the span is 3 to 91, both in days.

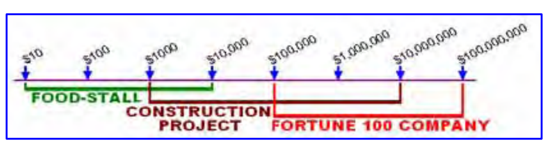

Figure 6 – Spans for Various Organisations

It may be seen that spans for various industries may vary within a range, as schematically shown in figure 6 for cash flows. Author has broached this approach earlier in reference 10.

Author presents tables 6 and 7 as his proposals for likelihood and severity scale ranges. In practice, there is generally no zero likelihood and no zero severity for any mishap. Likewise, 100% likelihood is not a realistic situation, just as a 100% severe event defies definition.

Table 6 – Likelihood Range Scale (LRS)

LS No.	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
Probability (% of time)	<1	1-5	5-10	10-20	20-30	30-40	40-50	50-65	65-80	>80
Frequency, 1 event every x, i.e. = y events per year	30-100 yrs = 0.01-0.033	10-30 yrs = 0.033-0.1	3 - 10 yrs = 0.1-0.33	1 - 3 yrs = 0.33-1.0	4 mths – 1 yr = 1-3.3	1 - 4 mths = 3.3-12	1 week-1mth = 12-52	2-7 days = 52-183	1/2 -2 days = 183-730	3 hrs-1/2 day = 730-2920

So the minimum is usually some trivial, practically insignificant level of the variable concerned; and the maximum is often set at some credible highest value.

Author has attempted to make frequency and physical harm MC/RT intervals – and to a certain extent the likelihood scale also – follow a geometric progression, to make them roughly equal in logarithmic scale (a la the Richter Scale) to reflect the fact that assessors and management are not as interested in arithmetic increments as in geometrical jumps of a variable. As an example, a jump from $10 to $20 will not matter as much as a jump from $10 to $100.

Table 7 – Severity Range Scale (SRS)

SS No.	MC or RT	$ Loss, Cost	Physical harm	Environmental Impact
S1	3 H – 1/2 D	$1 – $10	Minor cut, bruise and scratch, light headache	Little to Site/FH
S2	1/2 – 2 D	$10 – $100	Cut requiring stitches, foreign body in eye, minor machine pinch, 1st degree burn, throat irritation	Site/FH to Site/FD
S3	2 – 7 D	$100 – $1000	Deep cut, eye injury, crushed finger or toe, minor 2nd degree burn, minor allergy	Site/FD to Site/FM
S4	1 week – 1 M	$1000 – $10,000	Simple fracture, dislocation, cut finger or toe, hit in chest or stomach, eye damage, major 2nd degree burn, major allergy, breathing difficulty, heat stroke, skin problem, minor toxicity	Site/FM to (Site/FY, or Local/FH)
S5	1 – 4 M	$10,000 – $100,000	Compound fracture, cut arm or leg, back pain, minor amputation, punctured chest or stomach, head injury, spine injury, loss of eye, hearing damage, minor 3rd degree burn, major toxicity	(Site/FY, , or Local/FH) to Local/FD
S6	4 M – 1 Y	$100,000 – $1m	Major amputation, multiple fracture, major 3rd degree burn, crush/crash/paralysing/brain injury	Local/FD to Local/FM
S7	1 – 3 Y	$1m – $10m	One to three deaths, many seriously injured, site seriously affected, local collapse	Local/FM to (Local/FY, or Regional /FH)
S8	3 – 10 Y	$10m – $100m	Many deaths, locality seriously affected, township-wide disaster	(Local/FY, or Regional/FH) to Regional/FD
S9	10 – 30 Y	$100m – $1billion	Hundreds of deaths, epidemic, entire state seriously affected, regional disaster	Regional/FD to Regional/FM
S10	30 – 100 Y	$1billion – $10billion	Thousands of deaths, entire country/nation-wide disaster	Regional/FM to Regional/FY
MC = Medical Certificate, RT = Recovery Time, F = Few, H = Hour, D = Day, M = Month, Y - Year				

While the scales relate to fairly stable variations over time, dollar values have the disadvantage that historically and geographically they vary very widely. A long-term strategy to fix global costs may be to take a basic cost of living unit like a loaf of bread instead of any currency.

Natural disasters, nuclear wars, and events that happen once in thousands of years are 'off the scale', and are beyond our control. We may safely leave them to specialised think-tanks in rich countries to handle.

	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10
S10	10	20	30	40	50	60	70	80	90	100
S9	9	18	27	36	45	54	63	72	81	90
S8	8	16	24	32	40	48	56	64	72	80
S7	7	14	21	28	35	42	49	56	63	70
S6	6	12	18	24	30	36	42	48	54	60
S5	5	10	15	20	25	30	35	40	45	50
S4	4	8	12	16	20	24	28	32	36	40
S3	3	6	9	12	15	18	21	24	27	30
S2	2	4	6	8	10	12	14	16	18	20
S1	1	2	3	4	5	6	7	8	9	10

Figure 7 – Global Risk Matrix and Local Risk Matrix for Office

What if an assessor comes up with different values from different factors for likelihood and/or severity for a particular hazard? If the controls for the different factors are different, they should of course be kept separate till the end. Otherwise, a straight average of the multiple values, or better, a weighted average leaning towards the higher value(s) may be quite adequate. If for instance MC is 6 months and cost is \$8000, with indices S6 and S4, we may take it as average 5, or weighted towards the larger, say 5.3.

Without further exploration, author sees no violation of basic concept in multiplying fractional averages to find the risk, as that would preserve original assumptions intact instead of worsening them. Thus with severity 5.3 as above, if the likelihood was 2.5 then the risk would be 5.3×2.5, i.e. 13.25, rounded to 13.

Author realises that considerable work needs to be done by academics and industry experts and between countries before some consensus can be arrived at on the globalisation of L and S scales. Depending on interest and perceived utility, author is willing and eager to work with statisticians, medical personnel, other professionals and administrators to refine the groupings under each head, towards such unification.

The global risk matrix, with both L and S ranging from 1 to 10, will be 10×10, resulting in 100 cells, with the risk indices R (=L.S) ranging from 1 to 100, as shown in figure 7. In the figure, L1, L2, … L10 refer to likelihood levels, and S1, S2, …, S10 refer to severity levels, as defined in tables 6 and 7. The maximum value 100 may be used to visualise risk indices as percentages risks – for the global scale. Subsequent application consists of following steps:

<u>(1) Choice of Spans for Likelihoods and Severities in any Particular Job in the Project:</u> The spans are selected from the ranges to suit the industry and the project by listing all possible activities, and picking the local minimum and maximum hazard levels for the job (or other assignment) at hand.

As per conventional practice, we accomplish this by asking the following (and other similar) questions:

- What are the various steps in the job?
- What hazards can happen with each job step?
- What are the chances that each hazard may happen?
- How bad will the consequence be if and when it happens?

As an example, in an office, injuries will range from the global minimum S1 to simple fracture, and the like (S4), i.e. a span of four levels. But in a construction site, the maximum may extend to S7 or S8. In very hazardous environments and activities such as fire-fighting, some of the lower levels of severity may be dropped. Likewise, in a project lasting 5 years, the higher frequency levels will not apply.

<u>(2) Division of each Span into Three or More Levels for Assessment:</u> One may retain as many levels as are included in the respective spans: E.g. For the office we may take likelihood range may be from L3 to L7 and severity range may be from S1 to S4. Only in case that any span covers only two levels, one of the two may be sub-divided into two, to make up three levels.

<u>(3) Assessment of Likelihood and Severity of Various Activities in the Job:</u> We list all the activities for the job and write down likelihood and severity levels within the selected spans from the 10-point scales.

(4) Numerical Combination of Likelihoods and Severities by a Risk Matrix: We then list all the hazards along with the product of their likelihood and likelihood levels in the matrix. Unless both L and S spans range from 1 to 10, the local risk matrix will be a sub-set of the 10×10, as shown by the thick bordered box in figure 9 for the office assessment, with risk indices varying from 3 to 28. Author recommends that these numbers be retained so that all local risks may also be positioned within the same global scheme.

(5) Grouping of Risk Cells into Desired Number of Categories: Universal prescription of categorisation of risk indices is neither easy nor desirable, as the number of categories depends on management policy and control resources available. In the office example, to keep controls simple, only three categories will be defined as indicated in figure 8, together with control mantra-s which author regularly uses (ref. 5):

(i) 3-9 : Acceptable – "Don't worry about it!"
(ii) 10-20 : Tolerable – "Manage it!"
(iii) 21-28 : Unacceptable – "Don't do it"

	L3	L4	L5	L6	L7
S4	12	16	20	24	28
S3	9	12	15	18	21
S2	6	8	10	12	14
S1	3	4	5	6	7

Figure 8 – Local Risk Matrix

The number of categories may be increased if clear boundaries and distinct controls can be defined. Management of these risks would follow the usual hierarchy of controls.

Conclusion

Author has presented a scheme for the formalisation of likelihood and severity levels on a natural scale of 1 to 10, along the lines of Richter scale for earthquakes, and for combining them for risk assessment on a convenient and familiar scale of 1 to 100. The proposed scheme has the following additional advantages:

1. Common base of comparison and evaluation of performance and safety records.
2. Simpler, faster and more efficient formulation and decision-making in risk management.
3. Easily amenable to expansion to accommodate deca-scales for other parameters and factors.

The scheme needs to be fine-tuned before it is fully quantitative. But this numerical Deca-Scale system has established the framework for full quantification. Actually, even the tentative proposals herein are already quantitative when frequency scale in number of events per year and cost scale in dollars per event are chosen as parameters because: Risk = (Events per year) × (Dollars per event) = Dollars per year.

Author believes that his proposals will go a long way to provide risk assessors a reasonable numerical basis to pick applicable variations for the two critical parameters of risk appropriate to their particular workplace (or other activity). This may lead to better consistency across and between industries, and to greater exchange of valuable information and hence better safety around the world.

References

1. API RP 580, Risk-Based Inspection, American Petroleum Institute, Washington, D.C., May 2000
2. _____, Workplace Safety and Health Risk Management: Risk Assessment Guidelines, Ministry of Manpower, Singapore, 2006, 38p.
3. _____, AS/ANS 4360:1999:Risk Management, (Superseded), Australian and International Standards, SAI Global Webshop, http://www.saiglobal.com/shop/Script/Details.asp?DocN=stds000023835
4. Barringer, Paul, Risk-Based Decisions, http://www.barringer1.com/nov04prb.htm, 2006.
5. Krishnamurthy, N., Introduction to Risk Management, ISBN: 978-981-05-7924-1, 2007, 88p.
6. Krishnamurthy, N., "Psychology of Risk Management", Proceedings of the International System Safety Regional Conference 2008, ISSRC-2008, System Safety Society, Singapore Chapter, Singapore, 23-25 April 2008.
7. Hillson, David A., Describing likelihood: The limitations of natural language, Proceedings of the PMI Global Congress 2005, EMEA, presented in Edinburgh Scotland, 25 May 2005.
8. Garlick, Andy, Estimating – A Management Approach, Gower Publishing, USA, ISBN: 0 566 08776 6, July 2007, 260 p.

9. Stamatelatos, Michael G., "NASA Perspective on Risk Assessment Panel on Risk Aversion – Flying in the Face of Uncertainty", NRC Workshop on Stepping Stones in Space, February 24, 2004.
10. Krishnamurthy, N., "On Changing a Light Bulb", Safety Matters, Singapore Institute of Safety Officers, 2nd Quarter 2007, p. 12-16, http://www.profkrishna.com/ProfK-Assets/Publications.htm
11. Moore, David A., "The Use of a Ranking Matrix and Recommendation Prioritization System for Process Hazard Analysis Studies", Process Safety Progress, Vol. 16, No.2, American Institute of Chemical Engineers, 1997, p. 83-85.

Biography

N. Krishnamurthy, Ph.D., Consultant: Safety, Structures, and Computer Applications, Block 329, #12-260, Clementi Avenue 2, Singapore 120329, Telephone – +65-67743849, Facsimile – +65-67747142, E-mail – proscank@yahoo.com, Website – www.profkrishna.com

Dr. Krishnamurthy has more than five decades of experience in teaching, research, and consultancy in India, USA, and Singapore. He has authored or co-authored numerous journal papers and books including his latest book: Introduction to Risk Management. In recent years he has been active in construction safety and accident investigation, and delivering short courses and invited lectures on related topics in Singapore, Hong Kong, Malaysia, and India.