Identification of environmental loss indicators due to oil tanker failures

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Abstract. Consequence of failure (COF) estimation is a vital part of risk assessment and is practiced in various industries. In pipeline integrity managing systems, the COF basically consist of people, asset, environmental and reputation loss. Environmental consequence assessment for offshore pipeline in Malaysia is considered very general due to negligence of local factors. Moreover, the expert judgment as an internal stakeholder is very simple in the assessment as it does not consider the impact on the external stakeholders. Thus, this paper aimed to identify the environmental loss indicators for offshore spillage from tanker worldwide. A comprehensive environmental loss are crucial to be identified as a part of enhancing the accuracy of operating pipeline risk assessment in Malaysia with the involvement of external stakeholders. Hence the operator can choose the best maintenance strategy with optimum cost by ensuring the pipeline integrity is not neglected.

1. Introduction
Excess supply of oil caused oil prices to fall sharply and prices have fluctuated since 2014, valued at approximately $67 per barrel as of April 2018 [1]. Due to this, operators of oil and gas must be aware of all uncertainties towards the economic impact caused by oversupply, recession and accidents (lead to operation shutdown) in order to sustain the industry in long term. Cost optimization of pipeline maintenance is one of the strategies to upgrade the business operating plan. A better risk assessment can be developed in order to avoid unnecessary inspection of operating pipeline hence the overall cost can be reduced. The risk based assessment should be carried out accordingly without affecting the pipeline integrity rather than time based inspection which is incapable to detect real time damage. The risk based methods have been used to determine the optimal replacement of offshore process components, based on the likelihood and consequence of failure caused by time-dependent degradation mechanisms [2,3].

The current consequence assessment of pipeline integrity management was adopted from other international standards, which may over or underestimate the impact of pipeline failure. The whole risk assessment of pipeline integrity is crucial to be understood as it connotes the concept of failure prevention, inspection and repair which includes products, practices and services that help operator maximize their assets [4].

In Malaysia, the environmental consequence assessment in current practice of Petronas Technical Guideline (PTG) is considered very simple due to negligence of local factors. Consequence of failure incorporating environmental loss of operating marine pipeline can be quantified based on critical parameters such as service type, sensitivity area, product volume (oil and gas), response time to isolate, containment pressure and human activities [5]. According to DNV-RP-F107, the environmental loss consequence of any leakage in damaged pipeline should consider the polluting impacts on ecosystem in the water, including seabed vegetation, plankton, fish and sea mammals such as whales and seals [6]. The pollution also has impact on the coastal environment such as beaches and coastal regions that either have great value as refuge for birds or contain extraordinary
vegetation. Other than that, the seabirds, compromising birds living, mating or on passage in the area, and fish in fish farms and related industries in the area are also included. However, the local conditions should vary depending on the location of pipeline accidents. Knowledge of local conditions, past history, experience or similar accidents, need to be considered and incorporated to provide a realistic picture of environmental consequences model [7]. Moreover, not much work has been done in the risk assessment with regards to the protection of marine environment and especially to prevent the sea pollution [8]. There is a lack of factors capable of capturing the accurate impact of pipeline failure.

The practice of identifying environmental loss factor stated in the PTG is justified based on the expert point of view [5]. Expert judgement is very simple in order to avoid complexity in assessing the risk. As internal stakeholder of the company, this factor identification process is imbalanced and it is self centered assessment because it does not consider the impact on the external stakeholders e.g. fisheries, tourism, shipping etc. Generally, both qualitative and quantitative inputs in a systematic methodology of engineering studies of risk, cost and benefit as well stakeholders views to rank project alternatives, has yet to be fully developed for environmental decision making [9]. The external stakeholder’s perception is of utmost importance to retain a healthy business environment [10]. In UK Government Report regarding oil spillage response, the involvement of government agencies such as Centre for Environment, Fisheries and Aquaculture, Science (Cefas) on behalf of Oil Spill Response Forum (OSRF) are important to identify the gaps in current knowledge in monitoring the activities of Gulf of Mexico hence the overall review will be taken into consideration in the development of regulators’ policy and guidance [11]. Great effort is needed to develop a comprehensive consequence assessment incorporating the intangible elements of environmental loss for comprehensive pipeline risk assessment. To reach this milestone, a detailed investigation on environmental loss factors is crucial. Thus, the aim of this article is to comprehensively review and identify the environmental loss factors due to oil spillage as reported in selected offshore accidents case studies.

2. Literature Review

2.1. Environmental loss definition due to oil spillage

Environmental issues are continuously being debated because it is related to the development that might affect the entire environmental system. As stated by Alfsen and Sæbø; Heink and Kawarik [12,13]: “An environmental indicator is usually defined as a number indicating the state and development of the environment or conditions affecting the environment. The indicator is meant to give information in excess of what is directly measured or observed, i.e., the parameter value or statistical information. Thus, an indicator is seldom presented as a single datum, but it should be put in some context from which it is possible to infer what is indicated”.

Due to human activities, the impact to the environment is unavoidable and losses become serious issues as it bring many harmful side effects to the community. Moreover, there will always be controversy where intangible losses have to be evaluated in monetary terms [14]. The environmental issues should be considered as part of a comprehensive assessment and management program that emphasizes the potential environmental issues associated with offshore oil and gas development projects which includes air emissions, wastewater discharges, solid and liquid waste management, noise generation (including underwater), spills, energy efficiency and resource conservation [15].

Offshore oil spills can cause economic loss and harm to ecological system, public health and communities and the economic impacts to some extent can be reflected in the total amount of liability and compensational funds which are regulated according to legislation [16]. In order to prevent and control offshore oil spills, the governments around the world have taken measures in response to reduce the economic loss and ecological damage by environmental pollution accidents resulting from offshore oil spills, improve their abilities of marine environmental risk precaution and oil spill pollution emergency disposal and to establish and perfect marine pollution emergency mechanisms [17,18]. The restoration time and cost for mitigation can be estimated depending on the severity of the environmental loss [19].

According to International Tanker Oil Pollution Federation (ITOPF), in Malaysia, the Department of Environment (DOE) has overall responsibility for oil response with the major operating role falling to the Marine Department of the Ministry of Transport [20]. For major oil spill, the coordination is carried out by the National Oil Spill Control Committee (NOSCC) chaired by the director-general of the DOE. The Malaysian National Oil Spill Contingency Plan (NOSCP) is formulated to control oil spill occurring within Malaysian water. Monitoring of oil moving through the air, sea and land will also be carried out by 18 agencies involved and the information obtained will be used to develop strategies to control the oil spill and protect environmentally sensitive areas [21].
3. Methodology
The environmental loss factors are extracted from 11 case studies of offshore accidents worldwide i.e. tanker spillage. Oil spillage in offshore are crucial to be identified as it can bring many impacts; both short and long term which affect the whole community and offshore environment. The duration of the case studies is approximately forty years, from 1967 until 2006, which focused on tanker spillage only. The case studies highlight the amount of spillage and the impact of environmental loss. The studies on environmental loss are important in developing the consequences modelling of risk assessment of pipeline failure. The literature on environmental loss impact are reviewed through journals, conference proceedings, books and online sources.

4. Results and discussion
In this paper, the selected offshore accidents are focused on tanker spillage case studies. The selected cases are from 1967 to 2006 occurred worldwide. The duration is approximately forty years and it is adequate to determine the environmental loss factors.

4.1. Case study of year 1967 until 1976
In March 18, 1967, the world’s first major oil tanker accident occurred when a tanker named Torrey Canyon ran aground on Pollard’s Rock of the Seven Stones reef that lies to the northeast of the Isle of Scilly off the coast of Great Britain [22]. The tanker is a Liberia-registered tanker chartered to British Petroleum [23]. The amount of estimated spillage was 25 to 36 million gallons [24]. The spillage despoiled the Cornwall beaches and thousands of gallons were propelled by wind and current across the channel towards France [25]. The impact from the spill is still felt almost 50 years later. An unknown quantity of the oil remains in a Guernsey quarry [26]. The environmental impact, which caused an oil slick measuring 270 square miles, was disastrous and contaminated 180 miles of coastland [24]. An estimated 15,000 birds were killed, seals and other marine life also perished [25]. The flora of intertidal zone including seaweed, fishery and tourism industry were also affected. The clean toxic solvent-based cleaning agents were used and later the ocean was set on fire to burn away the oil by dropping bombs [24].

4.2. Case study of year 1977 until 1986
About 10 years later in March 17,1978, a tanker Amoco Cadiz also ran aground on Portsall Rocks, 5 km from the coast of Brittany, France and split into two and sank [27]. Amount of spillage, estimated at approximately 70 million gallons caused an oil slick 18 miles wide and 80 miles long, polluting approximately 200 miles of Brittany coastline [24, 28]. The spillage has caused short term consequences to the sheltered areas, sandy shores, upper shore vegetation, algae and interdial microfauna [29]. Two weeks after the accident, millions of dead molluscs, sea urchins and other benthic species washed ashore [30]. A large amount of dead tarred sea birds were found. Even though an estimated 15000 to 20000 sea birds died, the impact (0.1 bird per tonne of oil) was low [31]. The oil slick affected the various animal groups inhabiting the eelgrass beds [32]. Almost 10,000 persons were involved in cleaning up the oil slick and an estimated 200,000 tons of oil and debris were pumped and gathered [33]. In 1978, the accident was estimated to have caused $250 million in damage to fisheries and tourist amenities [27].

On November 15, 1979, a Romanian tanker INDEPENDENTA collided with the Greek cargo ship EVRIALI off Haydarpasa at the entrance to the Bosphorus, in Turkey, causing the spillage of 93,800 tonnes of Libyan Es Sider crude oil before catching fire with an additional 260 tonnes of heavy fuel oil bunkers on-board [34]. It caused heavy sea and air pollution not only in the entrance to the Strait but also in the Sea of Marmara [35]. Spilled oil caused heavy contamination on the sea and shores of the Sea of Marmara and the Istanbul Strait with the bottom of the sea, an area of about 5.5 km in diameter, covered with a thick tar due to sinking crude oil [35, 36]. Many fish and crustacean species swim on the surface during the early stage of their life and they are exceedingly affected by oil on the sea [35,37]. Within this area, only nine species of benthos were recorded alive and mortality rate was estimated at 96 % [36,38].

A tanker Castillo de Bellver owned by Empressa Nacional Eclano, the Spanish Government Shipping Line, caught in fire on March 6, 1983 en route from the Persian Gulf to Spain with 250 000 tons of crude oil [39]. The fire occurred about 70 miles north-west of Cape Town, South Africa [22,40]. The accident area is an ecologically and economically sensitive area as it is rich with flora and fauna and also home to a large seabird population, 50% of South African lobster and fish [41]. Due to the natural dispersion, impact on both the fishing grounds and the fish stocks was probably negligible [42]. Some 1,500 gannets, covered in oil, were
4.3 Case study of year 1987 until 1996

One of the biggest oil spills in history occurred on March 24, 1989, when the tanker Exxon Valdez hit a reef dumping 11 million gallons of crude oil into Prince William Sound [24]. The spill impact was significant as reported by Exxon Valdez Oil Spill Commission [43]. The toll on birds in the region, such as Black Oystercatchers, murres, marbled, murrelets, cormorants, harlequin ducks, pigeon guillemots and loons, was significant. Fish populations in the area of the spill were exposed to oil during early development, leading to a collapse of the population in 1993 and 1994. Sea mammals were also greatly affected. Intertidal and subtidal ecologies were significantly damaged. The invertebrates and vegetation were damaged in these oiled areas. Eelgrass was of particular concern since it serves as important nesting sites for birds. The fishermen’s income was also affected due to eighty-five percent decrease in the population of Pacific herring and pink salmon spawning streams, estimated to be about $287 million dollars. Recreational and sportfishing was greatly damaged with an estimated loss of around $580 million [44,45]. The spill had both short-term and long-term economic effects, which include the loss of recreational sports, fisheries, reduced tourism, and an estimate of what economists call "existence value", which is the value to the public of a pristine Prince William Sound [46]. Exxon has paid over USD3.8 billion as a result of the accident, including compensatory payments, cleanup payments, settlements and fines [47].

On January 19, 1991, during the Gulf War, Iraqi forces attempted to prevent American soldiers from landing by opening valves at an offshore oil terminal and dumping oil from tankers resulting in a 4 inch thick oil slick spread across 4,000 square miles in the Persian Gulf [24]. An estimated 6 to 8 million barrels (252 to 336 million gallons) of oil spilt into the Gulf waters [48]. Between March and May 1991, about 905 thousand barrels of oil washed ashore along much of the coastline from Kuwait south to the Abu Ali peninsula, a hook of land which halted the southern advance of the spill in Saudi Arabia [49]. The spills immediately killed at least 56 sea turtles, 32 dugongs, 33 porpoises, 1,500 snakes and uncounted birds and fish [50]. The fishing industry was decimated after the oil spill and a 2003 U.S. study found huge quantities of oil in the sediment of salt marshes, mudflats and mangroves on the coast of Saudi Arabia [51]. More than one million barrels of oil were collected offshore using skimmer ships by Saudi Aramco while more than half a million barrels were collected on the shoreline by means of booms and skimmers [49,52].

In the same year, on April 11, 1991, a ship named MT Haven owned by Amoco exploded, caught fire and sank off the coast of Genoa, Italy, spilling 50,000 tonnes of crude oil into the Mediterranean [53]. Approximately 30,000 tonnes of cargo oil was released to the sea, of which only one-tenth reached the shoreline beaches along the Italian Riviera [54]. According to Cedre, the immediate ecological consequences observed were the oiling of around 100 birds and the degradation of marine life in the surface layers and on the shore, with significant impact on fauna [55]. A 43% reduction in fish populations was estimated in certain fishing areas. To contain the environmental damage, the anti-pollution vessels were operated for 8,000 hours, 11,000 tonnes of emulsion were collected at sea and about 20,000 meters of booms were employed [56]. The IOPC (International Oil Pollution Compensation) Fund noted payments of 95.5 billion Lira were made to Italian claimants including fishermen and tourist businesses, as well as 23 million Francs to French claimants, primarily for clean-up [57].

Another tanker, MV BRAER, which carried 84,700 tonnes of Norwegian Gullfaks crude oil and 1,500 tonnes of heavy bunker oil, ran aground on January 5, 1993 in severe weather conditions on Shetland, Scotland due to heavy seas that broke the ship apart [58]. According to Harris, the spillage affected an area of international environmental importance and threatened the local economy with the land beyond the shoreline polluted by airborne oil spray carried on the storm force winds [59]. Aerial spraying of dispersant on oil on the sea took place on three days with some environmentally sensitive areas protected by booms and dams [59]. Forbes reported that a number of persons had suffered from acute effects of the oil mist, e.g. headache, throat, skin irritation and itchy eyes, but no evidence of chronic effects or long term illness was found due to the spillage [60]. The incident also caused a serious impact on the seafood industry due to the physical presence of oil in the water column and on the seabed resulted in fishing and salmon farming being prohibited within a 400 mile Fisheries Exclusion Zone which was established off the southwest of Shetland [61]. Other animals, such as Grey seals molting in Shetland during the oil spill, may have been acutely affected by exposure to hydrocarbons [62]. However, the impact on the intertidal habitat was minimal and most shores had recovered within a year [63].

On February 15, 1996, a tanker, Sea Empress became grounded at the entrance to the Milford Haven Waterway in Pembrokeshire, Wales, causing 72,000 tons of crude oil to spill into the sea within the Pembrokeshire Coast National Park i.e. one of Europe’s most important and sensitive wildlife and marine
conservation areas [64]. Report by Edwards and White stated that there were adverse impacts on fisheries, wildlife (particularly overwintering birds), tourism, amenity and recovery [65]. Although not complete, wildlife populations remain depleted and further monitoring is needed, including monitoring of fish stocks. Some 200 km of coastline, which included the National Park, was contaminated and a major shoreline clean-up effort had to be mounted that involved mechanical and manual recovery, trenching, beach washing, and the use of dispersants and sorbents. The cost of payments to claimants due to the spillage is USD $47 million [66,67].

4.4. Case study of year 1997 until 2006
Erika, a tanker carrying around 31,000 tonnes of heavy fuel oil as cargo, broke in two in a severe storm in the Bay of Biscay on December 12, 1999, 60 miles from the coast of Brittany. About 20,000 tonnes of oil were spilled and the bow sank on December 12 and the stern on the following day [68]. More than 400 km of shoreline were affected by oil and cleaning efforts were conducted over a period of one year with emphasis on the shoreline clean up [69]. Castège et al. reported that the impact of the spill on seabirds varied among species i.e. some declined such as razorbill and common scoter, whereas others remained stable such as guillemot and the gannet, the two most affected species [70]. Also, north of the Bay of Biscay, the least often found bird species decreased very sharply [70]. The affected coastline caused a large number of compensation claims to the industries such as coastal fisheries, mariculture (oysters and mussels) and tourism throughout southern Brittany and the Vendée [68].

In November 2002, Prestige oil spill occurred in Galicia, Northern Spain caused by oil tanker MV Prestige, which spilled 50,000 tonnes polluting the coast and affecting the wildlife, environment and the region's fishing [71]. It is estimated the clean up cost for the Galician coast is $2.8 billion [72]. It is found that around 25,000 sea birds were dead or injured as the result of exposure to the pollution (records show 23,428 birds found by May 2003 and 75 percent of the animals were found dead [73]. Due to the spillage, the cost environmental damaged was almost € 575 million (2006 Euro) and the most crucial sectors were fishing and tourism [74].

| No | Date       | Case                     | Owner                      | Operator                  | Spillage (million gallons) | Cause of accident         |
|----|------------|--------------------------|----------------------------|---------------------------|----------------------------|----------------------------|
| 1  | 18-Mar-67  | Torrey Canyon Oil Spill   | Baracuda Tanker Corporation | British Petroleum          | 25-36                      | Hit a reef                 |
| 2  | 17-Mar-78  | Amoco Cadiz Oil Spill     | Amoco                      | NA                        | 70                         | Ran aground, split into two and sank |
| 3  | 15-Nov-79  | MT INDEPENDETA Spill      | Romanian crude oil carrier | NA                        | 28.5                       | Collided with other ship and caught fire |
| 4  | 6-Aug-83   | Castillo de Bellver Oil Spill | Empressa Nacional Elcano   | NA                        | 79                         | Caught fire                |
| 5  | 24-Mar-89  | Exxon Valdez Oil Spill    | Exxon                      | NA                        | 11                         | Hit a reef                 |
| 6  | 19-Jan-91  | Arabian Gulf/Kuwait Spill | Kuwait Petroleum Corporation | NA                        | 380-520                    | Gulf War                   |
| 7  | 11-Apr-91  | M/T Haven Oil Spill       | Amoco                      | NA                        | 45                         | Ageing ship and lack of maintenance |
| 8  | 5-Jan-93   | MV BRAER Spill            | Braer Corporation          | NA                        | 25.5                       | Ship lost power due to seawater contamination of the ship's heavy fuel oil and ran aground. Grounded after entering a channel and hit rocks |
| 9  | 15-Feb-96  | Sea Empress Oil Spill     | Oriental Ocean Shipping    | NA                        | 21                         | Ship lost power due to seawater contamination of the ship's heavy fuel oil and ran aground. Grounded after entering a channel and hit rocks |
| 10 | 12-Dec-99  | ERIKA Oil Spills          | Panship                    | NA                        | 7.6                        | Broke into two due to heavy storm |
| 11 | 13-Nov-02  | Prestige Oil Spill        | Universe Maritime Ltd.     | NA                        | 15.2                       | Hull breach                |

*NA: not available

4.5 Environmental loss indicators
The environmental loss due to oil spillage is disastrous and harmful to human and ecology system of living organisms. The Exxon Valdez has the worst environmental impact and it is still felt, especially by the countries affected. The operator lost a huge amount of money due to compensation to the victims affected by the accident. The details of the offshore accidents i.e. caused and amount of spillage are listed in Table 1. Through the case
studies, the environmental loss factors were identified. The factors are summarized in Table 2 showing the losses for each case.

Table 2 shows all 11 cases of tankers accident spilt oil into the ocean and consequently affect the marine environment. Oil slicks from these tankers were reported had reached the nearest beach and coastal area, simultaneously affect the plants of a particular region. Air pollution is the least factor reported in the tanker accident case study. The hot oil dispersed various dangerous gaseous substances. However, it may be considered negligible due to the condition and location of the accident afar from public. It is important to understand the impact of the environmental loss resulting from oil pollution. The spill risks will grow with more oil spill accidents and the damage to marine environment is highly influential [18]. The environmental loss indicators and definitions due to the spillage are extracted from the case studies and summarized in Table 3.

| Case No | Offshore - marine environment affected | Beaches/Onshore affected | Flora | Fauna | Fisheries | Tourism/Recreational | Air Pollution | Clean-up |
|---------|---------------------------------------|--------------------------|-------|-------|-----------|----------------------|--------------|---------|
| 1       | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| 2       | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| 3       | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| 4       | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| 5       | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| 6       | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| 7       | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| 8       | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| 9       | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| 10      | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| 11      | /                                     | /                        | /     | /     | /         | /                    | /            | /       |
| TOTAL   | 11                                    | 11                       | 10    | 11    | 9         | 6                    | 2            | 9       |

5. Conclusion

This article has reviewed previous offshore accidents and shows that spillage lead to environmental impact and affected various types of stakeholders i.e. from marine and coastal industries. The owner or operator of oil and gas companies are responsible for environmental loss and wise decision making is needed in order to mitigate and respond to the spillage, for example clean up type and response time. This article has extensively discussed and reviewed the environmental loss of each spillage accident. The environmental loss factors are identified through 11 case studies of major oil and gas offshore accidents from 1967 to 2006.

Eight factors were identified as indicating the environmental impact to stakeholders and ecosystem after an accident. These environmental loss factors may help a pipeline operator to determine which factors need to be focused based on the reviewed cases. In a future research, a prioritization method is recommended using suitable Multicriteria Decision Making (MCDM) in environmental related projects because it involve many different stakeholders with different priorities and objectives [9]. In short, the method can be utilized for developing a more comprehensive risk assessment in the pipeline integrity management system. Hence, a reliable, safe and cost effective offshore pipeline is guaranteed.

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