Original Article

Evaluation of Process Safety Management Implementation in an Oil Field Services Company

Ong Huoy Ying,[a] Mohamad Syazarudin Md Said[a,*]

[a]*Safety Engineering Interest Group, Department of Chemical & Environmental Engineering, Faculty of Engineering, UPM, 43400 Serdang, Selangor*

*Corresponding author: syazarudin@upm.edu.my

ABSTRACT: *Serious injury and fatality incidents are frequently occurring in the oil and gas industry due to high risk operations. Process Safety Management (PSM) is a management system that is attentive to the prevention, preparedness, mitigation, response and restoration of energy release from process in a facility. Despite the fact that company A has a comprehensive PSM system in place, its pipeline services division suffered a fatality and a loss time injury incident in eight months gap for its global operation. The purpose of this study is to evaluate the knowledge of employees on PSM by conducting a survey and by auditing the implementation of PSM by division of pipeline services. Cause mapping was used to analyse the contributory causes of PSM implementation. The results of survey show that 50% of the questions were answered correctly by 59 respondents in knowledge session, low communication level and moderate implementation level of PSM. The findings of the audit conclude that PSM has been partially implemented in operation. The contributory causes of partially implemented PSM are due to no enforcement from headquarters, improperly rolled out and ineffective PSM programme training, no legal and client requirements on PSM in Malaysia, and high implementation costs. Improved implementation of PSM could reduce the rate of incidents in the future.*

Keywords: *Cause Mapping, Oil and Gas, Process Safety Management, PSM Audit*

1.0 INTRODUCTION

Many chemical processing plants were constructed in 1950 during the industrial revolution to satisfy the industrial needs through the use of machinery for replacing work by hand at home. Since 1984, however, numbers of safety disasters have continuously occurred in close gap due to insufficient preventive measures (Long, 2009). Incidental disasters such as the 1984 Bhopal disaster in India caused thousands of deaths and the 1989 explosion in Pasadena, Texas caused 23 deaths. (Pasman, 2015). In 1976, a dioxin contamination from runaway reaction at Seveso, Italy led to serious environmental consequences where nearly 81000 animals died (Fabiano et al., 2017). China Tianjin's explosion of ammonium nitrate in 2015 resulted in 173 deaths due to improper storage (Huang & Zhang, 2015). Qingdao, China's pipeline explosion in 2013 and Kaohsiung, Taiwan's gas explosion in 2014 share similar causes where hydrocarbon leakage from underground pipelines to municipal drainage systems resulted in vapor cloud explosions (Halim & Mannan, 2018).

In the wake of these disasters, Occupational Safety and Health Administration from United States introduced Process Safety Management which is regulated under Process Safety Management Standard, 29 CFR 1910.119, titled Process Safety Management of Highly Hazardous Chemicals in the year of 1990 and it was enacted in 1992 (Long, 2009). The process safety management system consists of 14 elements and its intention is to prevent the occurrence of major incident such as explosion, fire and toxic release (Mohd Shariff et al., 2016).

According to a study conducted in South Korea's chemical industry, it found that the incident rate of fatality, injury and near miss have been reduced by 62%, 58% and 82% respectively after 7 years of implementation in PSM (Kwon, 2006).

Number of hazards are involved during the maintenance of oil and gas pipeline due to the interface of numerous risk factors such as personnel, environment and equipment (Yu et al., 2018). Pipeline's servicers are possible to have fatal injury during pipeline construction, assemble and inspection operation with the condition of their presence and incident event will match (Vtorushina et al., 2017). The major risk found in their operation is high pressure. A Safety and Health Information Bulletin was shared by United States Department of Labor (2004), two workers were killed during testing operation process of the pipeline, they got struck by temporary de-watering piping due to excessive air pressure in the line. As reported by newspaper, two workers got killed and one hurt during a pipeline maintenance work at South Texas Pipeline due to sudden release of 800 pounds of pressure ("2 Workers Killed", 2016).

Company A is an oil and gas service provider to major operators and headquarters in the United States. They have a division of pipeline services that deals with high pressure in their job activity. Although there was a comprehensive process safety management system in place, in an 8-months gap, the pipeline services division had 1 fatality and 1 time injury loss incident. In this study, survey study, audit and cause mapping was conducted to evaluate the implementation of process safety management in Company A's pipeline services division.

2.0 METHOD

In this study, three methods were conducted to evaluate the implementation of PSM of Company A's pipeline division, which are survey, audit and cause mapping.

2.1 Survey

The survey was conducted to find out the level of communication of PSM in the knowledge of the pipeline services division of employees in PSM and the implementation of PSM in their daily work activities. The questionnaire consists of 5 Likert Scale styled questions and multiple choices. The similar 5 Likert Scale styled questionnaire survey was also practiced by Tang et al. (2017) study on Factors Affecting Safety of Processes in the Malaysian Oil and Gas Industry. Developed questionnaire was distributed to 10 employees who are excluded from the targeted study group and improvements were made during the pilot study. The Cronbach's α obtained is 0.829, which is more than 0.80, indicating that the items show good internal consistency (Rattray & Jones, 2007). Based on the calculation using the formula of Krejcie and Morgan as shown in equation 1 below, the sampling size determined for this study is 59 based on the confidence level is 95% and the population is 70. Inferential statistics will be at 0.05 significance level (Walters et al. , 2017).

$$S = X2NP\ (1-P)/\ d2\ (N-1) + X2P(1-P) \qquad \text{(Eq.1)}$$

The finalised questionnaire consists of a total of 30 questions distributed to 59 employees of the pipeline division who work on the operation site using a simple random sampling method. The data collected from questionnaires were then analysed using IBM Statistical Package for Social Scientists (SPSS) Statistics 21.0.

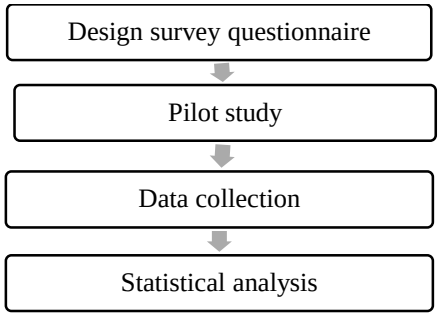

Figure 1 Flowchart of Methodology for Survey Study

Table 1 Rating Based on Mean Score

No.	Mean Value	Rating
1	1.00 – 2.33	Low
2	2.34 – 3.67	Average
3	3.68 – 5.00	High

2.2 Audit

An audit was conducted on the division of pipeline services based on the process safety management procedure of the company to evaluate compliance with the process safety management system of Company A. A robust audit programme involves management representatives and subject matter experts to ask questions on site (Rains, 2009). The audit was divided into three main parts which are reviewing evidence and documentation, interview field employees and site inspection (Norozi et al., 2013). As mentioned earlier, the audit conducted was only focus on elements fall under category of managing risk based on Company A process safety management system. Therefore, the gap analysis of process safety management implementation and its company system was identified based on the audit results. An audit checklist on the implementation of PSM was drawn up based on the Company A PSM procedure. Score for implementation compliance was given to each audited elements and sub-elements, ranging from 1 to 4 where 4 is fully implemented. Table 2 and 3 below shows the scores that indicate the compliance.

Table 2 Audit Scoring and Indicator

Scoring	Indicator
1	Awareness
2	Partial Implementation
3	Implemented but Needs Improvement
4	Fully Implemented

The total scoring of all elements is summed up and divided into total elements in order to obtain the final level of compliance to answer Objective 2 for this study. This audit checklist contains a total of 32 sub-elements based on Company A process safety management procedure.

Table 3 Scoring for Audit Implementation Level

Scoring	Implementation Level
1-1.9	Awareness
2-2.9	Partial Implementation
3-3.9	Implemented but Needs Improvement
4	Fully Implemented

2.3 Cause Mapping Analysis

Cause mapping analysis was also being conducted in this study, the outcome from survey study and audit were used to analyse the causes of implementation level of process safety management for pipeline services division. By using cause mapping, topics and their related causes could be bring together into hierarchical trees by asking "why" to sort problems from their root causes (Wagner, 2012). Thierry et al. (2017) has also applied cause mapping method to identified the root cause of ineffective and inefficient healthcare technology management in their study.

3.0 RESULTS AND DISCUSSION

3.1 Survey

3.1.1 Demographic

Based on the demographic data collected for this study, 12% of the 59 respondents are aged 21 to 30 and 78% are aged 31 to 40. Furthermore, 7% of them are between 41 and 50 years of age and the remaining 3% are over 50 years of age. Most respondents are between the ages of 31-40. Because of this company's minimum hiring requirement, all respondents will have at least 'Sijil Pelajaran Malaysia' SPM or Malaysian Education Certificate. SPM is a national examination taken by all fifth form secondary school students in Malaysia. 51% of the respondents are having SPM, 14% are having diploma certification and 36% are having certification in Bachelor Degree. Company hiring requirement for an operator's position is to require a minimum SPM level and a Bachelor's level for an engineer's position. Of the 59 respondents, 36% are engineers and 64% are operators. Due to job and contract requirements, the number of operators is always more than engineers. Engineer assigned as a project lead on site and operators are more towards to hands on skill job. According to the questionnaire received, 12% of the respondents have less than 3 years of working experience in this Company and 37% of them have being with this Company for 4 to 6 years. In addition, 42% of the respondents have 7 to 9 years working experience with this Company and only 9% of the respondents have been working with this Company for more than 9 years.

3.1.2 Communication Level of PSM

Table 4 Descriptive Data for Communication Level of PSM

No	Questions	N	Mean	Communication Level of PSM
Q5	I'm knowledgeable in Company's PSM	59	2.2373	Low
Q6	I have received PSM related training provided by company	59	2.0508	Low
Q7	My N+1 / PM /PL always educate and remind me about PSM	59	2.1695	Low
Q8	I received PSM related information / memo or email circulation frequently from company	59	1.9322	Low
Q9	I understand every clauses in Company PSM procedure	59	1.9153	Low
	Valid N (listwise)	59		
	Average		**2.0610**	**Low**

Table 4 above shows that this section contains a total of 5 questions and 59 respondents have answered them. The mean value obtained Q5 is 2.24, Q6 is 2.05 and Q7 is 2.17. However, there is an even lower mean value found for Q8 and Q9 which is 1.93 and 1.91. The results obtained for each questions are low level of PSM communication, thus, the average result obtained for this section is also low communication level As a result, it shows that superiors are not committed to cascading PSM-related information to their employees, which causes employees not to be trained with PSM knowledge Email circulation is the easiest way to communicate in Company A because all employees have access to corporate email and intranet, but the resources are not being used.

3.1.3 Knowledge level of Employees' on PSM

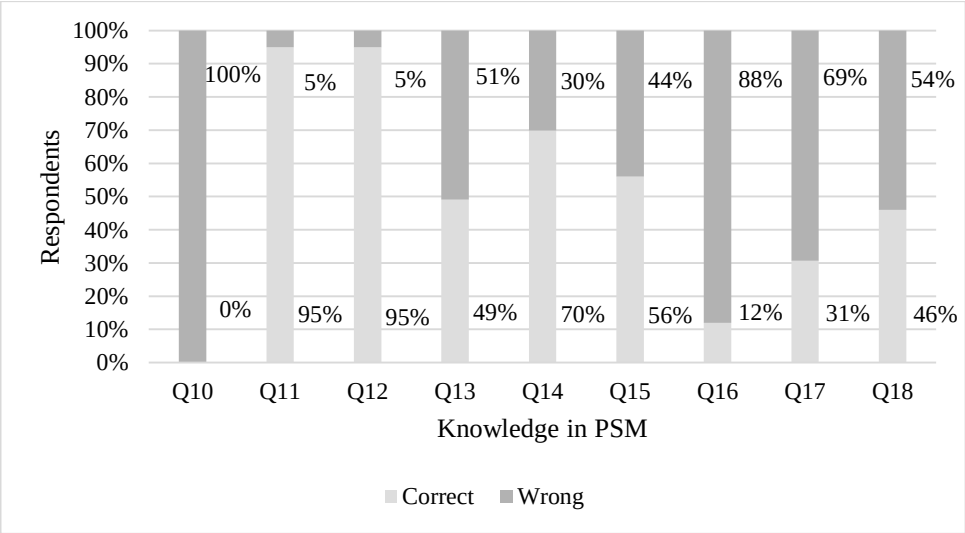

Figure 2 Result for Q10 to Q18, Percentage of Correct and Wrong Answer Provided by Respondent

Fig. 2 shows the percentage of respondents correct and incorrect response through survey questionnaires. Based on the questionnaire analysis for this section, none of the respondents had obtained 100% correct answers to all these questions they had answered during the training. The total elements found in the Company's process safety management system in Q10 could not be remembered by all respondents. However, in Q11 and Q12, 95% of respondents are able to respond to the basic principles of process safety. And, despite multiple choices in Q13, 51% of respondents were unable to define what process safety incident is.

With the percentage of 70% and 56% respectively, more than 50% of respondents able to answer Q14 and Q15 which are process safety barrier related questions. In Q16, a total of 88% of respondents were unable to obtain the correct response to the BowTie risk assessment method. And in Q17, 69% of respondents were unable to remember the total number of Critical Upstream Process Safety Requirements. 54% of respondents do not know what the process safety risks are for their job nature for the last question in this knowledge test session.

Table 5 List of Questions for Q10 to Q18

No.	Questions
Q10	How many elements found in Company Process Safety Management System?
Q11	Upstream Process Safety is
Q12	Personal safety focuses on individual behaviour whereas process safety focuses on equipment, process and people
Q13	Process Safety Incidents are of:
Q14	What method helps determine barriers to protect the top event from occurring and minimize consequences?
Q15	At our company, what are considered as barriers to prevent process safety incident from occurring?
Q16	The BowTie Risk Assessment method has the following key elements EXCEPT:
Q17	How many Critical Upstream Process Safety Requirements are there in Company?
Q18	The following are Process Safety Risk for our division EXCEPT?

There are several possible reasons of respondents unable to answer those questions in questionnaire which are they do not implement process safety management system after the taken the training, thus, the knowledge is fading away with time. Secondly, there is no refresher training needed for this training course, thus, respondent might sat for the training many years ago as the majority of the respondents are having working experience from 4 to 9 years based on the demographic data obtained from this survey. As mentioned by Sutton (2015), training has to be an on-going process due to employee's performance will be declining if there is no further training is carried out. Thirdly, company PSM training was conducted through online, thus, employee is able to seek for co-worker assistance to answer exam question in the training module.

3.1.4 Implementation level of PSM

Table 6 Descriptive Data for Implementation Level of PSM

No.	Questions	N	Mean	Implementation Level of PSM
Q19	Current project SOP cover PSM	59	2.3220	Low
Q20	Project induction covers PSM topic such as operating procedures, ERP, MOC and etc.	59	3.4915	Average
Q21	Fully utilized all the PSM related document which are made available in company online database	59	2.6780	Average
Q22	Fully utilized the BowTie risk assessment for my division which is made available in company online database	59	2.0169	Low
Q23	Documentation outlining the protective systems installed to prevent process safety related incidents	59	3.5085	Average
Q24	Utilized BowTie risk assessment or an alternative method such as hazard risk assessment to review process safety risks prior project started	59	3.9831	High
Q25	Select the right barriers for the hazards and risks	59	3.5085	Average
Q26	Active monitoring of barriers strength	59	2.8475	Average
Q27	All the safety equipment/ barriers such as pressure relief devices, pressure control equipment and etc. are always in use during operation	59	3.8305	High
Q28	Safety instrumentation and alarms such as emergency responses systems, alarms and sensors are in use during operation	59	2.7627	Average
Q29	A copy of project ERP in made available on site	59	2.8305	Average
Q30	MOC is always being raised when there is any deviation from procedure	59	3.1356	Average
	Valid N (listwise)	59		
	Average		**3.0763**	**Average**

There were 12 questions in this section based on Table 6, and all respondents have answered them. Out of 12 questions, 2 obtained a mean value of less than 2.33 indicating the low level of implementation, 8 achieved the mean value between 2.34 and 3.67 indicating the average level of implementation and 2, the mean value reached more than 3.67 indicating high level of PSM implementation. which is not fully complied with Company's process safety management system requirement. The total mean value for this questionnaire section shows the average level of implementation of process safety management in the division of pipeline services that is not fully compliant with the requirement of the Company's process safety management system. The result obtained is an average level of implementation may be due to employees not being aware of the requirement of company PSM or negligence due to no superior enforcement. A study found that Malaysians still lack understanding and implementation of PSM and not many PSM experts are available in Malaysia (Abu Bakar et

al., 2017). Unlike other countries such as the United States, the United Kingdom, Japan and Singapore, Malaysia still does not have a good approach to manage PSM.

3.2 Audit

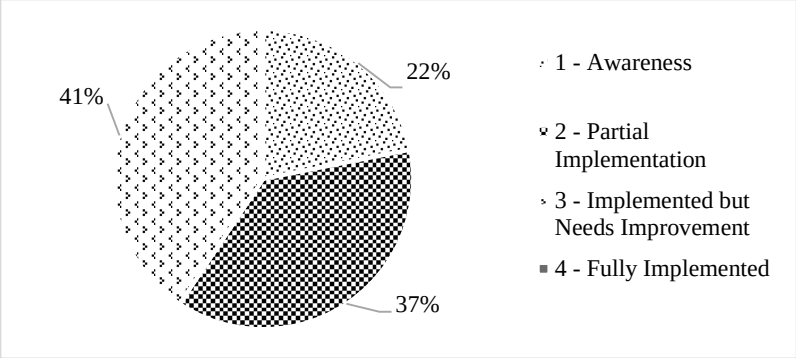

Figure 3 Overall Audit Result

Table 7 Audit Scoring

No.	Audit Element	Mean	Implementation Level
1	Operating Procedure	2.6	Partial Implementation
2	Asset Integrity and Reliability	2.6	Partial Implementation
3	Operation Management	2.7	Partial Implementation
4	Management of Change	1.4	Awareness
5	Human Factors	2.0	Awareness
6	Emergency Management	1.3	Awareness
	Average	**2.1**	**Partial Implementation**

Based on Fig. 3, there are 7 findings of awareness which is 22% of the total scores, 12 partial findings of implementation which is 37% of the total scores, 13 implemented but needs findings of improvement which is 41% of the total scores, 0 findings on fully implemented. Referring to Table 7, the audit checklist contains 6 elements, 3 of 6 elements found partially implemented, and 3 of the elements found during audit only at the level of awareness.

Operating procedure is retrievable on site during the interview session and engineers are aware of the latest revision of the operating procedure. However, most operators haven't seen the procedure and don't know the latest revision number. This is because engineers are accessible to the company's project server but not accessible to operators. This may cause miscommunication if any member of the team refers to the obsolete procedure during job execution and it has the possibility of causing an incident if the operator operates the equipment at the wrong working pressure.

During the audit, testing and calibration certificates are found on site, but feedback from the team is that they experienced equipment breakdown during the operation. Although the calibration and maintenance of the equipment is performed in conjunction with the issuance of the certificate prior to mobilisation, it is performed only by the employee of the company, not by the competent person from third party service provider. This may affect the quality and reliability of the equipment's calibration and maintenance. All the equipment came along with on-site testing and maintenance certificates, but some small items such as hose and sling certificates are not found on-site.

The operation management execution plan was found to focus solely on equipment, process and staff management during operation, not much information was provided on staff competency, human factors and compliance with laws and regulations. Risk assessment was not carried out in a team of subject matter experts from the relevant department, but individually based on the interview session. Risk assessment should be conducted with participation of relevant department's representative, is a group-based approach, not individual approach (Ayres & Parra, 2016). Yet, the risk assessment has been discussed together with client during the HAZID session prior mobilization. The competent management program was found not in accordance to company's requirement, improper and ineffective competency management program practice might lead to incident happen due to employees do not know how to operate the equipment safely.

Based on the audit interview session, MOC was not raised for minor process and equipment changes such as increased operating pressure and changes in the type of hose used. However, risk assessment was not conducted for the raised MOC, but only fill out the MOC form. No evidence of toolbox talk or meeting attendance list found for communication of MOC raised. The MOC process only involved engineer and client in charge but not the operator, operators are not aware of the MOC raised during interview session.

The 24 hours operation is run by 2 shifts of employees and each shift works 12 hours. Employees are given sufficient rest time to avoid fatigue. However, it was found that the work load on engineers are over burden which caused them do not have sufficient rest time as they are the overall person in charge in the project where they have to deal directly with the working team and client. This cause insufficient rest and increased in stress level to the engineer, and might lead to wrong decision making during the project execution due to fatigue.

During the audit, project specific emergency response plan is not available but employees have undergone site orientation conducted by client. In case of emergency, client will be the incident commander due to they are the site owner. Employees participated in facility's emergency drill which is conducted by client which participation is mandatory. On the other hand, there is no emergency drill conducted by Company project team. Risk-based contingency planning shall be performed and implemented as required and follow Company's global contingency planning processes. Yet, the contingency plan is not found or implemented on site.

3.3 Cause Mapping Analysis

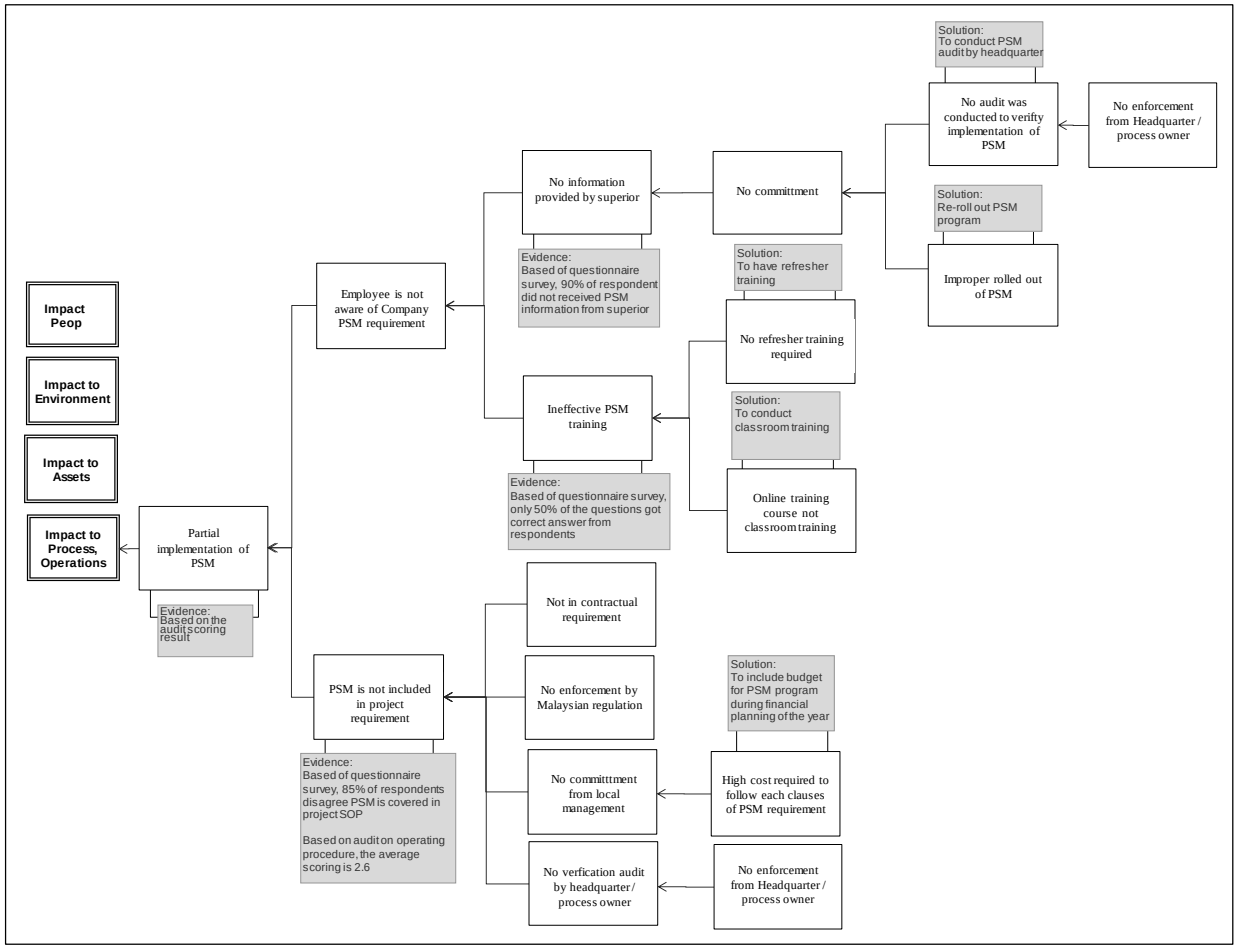

Figure 4 Cause Mapping Analysis

There are few root causes to be identified based on the cause mapping analysis in Fig. 4. One of the causes of partial implementation of PSM is that employees are not aware of the company's PSM requirement because no information is provided by their superior, which is obtained from the survey findings of the questionnaire, 90% of respondents said they did not receive PSM related information from their superior. This shows that lack of commitment to PSM by superior, and the possible cause is that no PSM verification audit was conducted by headquarters or process owner. And another possible reason is improperly rolled out of PSM where employees and superiors do not know their role and responsibility in PSM. Internal audit is necessary to be conducted to ensure system is in place and implemented effectively, issues are identified before it being identified by customer or legal authority (Swainson, 2018).

Another cause of employees being unaware of the company's PSM requirement is that ineffective PSM training was provided to employees due to online training and no refresher training required. A study found that students unable to speak out their thoughts and ideas while doing online course and them feeling lost in the cyberspace (Mansour & Mupinga, 2007). On the contrary, students able to ask question and additional input with the physical presence of teacher in the classroom (Mansour & Mupinga, 2007).

Another reason why Company A pipeline services partially implement PSM is that PSM is not included in the project requirement. This is because PSM is not listed by the customer under contractual requirement and does not cover any of the regulations of Malaysia. Implementation of PSM in Malaysia is purely based on company's initiative (Abu Bakar et al., 2017). In addition, there is no commitment from local management, this might be due to high cost required to implement each clauses of Company PSM procedure. Last but not least,

there is no verification audit by headquarter or process owner, thus, local team may just skip the tedious process of implementing PSM.

Cause mapping in Fig. 4 analysed the contributory factor or root cause of the Company's pipeline services division partial implementation of PSM in order to respond to Objective 3 of this study. The possible root causes are no enforcement from headquarters, which is also the process owner, improperly roll-out of the process safety management programme, ineffective process safety management training, no legal and customer requirements for process safety management in Malaysia and high implementation costs.

4.0 CONCLUSION

In the wake of disaster incident and enforcement by United States OSHA department, numerous companies have started to implement process safety management system in their organization. Based on the results obtained from questionnaire conducted in this study, the communication level of process safety management in pipeline services division of Company A is low, only 50% of the questions got answered correctly by a total number of 59 respondents and implementation level of process safety management is moderate. From the result obtained from audit, it also indicates that implementation of process safety management by pipelines services of Company A is only partial implementation. The root causes of failure to fully implement the process safety management system found in this study are no enforcement from headquarters that is also the process owner, improperly rolled out of the process safety management programme, ineffective process safety management training, no legal and client requirement for process safety management in Malaysia, and high implementation costs.

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