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Technical preparedness in Southeast Asia region for onshore dismantling of offshore structures: Gaps and opportunities

Jing-Shuo Leow[1], Jing-Shun Leow[1], Hooi-Siang Kang*[1,2], Omar Yaakob[1,2], Wonsiri Punurai[3], Sari Amelia[4] and Huyen Thi Le[5]

[1]Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia
[2]Marine Technology Centre, Institute for Vehicle and Systems and Engineering, Universiti Teknologi Malaysia, Johor Bahru 81310, Malaysia
[3]Department of Civil and Environmental Engineering, Faculty of Engineering, Mahidol University, Thailand
[4]Institut Teknologi Bandung, Jl. Ganesa No.10, Lb. Siliwangi, Kecamatan Coblong, Kota Bandung, Jawa Barat 40132, Indonesia
[5]PetroVietnam University, 762 Cach Mang Thang Tam Street, Long Toan Ward, Ba Ria City, Ba Ria-Vung Tau Province 790000, Vietnam

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Abstract. An onshore dismantling yard is an important part in the supply chain of the offshore oil and gas decommissioning industry. However, despite having more than 500 offshore structures to be decommissioned in the Southeast Asia region, there are a very limited number of well-equipped dismantling yards to fully execute the onshore dismantling. Recent investigations discovered that shipbuilding and offshore structure fabrication yards are still potential options for upgrades to include dismantling. Despite the huge potential opportunities from upgrading to dismantling, research studies on this area are relatively scarce, and most past studies mainly focused on the North Sea region. To date, the potential opportunities of Southeast Asia and Malaysia yards to develop onshore dismantling capability are still unclear. The aim of this study is to identify the criteria to develop a technical preparedness checklist to evaluate an onshore dismantling yard; consequently, this will assist with assessing and bridging the gaps and identify the opportunity of developing an onshore dismantling yard in Southeast Asia region. Requirements for onshore dismantling and related rules and regulations have been investigated and summarized in the form of checklist. Findings from this study can help local oil and gas operators to pursue more local solutions and resilient supply chain performance.

Keywords: abandonment; decommissioning; offshore structures; onshore dismantling; Southeast Asia

1. Introduction

Decommissioning is the final stage in the lifecycle of an industrial facility. When an offshore structure reaches its end of life, by law, the owner of the asset is not allowed to simply abandon the structure; by regulation of offshore decommissioning under the international regulation such as Geneva Convention 1958, The third United Nations convention on the law of the Sea (UNCLOS) 1982 and International Maritime Organisation (IMO) Guidelines and Standards 1989, and the

*Corresponding author, E-mail: kanghs@utm.my

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Fig. 1 Decommission of obsolete offshore structure (BSEE 2016)

national laws respectively (Love 2019, Techera and Chandler 2015, PSA 2015, BESS 2011, Government of USA 2014). Although decommissioning based on the current practices will not generate net profits to the asset's owner, the decommissioning stage is abided to yield a balance in minimizing financial expenditures and to endure well-being to both society and the environment.

Decommissioning of an offshore structure can be categorized into eight processes (Day and Gusmitta 2016, Fam *et al*. 2018). It starts with planning, covering review of all records, field inspection of the equipment, and platform structural condition. After the planning process, well abandonment, which is the first offshore operation, will be executed, in which non-productive well bores will be permanently plugged and abandoned. The process continues with pre-abandonment surveys, where knowledge about the existing platform and its condition will be gathered. Then, detailed engineering will take place and an abandonment plan will be developed. After that, production is shut down of the offshore installation, all process equipment and facilities will shut down, waste streams will be removed, and associated activities will be conducted to prepare the platform for removal. In the fifth stage, which is structural removal stage, the structure will be removed from the site by following the sequence of the first deck or floating production facility from the site, followed by removal of the jacket, and bottom tether structures or gravity base. Then, the disposal operation will take place. At the last stage, which is site clearance, the sea-floor debris will be cleaned. Fig. 1 below shows structural removal operation via offshore lifting method.

Among these processes, onshore dismantling is the major activity in the disposal process (Li and Hu 2021, Martins *et al.* 2020, Fowler *et al*. 2019). The works during onshore dismantling include dismantling the platform structures into smaller pieces and modules, reusing and recycling the dismantled equipment and materials, and handling the hazardous wastes and unused components according to their properties (Shell 2019). Fig. 2 follow shows the photomontage of the onshore dismantling site with a Brent Topside on the dismantling area.

Despite the increasing number of offshore structures required to be decommissioned in Southeast Asia, the number of yards that can receive the decommissioned structures for dismantling is insufficient. Currently, there are only six onshore dismantling yards in Thailand that have the capacity to receive the onshore dismantling projects. However, the domestic regulation in Thailand does not allow these decommissioning yards to receive structures to be decommissioned from other countries due to restrictions of transboundary movements of hazardous wastes. Therefore, the oil

Fig. 2 Topside structures placement during onshore dismantling (Shell 2019)

and gas operators in the Southeast Asia countries need to develop their own onshore dismantling supply chain within their countries. The aim of this study is to identify the criteria for a technical preparedness checklist for evaluating onshore dismantling yard, assessing and bridging the gaps, as well as identifying the opportunity of onshore dismantling yards in the Southeast Asia region.

This paper is divided into five sections. The first section is a literature review identifying the activities that are conducted at the yard during the dismantling operation; majorly referred from the past decommissioning project report from the North Sea, as shown in Section 2. The second section outlines the rules and regulations from the international, regional and national acts, conventions, codes, and guidelines of practice, to prepare the technical preparedness checklist, the outcome is shown in Section 3. The third section presents the onshore dismantling yard technical preparedness checklist, established based on the regulations as discussed in Section 3. Finally, Section 4 presents some previous assessment studies done in North Sea. The fourth section aims to bridge the gap and identify the opportunity of the local onshore dismantling yard in Southeast Asia region. The outcome of this study is presented in Section 5.

2. Onshore dismantling activities

Onshore dismantling is a specialized business which requires appropriate facilities or a purpose-built dismantling site in order to undertake these activities in an environmentally acceptable manner (TSB Offshore 2015). The selection on the dismantling yard needs to fulfil nine criteria (SHL 2011), covering sailing distance from the yard's location, water depth at the port, offloading and heavy lift capabilities, yard space, bonded areas and storage capacity, adequacy of safety, environmental and waste management systems, decontamination facilities, security arrangements, and adequacy of material control procedures.

There are seven major activities during the onshore dismantling process (Shell 2019, CRF Consultant 2016), as follow:

- Firstly, the structure to be decommissioned will be offloaded at the quay site, and then loaded in the dismantling area. The dismantling area must be equipped with impermeable surface that can collect rainwater, to prevent it from flowing into the soil layer (Olivares 2021).

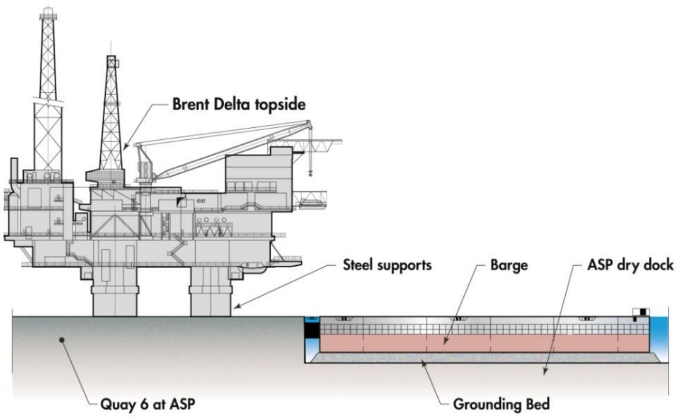

Fig. 3 Topside load-in operation (Shell 2019)

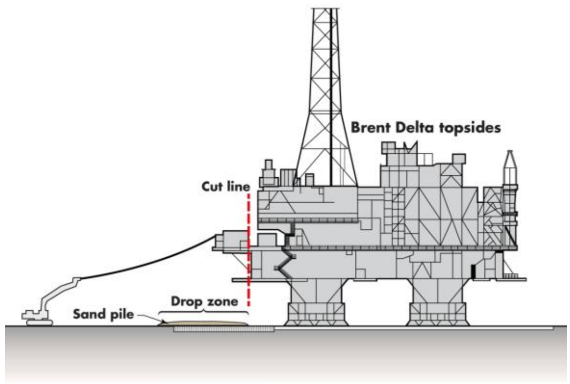

Fig. 4 Main structure dismantling process via cut and put method (Shell 2019)

- Secondly is the installation of scaffolds to access the structure to be decommissioned. The personnel at the yard should have easy access to the structure for the remaining preparation.
- Thirdly is preparation of an inventory mapping of hazardous waste residues.
- Fourth is the removal and decontamination of hazardous waste residues in the structure, according to safety regulations to minimize detrimental health and safety impacts for the next processes.
- Fifth, reusable or resalable inventories will be removed from the structure.
- Sixth, the main structure will be dismantled or demolished. According to Code of Practice for Full and Partial Demolition BS 6187 (BS 6187, 2016), the three main types of deconstruction process for the primary block breaking are demolition by tower and high reach cranes, demolition by machines, and demolition by chemical. In addition, the two prevailing types for secondary block breaking are demolition by hand jetting and demolition by water jetting.
- Lastly, hazardous wastes and scrapped materials must be well-managed and temporarily stored in a secured and appropriate facility, before sending them for further processing.

Figs. 3 and 4 follow show the past project site photos and the structure dismantling process taken from Brent Delta Topside decommissioning operation.

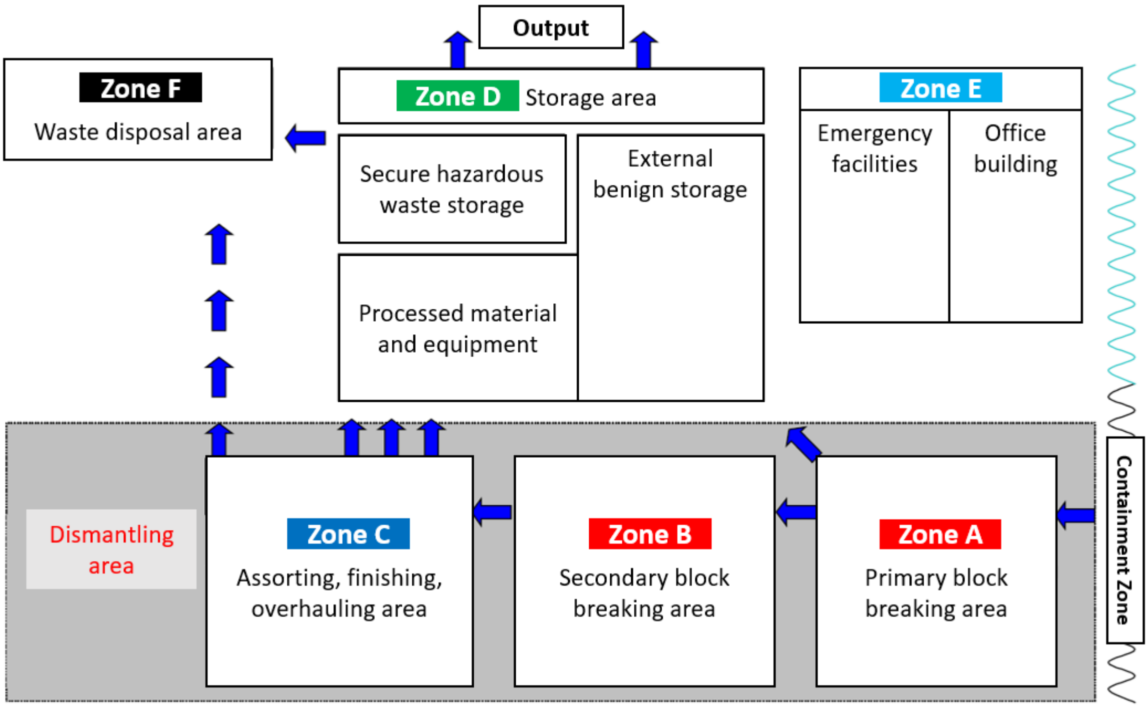

Fig. 5 Layout of ship recycling yard as suggested by UNEP (UNEP 2003)

3. Regulations in recycling activities for marine structures

According to the marine warranty surveyor (MWS) guideline (DNV 2021), the guidelines and regulation for decommissioning offshore structures are still mainly based on the policies and laws of the country where the offshore structure is located. The international legal framework and guidelines for ship recycling, on the other hand, is relatively mature and well-accepted. Therefore, some of the regulations for ship breaking and recycling, such as the Basel Convention (1989) on the Control of Trans-boundary Movement of Hazardous Wastes and Disposal and Hong Kong Convention (IMO 2009) are often considered as references during the implementation of offshore decommissioning projects.

The Basel Convention (UNEP 2003) provides technical guidelines for environmentally sound management of the full and partial dismantling of ships. The Basel Convention also regulates the Control of Trans-boundary Movement of Hazardous Wastes and Disposal (UNEP 1989). Meanwhile, the Hong Kong Convention (2009) (IMO 2009) regulates ship recycling as an activity of partial or complete deconstructing / dismantling of a ship at a ship recycling facility, as to recover reusable materials and components for reprocessing and reuse. During the ship recycling process, the decontamination of the contaminated equipment will be taken care of by the yard, however the yard will not handle the further processing or disposal operation of the hazardous material resulted from the decontamination process, it will be taken out by the outsourced contractor (Fariya 2016).

In practice, both decommissioning of offshore structures and ship breaking activities do share certain similarities in the processes, facilities, and hazardous materials management. Fig. 5 shows a conceptual yard layout of a ship-breaking activity with the flow of ship recycling process at each zone, as proposed in United Nations Environment Program (UNEP). This layout is commonly used for decommissioning yards as well. The processes start with the placement of the structure at the yard on the Containment Zone. Then, the structure will be located in the dismantling area for several stages of dismantling and demolition (Zone A and Zone B). The demolished materials must be sorted, decontaminated, and overhauled, according to their material properties, in Zone C. Finally, the materials will be sent to Zone D for storage, or Zone F for hazardous wastes disposal works.

The facilities required in different zones for both onshore dismantling and ship breaking activities are fundamentally similar as well, except for the Containment Zone. For ship breaking activities, the facilities setup for the Containment Zone depends on different ship breaking methods. For instance, dry-dock is needed for dry-dock method, berth and quay are needed for alongside method, concrete slipway is required for landing method, while a working beach with inter-tidal zone is required for beaching method (Barua *et al*. 2018). On the other hand, for offshore structure recycling, the required aspects in the Containment Zone are adequate quay size and water depth near the quay side for offloading purpose.

In Malaysia, Petroleum Nasional Berhad (PETRONAS) is the sole concessionaire of petroleum resources and will oversee all aspects of decommissioning for Malaysia's upstream facilities. In PETRONAS, a part of the upstream division unit, Malaysia Petroleum Management (MPM) has the role as the custodian and statutory manager to oversee the decommissioning process (Jagerroos and Kayleigh 2019). The applicable guidelines for the decommissioning activities in Malaysia (DOE, 2019) would include PETRONAS Procedures and Guidelines for Upstream Activities (Petronas 2020), Environmental Guidelines for Decommissioning of Oil and Gas Facilities in Malaysia by Department of Environment (DOE) (DOE 2019) and Decommissioning Guidelines for Oil & Gas Facilities by ASEAN Council on Petroleum (ASCOPE) (ASCOPE 2012). The domestic guidelines for handling the hazardous wastes are Guidelines for Decommissioning of Facilities with Radioactive Materials by Atomic Energy Licensing Board (AELB) (AELB 2008), Guidelines on Radiological Monitoring for Oil and Gas Facilities Operators Associated with TENORM by AELB (AELB 2016), Guidelines on Mercury Management in Oil and Gas Industry by Department of Occupational Safety and Health 2011 (DOSH 2011), Code of Practice on Radiation Protection relating to TENORM in Oil and Gas Facilities (AELB 2016), National Oil Spill Contingency Plan (DOE 2000), and Contaminated Land Management and Control Guideline (DOE 2009), Environmental Impact Assessment Guideline in Malaysia (DOE 2016), and Environmental Essential for Siting of Industries in Malaysia (DOE 2017).

International regulations with regards to oil and gas decommissioning projects that the Malaysian authority has ratified are UNCLOS 1982, IMO Guidelines & Standards 1989, Basel Convention 1989, International Convention for the Prevention of Pollution from Ships 1973, and the modifying Protocol 1978 of the International Convention for the Prevention of Pollution from Ships 1973 (MARPOL 73/78) (DOE 2019). The domestic laws and regulations (DOE 2019, Petronas, 2020) in this area include Petroleum Development Act 1974, Exclusive Economic Zone Act 1984, Continental Shelf Act 1966 (Revised 1972), Merchant Shipping Ordinance 1952, Environmental Quality Act 1974 and its regulations thereunder, Occupational Safety and Health Act 1994, Factory and Machinery Act 1967, Malaysian Maritime Enforcement Agency Act 2004, Atomic Energy Licensing Act 1984, Fisheries Act 1985, Customs Duties (Exemption) Order 2013, Petroleum (Safety Measures) Act 1984, Merchant Shipping Act (Oil Pollution) Act 1994, Petroleum (Safety Measures) Act 1984, as well as Protected Areas and Protected Places Act 1959.

4. Onshore dismantling facilities preparedness

Guidelines from the North Sea region (Shell 2019, DECOM North Sea 2018, EU Commission, 2013) specify the requirements for respective facilities to handle hazardous wastes. Such regulations can also be found in Malaysia (DOE 2019, Petronas 2020, Petronas 2019). In general, in order to carry out onshore dismantling activities, the yard needs to have appropriate waste handling licenses as well as being capable of preparing the detailed inventory of hazardous materials, which requires a detailed survey and screening process as to identify the location and number of hazardous residues accurately. The yard also needs to have a dismantling area with an impermeable surface, drainage, and wastewater treatment system. The workers need to have appropriate equipment, personal protective equipment, and training for the removal operation of hazardous residues. A dedicated and covered workshop must be certified for decontamination operation. Finally, the yard must prepare a certified storage area to safely keep the scraps.

A survey by the UK government on 19 decommissioning yards in the North Sea region (CRF Consultants 2016) is a reliable and important guideline to identify the gaps of technical preparedness for onshore dismantling facilities. The survey investigated six major criteria to evaluate the yards' preparedness to receive a dismantling project, inclusive of location properties, facilities capacities, sea accessibility, distance to waste disposal/further processing site, the presence of waste license, and the presence of liquid containment system at the dismantling area. The first three criteria can be regarded as the location, facilities, and accessibility aspects, while the fourth to sixth criteria in (CRF Consultants 2016) focus more on the hazardous wastes handling capabilities.

4.1 Location, facilities, and accessibility aspects

The technical preparedness from a location aspect examines three criteria, (i) whether the yard has decommissioning projects track records, (ii) the readiness of the yard's facilities to receive decommissioned platforms and their materials without the need of significant or large investment, as well as (iii) whether the yard has licensing in place for handling waste. The study (CRF Consultants 2016) found the majority of the yards in their survey have built facilities and currently perform business with the marine or offshore industry, but most of these yards may need to acquire permits for handling the waste during the decommissioning activities. Facility capacity indicates the size of vessel and barges that the yard's quay facilities are capable to berth and offload, the sufficiency of the dismantling area for set-down and deconstruction/demolition of large offshore decommissioned modules and jackets, the availability of containment systems for run-down liquids, and the capacity of deconstruction/demolition equipment, such as cranes in place, to support the works (CRF Consultants 2016). Sea accessibility means the sailing distance from the yard to the offshore decommissioning field, the sea access for heavy lift vessels and barges, the vessel/barge's draft, and air draft restrictions, as well as all-year weather accessibility (CRF Consultants 2016).

The required facilities for each zone as categorized in Fig. 5 are listed in Table 1 which shows a compilation from multiple references on the evaluation of facility's readiness to be a decommissioning yard.

4.2 Technical preparedness checklist of onshore dismantling yard

Table 1 summarizes important parameters for evaluating the technical preparedness of an onshore dismantling yard, based on the regulations and guidelines as mentioned in Section 3 and the

Table 1 Checklist of recycling facilities (Shell 2019, CRF Consultants 2016, IMO 2009, UNEP 2003, EU Commission 2013, KLIF 2011)

Zone	Characteristic		Description
	Site Description	Site General Info	Facility Location
			Facility Area (m^2)
			Distance to Open Sea
			Restriction In the Approach Channel (Air Draft/Width)
			Approach Channel Depth (m)
			Past Offshore Construction Project
			Demolition License Permit
		Site Restriction	Limit for Release to Air
			Limit for Release to Water
			Noise Limit
			Permitted Working Hour
			Requirement Related to Specific Area
			Requirement For an Impermeable Surface
		Facility Future Potential	Industrial Footprint Area (m^2)
			Potential Area for Future Development (m^2)
		On land Transportation	On land Transportation Facilities
D	Facilities Information	Storage Area Info	Storage Area Size (m^2)
			Storage Site Characteristic
C		Workshop's Info	Workshop Number
			Workshop Type
			Workshop Area (m^2)
A, B		Heavy Lifting Machine Info	Crane Number
			Crane Type
			Crane Capacity (t)
E		Emergency Facilities	Quarantine Areas (m^2)
			Emergency Areas (m^2)
A, B	Working Area Information	Load-In Capabilities	Bollard Pull Capacity (t)
			Load-In Points Capacity (t/m^2)
		Quay Info	Quay Numbers
			Quay Foundation Bearing Capacity (t/m^2)
			Berthing Capacity
			Water depth Near Quay (m)
		Working Area Properties	Facilities to Contain Liquid Waste Within Working Area
			Working Area Size (m^2)
			Impermeable Surface
D	Scrap Storage Area Information	Laydown and Pad Info	Laydown Area Size (m^2)
			Pad Capacity (Length and Maximum Pressure)
			Pad Characteristic (Material)
			Presence/Availability of Impermeable Surface
C, D	Waste Management Information		Waste Handling Capacity (ton per year)
			Distance to Solid Waste Management Center

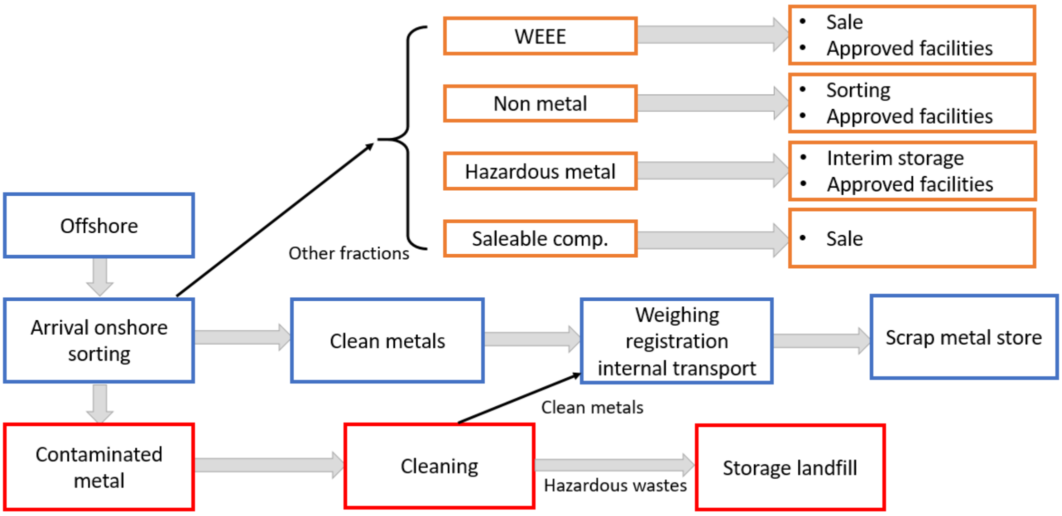

Fig. 6 Materials management for onshore dismantling (CRF Consultants 2016)

guidelines from the previous survey done in North Sea region as mentioned in Section 4.1 and 4.2.

4.2 Hazardous wastes handling capabilities

Fig. 6 shows the flow chart for materials management of decommissioned structures. Generally, the materials will be sorted into three main categories, which are clean metals from the substructure, contaminated metals from the substructure, and other which is a small fraction of materials. Contaminated metals will be sorted out and cleaned up to extract the clean metal and filter out hazardous wastes. Hazardous wastes will later be transferred to storage, and then undergo a decontamination processes. On the other hand, clean metals will undergo weighing, registration, an internal transport process, and finally go to a scrap metal store. The other materials, such as waste electrical and electronic equipment (WEEE), non-metal, hazardous metal, and saleable components, will be either be earmarked for sale, for further sorting, or stored in the approved facilities.

Typically, there are 25 types of hazardous waste residues commonly found in decommissioned offshore structures (UNEP 2003, SEPA 2018). Hazardous waste residues will be categorized as primary and non-primary hazardous material according to the level of toxicity, which differ by countries, depending on their interpretation of classification. Among these 25 types, four are categorized as primary hazardous material by both Malaysia (DOE 2019, Petronas 2019) and North Sea (DECOM North Sea 2018, EU Commission 2013, ABS 2018) countries, which are natural occurring radioactive material (NORM) or low specific activity (LSA) material, mercury, asbestos, and polychlorinated biphenyls (PCB). NORM can be found in the production equipment (DOE 2019, DECOM North Sea 2018, SEPA 2018), mercury can be found in production equipment, as well as WEEE (DOE 2019, DECOM North Sea 2018, SEPA 2018), asbestos is from the engine room, flooring, and insulation section (Du *et al*. 2018), while PCB is from the paints and WEEE (KLIF 2011). Chemicals, diesel, pyrophoric iron scale, and hydraulic oil/grease/lubricants are categorized as primary hazardous materials in Malaysia (DOE 2019, Petronas 2019). The side effects of some hazardous materials are listed in Table 2.

Table 2 Side effects of hazardous materials from offshore structures (SEPA 2018, ABS 2018, Du *et al.* 2018, KLIF 2011)

Hazardous Materials	Side Effect
LSA	Emits hazardous radiation that could harm human body
Asbestos	It could accumulate in human body for a long time and cause lung cancer. Symptoms may not show up until many years after exposure.
Mercury	Toxic, bio accumulative, and affects the nervous system
PCB	It could be associated with cancer, liver, neurological, and immune system damage.
Lead	Damage to neurological system, hearing, vision, reproductive system, blood vessels, kidneys, and heart, especially to children's physical and neurological development
Cadmium	Leads to cancer and organ system toxicity such as skeletal, urinary, reproductive, cardiovascular, central, and peripheral nervous, and respiratory systems
Hexavalent chromium	Leads to lung cancer, irritation or damage to nose, skin and eyes
Oil and fuel	Poisonous through inhalation or consumption of contaminated water or fish. May result in fire and explosion.
Polyvinyl chloride (PVC)	May induce cancers, asthma, and impairment to human reproduction systems. Burning may generate carbon monoxide, and highly toxic dioxins and furans etc. Burial may release chemicals to groundwater.
Halon Gas	Environment pollution.
Organotin compounds	Contaminate sea products, leading to potential hazardous effect on human health.
Chloroparaffins	Suspected of causing cancer in humans. Material is considered as endocrine disruptors.
Phthalates	Interferes with the production of male sex hormone

5. Bridging the gaps

5.1 Shortage of onshore dismantling yard supply in Southeast Asia

In Southeast Asian waters, currently there are more than 444 offshore installations that have been in service more than 20 years, while another 389 have exceeded 30-year service life but still in operation (Lyons 2012). Many of them are expected to begin the decommissioning process within the next few years. Most of these structures are located in Malaysia, Thailand, and Indonesia with more than 200 fixed offshore structures exceeding the typical design life of the platforms (25 to 30 years). The oldest platform in Malaysia is still in operation after more than 50 years (Ng *et al.* 2019).

The reasons for the slow progress of the decommissioning activities in the Southeast Asia region are due to limited capacity and lack of experience in the supply chain to reliably support this work (Ahiaga *et al*. 2017). For other decommissioning activities as mentioned in Section 1, such as structural removal operation, it is relatively easier for the local operator to hire or outsource the work scope to international contractor, as well as to charter their heavy lifting vessel and transportation barge for the operation. However, for the disposal or onshore dismantling activity, it is difficult for the operator to outsource it to an international contractor due to the ratification of the Basel Convention in the Southeast Asia region (ASCOPE 2012), which restricts the transboundary movement of waste. In order to outsource the disposal activity, the operator not only needs to consider the commercial perspective of the operation, but also needs to have the agreement of both the platforms' origin country government and the receiving country government.

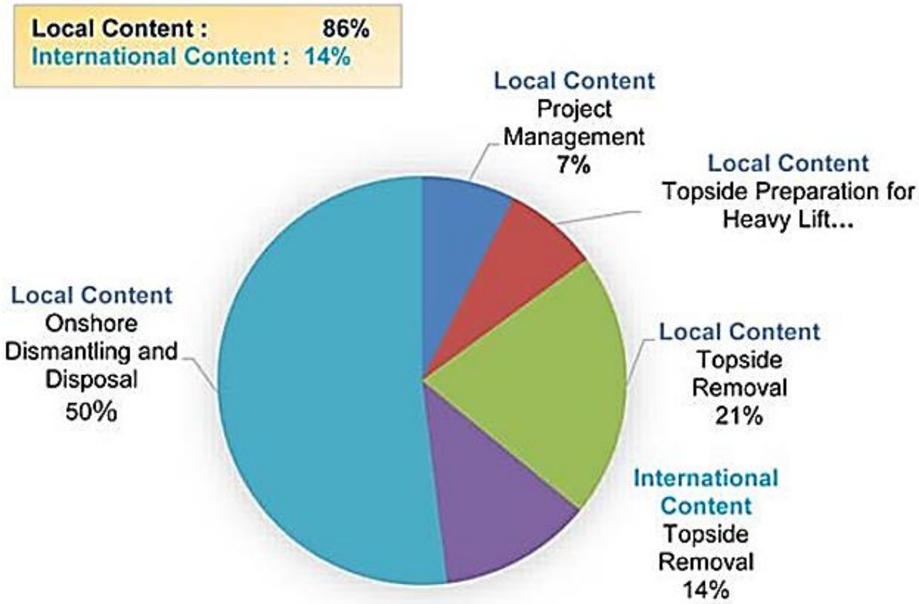

Fig. 7 Cost components division of decommissioning projects in Thailand. (Jagerroos and Kayleigh 2019)

From the cost breakdown of previous project experience in Thailand (Jagerroos and Kayleigh 2019) as shown in Fig. 7, the cost incurred from the disposal process can be up to 50% of the cost for the decommissioning project. As the number of aging structures in the Southeast Asia increases, the need to solve the bottleneck issue of local onshore dismantling yard supply will become more urgent, it opens up a great opportunity to the local contractor for filling up the demand of market gap.

5.2 Upgrading shipbuilding yard into onshore dismantling yard

Shipbuilding yards have high potential to be upgraded for onshore dismantling activities due to the presence of primary facilities for the operation (DECOM Tools 2019, FGV Energia 2021, Brown 2014). For instance, a shipbuilding yard generally has the quay facility for structure load-in/offloading operations, a large fabrication area which could be upgraded into a dismantling area, and machineries for the dismantling activities. However, the onshore dismantling of offshore structures is not a simple reverse engineering of a building. The appropriate methods for safe handling of residues of hazardous wastes accumulated during the oil and gas production during the onshore dismantling are crucial aspects for a successful project implementation. Typically, before upgrading, a shipbuilding yard does not have sufficient waste handling capability to support the dismantling activities.

According to the regulations and guidelines as shown in Section 3, the waste handling facility that a shipbuilding yard normally requires would be a dismantling area for primary and secondary block breaking, Zone C (decontamination workshop), and Zone D for hazardous material storage. These facilities are vital to support the hazardous waste removal activities, which cover the inventory mapping of hazardous residues, hazardous residues removal, decontamination, and storage. The

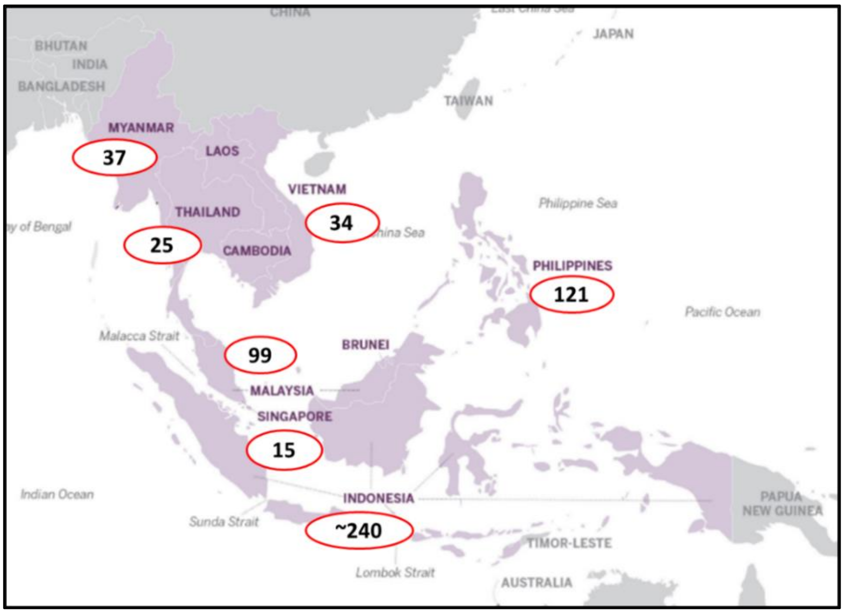

Fig. 8 Number of shipyards in the Southeast Asia region. (Note: Statistics of Brunei and Cambodia are not included)

waste handling activities are required to be accomplished safely and environmentally friendly according to the regulations, such as DOE (2019), UNCLOS (1982), London Dumping Convention (1972) (IMO, 1972), and London Protocol (1996) (IMO, 1996).

When planning for the requirement of new facilities on an existing shipbuilding yard, there will be a number of constraints that need to be addressed, such as location of the existing production facilities, position of vital shipyard facilities, such as building berth and dry dock, shape of the land, size of the land, and access to waterfront. Besides, unlike fabrication assembly process, the nature of structural demolition would cause dust and hazards around the operation side, and therefore necessitates the creation of an exclusion zone around the demolition site to cater this effect. Hence, careful planning of the dismantling area location is required to prevent onshore dismantling activities from affecting the original main fabrication business of the yard. Moreover, due to the nature of the onshore dismantling activities that deal with hazardous residuals, the concern upon other stakeholders and citizens nearby could affect the success of the establishment of a dismantling yard.

There have been a number of successful cases of upgrading shipbuilding yards to acquire onshore dismantling capabilities, including two established dismantling yards in Southeast Asia. The two dismantling yards are located in Thailand, and they are currently operating fabrication and dismantling concurrently in the yard. The North Sea region shipyards also integrate the dismantling area, such as Able Seaton Port, Swan Hunter shipyard, and Harland & Woff shipyard, which have fabrication histories. In the Southeast Asia (SEA) region, there are 240 shipyards in Indonesia (IPERINDO 2020), 99 shipyards in Malaysia (MIGHT 2017), 37 shipyards in Myanmar (Maung, 2014), 121 shipyards in the Philippines (UNESCAP 2013), 15 shipyards in Singapore (ASMI 2020), 25 shipyards in Thailand (TSBA 2020) and 34 shipyards in Vietnam (SBIC 2015), as shown in Fig. 8. Most of the shipyards in the Southeast Asia region focus on the business of shipbuilding and ship repairing (SBSR), and relevant services. In some SEA countries, their major shipyards have a more

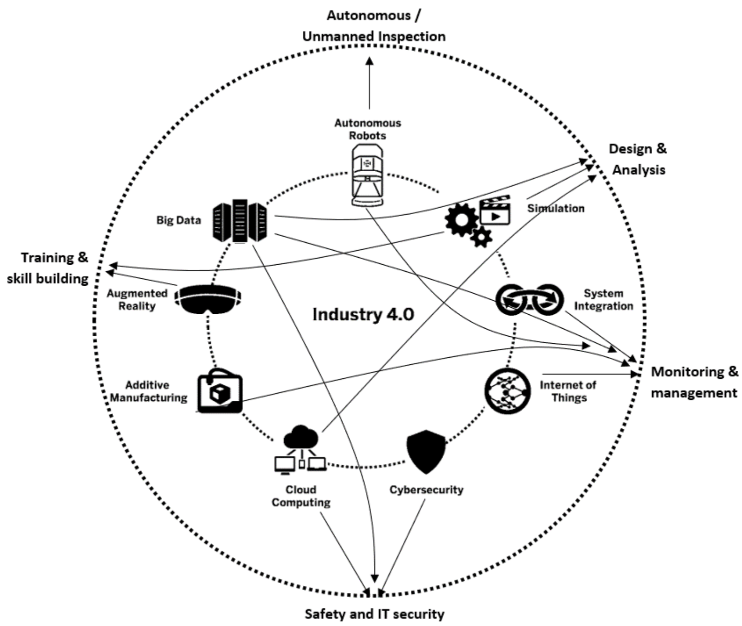

Fig. 9 Main pillars of Industry 4.0 and their relation to decommissioning

diversified businesses, such as conducting fabrication for offshore oil and gas structures, as well as SBSR services.

5.3 Integration of Industry 4.0-based technologies into onshore dismantling yard

Further integration of Industry 4.0-based production and manufacturing technologies advancements can be another critical game changer. The main pillars of Industry 4.0 are autonomous robots, simulation, system integration, internet-of-things, cybersecurity, cloud computing, additive manufacturing, augmented reality, and big data (Fig. 9). These main pillars can be extended to the proposed Industry 4.0-based production and manufacturing technologies, particularly relative to decommissioning activities, such as design and analysis, monitoring and management, safety and information technology (IT) security, training and skill building, autonomous execution, and unmanned inspection.

Digitalization is one of the key elements of the technological drive of Industry 4.0 (Rivas 2018). New processes/approaches to track the latest status from thousands of hazardous material wastes now are possible via a centralized database through transformative digital technologies. Vertical integration will optimize the digital maintenance and energy consumption of machines through advanced information systems. The concept of digitalization aims for human-robot interaction for various high-risk cleansing tasks. For instance, in nuclear decommissioning industry, workers can rely on tele-operated robots that can be remotely controlled to operate high-risk cleansing in a safe and efficient manner (Ghosh *et al.* 2020). Moreover, big data mining will make it possible to get useful information from huge amount of data. Industry 4.0 also eases the control of hazardous waste management during decommissioning process via system integration and internet-of-things, such as implementing data integration framework for decommissioning waste management (Akinyemi *et al.*

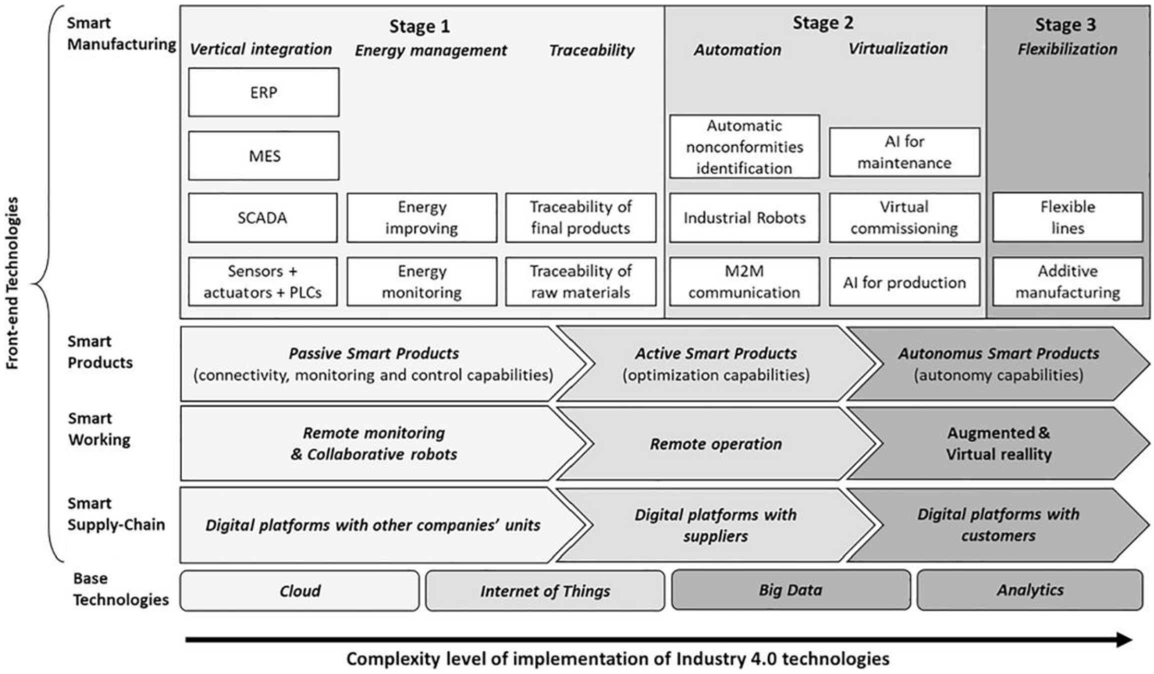

Fig. 10 Roadmap of implementing Industry 4.0 (Frank *et al*. 2019)

2020) into the 5D building information modelling (BIM) technology (Tan *et al*. 2021). This policy enables a simultaneous partnership between stakeholders to monitor the status of traceable hazardous wastes. Normally the implementation of Industry 4.0 will consist of several stages and progress from time by time. Fig. 10 shows the roadmap of Industry 4.0 technologies implementation patterns.

6. Conclusions

Despite the expected high demands for offshore structures decommissioning in the Southeast Asia region, the number of available onshore dismantling facilities in this region is relatively scarce. Upgrading the existing shipbuilding yards in this region should provide a time-effective solution, but the technical gaps in both facilities and environmental sustainability must be clearly identified. Through this study, the nature of onshore dismantling activities has been systematically investigated. Rules and regulations from ship breaking industry have been reviewed. The experience of onshore dismantling from the North Sea region is regarded as the major criterion to identify the technical gaps for the modification/upgrade of shipyards in the Southeast Asia region. A vital aspect to bridge the gaps between shipyards and qualified decommissioning yards is the capability of handling hazardous wastes. The findings in this review will hopefully provide a strategic direction to improve the resilience of local supply chain in providing decommissioning services without environmental compromise.

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