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An Advanced Risk Matrix Analysis Approach for Safety Evaluation at Major Ports in Malaysia

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ABSTRACT

In this study, the risk factors of port operations were analysed using proposed advance risk matrix analysis. The risk was identified by combination of intensive literature review and brainstorming with port experts. The risk identified was analysed by using risk matrix techniques where the risk likelihood, risk severity and risk frequency was determined. The questionnaire form was used in order to ease the data collection process and distributed to one multipurpose port of one major ports in Malaysia. Based on analysis, the risk factor of accident for handling cargo at port were summarized, based on risk rating, it can be found R2 (Communication misunderstanding) was the highest risk fact for all of three ports, Port A, B and C. Meanwhile the lowest risk factors for Port A and Port C was R18 (Day Vs Night) and for Port B was R18 (Requisite safety facilities and equipment tallied with standards). It was found that Port C was found as the riskiest port compared to Port A and Port B as the number of risk factors in risk level III was higher compared from both Ports. The outcome of the study was development of risk management framework for safety evaluation in port industry in Malaysia.

Keywords:
Risk Matrix, Risk Analysis, Port operations, Risk Management, Transports and Logistics

1. Introduction

Recently, attempts have been made to cover port terminal activities [1-5]. It has been argued that port professionals (e.g. port risk managers and port auditors) are facing the lack of an appropriate methodology and evaluation techniques to support their risk management [6-10]. This has led to poor implementation of risk management in the industry especially in occupational safety and health management.

Based on literature addressing risk management framework at port, many focused on maritime risk analysis issues by implementing descriptive or qualitative approaches and developing a robust and efficient quantitative risk analysis approach in order to prioritize hazards in ports [11-17]. However, there are relatively few studies on port safety and risk focusing on port terminal activities which agree by Fabiano, *et al*., [13].

In 2010, Fabiano *et al*. [13] studied interaction of human factor with accident in port. It was found that the human factor was not the ultimate factor, but the most vital factor is technical or technology factor instead.

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Shang and Tseng [14] conducted a case study at exclusive container terminals at Kaohsiung port in Taiwan using fuzzy risk assessment steps to evaluate safety operations in. The study first employs three risk assessment steps which were risk identification, risk assessment and risk evaluation. A total of four dimensions with 16 risk factors from the literature and interviews with experts was identified. After proposing a systematic fuzzy risk analysis and evaluation steps in order to determine risk levels, this article conducts an empirical study of Kaohsiung port. It was found that the leading factor influencing risk frequency is ‘‘communication misunderstanding,’’, the leading factor influencing risk severity is ‘‘human negligence and error,’’ which falls under high risk area, while the other 13 risk factors are in the medium-risk area, and no risk factors are in the low-risk area.

Tseng and Pilcher [8] studied the safety performance by using risk analysis at port of Kaohsiung. The study was conducted qualitatively using interview. There were five risk area highlighted which pertaining regulations, facilities, human factors, force majeure event and management. Author highly recommended that the need for more in-depth semiquantitative and quantitative studies to fully explore the relationships between the factors involved.

Pallis [8] proposed Port Risk Assessment (PRA). The author builds up the methodology with reference to the Formal Safety Assessment (FSA) by gathering the port expert judgment and existing literature to support the study [8]. The validation of method was conducted by empirical study at two container terminals of Greece. The proposed PRA methodology examined human and environmental risk incidents through a four years period of time and interview port experts to determine the risk control options. All the proposed risk control options are found to be economically effective towards the control of human-related risks and the risk exposure able to be reduce accordingly. Author recommended and highlighted to investigate the influence of other related risks, such as machinery, security and natural risks, into the overall equation of port risks. Moreover, the PRA methodology, should take into account further environmental risks, regarding chemical contaminants, ships and cars emissions, air toxics and noise pollution. The proposed PRA methodology was proposed to be tested in other container terminals in Greece, across Europe and other continents, as well as in other port segments.

It shows that the risk identified in previous literature did not fix on specific risk and contributing factor are might not the same in all industry. However, for port safety research, many studies focused on few risk factors which were human, machine and environment. As discussed earlier, man risk factor was widely study and found to be the riskiest in many studies.

2. Methodology

In this study, to analyse the risk factors of handling and storage of cargo at ports, this article applied the Hazard Identification, Risk Assessment, Risk Control (HIRARC) method as the main analysis tool. Hazard identification, risk assessment and risk control framework (HIRARC) using Risk assessment table or risk matrix has been widely used in many studies in other application such as hotel service, Hydroelectrical power generation plant, school or education, crane operation, road accidents and manufacturing as well. The main steps of the HIRARC method are mainly used by the research of risk management. The method to be taken are described in the figure 1 below.

The research is based on the four steps of the risk management procedures, which are risk classify activities, risk identification, risk analysis and estimation and risk control as showed in Figure 1. First step, to classify activities, we visited and had a briefing from port professionals. Second step, in order to identify the risk and hazard, the intensive literature review and brainstorming with port experts was conducted. Third step, we analyzed and measured individual risk factors in risk frequency, risk likelihood and risk severity by using a five-point Likert-type scale in questionnaires. Then, risk analysis and estimation were conducted, given the frequency and the severity of the accident, and analyzed the risk causes. Fourth step, the risk control option which based on hierarchy of control were proposed.

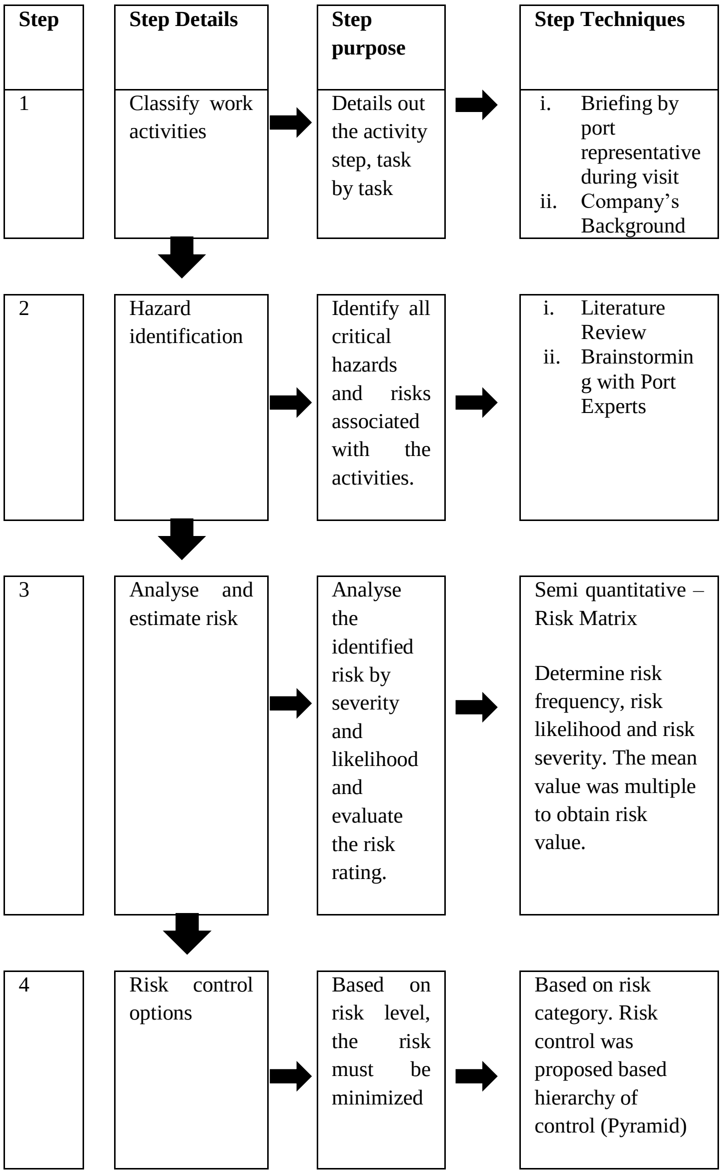

Fig. 1. Hazard Identification, Risk Assessment, Risk Control (HIRARC) method

In this study, the risk assessment criteria were defined and described. The risk assessment criteria were validated by port experts. In this study, likelihood of occurrence, it was defined as five scale from 1 (very unlikely) to 5 (Certain) as tabulated in table 1. In this stage, the likelihood shall be considered without the presence of control measure. In order to reduce the uncertainty and bias, the parameter of risk likelihood was explained based on percentage bases and number of occurrences.

Table 1
Likelihood of occurrence (L) (Adapted from Formal Safety Assessment with Enhancement) [18]

	Likelihood of Occurrence (L)	**Percentage basis**	**Number of occurrences**
1	Very unlikely	The probability to happen is extremely small (< 1%)	No case so far
2	Unlikely	Could happen, however very rare (1 to 9%)	One case in 5 to 10 years
3	Likely	Chances to happen is relatively high (10 to 59%)	One case in 1 to 5 year
4	Most likely	Can happen frequently (60 to 94%)	One case within 6 months to 1 year
5	Certain	Expected to happen (95 to 100%)	Once case in less than 6 months

As for severity of the occurrence, it was defined as five scale as tabulated in table 2. In order to reduce the biased and increase the uncertainty, the variables description was explained better. The consequence was made based on judgement on the impact to people, asset, environment and image of the organization.

Table 2
Severity of Harm (S) (Adapted from Formal Safety Assessment with Enhancement) [18]

Level	Risk Level
1	Negligible
2	Minor
3	Major
4	Critical
5	Catastrophe

The frequency is based on the activity conducted. In this study the frequency was calculated and defined based on five scale according to the value tabulated in table 3. The details of frequency were explained based in yearly, monthly, weekly, daily and hourly.

Table 3
Frequency of activity (F) [18]

Frequency of Activity (F)		
1	Yearly	1 to 10 times in a year
2	Monthly	1 to 3 times in a month
3	Weekly	1 to 3 times in a week
4	Daily	1 to 5 times in a day
5	Hourly	Once or more in an hour, or > 5 times in a day

In order to analyse the risk, the risk likelihood, risk frequency and risk severity was calculated as equation 1 as below,

$$\text{Risk Value} = L \times S \times F \quad (1)$$

where Likelihood of Occurrence (L), Severity of Harm (S) (The value of S shall be taken as the highest value of People, Asset, Environment, and Image) and Frequency of Activity (F) are the variables.

Risk Control

Based on the risk calculation, the modified risk matrix will be categorized into five categories as tabulated in Table 3.9, which are Trivial (I) (RR=0.1-9), Acceptable (II) (RR=10-26), Moderate (III) (RR=27-47), Significant (IV) (RR=48-65) and Unacceptable (V) (≥65). This was made based on As Low As Reasonable Practice (ALARP) region. The action needs to be taken and time scale for corrective action plan (new risk control) was also proposed as tabulated in table 4. In this study, the action plan and time scale were derived. This was proposed for decision making purposed. Based on the risk category and risk level, we proposed detail description on action plan need to be taken and duration for mitigating the risk.

Table 4
Risk level and Action to be Taken [18]

Risk Rating	Risk Category	Risk Level	Action and Time Scale
1-9	I	Trivial	No action required
10-26	II	Acceptable	No additional controls required. Monitoring required in ensuring existing controls are maintained.
27-47	III	Moderate	Efforts may be made to reduce the risk. Risk reduction measures should be implemented within a defined period of time (12 months).
48-64	IV	Significant	Efforts shall be made to reduce the risk. Risk reduction measures should be implemented within a defined period of time (6 months).
>= 65	V	Unacceptable	Work should not be started until the risk has been reduced. Considerable resources shall be allocated to reduce the risk. If the risk hinders work in progress, urgent action (within 7 working days, min, and admin control) shall be taken.

Once the risk was evaluated and categorized, the risk control was proposed based on hierarchy of control as in figure 3. In this study, the risk control is proposed based on hierarchy of control adapted from Hazard Identification, Risk Assessment, Risk /Control (HIRARC) guideline, 2008.

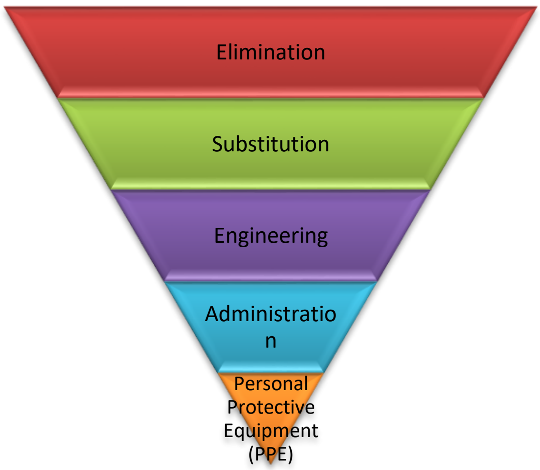

Fig. 2. Hierarchy of Control

2.6 Risk Identification

In identifying the critical risk factors of handling cargo activities in port, combination of literature reviews and brainstorming with port experts were conducted. The same method practiced by Mokhtari *et al.*, [10]. Brainstorming with port expert by using cause and effect diagram was conducted to ensure that the factors which are important indicated by the relevant literature but not suitable to handling activities for port terminal operation will be eliminated. Total of 20 risk factors was finalized as showed in Figure 3 below.

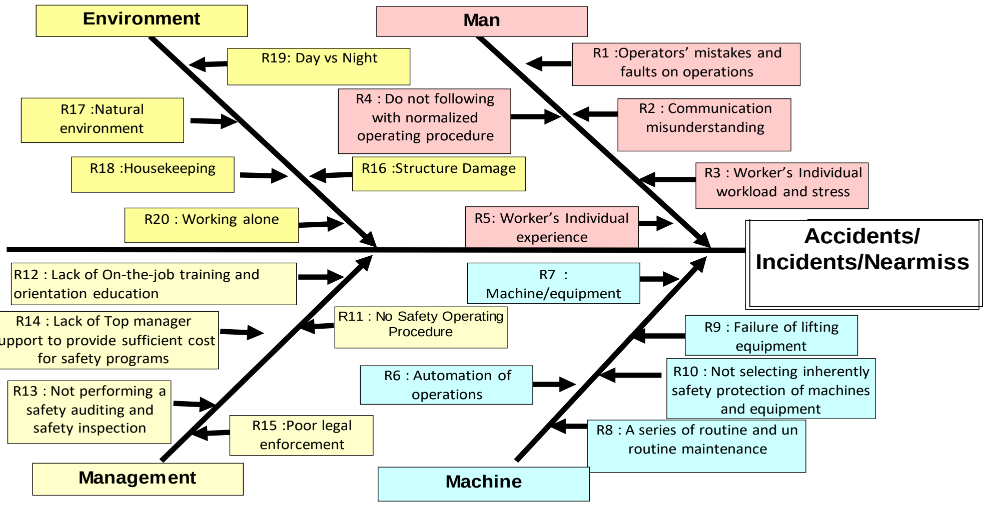

Fig. 3. Risk Identification by Ishikawa Diagram (Cause and Effect Diagram)

2.7 Data Collection

In order to conduct the risk assessment, the identified risk factor and developed risk assessment criteria were transformed into questionnaire form. This is to ease the data collection process. Survey research design through the distribution of the questionnaire were used for research methodology. There were two part of questionnaires were constructed in this study. Fist part was demographic information which consist of respondent's background. Second part were risk assessment questions where identified twenty-eight risk factors by port experts was listed in figure 3 above. The risk frequency, risk likelihood, risk severity was converted into five likert scale. The questionnaire was distributed and collected from three of major multipurpose ports (Port A, Port B and Port C) in Malaysia.

Port A located in central region of Peninsular Malaysia, Port B located in west region of Peninsular Malaysia and Port B located in Sarawak region. The three ports are multipurpose port which has various operations of port services involving container operations, liquid bulk operations, dry bulk operation, ferry operations, vehicle transit centres, roll on-roll out operation, marine services, and dangerous goods storage operations. Port experts which were involved in terminal operations were invited to complete the questionnaire. To increase the response rate, the questionnaire was completed during interviews conducted by the authors. A total of 214 valid samples were distributed and collected out of the 300 questionnaires distributed as showed in Table 5 below. Since Deakin et al. 2014 stated that five to seven Decision Makings are sufficient when dealing with group decision making problems, and as risk assessments can be generated by a group of professional experts, the number of responses was deemed acceptable. The same method was applied by Yang *et al.*, [2].

Table 5
Risk Analysis and Estimation

Port	Total Survey Distributed	Total Survey Collected	Total Valid Survey
A	100	87	82
B	100	87	67
C	100	67	58
Total	300	241	214

3. Results

3.1 Risk Assessment

In order to analyse the risk, the mean value of risk frequency, risk likelihood and risk severity was multiple to obtain the risk rating. According to Table 6, based on risk rating, it can be found R2 (Communication misunderstanding) was the highest risk factors for all of three ports, Port A, B and C. Meanwhile the lowest risk factors for Port A and Port C was R18 (Day Vs Night) and for Port B was R18 (Requisite safety facilities and equipment tallied with standards). Findings for R2 as the highest risk were similar to the findings by Ding and Tseng [14].

Table 6
Risk Analysis and Estimation

		Port A				Port B				Port C			
		F	L	C	RR	F	L	C	RR	F	L	C	RR
Man	R1	3.52	3.08	2.6	28.19	3.58	3.17	2.69	30.53	3.54	3.21	2.69	30.57
	R2	3.82	3.48	3.28	43.60	3.81	3.6	3.29	45.13	3.83	3.54	3.37	45.69
	R3	3.62	3.36	2.6	31.62	3.44	3.35	2.54	29.27	3.58	3.27	2.54	29.73
	R4	3.42	3.06	3.34	34.95	3.58	3.04	3.27	35.59	3.56	3.06	3.21	34.97
	R5	3.56	2.68	2.3	21.94	3.4	2.65	2.21	19.91	3.4	2.71	2.42	22.30
Machine	R6	2.92	2.98	2.88	25.06	2.9	2.94	2.88	24.55	2.83	3.02	2.87	24.53
	R7	2.96	3.2	2.7	25.57	3.04	3.06	2.77	25.77	3.17	3.1	2.79	27.42
	R8	2.8	2.8	2.42	18.97	2.88	2.71	2.52	19.67	2.92	2.79	2.50	20.37
	R9	3.66	2.56	2.5	23.42	3.52	2.67	2.52	23.68	3.67	2.62	2.52	24.23
	R10	3.44	2.48	2.18	18.60	3.38	2.54	2.35	20.18	3.56	2.65	2.23	21.04
Management	R11	2.96	2.68	2.86	22.69	2.88	2.69	2.85	22.08	2.87	2.73	2.83	22.17
	R12	2.94	3	2.92	25.75	3.04	2.96	2.94	26.46	3.12	3.04	3.00	28.45
	R13	2.94	2.82	3.12	25.87	2.88	2.88	3	24.88	3.04	2.87	3.06	26.70
	R14	3.06	3	3.08	28.27	3.1	2.98	2.94	27.16	3.13	3.25	3.25	33.06
	R15	2.92	2.72	2.74	21.76	3	2.71	2.75	22.36	3.04	2.71	3.00	24.72
Environment	R16	3.24	3.18	2.92	30.09	3.25	3.13	2.92	29.70	3.29	3.23	3.06	32.52
	R17	2.98	2.92	3.6	31.33	2.98	2.83	3.63	30.61	2.98	3	3.50	31.29
	R18	3.12	2.68	2.7	22.58	3.08	2.56	2.71	21.37	3.04	2.62	2.71	21.58
	R19	3.24	2.58	2.28	19.06	3.04	2.6	2.29	18.10	3.12	2.63	2.17	17.81
	R20	3.4	3.04	2.84	29.35	3.23	2.96	2.83	27.06	3.46	2.96	2.81	28.78
F-Frequency, L-Likelihood, S-Severity, RR-Risk Rating													

3.2 Risk Evaluation

The risk factor was evaluated based on risk rating calculated. As showed in table 6, it can be found that for Port A, 35% of risk factors fall under risk level III (Moderate) and 65% falls under risk level II (acceptable). For Port B, 35% of risk factors fall under risk level III (Moderate) and 65% falls under risk level II (acceptable). Meanwhile for Port C, 50% of risk factors fall under risk level III (Moderate) and 50% falls under risk level II (acceptable). Any risk factors fall under risk level II, no additional controls required, however, monitoring required in ensuring existing controls are maintained. For risk factor falls under risk level III, efforts or risk control may be made to reduce the risk. Risk reduction measures should be implemented within a defined period of time (12 months).

Based on the results, in terms of safety evaluation, Port C was found as the most risky port compared to Port A and Port B as the number of risk factors in risk level III was higher compared from both Ports.

Table 6
Risk Analysis and Estimation

	Risk	Risk Descriptions	Port A		Port B		Port C	
Man	R1	Operators' mistakes and faults on operations	28.19	II	30.53	III	30.57	III
	R2	Communication misunderstanding	43.60	III	45.13	III	45.69	III
	R3	Worker's Individual workload and stress	31.62	III	29.27	III	29.73	III
	R4	Do not following with normalized operating procedure	34.95	III	35.59	III	34.97	III
	R5	Worker's Individual experience	21.94	II	19.91	II	22.30	II
Machine	R6	Automation of operations	25.06	II	24.55	II	24.53	II
	R7	Machine/equipment conditions	25.57	II	25.77	II	27.42	III
	R8	A series of routine and un routine maintenance	18.97	II	19.67	II	20.37	II
	R9	Failure of lifting equipment	23.42	II	23.68	II	24.23	II
	R10	Not selecting inherently safety protection of machines and equipment	17.53	II	19.43	II	17.43	II
Management	R11	No Safety Operating Procedure	22.69	II	22.08	II	22.17	II
	R12	Lack of On-the-job training and orientation education	25.75	II	26.46	II	28.45	III
	R13	Not performing a safety auditing and safety inspection	25.87	II	24.88	II	26.70	II
	R14	Lack of top manager support to provide sufficient cost for safety programs	28.27	III	27.16	III	33.06	III
	R15	Poor legal guidelines	23.78	II	23.06	II	25.93	II
Environment	R16	Structure Damage	30.09	III	29.70	III	32.52	III
	R17	Natural environment	31.33	III	30.61	III	31.29	III
	R18	Housekeeping	22.58	II	21.37	II	21.58	II
	R19	Day vs Night	19.06	II	18.10	II	17.81	II
	R20	Working alone	29.35	III	27.06	III	28.78	III

3.3 Risk Control

Based on the risk analysis earlier, the risk that falls under risk category III (moderate level) required additional risk control. Listed below, the risk control proposed to reduce the risk value accordingly. However, the risk control shall not be limited to below proposal only. The port's management shall implement any management program in order to control and reduce the risk.

Table 6
Propose Risk Control

Risk Factor	Propose Risk Control
Man	• Administration: a. Safe work procedures - Workers can be required to use standardized safety practices. The employer is expected to ensure that workers follow these practices. Work procedures must be periodically reviewed with workers and updated. b. Supervision and training – Initial training on safe work procedures and refresher training should be offered. Appropriate supervision to assist workers in identifying possible hazards and evaluating work procedures.
Machine	• Elimination: Remove faulty machine/equipment • Administration: Housekeeping, repair and maintenance programs - Housekeeping includes cleaning, waste disposal and spill clean-up. Tools, equipment and machinery are less likely to cause injury if they are kept clean and well maintained.
Managemen t	• Administration: a. Walkabout or toolbox b. Safety KPI appraisal of top management c. Scheduled Inspection
Environment	• Administration: a. Safe work procedures - Workers can be required to use standardised safety practices. The employer is expected to ensure that workers follow these practices. Work procedures must be periodically reviewed with workers and updated. b. Supervision and training – Initial training on safe work procedures and refresher training should be offered. Appropriate supervision to assist workers in identifying possible hazards and evaluating work procedures.

4. Conclusions

In this study, the risk factors of port operations were analysed using proposed advance risk matrix analysis. The risk was identified by combination of intensive literature review and brainstorming with port experts. The risk identified was analysed by using risk matrix techniques where the risk likelihood, risk severity and risk frequency was determined. The questionnaire form was used in order to ease the data collection process and distributed to one multipurpose port of one major ports in Malaysia. Based on analysis, the risk factor of accident for handling cargo at port were summarized, based on risk rating, it can be found R2 (Communication misunderstanding) was the highest risk fact for all of three ports, Port A, B and C. Meanwhile the lowest risk factors for Port A and Port C was R18 (Day Vs Night) and for Port B was R18 (Requisite safety facilities and equipment tallied with standards). It can be found that for Port A, 35% of risk factors fall under risk level III (Moderate) and 65% falls under risk level II (acceptable). For Port B, 35% of risk factors fall under risk level III (Moderate) and 65% falls under risk level II (acceptable). Meanwhile for Port C, 50% of risk factors fall under risk level III (Moderate) and 50% falls under risk level II (acceptable). Based on the results, in terms of safety evaluation, Port C was found as the riskiest port compared to Port A and Port B as the number of risk factors in risk level III was higher compared from both Ports.

Outcomes of the research is crucial as supplement to the current knowledge of the risk assessment of such systems, risk assessment models and general guidelines on the improvement of current frameworks and procedures. Concurrently, this study shall benefit the participate port in analyzing the risk management system particularly. With the result of this research, the port management can arrange any counter measures to increase the worker's safety awareness and culture in port. Besides, the authority such as department of occupational safety and health (DOSH), port authorities and marine department also will be benefit from this research for guideline formulation purposes. The research investigated the risk of accident for handling cargo at one of multipurpose port in Malaysia. Further research therefore could expand the scope of the study to major ports in Malaysia and the whole port operations.

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