

**LIFE CYCLE COST ANALYSIS OF A FLOATING PRODUCTION  
STORAGE OFFLOADING VESSEL**

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*To my beloved wife Intan Wirdati binti Suhaimi and my children on their sincere prayers, understanding and full support.*

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## ABSTRACT

The focus of this study is to understand the essential characteristics of various lifecycle cost methodologies and tools available. Life cycle cost (LCC) analysis is summarized as an economics model for evaluating the total cost of ownership of an asset. In combination with the technical aspects of a Floating, Production, Storage and Offloading (FPSO) vessel, the aim of this study is to develop a lifecycle cost estimation framework for an FPSO as per the problem statement discussed in Section 1.2. Various conceptual lifecycle cost models were reviewed with emphasis on the lifecycle stages and the correlation to the specific lifecycle activities assessed. Consequently, a standard conceptual life cycle costing model and its cost breakdown structure were developed and integrated into a proposed LCC framework for an FPSO. The main elements of the lifecycle cost model are the capital, operating and salvage expenditure. The breakdown of the capital expenditure into several key areas made this LCC model distinctive. Following the development of a lifecycle cost model is the application of the framework to a high level cost estimation case study. Following that is the identification of the critical factors that influence the FPSO economic evaluation criteria through a sensitivity analysis of the LCC model followed by the discussion of results and the findings presented. The results of the LCCA identified that the main cost drivers of the FPSO are the topsides capital expenditure and the operating cost. The discount rate used in the LCCA has also significant impacts on the net present value (NPV) of the LCCA. Key areas for future work were identified based on the consequent research findings. The deployment of the findings of this research within the industry could offer various strategic benefits that come with the formalization of the life cycle cost framework.

## ABSTRAK

Tumpuan kajian ini bertujuan untuk memahami ciri-ciri penting dalam pelbagai metodologi kos kitaran hayat dan kaedah yang sedia ada. *Life cycle cost* (LCC) analisis dirumuskan sebagai model ekonomi untuk menilai jumlah kos pemilikan aset. Digabungkan dengan aspek-aspek teknikal sebuah kapal *Floating, Production, Storage and Offloading* (FPSO), tujuan kajian ini adalah untuk membangunkan satu rangka kerja anggaran kos kitaran hayat bagi FPSO seperti yang dibincangkan dalam permasalahan kajian Seksyen 1.2. Pelbagai model kos kitaran konsep telah dikaji semula dengan penekanan kepada peringkat kitaran hayat dan juga pertalian dengan aktiviti kitaran yang spesifik. Seterusnya, satu konsep kos kitaran hidup model yang standard bersama struktur pecahan kos telah dibangunkan dan disepadukan ke dalam cadangan rangka kerja LCC FPSO. Unsur-unsur utama model kos kitaran hayat adalah perbelanjaan modal, kos operasi dan *salvage*. Pecahan perbelanjaan modal ke beberapa bidang utama menjadikan model LCC ini tersendiri dari kajian-kajian yang terdahulu. Berikutan pembangunan model kos kitaran hayat, langkah seterusnya adalah penggunaan rangka kerja tersebut ke atas suatu kajian kes peringkat tinggi. Berikutan itu adalah langkah mengenal pasti faktor kritikal yang mempengaruhi kriteria penilaian ekonomi FPSO melalui kajian sensitiviti model LCC diikuti dengan perbincangan mengenai keputusan dan pembentangan penemuan. Keputusan analisis kos kitaran hayat telah mengenal pasti bahawa pemacu kos utama FPSO adalah perbelanjaan modal *topsides* dan kos operasi. Kadar diskaun yang digunakan dalam analisis kos kitaran hayat juga mempunyai impak yang besar ke atas *net present value* (NPV) analisis LCC. Bidang utama untuk kajian masa depan telah dikenal pasti berdasarkan penemuan penyelidikan. Pelaksanaan hasil kajian ini di dalam industri boleh menawarkan pelbagai manfaat strategik yang timbul selaras dengan formalisasi rangka kerja LCC tersebut.

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**LIST OF ABBREVIATIONS**

AC	-	Air Conditioning
AEV	-	Annual Equivalent Value
AHU	-	Air Handling Unit
AIRR	-	Adjusted Internal Rate of Return
BOA	-	Bill of Activities
BOM	-	Bill of Material
CALM	-	Catenary Anchor Leg Mooring
CAPEX	-	Capital Expenditure
CBS	-	Cost Breakdown System
CCR	-	Central Control Room
CCTV	-	Closed Circuit Television
CER	-	Cost Estimation Relationship
COPT	-	Cargo Oil Pump Turbine
COW	-	Crude Oil Washing
DOE	-	Department of Energy
DP	-	Dynamic Positioning
E&I	-	Electrical & Instrument
ECR	-	Engine Control Room
EU	-	European Union
FEMP	-	Federal Energy Management Program
FPSO	-	Floating Production Storage Offloading
FSO	-	Floating Storage Offloading
GMDSS	-	Global Maritime Distress and Safety System
HFO	-	Heavy Fuel Oil
HOSCO	-	Hebei Ocean Shipping Company
HSE	-	Health, Safety & Environment

HVAC	-	Heating, Ventilation & Air Conditioning
ICPP	-	Impressed Current Cathodic Protection
IG	-	Inert Gas
IMO	-	International Maritime Organization
INMARSAT	-	International Maritime Satellite Organization
IRR	-	Internal Rate of Return
ISO	-	International Standards Organization
ISPS	-	International Ship and Port Facility Security
LCCA	-	Life Cycle Cost Analysis
LAN	-	Local Area Network
MGO	-	Marine Gas Oil
NB	-	Net Benefit
NIST	-	National Institute of Standards and Technology
NPC	-	Net Present Cost
NS	-	Net Saving
OOL	-	Oil Offloading Line
OP	-	Operation Profile
OPEX	-	Operating Expenditure
P&I	-	Protection & Indemnity
P/V	-	Pressure / vacuum
PABX	-	Private Automatic Branch Exchange
PAGA	-	Public Address/General Alarm
PB	-	Payback
POB	-	Personnel on Board
PV	-	Present Value
ROI	-	Return on Investment
SBM	-	Single Buoy Mooring
SCCS	-	Standard Cost Coding System
SIR	-	Saving to Investment Ratio
SURF	-	Subsea, Umbilical Riser and Flowline
TEG	-	Triethylene Glycol
TLP	-	Tension Leg Platform
UPS	-	Uninterruptible Power Supply

UWILD	-	Underwater Inspection in Lieu of Dry-docking
VELPA	-	Vertically Loaded Plate Anchor
VLCC	-	Very Large Crude Carrier
VSAT	-	Very Small Aperture Terminal
WBS	-	Work Breakdown System

## LIST OF SYMBOLS

$C_{II-1}$	-	Acquisition or procurement cost
$C_{II-2}$	-	Initial logistic cost
$C_{II-3}$	-	Recurring cost
$C_{III-1}$	-	Research and development cost
$C_{III-2}$	-	Cost of associated systems
$C_{III-3}$	-	Investment cost
$C_{III-4}$	-	Termination cost
$C_{III-5}$	-	Operating and support cost
$C_{VI-1}$	-	Research and development cost
$C_{VI-2}$	-	Investment cost
$C_{VI-3}$	-	Operating and support cost
$C_{ADF}$	-	Activity definition
$C_{ADV}$	-	Activity driver
$C_{capex}$	-	Capital expenditure cost
$C_{CDV}$	-	Cost driver
$C_{cls}$	-	Classification cost
$C_{comm}$	-	Communication cost
$C_{cons}$	-	Consumables cost
$C_{conv}$	-	Conversion cost
$C_{cp}$	-	Conceptual phase cost
$C_{ctrg}$	-	Catering cost
$C_{dcm}$	-	Decommissioning cost
$C_{demo}$	-	Demolition cost
$C_{dp}$	-	Definition phase cost
$C_{fc}$	-	Fuel cost
$C_{fl}$	-	Finance & legal cost



$C_{IA}$	-	Initial acquisition cost
$C_{ins}$	-	Insurance cost
$C_{IS}$	-	Initial spares cost
$C_{istl}$	-	Installation cost
$C_{l/o}$	-	Lube oil cost
$C_{lbr}$	-	Labor cost
$C_{lfext}$	-	Life extension cost
$C_{log}$	-	Logistic cost
$C_M$	-	Maintenance cost
$C_{maint}$	-	Maintenance and repair cost
$C_{me}$	-	Mooring equipment cost
$C_{mh}$	-	Maintenance healthcare cost
$C_{mo}$	-	Major overhaul cost
$C_{mr}$	-	Major repair cost
$C_{nb}$	-	Newbuild vessel cost
$C_{nm}$	-	Normal maintenance cost
$C_{nr}$	-	Normal repair cost
$C_{opex}$	-	Operating expenditure cost
$C_{ops}$	-	Operating cost
$C_{ops}$	-	Operational phase cost
$C_{os}$	-	Operation and support cost
$C_{OV}$	-	Overhaul cost
$C_{pc}$	-	Production and construction cost
$C_{pe}$	-	Project execution cost
$C_{pp}$	-	Procurement phase cost
$C_{rc}$	-	Vessel refurbishment & conversion cost
$C_{RD}$	-	Resource driver
$C_{rd}$	-	Research and development cost
$C_{re}$	-	Rental equipment cost
$C_{riskEX\_A}$	-	Accident risk expenditure
$C_{riskEX\_F}$	-	Failure risk expenditure
$C_{rpr}$	-	Repair cost
$C_{rsdl}$	-	Residual cost

$C_{rt}$	-	Retirement and disposal cost
$C_{sb}$	-	Shore base cost
$C_{scrp}$	-	Scrap cost
$C_{slv}$	-	Salvage cost
$C_{spr}$	-	Spares cost
$C_{sr}$	-	Vessel steel renewal cost
$C_{te}$	-	Topsides equipment cost
$C_{tl}$	-	Tool cost
$C_{tm}$	-	Transport cost
$C_{trv}$	-	Travel cost
$C_{va}$	-	Vessel acquisition cost
$E$	-	Energy cost
$I$	-	Investment cost
$LCC$	-	Lifecycle cost
$NRC$	-	Operating expenditure cost
$OM\&R$	-	Non-fuel operating, maintenance & repair cost
$RC$	-	Capital expenditure cost
$R_{EPL}$	-	Capital replacement cost
$R_{ES}$	-	Residual value less disposal cost
$R_I$	-	Revenue impact
$W_a$	-	Water cost

## **CHAPTER 1**

### **INTRODUCTION**

Oil is one of the major if not the most important element of the global economy. Its uses are widespread throughout the economy primarily as a source of energy. The global consumption is estimated to be 30 billion of barrels annually and is booming each year. Oil is also used as raw material for various petrochemical industries, pharmaceuticals, solvents, fertilizers, pesticides, and plastics.

The earliest onshore oil industry was started around the 8<sup>th</sup> century. The oil was used for producing tar to pave the streets of Baghdad. Since then, man has expanded the search from oil from land to offshore. Offshore production first began in the late 1940s. In 1947, Kerr-McGee Corporation drilled the first well from a fixed platform offshore out-of-sight of land (Chakrabarti, 2005). The ever increasing growth rate in oil demand has led the industry towards offshore oilfields in deeper waters. However, there is a limit to the water depth where it is economically feasible to install a fixed oil platform. Depending on the field reserves, the water depth limit for fixed platform is in the region of 300 meters and in the range of 200 km offshore. The limits are mainly due to the structural and infrastructure constraints.

Fixed offshore platforms soon evolve to floating offshore platforms in the 1970s. The first FPSO was deployed on the Castellon field in the Spanish Mediterranean by Shell in 1977 (Paik et al, 2007). The FPSO was designed and built by Single Buoy Moorings (SBM). Consequently, FPSO is the preferred solution for deep water oilfields due to technological and economic reasons.

## **1.1. Background**

### **1.1.1. Floating, Production, Storage and Offloading**

The acronym FPSO stands for Floating, Production, Storage and Offloading. Its acronym also defines its main functions. The functions of an FPSO (Neto et al, 2001) are:

- i. To process oil and gas through its onboard process facilities.
- ii. Import oil and gas through the subsea riser system.
- iii. Export oil, gas and water through its riser and offloading system.
- iv. Storage of oil on board via the cargo tanks.
- v. Floating and station keeping through its mooring system.

The FPSO is basically floating and moored offshore in water depths ranging from 200 meters to deep water of more than 1500 meters. The mooring system can either be spread moored or allowed to free weathervane through a turret system. The turret system can either be an internal or external system with the options of permanent or disconnection in case of iceberg or storm.

The primary role of an FPSO is the production of oil from crude oil extracted from subsea wells. Crude oil is a mixture of hydrocarbons in various states from almost solid to a gaseous state. Initial crude oil is often mixed with gas, water and sand in an emulsified form. The oil will be separated from the gas and produced water (*produced water* is a term used in the oil industry to describe water that is produced along with the oil and gas) and it is usually routed to a coalescer before being metered and stored in the cargo hull.

The produced water is often routed to a hydrocyclone to remove entrained oil and solids and then either re-injected into the reservoir or dumped overboard depending on the circumstances and cleanliness of the water. The associated gas is initially dubbed "wet gas" as it is saturated with water and liquid alkanes. The gas is typically routed through scrubbers, compressors and coolers which will remove the bulk of the liquids. This "dry gas" may be exported, re-injected into the reservoir, used for gas lift, flared or used as fuel for the FPSO power generators.

Apart from FPSO, there are other floating solutions which have oil production facilities but not the storage capability. These are the Tension Leg Platform (TLP), Semi-submersible and Spar.

A Tension Leg Platform (TLP) is a buoyant platform held in place by a mooring system. The TLP concept is similar to conventional fixed platforms except that the platform is maintained on location through the use of moorings held in tension by the buoyancy of the hull. The mooring system is a set of tension legs or tendons attached to the platform and connected to a template or foundation on the seafloor. The template is held in place by piles driven into the seafloor. This method dampens the vertical motions of the platform, but allows for horizontal movements. The topside facilities (processing facilities, pipelines, and surface trees) of the TLP and most of the daily operations are the same as for a conventional fixed platform and FPSO.

A semi-submersible is a floating structure with good stability and sea keeping characteristics. The semi-submersible vessel design is commonly used in a number of specific offshore roles such as for offshore drilling rigs, safety vessels, oil production platforms and heavy lift cranes. A semi-submersible obtains its buoyancy from ballasted, watertight pontoons located below the ocean surface and wave action. The operating deck can be located high above the sea level due to the good stability of the semi-submersible, and therefore the operating deck is kept well away from the waves. Structural columns connect the pontoons and operating deck. With its hull structure submerged at a deep draft, the semi-submersible is less affected by wave loadings than a normal ship. With a small water-plane area, however, the semi-submersible is sensitive to load changes, and therefore must be carefully trimmed to maintain stability. The semi-submersible is moored by a conventional anchor spread mooring system.

A spar is a deep-draft floating caisson, which is a hollow cylindrical structure similar to a very large buoy. The spar relies on a conventional anchor spread mooring system for its station keeping. Most of the structure is submerged underwater. Historically, spars were used as marker buoys and for gathering oceanographic data. At present, the spar design is now being used for drilling, production or for both functions. The distinctive feature of a spar is its deep-draft hull, which produces very favorable motion characteristics compared to other floating concepts. Low motions and a protected center-well also provide an excellent configuration for deepwater operations up to 3000 meters of water depth.

FPSO has a typical ship-shaped hull configuration. This is inherent from the physical characteristics of its original donor tanker vessel. The current trend of FPSO is towards conversion of former trading oil tankers. Recent development in design has introduced cylindrical shape FPSO design which eliminates the requirement for a weathervaning system. Most FPSOs are converted from ocean going tankers but some are fit for purpose new build hull.

The storage capacity of the FPSO is dependent on the size of the vessel. A typical FPSO converted from a Very Large Crude Carrier (VLCC) is able to store more than 1 million barrels of oil. There is also particular demand for FSOs which is basically an FPSO without the production capacity.

The offloading operations to the shuttle tankers can be done through several means such as tandem offloading, side by side and via Oil offloading lines (OOL) to a Catenary Anchor Leg Mooring (CALM) buoy. The main advantage of this offloading method is that no pipeline infrastructure is required which can be very cost prohibitive especially in deep water.

The advantages of an FPSO are its simplicity, versatility, mobility and flexibility. The simplicity of the FPSO concept is that it converts the hull from an existing tanker vessel. This enables short construction time, fast deployment and lower costs suitable for marginal field developments or harsh environments which otherwise would be economically not feasible. The FPSO provides its own storage capacity thus eliminating the need of any pipeline infrastructure. It is able to be located further offshore and it has wide deck areas to allow for higher capacity process and utility facilities. It has high load capacity and able to withstand the mooring and riser loads in severe environments. It is designed for up to 100 years storm conditions including damage conditions. The FPSO are inherently tanker vessel based design. There is an active market for used tanker vessels. Tanker vessels have huge payload capacity. Another safety aspect of the FPSO is that it can be designed to be disconnected from its mooring systems. This is critical in the wake of the Katrina storm which wreaked havoc to the offshore industry in the Gulf of Mexico. The FPSO industry is focused on marginal, low cost and fast track fields as the giant oil field discoveries of previous years are becoming scarcer. FPSO are less sensitive to water depth which adds to its versatility.

On the other hand, the FPSO has its drawbacks. It requires steel renewal and modifications within enclosed space. During operations, hot swap and hot work

activities are often difficult. It needs to meet the stipulated class requirements. It also requires additional marine equipment and specialized crew thus incurring additional operating expenditure. It requires frequent offloading operations involving shuttle tankers. There is a high risk of environmental disaster in case of collision or accident due to its large storage capacity. The industry is rather fragmented due to its relatively young age. No standardization of equipment leads to higher cost. It requires subsea tieback to subsea trees which translates to higher well maintenance cost. Most often there are project cost overruns due to inexperienced or newcomer players and contributes to creating perceptions that the industry is of least trustworthy.

The major elements of the FPSO are the mooring, topsides and hull components. The mooring system can either be a combination of external, internal, permanent, disconnectable, spread moored or dynamic positioning (DP) system. The Topsides modules typically consist of the process, utilities and living quarter module. The hull is typically double hulled and converted from an existing tanker vessel. The FPSO contract is divided into the bare boat and operations charter. The FPSO needs to be operated safely and efficiently. It requires a proper repair and maintenance regime. From time to time, it will undergo a series of class survey and inspection routines. At the end of its intended life it will be decommissioned and possibly relocated to another field.



### 1.1.2. Life Cycle Cost Analysis

The practice of lifecycle cost analysis has been introduced in the 1960s in the United States initially for the procurement of defense related assets (Emblemsvag, 2003). Consequently, the practice has been expanded to cover aspects of public expenditure such as buildings and highways in the late seventies (Dhillon, 2010). In the oil and gas industry, an international standard under the number of EN ISO 15663 (2006) was introduced to provide guidance on the application of a life cycle costing methodology.

Lifecycle is defined as the total cost of ownership from its acquisition and construction, through its operation and up to its end of its useful life. A more popular term for the period of lifecycle is from “cradle to grave”.

The main objectives of LCCA are (Woodward, 1997):

- i. Effective assessment of all options for decision making.
- ii. Overall consideration of the significant impacts of all costs rather than only initial investment cost.
- iii. Assistance in the effective management of the asset throughout the lifecycle.
- iv. Making selection easier between different solutions.

One of the critical elements of an LCCA is cost. Cost is generally divided into several categories such as initial, operating, maintenance and decommissioning cost profiles. The established method for an economic evaluation of a given asset is the discounted cash flow approach. This takes into account the values of money either future or present which is determined by the discount rate.

## **1.2. Problem Statement**

The typical approach of the FPSO industry is to assess the financial viability of any project on the basis of the lowest capital expenditure. Progress has been made in the oil and gas industry by the introduction of EN ISO 15663 (2006). This standard is aimed mainly on providing a general guideline for a lifecycle cost analysis for the whole industry. The issue at hand is the wide spectrum of the oil and gas industry ranging from upstream activities such as offshore drilling right down to the downstream activities such as oil refinery. Further work needs to be performed to detail out the specific cost elements for the various stages of the oil and gas industry specifically the FPSO industry. The key factor of performing a sound lifecycle cost analysis of an FPSO is mainly driven by the specific cost elements and the methodology of cost estimation. Consequently, this research is being proposed to address the development of a specific lifecycle cost estimating framework for an FPSO, identification of the critical factors that influence the FPSO economic evaluation criteria and further study of the identified critical factors.

## **1.3. Research Objectives**

The main aim of this research is to present a comprehensive framework for the cost elements and cost estimation methodology for the lifecycle cost analysis of an FPSO.

To achieve the aim above, several objectives were defined below:

- i. Identify FPSO cost parameters and characteristics.
- ii. Identify various lifecycle cost methodologies and approaches.

- iii. Formation of conceptual lifecycle cost methodology and cost breakdown structure for an FPSO.
- iv. Identify high level cost drivers for an FPSO.
- v. Development of a lifecycle cost estimation framework for an FPSO.
- vi. Assessment of the framework with a case study.

#### **1.4. Research Questions**

The critical questions posed for this particular research:

- i. What is the specific breakdown of cost profiles of an FPSO LCCA?
- ii. What is the general context for the cost estimation approach of an FPSO LCCA?
- iii. What are the critical cost drivers?

#### **1.5. Research Scope**

The study will examine the specific cost profiles of an FPSO life cycle cost analysis derived from the general approaches presented in the existing available literature review. The derivation of the cost estimation approach will be discussed and analyzed. This study will also gather pertinent data related to the cost elements. Specific FPSO cost elements and estimation methodology will be the focus of this research. The study will be limited to the capital expenditure, operating, maintenance and salvage cost profiles of the FPSO.

## **1.6. Significance of Findings**

This research will be a significant effort in the development of specific framework for lifecycle cost estimation for an FPSO and its relevant cost profiles. This study will also be beneficial to the decision makers when they employ the optimum approach particularly in different concepts related to the use of cost effective solutions. By understanding the needs of the industry and benefits of comprehensive lifecycle cost analysis, the interested parties can be assured of a competitive advantage. Moreover, this research will provide recommendations based on the identification of the FPSO critical cost drivers.

Furthermore, this research will be helpful to the FPSO industry and decision makers in informed decision making. It will also serve as a future reference for researchers on the subject of FPSO life cycle cost analysis. Importantly, this research will support the various stakeholders on concept selection, investment choice and operating strategy.

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