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A Case Study of Asset Integrity and Process Safety Management of Major Oil and Gas Companies in Malaysia

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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Case Study

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ABSTRACT

Asset integrity is closely intertwined with process safety where the latter is often perceived to be equivalent or a subset of the former. In Malaysia, the requirements for offshore process safety are set by Petronas assuming exclusive rights to petroleum in the nation. It imposes and enforces these requirements on oil and gas companies entering into its production sharing contracts via the common law. Process safety management in Malaysia is strongly influenced by the US OSHA 3132 with elements comprising process safety information, process hazard analysis, operating procedures, employee participation, training, contractors, pre-startup safety review, mechanical integrity, hot work permit, management of change, incident investigation, emergency planning and response as well as compliance audits. These elements are largely included in the Mandatory Control Framework of Petronas and the trio of design, technical and operating integrity adopted in the process safety management of other oil and gas companies. These management practices align with the reiterative plan-do-check-act model. Process safety performance is also gauged with indicators suggested by international institutions such as the American Petroleum Institute. On top of the Control of Industrial Major Accident Hazards Regulations 1996 for onshore processes, this study deems that establishing statutory law for offshore installations will be beneficial to propel offshore safety in Malaysia to a greater height.

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1. INTRODUCTION

Development of safety in the Malaysian offshore operations is closely tied to the global advancement in safety. An important milestone in the safety of oil and gas operations in Malaysia is the enactment of the Petroleum (Safety Measures) Act in 1984 which regulates activities related to transportation, storage and utilization of petroleum [1]. A subsidiary law, namely Petroleum (Safety Measures) (Transportation of Petroleum by Pipelines) Regulations 1985 were made under the Act [2]. Prior to enactment of the Act, the Factory and Machinery Act (FMA) already came into force in 1967 providing governance over safety, health and welfare of workers in factories as well as registration and inspection of machinery. The FMA identifies a platform as a factory with well-defined boundary and machinery to perform various operations. Offshore oil and gas platforms are therefore subject to the FMA [3]. Petroleum Mining Act was passed a year before the FMA but deals with matters related to application of exploration license or petroleum agreement, hence limited implications on safety of offshore operations [4].

Due to shortcomings of the FMA which was prescriptive with limited scope of application, it was superseded by the Occupational Safety and Health Act (OSHA) 1994 [5]. The Act came into force to promote and maintain safety and health at work including offshore installations. It mandates establishment of safety committee, employment of safety officers, conducting of chemical health risk assessment at facilities with industrial major accidents hazards, industrial hygiene monitoring and medical surveillance of workers, among other safety measures [6]. Despite the progress made in safety and health legislation, there is generally a lack of clear guidelines on the execution of offshore safety in the oil and gas industry. The Petroleum (Safety Measures) Act 1984 provides the framework for transportation, storage and handling of petroleum but does not outline the crucial safety aspects of offshore oil and gas operations [2]. The FMA adopts a prescriptive approach on elements of safety encompassing competence of machines' operators, registration of factory and machinery, specifications of hoisting machines and pressure vessels as well as risk-based inspections [7]. It does not adequately address the critical aspects of offshore oil and gas safety. The superseding OSHA 1994 employs a self-regulatory approach, focusing mainly on establishment of safety management which inclines towards the general occupational domain and its emphasis on the control of major accident hazards is often confined to onshore facilities [5].

The safety and health laws come short in addressing the safety of offshore oil and gas operations which extend beyond personal safety to process safety and asset integrity [8]. Process safety events comprising fire, explosion, major leakage and spillage often pose serious consequences such as multiple injuries, fatalities as well as extensive property and environmental damages [2]. Many countries have enacted laws to address offshore safety specifically. The United Kingdom enacted the Offshore Safety Act 1992 as an extension to the overarching Health and Safety at Work etc. Act 1974. The Act focuses on the safety, health and welfare of offshore workers particularly in the aspects of construction, operation and decommissioning of offshore installations, as well as ensuring security of petroleum and petroleum products [9]. Instances of regulations made under the Act are the Offshore Installations (Safety Case) Regulations 1992 and The Offshore Installations (Prevention of Fire and Explosion, and Emergency Response) Regulations 1995 [10].The Offshore Petroleum (Safety) Regulations 2009 under the purview of the Commonwealth of Australia set the requirements for operators, safety cases, validation and accidents notification of offshore facilities. The regulations also provide for occupational health and safety, in addition to diving of offshore workers [11]. In response to the Deepwater Horizon explosion in 2010, the United States established the Bureau of Safety and Environmental Enforcement (BSEE) to strictly regulate safety and environmental protection offshore [12]. In Malaysia, there is an apparent lack of laws and guidelines for various aspects of offshore installations. The oil and gas players therein often resort to international standards particularly those of the American Petroleum Institute (API) and the International Organization for Standardization (ISO) [13]. The national oil and gas company, the Petroliam Nasional Berhad, commonly known as Petronas, having given the sole power to explore and exploit onshore and offshore oil and gas resources, stipulates the requirements for companies wishing to be granted license to supply goods and services to Petronas. Frequently, it dictates the standards its contractors and partners need to meet [14].

2. REVIEW OF ASSET INTEGRITY MANAGEMENT PRACTICES

In the offshore sector, asset integrity management is at the centre of safety management and has overlapping features with process safety. Asset integrity management encompasses the management of people, systems, processes and resources to ensure assets operate with minimal risks to employees, the public and the environment [15]. There are three main aspects of asset integrity management, i.e. structural, technical and operating integrity [16].

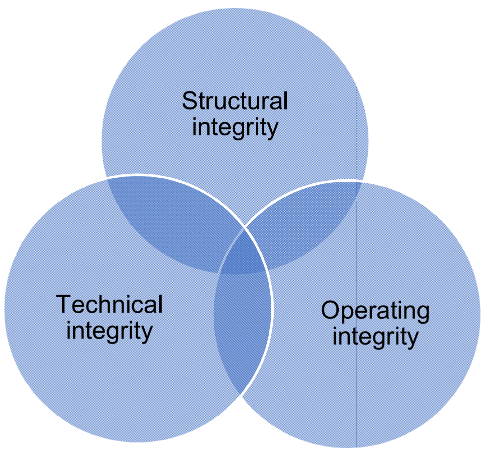

Fig. 1. Elements of asset integrity management [16]

Asset integrity management of offshore operations began to receive attention after the Piper Alpha accident in 1988, which prompted oil and gas operators to review their strategies in assessing and managing integrity of their installations [17]. Asset integrity management post-Piper Alpha was adopted in response to the increasing pressure to ensure safety of oil platforms due to emergence of more stringent safety legislations [18]. Among the measures taken to enhance asset integrity were improving permit-to-work system, relocation of pipeline emergency shutdown valves and installation of isolation devices [16]. Asset integrity and process safety are similar in many respects. It adopts multiple safety approaches such as barrier-based system, safer designs and reliability engineering [19]. Asset integrity management spans the entire life-cycle of a platform. Process safety can be understood as the operational aspect of asset integrity, though in practice, asset integrity is often oriented towards the hard barriers of a system comprising for instance structures, piping and instrumentation, and equipment (19,20].

Therefore, taking into account the subtle distinction in the practical aspect of asset integrity and process safety, safety on offshore oil and gas platforms can be classified into two major domains i.e. personal safety and asset integrity, equivalent to or encompassing process safety [21]. Asset integrity management practices in Malaysia are typically guided by legislation of other countries such as the Offshore Installation (Safety Case) Regulations 1992 and international standards particularly those of the API [10,13]. Asset integrity management starts from the development phase of an offshore project, commencing with evaluation and review of development options and initial operations assessment [22]. Once the development option is finalized, the concept is formulated and evaluated. Initial analysis of hazard and effect management process (HEMP) is conducted for each concept option and the proposed concept is reviewed to ensure the 'ALARP' approach has been practiced whereby risks identified are reduced to as low as reasonably practicable [22].

Front end engineering design (FEED) commences upon finalization of the project concept. Another HEMP analysis is carried out for FEED. Techniques for HEMP analysis vary. The most commonly used HEMP technique is called the Bowtie method, deriving its name from the diagram showing the cause and effect relationships of risks identified which looks like a bowtie (Fig. 2) [23]. The Bowtie method not only identifies potential accidents arising from a hazard, it also identifies control measures for the scenarios and the ways the control measures could fail. It provides a means to 'ALARP' in risk management [24]. The Bowtie diagram was said to have made its debut at the University of Queensland, Australia in 1979 but its origin and development remains unverified [25]. The method was first adopted by the Royal Dutch Shell and is now widely used by industries and regulators. The Bowtie forms part of risk-based approach in safety management which involves risk assessment to better define the magnitude of an industrial occurrence, the frequency of occurrence and the effectiveness of barriers to control the risks [22].

Determination of groups of safety critical elements (SCEs) follows the HEMP in design stage, and subsequently, operation envelope as well as performance standards are defined [22].

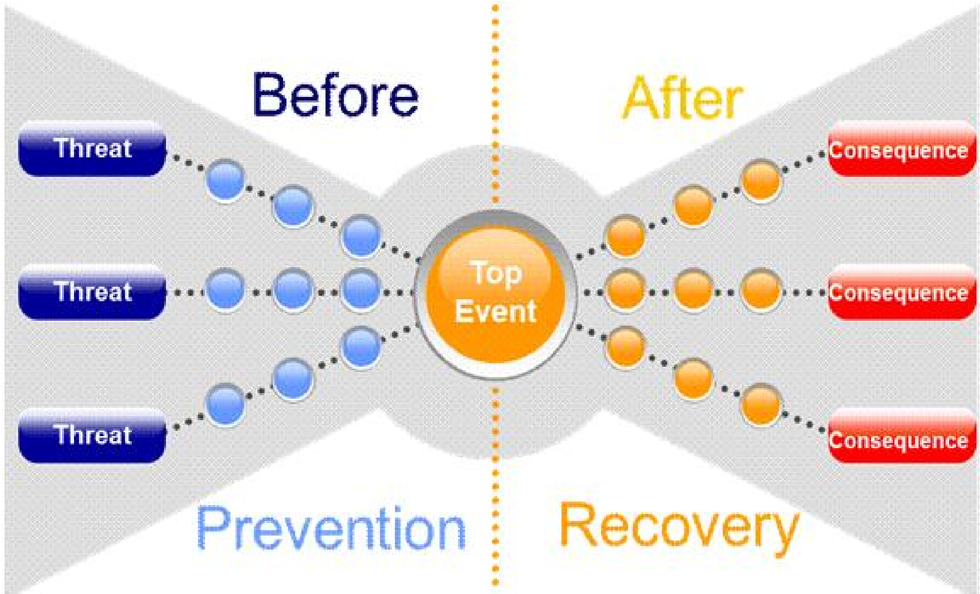

Fig. 2. Bowtie diagram [25]

Design safety case is often formulated at this stage as required by the legislations in the UK and Australia. In 2016, Brunei adds to the list of countries requiring safety case for offshore installations prior to operations [26]. In execution phase, the detailed facilities design is already in place. Refined HEMP analyses with specific bowties are conducted. SCEs identified are entered into asset register and loaded into computerized maintenance management system [27]. The design performance standards and assurance measures are refined, and the operational phase performance standards and assurance measures are established. Operations safety case is formulated as an extension to the design safety case [22]. Facilities are then constructed and the operational readiness and assurance plan is executed. Commissioning and handover of facilities to operators mark the end of this stage [28].

During operation, the SCE performance assurance tasks and measures are managed, with deviations controlled. Reporting of SCE status and key performance index as well as management of change also take place during this stage [27]. With increasing emphasis placed on human and organizational factors in safety management, measures to reduce fatigue and musculoskeletal disorders, increase alertness, assure competence as well as to increase safety culture and behaviour are incorporated into lifecycle of offshore installations starting from FEED to decommissioning [29,30]. An overview of asset integrity management of offshore platform is shown in Table 1.

Zooming in to specific domains of asset integrity management, technical integrity management involves identifying SCEs and performance standards using HEMP, establishing and executing maintenance, inspection and test plan, as well as monitoring the SCE functions and taking corrective actions where necessary [22]. Different oil and gas companies may have different approaches in monitoring the SCE functions. One of the methods is facility status reporting. Between 2004 and 2007, the HSE (2008) initiated the Asset Integrity Key Program, focusing on maintenance management of safety critical elements (SCEs) of offshore installations comprising fixed installations, floating production, floating production storage and offloading vessels and mobile drilling rigs [31]. Participating oil and gas companies align their facility status reporting to the recommendations of the HSE, incorporating the suggested elements and the traffic light system to indicate compliance status of the SCEs where red indicates non-compliance, amber indicates isolated failure and green indicates compliance [32]. However, facility status reporting does not incorporate sufficient leading indicators which capture the preventive effort made in managing major hazards and does not place sufficient emphasis on safety culture and human factors [32].

Table 1. Overview of Asset Integrity Management of Offshore Platform [22]

Step		Element
1.	Identify and assess	• Formulate and evaluate development options • Review development options • Initial operations assessment
2.	Select	• Formulate and evaluate concept • Initial HEMP analysis for each option (HAZID) • Review proposed concept – demonstrate ALARP • Operations philosophy development
3.	Define	• Front End Engineering Design (FEED) • HEMP analyses for FEED – Bowties • SCE group determination • Operation envelope definition • Design performance standards • Design safety case • Basis for Design
4.	Execute	• Detailed facilities design • Refined HEMP analyses with specific bowties • SCE identification in asset register • Refined design performance standards and assurance measures • Operate phase performance standards and assurance measures • Operations safety case • Construct facilities • Commission and handover to asset owner
5.	Operate	• Manage SCE performance assurance tasks and measures • Deviation control • SCE status and KPI reporting • Management of change process

Note: HAZID = Hazard identification; KPI = Key performance index

Category	Green Prev	Green Corr	Amber Prev	Amber Corr	Red Prev	Red Corr	Dev Prev	Dev Corr
SI Structural Integrity	54	121	0	0	0	0		7
PC Process Containment	821	394	3	3	7	2	16	14
IC Ignition Control Systems	690	156	0	0	0	0		2
DS Detection Systems	72	15	1	0	0	0		
PS Protection Systems	145	35	1	0	0	0	1	
SD Shutdown Systems	62	22	0	0	0	0		
ER Emergency Response	79	14	3	0	0	0		
LS Life Saving Systems	31	7	0	0	0	0		
Non SCE Items	723	678	1	0	0	0	6	7
Competency Deviations		0		0		0		2
Standards Deviations		0		0		0		59
Total	2677	1442	9	3	7	2	23	91

Fig. 3. An example of facility status reporting adopted by an oil and gas platform

Operating integrity engages active identification and management of vulnerabilities, risk assessment, risk control, control measure implementation as well as review by senior leadership [24]. Operating integrity ensures processes are within operating and pressure/ temperature envelop. It involves constant review of operating performance at various levels and management of alarm, for instance via alarm steering committee, alarms database to capture alarm purpose, and automatic suppression to eliminate false alarms [24].

Structural integrity focuses on ensuring offshore installations are able to support a designed load without failing and incorporation of past failures into future designs [28]. Early development of structural integrity management was associated with aging of offshore installations, failure to follow good practice and shortcomings in guidance documents. To date, the structural integrity management framework is provided by API and ISO [33].

3. METHODS

This case study aims to examine the asset integrity management practices of two major oil and gas companies in Malaysia qualitatively. The companies comprised a national company and an international company. Specifically, their process safety management (PSM) was examined as a subset of asset integrity management, particularly against the aspects illustrated in Section 2. Their current PSM was also compared against a widely recognized standard, namely the OSHA 3132 – Process Safety Management Standard. This case study therefore, serves to share the experiences of asset integrity management in Malaysia.

4. RESULTS AND DISCUSSIONS

Process safety management (PSM) practiced by the oil and gas companies in Malaysia is influenced by international standards and the practices of international oil and gas companies collaborating with Petronas in various upstream oil and gas activities [21]. Petronas defines the requirements for PSM to be met or exceeded by its collaborators which may have more mature PSM practices. Petronas has a Mandatory Control Framework based on the Plan-Do-Check-Act continuous improvement cycle which integrates PSM as shown in Fig. 4 [27].

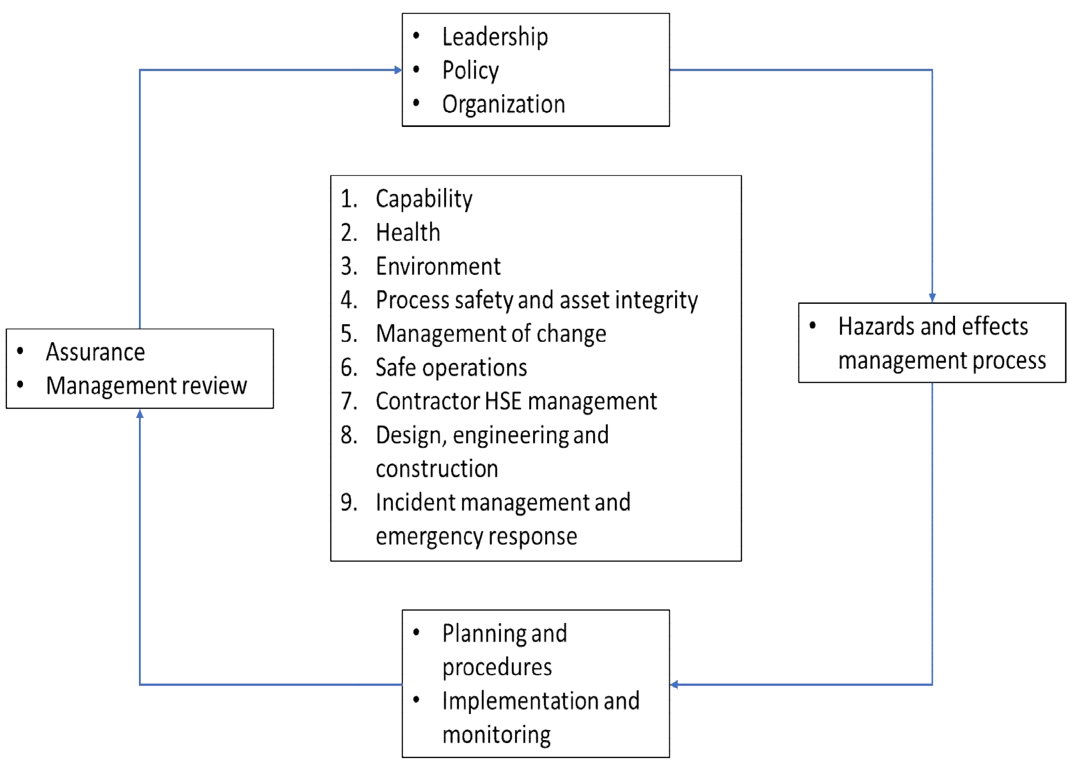

Fig. 4. Mandatory Control Framework adopted by Petronas [27]

Though singling out process safety and asset integrity as a component of the framework, other components of the framework seem to overlap with the process safety and asset integrity. These include management of change, safe operations, design, engineering and construction as well as incident management and emergency response, all of which are the subsets of process safety and asset integrity [22]. The process safety elements stipulated by Petronas comprising process safety information, process hazard analysis, pre-activity safety review, management of change, operating procedures, proprietary and licensed technology assessment, design integrity, mechanical integrity, design and engineering process safety requisites, contractor HSE and emergency preparedness, also suggest overlapping components of the framework with the overarching process safety and asset integrity [27]. These components align with OSHA 3132 – Process Safety Management Standard [34]. OSHA 3132 has strong influence on the PSM of major oil and gas companies in Malaysia, be it local or international. The first element of OSHA 3132 is process safety information which requires employers to compile process safety information capturing highly hazardous chemicals used or produced as well as technology and equipment adopted in the process [34]. Process hazard analysis comes subsequently mandating an initial process hazard analysis followed by periodic updating and revalidation to ensure its currency. Next, operating procedures are to be developed in reference to the process safety information. They often prescribe safe work practices such as lockout/tagout, entry control, etc. applicable to both direct employees and contractors [34].

The employers will also have to develop an employee participation action plan and grant the access of employees to crucial information as required by the standard [34]. Training forms a crucial element of PSM to safeguard employees' safety and build their competence in discharging duties and responsibilities specified in the operating procedures [35]. OSHA 3132 also provides for contractors' safety in recognition of the presence of different contractors onsite for maintenance or repair, turnaround, major renovation, or specialty work on or adjacent to a covered process [34]. Pre-startup safety review as a PSM element ensures up-to-specification construction and equipment, the availability of safety, operating, maintenance and emergency procedures as well as the execution of process hazard analysis [27]. OSHA 3132 requires hot work permit for hot work operations. Management of change is another critical PSM element which prompts detailed evaluation of changes proposed to permit necessary amendments of operating procedures in line with the changes [34]. PSM should incorporate incident investigation to identify root causes and escalation pathways of events for development and implementation of relevant corrective measures [35]. OSHA 3132 demands the inclusion of emergency planning and response which involves development and execution of emergency action plan parallel to OSHA requirements [34]. Finally, compliance audit is a must in PSM to gauge the effectiveness of PSM, warrant compliance and verify adequacy of PSM procedures and practices [22]. These PSM elements also reflect the plan-do-check-act model to drive continuous improvement [36].

While different oil and gas companies in Malaysia may have slightly different lists of process safety elements, the essence remains the same. A major international oil and gas company in Malaysia upholds a model of PSM similar to that in Fig. 1. The model is shown in Fig. 5. The model shows elements similar to asset integrity management, except that structural integrity is replaced by design integrity [22]. Design integrity here emphasizes the design of process equipment rather than the entire structure of a platform or plant. It centers on identifying major hazards, creating barriers for hazards to prevent incidents and minimize escalation, and setting performance standards for the barriers [22]. This could also imply a

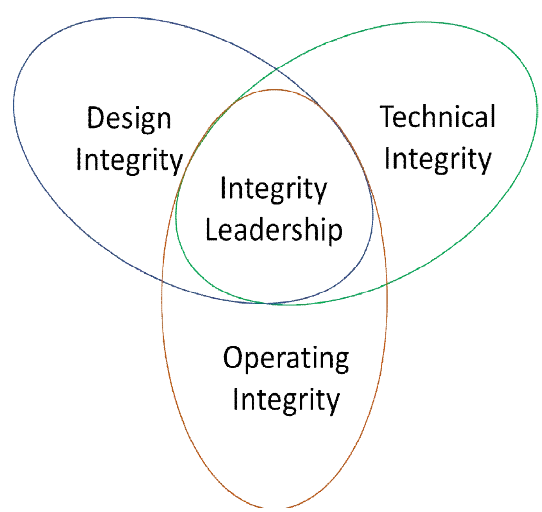

Fig. 5. PSM model of an international oil and gas company in Malaysia [22]

difference of PSM from asset integrity management wherein the latter is inclusive of all process and non-process structures. Albeit, leadership is instrumental in driving both PSM and asset integrity management as leaders are deemed to create cultures [22]. Leadership is also captured in the Mandatory Control Framework of Petronas [27]. While the PSM model in Fig. 5 is generalized, the actual PSM practices of the company follow the reiterative plan-do-act-check where a control and assurance strategy involving independent technical authorities followed by an audit and review strategy are incorporated [31]. Its asset integrity management follows the steps in Table 1 closely.

Performance indicators are important to check the effectiveness of PSM to enable its continuous improvement [35]. PSM of the oil and gas companies in Malaysia often adopts a tier-approach promulgated by the API consisting of a mix of leading and lagging indicators to monitor various process safety elements [37]. Lagging indicators measure number of incidents, injuries and damages beyond a certain level of seriousness. Leading indicators, on the other hand, provide indications of deviation from the ideal situation by assessing inputs to safety [37] and are typified by indicators measuring mechanical integrity, action items follow-ups as well as training and competence [38]. In the context of oil and gas process safety, leading indicators can be alarms, preventive and corrective maintenance of SCE, audits and review, whereas lagging indicators are usually leakages, spills and incidents. The tiered process safety performance indicators recommended in API-RP 754 is shown below [39].

Generally, the asset integrity management of Petronas follows Table 1 closely, as shown in Fig. 7. below. Its SCE barriers are also similar to that adopted internationally as shown Fig. 8. The same has been observed for the international oil and gas company examined where the asset integrity management mirrors Table 1 and the SCE barriers are the same as Fig. 8.

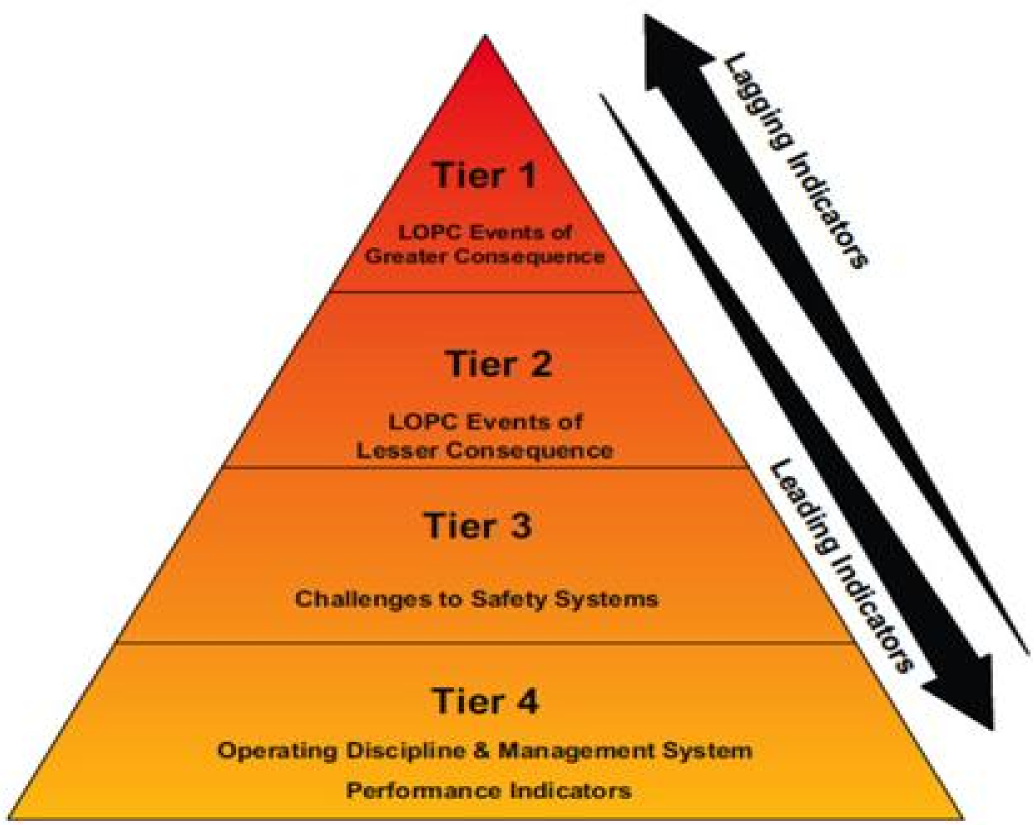

Fig. 6. Tiered process safety indicator of API-RP 754 [39]

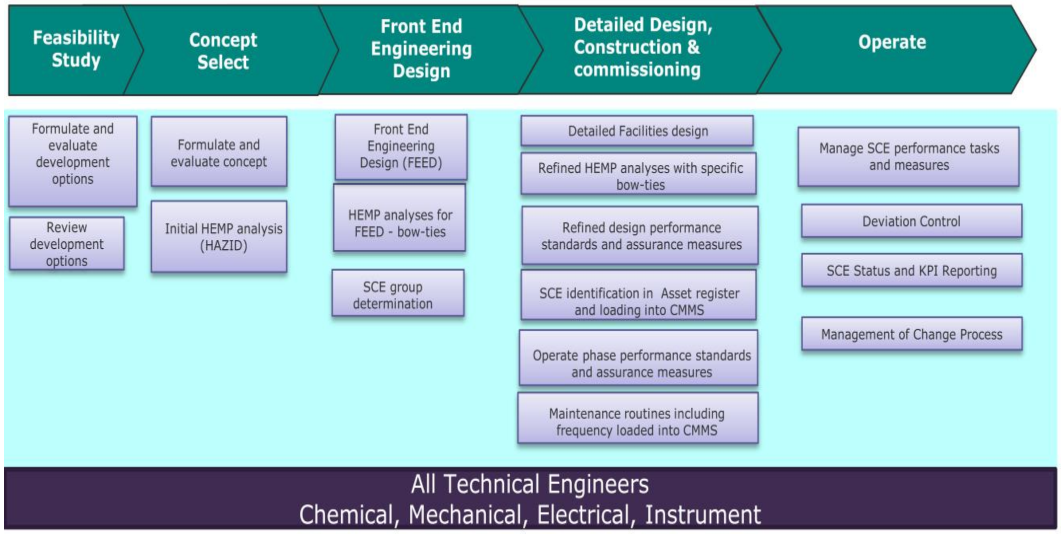

Fig. 7. Asset integrity management adopted by Petronas [27]
Note: CMMS = Computerized Maintenance and Management System

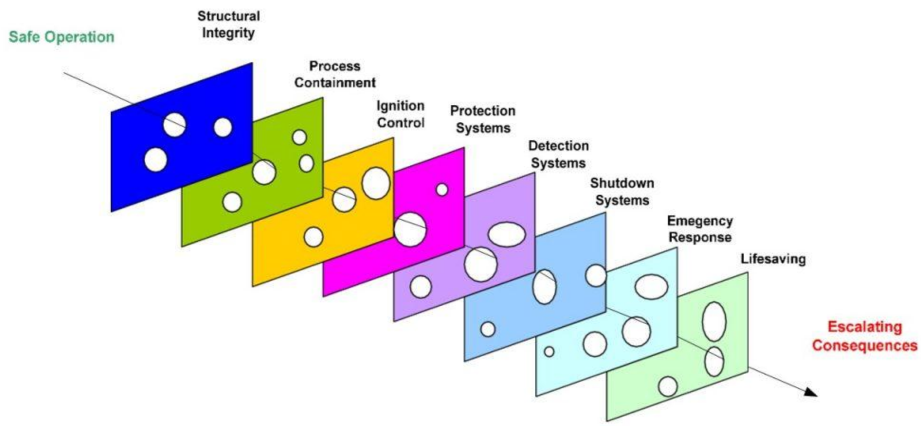

Fig. 8. SCE groups in asset integrity management depicted in the 'Swiss Cheese Model'

To date, the oil and gas sector continues to strive for improvement in safety performance measurement via refinement of indicator system for performance measurement and evaluation. There are numerous guidelines for development of indicators for facilities posing major hazards such as explosion, fire and leakage. Five (5) important ones that are worth mentioning are [40,41,42,37,39]:

1. Developing process safety indicators, by Health and Safety Executive (HSE) (2006)
2. Guidance on developing safety performance indicators related to chemical accident prevention, preparedness and response for industry, by Organization for Economic Co-operation and Development (OECD).
3. Process safety – recommended practice on key performance indicators, by International Association of Oil & Gas Producers (IOGP).
4. Process safety leading and lagging metrics, by Center for Chemical Process Safety (CCPS).
5. Process safety performance indicators for the refining and petrochemical industries, by API.

Table 2. Comparison between the major guides for safety performance indicators development

Aspects	HSE	OECD	API	CCPS	IOGP
Sector intended	Major hazard installations	Entities posing risk of major accident	Refining and petrochemical industries	Chemical and petroleum industries	Upstream oil and gas activities, e.g. exploration and production
Term used for safety indicators	Process safety performance indicators	Safety performance indicators	Process safety indicators	Process safety metrics	Key performance indicators (KPIs)
Approach/ type of indicators	Dual assurance, using both leading and lagging indicators	Outcome indicators and activities indicators	Tier approach*, from leading indicators at the bottom tier to lagging indicators at the top tier.	Tier approach, from leading metrics at the bottom tier to lagging metrics at the top tier. Use of "near miss" and other internal lagging metrics in between the topmost and bottommost tiers.	Tier approach, from leading indicators at the bottom tier to lagging indicators at the top tier. Tier 1 and 2 indicators are commonly used for corporate reporting while Tier 3 and 4 indicators monitor safety performance at facility level.
Classification of indicators	Based on organisational level, i.e.: 1. Corporate level indicators 2. Site level indicators 3. Installation/ plant or facility level indicators	Based on critical areas, i.e.: 1. Policies, personal and general management of safety 2. General procedures 3. Technical 4. External co-operation 5. Emergency Preparedness and Response 6. Accident/ near-miss reporting and investigation	Based on tier/ level of severity, i.e.: 1. Tier 1 – LOPC events of greater consequence 2. Tier 2 – LOPC events of lesser consequence 3. Tier 3 – Challenges to safety system 4. Tier 4 – Operating discipline and management system performance indicators	Based on tier/ level of severity, i.e.: 1. Tier 1 – Process safety incident 2. Tier 2 – Process safety event 3. Near miss 4. Unsafe behaviours or insufficient operating discipline	Based on tier/ level of severity similar to that of API's. Hierarchy of asset integrity KPIs in the guide demonstrates indicators classification based on organizational levels.
Metrics definition	Not specified	Five categories:	Specific metrics provided	Specific metrics	Examples of metrics

Aspects	HSE	OECD	API	CCPS	IOGP
		1. People 2. Organisations 3. System/ processes 4. Physical plant/ processes 5. Hazard and risk measures	e.g. For lagging indicators: 1. Tier 1 process safety event rate 2. Tier 1 process safety event severity rate 3. Number of safety instrumented system activations 4. Number of mechanical trip activation For leading indicators: 1. Process hazard evaluations completion 2. Process safety action item closure 3. Procedures current and accurate	provided e.g. For lagging indicators: 1. Total count of process safety incidents 2. Process safety total incident rate 3. Process safety incident severity rate For leading indicators: 1. Mechanical integrity 2. Action items follow-up 3. Management of change	provided e.g. For lagging indicators: 1. Tier 1 process safety event rate 2. Tier 2 process safety event rate For leading indicators: 1. Management and workforce engagement on safety 2. Hazard identification 3. Competence of personnel

A summary highlighting major comparison between the five guidelines is shown in Table 2. These guidelines have strong influences on the safety performance measurement of oil and gas installations in Malaysia. In addition, Petronas, as the national oil and gas regulator is also making progress in developing its own guidelines such as the Petronas Procedures and Guidelines for Upstream Activities and the Petronas Risk-based Inspection.

5. CONCLUSION

PSM as an integral part of asset integrity management in Malaysia is heavily influenced by international standards and the practices employed by international oil and gas companies venturing into the Malaysia oil and gas industry. Its execution frequently relies on the national oil and gas company, Petronas. Petronas imposes its requirements on oil and gas companies entering into production sharing contracts with Petronas. With the exclusive rights conferred upon Petronas by the Petroleum Development Act 1974 to explore, exploit, win and secure petroleum onshore and offshore of Malaysia, all oil and gas companies wishing to exploit petroleum in Malaysia will be bound by production sharing contracts with Petronas. As such, PSM for offshore operations has been regulated under the common law and there is a lack of statutory law governing this implementation of offshore PSM. The law that comes closest to PSM in Malaysia is the Control of Industrial Major Accident Hazards (CIMAH) Regulations 1996 which applies to all major accident hazards facilities but its application to offshore installation is limited. The CIMAH report covering process safety information and process hazard analysis has been prepared for onshore facilities and not been extended to offshore installations. As offshore installations present a unique array of process safety concerns due to their environment and often remoteness, it is deemed that offshore safety laws will be beneficial to uplift offshore safety in Malaysia. Malaysia has great potential to assume a more important role in leading regional offshore PSM since it is a major oil and gas producing country and it has built up experiences in oil and gas safety, as well as the sectoral environmental remediation [43,44], particularly offshore operations over the years.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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