Developing a Construction Occupational Safety and Health Risk Assessment Matrix (COSHRAM) with Modifying Risk Factors

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ABSTRACT--- Common Risk Assessment Matrix (RAM) is universal and can be apply in any industries. The aims of this paper is to develop a Construction Occupational Safety and Health Risk Assessment Matrix (COSHRAM) which can ideally improve the risk action plan. A new element of modifying factors has been incorporated to systematically justify the residual risks. The COSHRAM was developed on the basis of historical accident data and data collected from the field survey. Six (6) Safety and Health Officer (SHO) divided into three (3) groups were selected to conduct field trials. Each group has conducted risk assessment using both common RAM and COSHRAM. Overall, three (3) types of activities, including twenty-one (21) sub-activities and fifty-nine (59) hazards have been evaluated. Paired t-test showed that result of the assessment between the common RAM and COSHRAM was significantly different (t=17.083, p < 0.05). Therefore, the COSHRAM is statistically acceptable and it resulted in better in terms of estimating the risks than the common RAM.

Keywords– Assessment matrix, construction, modifying factor, residual risk

I. INTRODUCTION

The risk assessment of occupational safety and health (OSH) at construction sites are currently conducted using th e common RAM. Such situation is particularly alarming because of management failures to identify the actual level of OSH risk and the type of control that should be implemented to prevent any occupational accident at the worksite. This is because most common RAM used in risk assessment process are designed for generic used, besides of its lack of specification of extensively studied variable and interdependencies to support and help the decision makers [1].

More aggravating, when common RAM tends to confuse ris k assessors with hazard description and interpretation of the likelihood of event operational definition, will encourage the m to make decisions based solely on their experience and knowledge [2].[3] strongly, criticizing common RAM are less than a useful depiction of risk management information without probabilistic uncert ainties models. The most popular common RAM can be the least effective, according to [4].

He also suggested that because of its many limitations, users of common RAM should be more cautious.

[5] identified common RAM as having several problematic mathematical features making it harder to evaluate risks, including poor resolution, discrepan cies, the inadequate allocation of resources and equivocal in puts and outputs. He implied that common RAM should be used only with prudence and vigilant explanations of encapsulated determinations. [6] lambasted the existing probabilistic occupational safety risk assessment (OSRA) models, which analysts require to make lenient estimates based on their own experience and notions.

This is mirrored in the variability of outcomes between an alysts and analysts.

He has developed a fuzzy Qualitative Risk Assessment Model (QRAM), which can better evaluate occupational saf ety and health risks than the OSRA models. [7] used a series of historical accident data to develop a RAM to evaluate the risk levels at different project phases. They discovered that RAM is advantageous in predicting the hi gh risk associated with construction activities and thereby pr eventing accidents. In [8], risk is defined as the effect of uncertainty on objectives. An effect is a deviation from expected outcomes either positive or negative. While uncertainty is the state, even partial, of deficiency of information related to, or understanding or knowledge of, an event, its consequence, or likelihood. Risk is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated “likelihood” of occurrence. Likelihood, defined in [9] as the chance of something and can be expressed qualitatively or quantitatively. A consequence is defined as the outcome of an event affecting the objectives. [10] have quantified the risk by multiplying the probability by consequences. The y divided the consequences into damage and health consequ ences. Whereas [1] evaluate the likelihood and consequences of safety and healt h risk separately.

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From the above literature, we can conclude that the occupati onal safety and health risk is calculated as set out in (1) without taking into account any other factors that contribute to the occurrence of the accident at work. The most common RAM is quite well known and is simply found in many references (i.e. [3], [4], [5], [7], [11], [12]).

$$\text{Risk} = \text{Likelihood (L)} \times \text{Consequences (C)} \quad (1)$$

In this research, Construction Occupational Safety and Health Risk Assessment Matrix (COSHRAM), is developed.The methodology for quantifying occupational sa fety and health risks in the development of COSHRAM is generally, still as outlined in [13].However, it is enhanced by taking into account the 'modifying factor'. It was developed on the basis of data analysis on the most factors that contribute to occupational accidents in the construction sector [14]. The factors involved were the allocation of the costs of acci dent prevention [15], [16], the frequency of OSH inspection at the worksite [17], the adequacy of OSH training [14], [18] and the effectiveness of OSH control measures [19].In determining the 'likelihood of an event occurrence,' the COSHRAM uses historical construction accident data, whereas for 'consequences' of hazard it refers to elements as characterized in [20] and [21].

II. METHODOLOGY

In this section, the common RAM used to assess occupational safety and health risks in construction projects are discussed and the COSHRAM, is presented.

Data Collection

This study uses a combination of primary and secondary data. Primary data was collected via an on-site survey and questionnaire to be answered by the identified Safety and Health Officer (SHO). A total of 430 respondents were engaged in this survey.
These data were thenstatistically analyzed and used to constr uct a 'modifying factor.'
In the meantime, secondary data comprising dataon construc tion occupational accidents for the period of 2008 - 2017, wereofficially obtained from DOSH and SOCSO. Thesedata, as well as primary data, were also statistically analyzedand used as input to a 'likelihood of an event occurrence.'

The COSHRAM Assumptions

The proposed COSHRAM evaluates safety and health risks in two phases.
During the first phase, safety and health risks are referred to as 'Initial Risk' (IR), while in the second phase they are referred to as 'Residual Risk' (RR).
In determining the risk levels and types of control measures to be implemented, the RR will be referred to as the overall r isk by worksite management.
IR is a safety and health risk that does not take into consideration the 'modifying factor,' while RR is a safety and health risk that takes into account the 'modifying factor.' In order to use the RAM approach, the IR equation should be in the format of 'Likeli hood x Consequences.' Thus, (1) is rewritten in accordance with the COSHRAM assumption, as shown in (2), but the likelihood and consequence values use the value as shown in Table 1 and Table 2. RR is quantified with (3), which also took into account the ' modifying factor' also known as 'm.' The value of 'm' can be found in Table 3, where 'm' is computed with (4).Both IR and RR values can be referred to in Table 4 to ascertain the risk category.
Guidelines for the use of Table 1 and Table 4 are referred to in Annex A and Annex B.

$$IR = \text{Likelihood (L)} \times \text{Consequences (C)} \quad (2)$$

$$RR = IR - (IR \times m) \quad (3)$$

$$m = (c + a + t + e) / 4 \quad (4)$$

Where:
c = Allocation of accident prevention cost, a = Frequency of OSH worksite inspection, t = Adequacy of OSH training, e = Effectiveness of OSH control measures.

Table 1. The likelihood of an event occurrence

Type of accident			Fall of person	Struck by falling object	Stepping on, striking against or struck by object (excluding falling object)	Caught in between objects	Overexertion or strenuous movement	Exposed to / Contact with extreme temperatures	Exposed to / Contact with electric current	Exposed to / Contact with harmful substances or radiations	Other types of accident
Likelihood	Almost Certain	5	> 4	> 3	> 5	> 2	> 3	> 1	> 1	> 1	> 3
	Likely	4	4	3	5	2	3	1	1	1	3
	Possible	3	3	2	4	1	2				2
	Remote	2	1-2	1	2-3		1				1
	Rare	1	0	0	0	0	0	0	0	0	0

Source: [23], [24]

Table 2. Consequences of hazard

Consequence (C)	Description	Rating
Catastrophic	Fatal injury or fatal occupational poisoning and disease or multiple serious bodily injury	5
Major	Serious bodily injury or life-threatening occupational poisoning and disease (includes amputations, major fractures, burns and corrosions, heat stroke, occupational cancer, acute poisoning etc.)	4
Moderate	Injury or occupational poisoning and disease requiring medical treatment leading to disability (includes musculoskeletal system disorders, infection, dermatitis, deafness etc.)	3
Minor	Injury or occupational poisoning and disease requiring medical treatment leading to temporary disability or first-aid only (includes minor fractures, cramp, minor cuts and bruises, irritation, ill-health with temporary discomfort etc.)	2
Negligible	Not likely to cause injury or occupational poisoning and disease	1

Source: [20], [21]

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Table 3. Modifying factor

Modifying factor (m)		Criteria
0.26	c1	The cost allocation for accident prevention is most adequate (more than 5% of the project's total cost).
0.53	a1	Carrying out OSH worksite inspections every month
0.26	t1	Conducting training for employees covering 100% of the training as recommended in Annex B
0.12	e1	Implementation of control measures significantly reduces the risk.
0.23	c2	Cost allocation for accident prevention is adequate (between 3% and 5% of the project's total cost).
0.14	a2	Carrying out OSH worksite inspections every 3 months
0.32	t2	Conducting OSH training for employees covering 75% of the training as recommended in Annex B
0.40	e2	Implementation of control measures reduces the risk.
0.14	c3	Cost allocation for accident prevention is moderately adequate (between 1% and 3% of the project's total cost).
0.31	a3	Carrying out worksite inspections every 6 months
0.25	t3	Conducting OSH training for employees covering 50% of the training as recommended in Annex B
0.21	e3	Implementation of control measures slightly reduces the risk.
0.38	c4	Cost allocation for accident prevention is not adequate (less than 1% of the project's total cost).
0.03	a4	Carrying out OSH worksite inspections once a year
0.17	t4	Conducting OSH training for employees covering 25% of the training as recommended in Annex B
0.25	e4	Implementation of control measures does not change the risk.
0.01	c5	Never allocate any accident prevention cost for the project
0.01	a5	Never perform any OSH worksite inspections at the project site
0.01	t5	Never conduct any OSH training for employees at the project site
0.03	e5	Implementation of control measures potentially increase the risk.

Table 4. The COSHRAM

			Consequences (C)				
			Negligible	Minor	Moderate	Major	Catastrophic
			1	2	3	4	5
Likelihood (L)	Almost Certain	5	5	10	15	20	25
	Likely	4	4	8	12	16	20
	Possible	3	3	6	9	12	15
	Remote	2	2	4	6	8	10
	Rare	1	1	2	3	4	5

Source: [8], [13]

The COSHRAM Components

As delineated in Table 4, matrix with 5 levels of likelihood and 5 levels of consequences for occupational saf ety and health areused.
The matrix was divided into four zones based on risk levels for the purpose of risk assessment.
The four zones are Low (L), Medium (M), High (H) and Ext reme (E) with ranges 1 - 3, 4 - 9, 10 - 19 and 20 - 25 representing Acceptable, Adequate, Tolerable and Unacc eptable as shown in Annex B.
Color coding is used to distinguish the various different zon es easily. The 'likelihood of an event occurrence' as portrayed in Table 1 was classified into nine types of accidents, namely: (1) fall of person, (2) struck by falling object, (3) stepping on, striking against or struck by object (excluding falling object), (4) overexertion or strenuous movement, (5) exposed to or contact with extreme temperature,(6) exposed to or contact with electric current, (7) exposed or in contact with harmful substances and (8) other types of accident, as recommended by ILO (1996). The description for all 'likelihood of an event occurrence' elements can be specif ically referred to in Annex A.
The black shaded area in Table 1 is due to accident data anal yzed discovering that the mean value for 'caught in between objects,' 'exposed to or contact with extreme temperature,' 'exposed to or contact with electric current,' and 'exposed to or contact with harmful substances or radiations' is one (1). Therefore, a value of less than one (1) should not be placed as a rating value for the 'likelihood of an event occurrence' The value for the ' rare ' row in Table 1 is set to zero (0) bec ause it is identified as rare to occur but the definite potential exists. On the basis of the literatures [20], [21] the ‘consequences of hazard’ is designed to be composed by: (1) catastrophic, (2) major, (3) moderate, (4) minor and (5) negligible, as presented in Table 2.The elements of the ‘mod ifying factor’ as displayed in Table 3 include: (1) the allocation of accident prevention costs, (2) the frequency of worksite OSH inspection, (3) the adequacy of OSH training and (4) the effectiveness of the OSH control measures.

Field test of COSHRAM

In order to evaluate the proposed COSHRAM, field tests arecarried out to compare it with common RAM. The kinds ofwork, activities, and hazards to be evaluated we re first identified by a discussion group involving six (6) SHOs with at least ten(10) years of experience of in the a ssessment of occupationalsafety and health risks at construct ion sites.As a result, three (3)types of work have been chosen for evaluation: excavatio n,scaffolding and concreting.All these types of work will co verseven (7) activities each. Overall, this study will assess fifty-nine (59) hazards, including thirty (30) hazards from excavation work,thirteen (13) hazards from scaffolding work and sixteen (16)hazards from concreting work.
Those same SHOs will also beengaged in field testing using the common RAM and theCOSHRAM. The paired t-test was used to evaluate thedifferences between these two RAM.

III. RESULTS AND DISCUSSION

Table 5 present a summarized comparison between the common RAM and the COSHRAM based on field test. According to the field test result, it was found that thirty-five (35) of the fifty-nine (59) hazard types assessed using both RAM types have shown a change in the risk zone.
Excavation and concreting each recorded the highest numbe

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r of risk zone changes by fifteen (15) followed by five (5) sc affolding.Whereas for the remainder of the hazard, the risk a ssessed using COSHRAM shows a decrease in risk value rat her than being assessed using common RAM. On the other hand, the paired sample statistics table shows the descriptive statistics of score of the common RAM and COSHRAM. The mean of common RAM is 12.75 (SD 4.89) and the COSHRAM is 9.71 (SD 3.61). The paired samples correlation table shows the strength of relationship between common RAM and COSHRAM is 0.994 which is positive strong relationship (p-value < 0.001). The paired sample test table shows the t statistics is 17.083 and p-value < 0.001. As displayed in Table 6, the two matrix are significantly different ($t=17.083$, $p < 0.05$). The mean of common RAM was significantly higher compared to the proposed COSHRAM.

Table 5. Comparison between common RAM and COSHRAM

Activity	Sub-Activity	Hazard	Risk in common RAM	Risk in COSHRAM
Excavation	1	1	12	9
		2	8	6
		3	6	4
	2	4	12	9
	3	5	20	16
		6	12	9
		7	9	7
		8	12	9
		9	15	12
	4	10	12	9
		11	15	12
		12	15	12
	5	13	15	12
		14	3	2
	6	15	12	9
		16	12	9
		17	16	12
		18	12	9
		19	12	9
		20	15	11
		21	15	11
		22	15	11
		23	15	11
		24	12	9
		25	20	16
		26	12	9
		27	4	3
		28	15	11
		29	10	8
	7	30	20	16
Scaffolding	1	31	9	7
		32	9	7
	2	33	12	9
		34	12	9
	3	35	8	6
		36	6	5
	4	37	12	9
		38	9	7
		39	12	9
		40	6	5
	5	41	12	9
	6	42	9	7
	7	43	6	5
Concreting	1	44	16	12
		45	10	8
	2	46	16	12
		47	10	8

Table 5. Cont..

Activity	Sub-Activity	Hazard	Risk in common RAM	Risk in COSHRAM
	3	48	10	8
		49	10	8
		50	25	18
		51	25	18
	4	52	10	8
		53	10	8
	5	54	20	15
		55	20	15
		56	10	8
	6	57	20	15
	7	58	10	8
		59	25	18

Table 6. Comparison of OSH risk between common RAM and the COSHRAM

Variable	Mean (SD)		Mean Differences (95% CI)	t Statistic (df)	p value
	Common RAM	COSH RAM			
OSH risk	12.75 (4.89)	9.71 (3.61)	3.03 (2.68, 3.40)	17.083 (58)	<0.001

*Paired t test

Hence, the COSHRAM is statistically acceptable and it resulted in better in terms of estimating the risk than the common RAM. This is because the use of the common RAM in the assessment of safety and health risks may lead t he risk assessor to overestimate the risk due to proximity bia s and the value of such tools is in the doubt [22]. In addition, the employer's willingness to ensure adequate ac cident prevention cost, regularly conducts OSH worksite inspections, provides appropriate OSH training for employees and ensures that O SH control measures are effective [14], [15], [16], [17], [18] has helped to reduce the risk of occupational accidents at co nstruction sites, in particular.

IV. CONCLUSION

The research introduced a new concept of semi-quantitative Construction Occupational Safety and Health Assessment Matrix (COSHRAM) in assessing construction safety and health risks. An additional modifying risk factors provides an enhanced understanding on how risk control measures affect the risk measurement. This matrix also emphasized on the importance of both Initial Risk (RR) and Residual Risk (RR). Hence, managing safety and health risks in construction industry using COSHRAM will provide better understanding on how the risk control measures influence the value of calculated risks.

V. APPENDIX

Annex A. Guidance for the likelihood of an occurrence of an event

Type of accident	Rating	Description
Falls of person	5	Likely to occur more than four (4) cases a year
	4	Likely to occur four (4) cases a year
	3	Likely to occur three (3) cases a year
	2	Likely to occur between one (1) and four (4) cases a year
	1	Not expected to occur but still possible
Struck by falling object	5	Likely to occur more than three (3) cases a year
	4	Likely to occur three (3) cases a year
	3	Likely to occur two (2) cases a year
	2	Likely to occur one (1) case a year
	1	Not expected to occur but still possible
Stepping on, striking against or struck by object (excl. falling object)	5	Likely to occur more than five (5) cases a year
	4	Likely to occur five (5) cases a year
	3	Likely to occur four (4) cases a year
	2	Likely to occur between two (2) and three (3) cases a year
	1	Not expected to occur but still possible
Caught in between objects	5	Likely to occur more than two (2) cases a year
	4	Likely to occur two (2) cases a year
	3	Likely to occur one (1) case a year
	2	[redacted]
	1	Not expected to occur but still possible
Overexertion or strenuous movement	5	Likely to occur more than three (3) cases a year
	4	Likely to occur three (3) cases a year
	3	Likely to occur two (2) cases a year
	2	Likely to occur one (1) case a year
	1	Not expected to occur but still possible
Exposed to / Contact with extreme temperatures	5	Likely to occur more than one (1) case a year
	4	Likely to occur one (1) case a year
	3	[redacted]
	2	
	1	Not expected to occur but still possible
Exposed to / Contact with electric current	5	Likely to occur more than one (1) case a year
	4	Likely to occur one (1) case a year
	3	[redacted]
	2	
	1	Not expected to occur but still possible
Exposed to / Contact with harmful substances or radiations	5	Likely to occur more than one (1) case a year
	4	Likely to occur one (1) case a year
	3	[redacted]
	2	
	1	Not expected to occur but still possible
Other types of accident	5	Likely to occur more than three (3) cases a year
	4	Likely to occur three (3) cases a year
	3	Likely to occur two (2) cases a year
	2	Likely to occur one (1) case a year
	1	Not expected to occur but still possible

Annex B. Guidance of COSHRAM risk zone

Zone	Range	Evaluation	Action
EXTREME	20 - 25	Unacceptable	Work should not be started or continued until the risk has been mitigated. Immediate action is required to reduce exposure. A detailed mitigation plan must be developed, implemented and monitored to reduce the risk before work is allowed to commence. Must be managed by senior site management with a detail treatment reported to Project Director, Financial Controller and Managing Director.
HIGH	10 - 19	Tolerable	High risk activities should cease immediately until further control measures to mitigate the risk are introduced. The continued effectiveness of control measured must be monitored periodically. Senior site management attention needed and management responsibility specified and a treatment reported to Project Director and Financial Director.
MEDIUM	4 - 9	Adequate	Medium risks should only be tolerated for the short-term and then only whilst further control measures to mitigate the risk are being planned and implemented by operational managers, within a defined time period.
LOW	1 - 3	Acceptable	Low risks are largely acceptable, monitor periodically to determine situation changes which may affect the risk, or after significant changes.

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