OCS Study
MMS 2007-031

Coastal Marine Institute

Idle Iron in the Gulf of Mexico

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

Cooperative Agreement
Coastal Marine Institute
Louisiana State University

OCS Study
MMS 2007-031

Coastal Marine Institute

Idle Iron in the Gulf of Mexico

Authors

Mark J. Kaiser
Allan G. Pulsipher

May 2007

Prepared under MMS Contract
1435-01-04-CA-32806-36184
by
Louisiana State University
Center for Energy Studies
Baton Rouge, Louisiana 70803

Published by

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region

Cooperative Agreement
Coastal Marine Institute
Louisiana State University

DISCLAIMER

This report was prepared under contract between the Minerals Management Service (MMS) and Louisiana State University's Center for Energy Studies. This report has been technically reviewed by MMS. Approval does not signify that the contents necessarily reflect the view and policies of the Service, nor does mention of trade names or commercial products constitute endorsement or recommendation for use. It is, however, exempt from review and compliance with MMS editorial standards.

REPORT AVAILABILITY

Extra copies of the report may be obtained from the Public Information Office (Mail Stop 5034) at the following address:

U.S. Department of the Interior
Minerals Management Service
Gulf of Mexico OCS Region
Public Information Office (MS 5034)
1201 Elmwood Park Boulevard
New Orleans, Louisiana 70123-2394
Telephone Number: 1-800-200-GULF or
504-736-2519

CITATION

Suggested citation:

Kaiser, M.J and A.G. Pulsipher. 2007. Idle iron in the Gulf of Mexico. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2007-031. 197 pp.

ABSTRACT

Offshore structures are installed to produce hydrocarbons, but at some point in time during the life cycle of the field, when the cost to operate a structure exceeds the income from production, the structure will exist as a liability instead of an asset. Federal regulations require that an offshore oil and gas lease be cleared of all structures within one year after production on the lease ceases. In recent years, the Minerals Management Service has begun to encourage operators to remove structures on producing leases that are no longer "economically viable." The purpose of this paper is to quantify the amount of idle iron that exists in the Gulf of Mexico and to describe its geographic distribution and ownership patterns. The basic question of what idle iron is and why it exists is addressed, followed by a discussion of the policy implications involved in the interpretation of federal regulations. Summary statistics that quantify and define the idle iron inventory is then presented.

TABLE OF CONTENTS

Page

TABLE OF CONTENTS
(continued)

TABLE OF CONTENTS
(continued)

Page

TABLE OF CONTENTS
(continued)

Page

TABLE OF CONTENTS
(continued)

Page

TABLE OF CONTENTS
(continued)

Page

TABLE OF CONTENTS
(continued)

Page

LIST OF FIGURES

LIST OF FIGURES
(continued)

LIST OF TABLES

LIST OF TABLES
(continued)

EXECUTIVE SUMMARY

Offshore structures are installed to produce hydrocarbons, but at some point in time during the life cycle of the field, when the cost to operate a structure exceeds the income from production, the structure will exist as a liability instead of an asset. Federal regulations require that offshore leases be cleared of all structures within one year after production on the lease ceases, but a producing lease can hold infrastructure idle for as long as the lease is producing. In Chapter 1, we quantify the amount of idle iron that exists in the Gulf of Mexico and describe its geographic distribution and ownership patterns. The basic question of why idle iron exists is addressed, followed by a discussion of the policy implications involved in the interpretation of federal regulations. Summary statistics that quantify and define the idle iron inventory in the Gulf of Mexico is presented.

At the end of 2003, 2,175 active (producing) structures, 1,227 idle (non-producing) structures, and 505 auxiliary (never-producing) structures associated with oil and gas production reside in the Outer Continental Shelf of the Gulf of Mexico. In recent years, the Minerals Management Service has begun to encourage operators to remove idle structures on producing leases that are no longer "economically viable." The purpose of Chapter 2 is to model alternative regulatory policies of structure removal and to compare the cost of each regulatory option. A description of the modeling framework and implementation results is presented.

Every component of an oil and gas structure follows a unique path during its life cycle, from fabrication through installation, decommissioning, and eventually, disposal. Decisions about when and how a structure is decommissioned involve issues of environmental protection, safety, cost, and strategic opportunity, and the factors that influence decision making are complicated and depend as much on the technical requirements and cost as on the preferences established by the operator and the scheduling of the operation. In Chapter 3, the pathways for material generated from decommissioning offshore structures are examined. The factors that influence decision making at each stage are reviewed, and the storage, reef, and scrap markets that have evolved along the Gulf coast are described. Conceptual economic models are developed to illustrate the tradeoffs involved in decommissioning, divestment, and disposition decision making.

Ship breaking and rig scrapping is the process in which a vessel or rig is broken down and recycled into salvageable components, cut into pieces, and transported to a domestic steel mill or exported on a cargo vessel. Ship breaking and rig scrapping do not play a major role in the material handled by scrap processors in the United States, but they are part of the unique industrial landscape associated with the offshore energy industry, and are the subject of Chapter 4. Breaking is a labor intensive, low technology, and relatively homogeneous industry. Work conditions are difficult, dangerous, and potentially hazardous; low wage rates reflect the skill levels required; and operations are not well suited for mechanization. Ship breaking and rig scrapping share many common features in workflows, worker safety, and environmental issues, but also have notable differences in breaking cost and the structure of the industry. The scrap and storage markets for ships and rigs in the Gulf of Mexico are first reviewed, and then disposal alternatives, inventory statistics, and the factors that influence breaking and disposal cost are described. The primary environmental protection and worker safety statutes are outlined along with a summary discussion of process workflows.

In Chapter 5, order-of-magnitude estimates of the amount of steel in the Gulf of Mexico associated with decommissioning are developed. Steel is the most important and widespread material used in the offshore industry, and its weight is an important factor in structure design, since the more a structure weighs the more it costs to fabricate, install, and remove. Weight comparisons are difficult to make, however, because many interdependent and unobservable factors influence its determination. Survey techniques and approximating relations are developed to provide first-order estimates for the quantity of steel destined for scrap, reef and storage markets. Weight algorithms are developed for both shallow and deepwater structures based on production capacity, deck area, water depth, and other factors. The amount of structural steel decommissioned in 2003 and its destination onshore is used to illustrate application of the algorithms.

CHAPTER 1: IDLE IRON IN THE GULF OF MEXICO

1.1. Introduction

The Outer Continental Shelf (OCS) of the Gulf of Mexico (GOM) begins seaward three nautical miles from the Louisiana, Alabama, and Mississippi shorelines, and three marine leagues (nine nautical miles) from the Texas and west Florida shorelines, and extends 200 miles through the Exclusive Economic Zone. The OCS is the federally regulated waters of the GOM and is the most extensively developed and mature offshore petroleum province in the world. More than 40,000 wells have been drilled in the OCS since offshore production began in 1947, and nearly 6,500 producing wells, 4,000 structures and 33,000 miles of pipeline are currently used in the production of oil and gas.

Oil and gas does not flow for free. Investment is required throughout the life cycle of every field, particularly during the exploration stage, where large capital outlays are required to drill wells. If the prospect is commercial, additional wells will be drilled to confirm and delineate the field, and equipment and infrastructure will be constructed and installed for production. In onshore developments, an assessment of the size of the field is useful but not always required. Onshore, productive wells are usually tied into an existing pipeline or gathering system, and the field grows gradually over time. In offshore developments, however, because the investment requirements are considerably more substantial, it is necessary to know before major capital outlays whether the field will be commercial. Several wells are normally drilled to delineate the field and provide an estimate of the total (expected) reserves in order to secure the financial resources for its development.

Offshore structures combine capital, labor, materials and fuel to produce hydrocarbons, and operate under the physical laws and engineering specification of the system, economic principles which determine the design and commerciality of production, and man-made rules governing operation and decommissioning activities. Significant interrelationships exist between the physical laws by which a system operates and the commercial rules and regulations established for the system.

Structures are installed to produce hydrocarbons, but at some point in time during the life cycle of the field, when the cost to operate a structure (maintenance, operating personnel, transportation, fuel, etc.) exceeds the income from production, the structure exists as a liability instead of an asset. If the production rate of the structure can be increased (through investment) or the operating costs can be reduced (through more efficient production practices, a farm-out arrangement, or unitization), the field will continue to produce until its "economic limit" is reached. Since 1947, over 2,300 structures have been removed from the GOM, and over the past decade, 125 structures have been removed annually (Figure A.1). Structures that exist on a lease that have not produced in the last year or serve a useful economic purpose are called "idle iron."

The purpose of this chapter is to quantify the amount of idle iron that exists in the Gulf of Mexico and to describe its geographic and ownership patterns. A description of the oil and gas infrastructure in the GOM is first reviewed, followed by the basic question of why idle iron exists. Summary statistics that quantify and define the idle iron inventory is then presented. Conclusions complete the paper.

1.2. Gulf of Mexico Infrastructure and Production

Offshore development strategies vary depending upon time of development; reserve size; proximity to existing infrastructure; and operating, economic, and strategic considerations (Graff, 1981; McClelland and Reifel, 1986). In water depths less than 1,000 ft or so, caissons, well protectors, and fixed platforms are employed extensively throughout the GOM (Figure A.2), as well as subsea[1] completions (Figure A.3). A caisson is a cylindrical or tapered tube enclosing a well conductor and is the minimum structure for offshore development of a well. Structures that provide support through a jacket to one or more wells with minimal production equipment and facilities are referred to as a well protector. Production from caissons, well protectors, and subsea completions is sent to processing facilities on a fixed platform prior to being transported to shore. Fixed platforms are large self-contained structures that include facilities for drilling, production, and combined operations. The distribution of structures according to type, water depth, and planning area is shown in Table A.1. An auxiliary structure is a structure that has never produced hydrocarbons, but serves in an auxiliary role, say as a quarters facility, flare tower, or storage platform.

Subsea systems are capable of producing hydrocarbons from reservoirs in all water depths and are frequently used in deepwater development, accounting for 164 of the 295 total subsea wells in the GOM (Baud et al., 2002). Compliant towers, spars, tension leg platforms, and floating production units are also employed in the deepwater (Figure A.4) but in considerably smaller numbers (Table A.2). Fixed platforms have an economic water depth limit of about 1,400 ft. while compliant towers have been employed in water depths from 1,000 to 3,000 ft. Tension leg platforms are the most common deepwater structure in the Gulf of Mexico. Spars, semisubmersible production units, and floating production, storage, and offloading systems may be used in water depths ranging up to and beyond 10,000 ft.

About 25 percent of the United States domestic oil and gas supply comes from the OCS, and in 2003, OCS lands averaged daily production of about 1.5 million barrels (MMbbl) of oil and 14.5 billion cubic feet (Bcf) of natural gas. The 2005 hurricane season significantly disrupted GOM production and was the worst in the history of the offshore, destroying over 123 structures and significantly damaging several dozen other structures.

1.3. Federal Regulations

Federal regulations require that all structures on a lease be removed within one year after the lease is terminated (*Federal Register*, 2002). Typically, a lease is terminated when production on the lease ceases, but if the operator intends to re-work well(s) or pursue additional drilling activity on the lease, or the lease contains an active pipeline, conditions may warrant the Minerals Management Service (MMS), the federal agency responsible for production and

[1] Subsea systems include seafloor and surface equipment. Seafloor equipment includes subsea wells, manifolds, control umbilicals, and flowlines. Surface equipment includes the control system and other production equipment located on a host platform.

decommissioning activities in the OCS, to grant an extension of the lease termination. Since several structures are usually located together on a lease, it is only when the last structure on a lease ceases production that all the structures on the lease are required to be removed. Operators may plug and abandon non-producing wells and remove isolated structures such as caissons and storage facilities on a productive lease early, if the removals can be scheduled to enhance decommissioning economics, but it is really only after the lease is terminated that federal regulations require all the structures to be removed.

Structures that exist on a lease that have not produced in the last year or do not serve a useful economic function are called idle iron, but because the economic purpose of a structure is unobservable, we restrict the definition of idle iron to those structures that exist on a lease that have not produced for at least one year. A structure is active if it is currently producing hydrocarbons. It is possible for an idle structure to produce in the future, but it is a rare occurrence. Once a structure becomes idle, it usually remains captured within this state.

1.4. Idle Iron Characteristics

Field development strategies represent a trade-off between production rates and capital expenditure. A high production rate requires a large capital investment in the form of the number and type of wells drilled, structure facilities, and the capacity of production equipment. High investment also requires a high rate of return to justify the increased capital risk and exposure, and so the preferences of the operator and their perceived risk-reward tradeoff will determine the design capacity of the field. In principle, if it takes n wells and k structures to drain a reservoir, then the n wells can be drilled and the k structures installed over a short-term ("fast-track") or long-term ("slow-track") horizon. A fast-track development requires a large initial capital expenditure to drill and construct the wells and to build, equip and install the infrastructure prior to the receipt of cash flow. Fast-track development maximizes production revenue but also incur a high level of capital risk. Slow-track developments minimizes capital exposure, reduces uncertainty, and may be more efficient since over time knowledge of the geologic and technical aspects of the field is enhanced allowing production plans and drilling activity to be optimized.

In every field development, wells are drilled and begin production at different periods of time, will stop production at different times, and thus will become idle before production ceases on the lease or the field is depleted. This is a natural characteristic of development. In fact, because of the nature of reservoirs, even if all wells were completed at exactly the same time, well production would still cease at various stages across the development life cycle. Structures that process and treat production will become idle unless additional wells are drilled or the function of the structure changes.

Conclusion: Idle iron is a normal characteristic of offshore development activity.

Operators have incentives to remove their idle structures in a timely manner: to avoid environmental and operational hazards; to reduce inspection and maintenance requirements, insurance premiums and liability; and to maintain good working relations with the MMS. On the other hand, operators also have a strong economic incentive to maintain structures offshore: to defer the cost of removal; to increase the opportunity for resale; to reduce the risk and expense of storing platforms in a fabrication yard; and to reduce the overall cost of decommissioning through scale economies, scheduling and shared mobilization.

Conclusion: The amount of idle iron depends upon operator preference and strategic objectives.

The occurrence of idle iron is also closely connected to regulations that govern the decommissioning activities of operators. The federal waters of the GOM are divided into three large planning areas labeled the Western, Central, and Eastern Gulf of Mexico. Each planning area is subdivided into smaller regions, called protraction areas, which in turn are divided into numbered blocks. A block is normally a nine square mile area (3 mile × 3 mile) consisting of 5,760 acres and is the smallest unit that can be leased for oil and gas exploration. Lease terms and dimensions vary with the time of the auction and the location of the lease, but most give the leaseholder the exclusive right to explore for oil and gas for a period of 5-10 years.

In federal waters, the end of life of a structure is generally defined as one year after production activities on the lease cease. The lease is the basic unit of analysis in federal regulations, but this is not the only choice, as both field and structure categorization levels provide possible alternatives.

1.4.1. Field Unit: If a field unit is selected as the basis[2] for decommissioning requirements, then in cases where the field overlaps more than one lease, after lease production ceases structures contained on a non-producing lease can be held by field production in much the same way as lease production can hold structures idle in federal waters. A field unit provides maximum operational efficiency and development optionality for the operator if the field is sufficiently large, but is also likely to promote a large inventory of idle iron. On the other hand, if one or more fields are contained within a lease, then a field unit will actually be more restrictive than the lease unit, since when field production ceases all structures will need to be removed even though the lease may still be producing from another field.

1.4.2. Structure Unit: If the categorization unit is selected on a structure basis this will induce a smaller inventory of idle iron but at the expense of reduced efficiencies and greater decommissioning cost. In principle, the inventory of idle iron should be nearly zero since when production on a structure ceases its removal would be performed within one year. In practice, because more than one structure is typically used to develop fields, either in close proximity (within a complex) or at a distance to other infrastructure, using a structural unit as the basis for decommissioning regulations offshore is not a realistic option.

1.4.3 Lease Unit: The selection of the lease as the basic unit in federal regulation is an attempt to balance the cost of decommissioning with efficiencies associated with scale economies, and appears as a reasonable compromise between the field and structure alternatives.

Conclusion: Idle iron derives from the choice of categorization unit employed in the regulatory structure.

[2] In Texas state waters, for instance, a field unit is applied in decommissioning requirements.

1.5. Parameters and Notation

1.5.1. Hydrocarbon Production: A well produces from a porous, permeable rock body lying underneath an impervious layer of rock that traps the resource. Many factors impact the rate at which hydrocarbons are produced, but the two primary factors are the geologic conditions and development plan (Hyne, 1995; Rose, 2001; Seba, 2003). The geologic conditions at the site – the type and characteristics of rock, reservoir drive, depth, thickness, fault mechanisms, and hydrocarbon properties – are essentially "fixed," while the development plan – well density, wellbore size, completion techniques, method of production, and equipment capacity – represent "design" parameters which are selected to maximize the return on capital. Trade-offs exist in the development plan as previously discussed.

Wells produce a mixture of oil, gas, and other material from one or more geologic zones. Petroleum reservoirs contain hydrocarbons in both liquid and gaseous states, and are typically mixed with produced water, sand, and other organic compounds containing small amounts of oxygen, nitrogen, sulfur, and sometimes, metals. If a well is produced from one zone, it is said to be a single completion; if more than one zone is produced at the same time the well is a multiple completion. Commingling is the mixing of the produced fluids from two or more zones by bringing it up the same tubing string. Commingling is not permitted in the GOM unless a special exemption has been granted. Production from multiple zones requires multiple tubing.

All wells need to be connected to a processing facility to separate the oil and gas and treat the hydrocarbon streams prior to its transportation to shore. The basic system collects production from each well or zone through an individual flowline. The flowlines are manifolded together and production from the combined well streams goes to the bulk separator. Liquid hydrocarbons are collected and sent to an oil treater, where it is sometimes necessary to heat the oil to facilitate the removal of latent gas and water. Produced water is treated to remove the latent oil and gas and is then injected back into the reservoir or deposited into the ocean.

The amount of hydrocarbons produced by well w from geologic zone z in month m is denoted $Q(w,z,m)$. Production is expressed in terms of barrels (bbl) of oil or cubic feet (cf) of gas, or in terms of barrels of oil equivalent[3] (BOE). If well production is aggregated across all producing zones within the well bore and across the season, annual well production in year t is computed as:

$$Q(w,t) = \sum_{z \in w} \sum_{m=1}^{12} Q(w,z,m).$$

Hydrocarbon reservoirs are a depleting resource. As a field is produced, the energy that causes the oil to flow into the wells is depleted or becomes less effective and the rate of production gradually decreases. If a well develops a problem in production or a workover (wellbore

[3] Barrels of oil equivalent is the amount of natural gas that has the same heat content of an average barrel of oil, with one BOE equal to about 6040 cf of gas. Oil and gas markets are not denominated in BOE's, but the "thermal equivalence" between oil and gas is useful to aggregate the well streams into one hydrocarbon stream. A BOE-denominated production stream combines all hydrocarbon sources: oil, solution gas (associated gas), nonassociated gas, and condensate (casinghead gasoline) on a heat content basis.

cleaning) is being performed, or if a well is shut-in due to a weather event (hurricane), production will temporarily terminate until the well is brought back on-line. A well is either producing (active) or non-producing (inactive) at any given time. Wells that are inactive for more than one year are considered idle.

Hydrocarbon production associated with a structure is the aggregate of its collection of wells:

$$Q(s, t) = \sum_{w \in s} Q(w, t).$$

In practice, the collection of wells associated with a structure may not be known precisely, since old wells may not have a structure identification code. To estimate structure production, a correspondence is required to identify unassigned wells with a given structure or set of structures. Production from wells with no structure identifiers are assigned based upon the criteria :

$$w^u \leftrightarrow \{s \mid \min_{s \in l} d(w^u, s)\},$$

where $d(w^u, s)$ represents the distance from unassigned well w^u to structure s and the minimization is performed with respect to all structures contained on the same leasehold l as the well.

Hydrocarbon production on lease l in year t is denoted by $Q(l, t)$ and is determined from the collection of all the structures contained on the lease:

$$Q(l,t) = \sum_{s \in l} Q(s,t).$$

A lease is either active or inactive in year t according to the value of $Q(l, t)$. An active lease has at least one producing structure and may contain idle structures. An inactive lease has no producing structures, but was once producing[4]. Active and inactive leases also contain auxiliary structures. In a limited number of cases, a lease can produce with no structures on the lease. If a well is drilled on leasehold l_A and its borehole traverses and produces from a zone lying underneath lease l_B, then the MMS will assign production to lease l_B even through the entry point of the well is located on l_A.

1.5.2. Lease Age and Idle Age: The age of structure s, $A(s)$, is defined as the difference between the installation time of the structure, $t_o = t_o(s)$, and the current (observation) time, τ: $A(s) = \tau - t_o$. The age of a lease is defined as the total age of all structures on the lease. If lease l contains k structures $\{s_1, \cdots, s_k\}$, then the total age of the lease, $A(l)$, is computed as:

[4] Note that a lease may also be inactive but under an active drilling (exploration) program. These leases do not contain any infrastructure.

$$A(l) = \sum_{i=1}^{k} A(s_i)\,.$$

The idle age of a structure is defined as the difference between the current time τ and the year of last production, t_{lp}. If production on a structure ceased in year t_{lp}, then the idle age of the structure, $I(s)$, is determined by: $I(s) = \tau - t_{lp}$.

The idle age of a lease is defined as the idle age of all the structures on the lease. If lease l contains k structures $\{s_1, \cdots, s_k\}$, then the total idle age of the lease, $I(l)$, is computed as:

$$I(l) = \sum_{i=1}^{k} I(s_i)\,.$$

The total lease age $T(l)$ can be decomposed in terms of the age of idle and active structures, as:

$$T(l) = \sum_{i=1}^{k} \{A(s_i) \mid I(s_i) = 0\} + \sum_{i=1}^{k} \{A(s_i) \mid I(s_i) > 0\}\,.$$

<u>1.5.3. Idle Time Proportion:</u> The ratio of a structure's idle age to its total age provides an indication of how long the idle structure has been inactive relative to the life cycle of production. The idle time proportion, $ITP(s)$, is defined as:

$$ITP(s) = \frac{I(s)}{T(s)}\,.$$

The idle time proportion of a structure is bound between zero and one: $ITP(s) = 0$ if the structure is active, and $0 < ITP(s) < 1$ if the structure is idle. The ratio $ITP(s)$ will change over time and approach one as the holding time of the structure increases.

The ratio of the lease idle years to the total lease age provides an indication of how long structures on the lease have been idle relative to the life cycle of production. The idle time proportion of lease l, $ITP(l)$, is defined as:

$$ITP(l) = \frac{\sum_{s \in l} I(s)}{\sum_{s \in l} A(s)} = \frac{I(l)}{T(l)}\,.$$

<u>1.5.4. Example:</u> Company X acquired the rights to explore for hydrocarbons on lease l in 1978, and by 1982, commercial quantities of oil were discovered in three different pay zones in a shallow and widely dispersed reservoir. A fixed platform *FP* was installed along with a quarters platform and first production started in 1985 from three dual completion wells. Two offset wells supported by caissons C_1 and C_2 were drilled in 1988 and tied back to the fixed platform, and in

1991, a well protector WP was installed over three in-fill wells to enhance the production rate of the field. Caisson C_1 stopped producing in 2000 and WP ceased production in 2001. The fixed platform currently maintains two producing wells and continues to process hydrocarbons from C_2.

Company X maintains two active structures ($NA(l) = 2$), one auxiliary structure ($NX(l) = 1$), and two inactive structures ($NI(l) = 2$) on lease l. The age and idle age vectors that characterize the lease relative to the observation year 2004 are as follows:

$$\{A(C_1) = 16,\ A(C_2) = 16,\ A(FP) = 19,\ A(WP) = 13\},$$

$$\{I(C_1) = 4,\ I(C_2) = 0,\ I(WP) = 3,\ I(FP) = 0\},$$

where all the values of age and idle age are represented in years. The total age of the lease is determined as:

$$T(l) = A(C_1) + A(C_2) + A(FP) + A(WP) = 64 \text{ years},$$

and the idle age of the lease is determined as:

$$I(l) = I(C_1) + I(WP) = 7 \text{ years}.$$

The average idle age of the idle structures on the lease is $I(l)/NI(l) = 3.5$ years. The total active age of the lease is determined as:

$$A(l) = A(C_2) + A(FP) = 35 \text{ years},$$

and the average age of active structures is $A(l)/NA(l) = 17.5$ years. The idle time proportion of each structure is computed as:

$$\{ITP(C_1) = 0.25,\ ITP(C_2) = 0,\ ITP(WP) = 0,\ ITP(FP) = 0.23\},$$

and the idle time proportion of the lease is $ITP(l) = 0.11$.

1.6. Working Interest Ownership

1.6.1. Joint Operating Agreements: To spread the cost and risk of exploration and production activities, oil and gas properties are typically jointly-owned by two or more working interest owners. A joint operation may be undertaken as a joint venture of undivided interest, legal partnership, or a jointly owned corporation (Gallun et al., 2001; Seba, 2003). Joint ventures of undivided interest are the most common form of joint operation. In an undivided interest, the parties share the interest in an entire lease. An undivided working interest owned by two or more parties is called a joint working interest and the most commonly encountered contract is the joint operating agreement (JOA). In a JOA one of the parties, typically the one with the largest interest percentage, is designated the operator and all the other working interest owners are non-operators. The operator manages the property and bills the non-operators for their portion of any cost incurred, but all the working interest owners participate in the property by voting on major decisions. Oil and gas companies often sell, trade, or exchange their interests in oil and gas properties to other parties, to further spread risk and share cost, as well as obtain financing, secure acreage, and to perform secondary recovery operations.

1.6.2. Working Interest Ownership: Each lease is associated with one or more operators and one or more working interest owners. The set of working interest owners varies across time with merger and acquisition activity, as new companies form and enter the business, and as other companies withdraw, exchange, or sell properties. The operator of a lease is typically one of the owners, but numerous third-party service companies (non-owners) also operate structures. Typically, there is one operator and multiple owners per leasehold, and the owner with the greatest share is usually the operator.

Let the universe of owners be denoted as $\{O_1,\ldots, O_n\}$ with owner O_i's percent ownership denoted by p_i, $i = 1,\ldots, n$. The percentage ownership in tract l is denoted as $(p_1, \ldots, p_n)$, and satisfies $0 \le p_i \le 1$ and $\sum p_i = 1$. If the operator corresponds to O_1, then usually $p_1 > \max(p_2, \ldots, p_n)$, but there is no "rule" or requirement to this effect and ownership patterns are variable and lease specific. In several old GOM leases, leases are split into two or more parts and ownership is given as a percent of the part and not the whole lease.

Each owner is assigned its portion of the number of active and idle structures, active and idle age, and production for the year 2003 according to the correspondence:

$$\psi(O_i) = \sum_l p_l(O_i)\psi(l),$$

where functional ψ is drawn from the set $\{NA, NI, A, I, Q\}$ and $p_l(O_i)$ assigns owner O_i's percentage contribution of the metric $\psi(l)$ according to the working interest ownership.

1.6.3. Example: Consider lease l_A and l_B, owners X, Y and Z, and working interest ownership vector (p_X, p_Y, p_Z). On lease l_A, X is the designated operator and the working interest ownership vector is (0.4, 0.3, 0.3). On lease l_B, Y and Z are the designated operators and the working interest ownership vector is (0.2, 0.5, 0.3). The number of active structures, number of idle structures, total age, idle age, active age, and production statistics on lease l_A and l_B are described as follows:

$$l_A = \{NA(l_A) = 4,\ NI(l_A) = 3,\ T(l_A) = 48,\ I(l_A) = 10,\ A(l_A) = 32,\ Q(l_A) = 200{,}000\},$$

$$l_B = \{NA(l_B) = 2,\ NI(l_B) = 4,\ T(l_B) = 28,\ I(l_B) = 21,\ A(l_B) = 18,\ Q(l_B) = 125{,}000\}.$$

Age is described in years and production in BOE. Working interest owners X, Y, and Z each hold a portion of the idle iron and production relative to their working interest ownership. For example, for owner X,

$$NI(\mathrm{X}) = \sum_l p_l(X)NI_l(\mathrm{X}) = (0.4)3 + (0.2)4 = 2.0,$$

$$Q(\mathrm{X}) = \sum_{l} p_l(X)Q_l(\mathrm{X}) = (0.4)200{,}000 + (0.2)125{,}000 = 105{,}000 \text{ BOE}.$$

Similarly, *NI*(Y) = 2.9, *NI*(Z) = 2.1, *Q*(Y) = 122,500 BOE, *Q*(Z) = 97,500 BOE.

1.7. Descriptive Statistics

<u>1.7.1. Number of Active and Idle Structures:</u> The data for this analysis was obtained through the Minerals Management Service TIMS database. At the end of 2003, there were 1,356 active leases and 273 inactive leases. Of the active leases, 334 are oil leases producing primarily oil. The total number of producing wells in the federal waters of the GOM is 6,427. A total of 9,453 wells were non-producing and idle with 90% of the total located on active leases (and held by lease production). There were 2,175 active structures, 898 idle structures, and 440 auxiliary structures on 1,356 active leases; and 329 idle structures and 65 auxiliary structures on 273 inactive leases (Table A.3). A total of 2,175 active structures, 1,227 idle structures, and 505 auxiliary structures, or 3,907 total structures, reside in the GOM. Most fixed platforms are active while almost half of all caissons are idle.

<u>1.7.2. Total Age and Idle Age – Active Leases:</u> Total operator experience in the GOM for all active structures is 41,577 years. The average age of caissons, well protectors, and fixed platforms is computed as:

$$\overline{A}\,(\mathrm{C}) = \frac{6{,}848 \text{ yr}}{503} = 13.6 \text{ yrs}, \;\; \overline{A}\,(\mathrm{WP}) = \frac{5{,}151 \text{ yr}}{225} = 22.8 \text{ yrs}, \;\; \overline{A}\,(\mathrm{FP}) = \frac{29{,}578 \text{ yr}}{1{,}447} = 20.4 \text{ yrs}.$$

The total idle age of caissons, well protectors, and fixed platforms across active GOM leaseholds is 7,056 years. There are more idle caissons than well protectors and fixed platforms combined, so it is not surprising that the total idle age of caissons exceeds the idle age of well protectors and fixed platforms. The average idle age per structure type is roughly comparable across structure type:

$$\bar{I}\,(\mathrm{CAIS}) = \frac{4{,}021 \text{ yr}}{484} = 8.3 \text{ yrs}, \;\; \bar{I}\,(\mathrm{WP}) = \frac{946 \text{ yr}}{136} = 7.0 \text{ yrs}, \;\; \bar{I}\,(\mathrm{FP}) = \frac{2{,}089 \text{ yr}}{278} = 7.5 \text{ yrs}.$$

As a percentage of total age, idle caissons have been inactive about one fifth of their lifetime, while well protectors and fixed platforms have been idle less than 10% of their life.

<u>1.7.3. Inactive Lease Inventory:</u> According to Federal regulations, operators are required to remove all structures on a lease within one year after the lease is terminated, which usually occurs when production on the lease ceases. Leases with no production, therefore, represent an inventory of structures that will be decommissioned in the near-future. The occurrence of the near-future can only be inferred, however, by the average idle age of structures that exist on inactive leases. The average idle age for structures on inactive leases is computed as:

$$\bar{I}\text{ (CAIS)} = \frac{558\text{ yr}}{114} = 4.9\text{ yrs},\ \bar{I}\text{ (WP)} = \frac{180\text{ yr}}{41} = 4.4\text{ yrs},\ \bar{I}\text{ (FP)} = \frac{565\text{ yr}}{172} = 3.3\text{ yrs},$$

indicating that the inventory of idle structures is reasonably young and will clear on average within three-five years. This is consistent with the storage data and removal trends observed in the GOM, since if 125 or so structures on average are removed at random from a collection of 394 = 329 + 65 idle structures, it will take about three years or so to deplete the inventory. If more than 125 structures are removed per year, then the inventory clearance time will be reduced; if less than 125 or so structures are removed, the idle age of the inventory will increase.

Structures on inactive leases represent an inventory of structures that are likely to be removed in the near-term, but may not be removed for various lease-specific reasons; e.g., the operator may request an extension to consider additional drilling opportunities on the lease or the MMS may allow the owner(s) to hold the structure if it is in close vicinity to an active lease or pipeline. Quantifying these cases is difficult at best and needs to be performed on a lease-by-lease basis. Inactive leases hold idle and auxiliary structures, and if auxiliary structures are still being used for production activities, the MMS will not terminate an inactive lease as long as the structures are being used to support production activity.

Nearly three-fourths of the 1,225 idle structures that exist on active leases are held by production and therefore permitted by federal regulation. The remaining 329 idle structures on inactive leases – about one-fourth of the total number of idle structures that exist – need to be examined on an individual basis to determine if the structure serves a useful economic purpose and if special permission has been granted for extension.

1.7.4. Distribution of Idle Structures – Active and Inactive Leases: The number of leases with *k* active structures is shown in Table A.4. The vast majority of active leases – nearly 70% – maintain only one active structure, while the remaining 30% of the active leases contains two or more active structures. Each row in Table A.4 depicts the number of *k* leases with *l* idle structures; e.g., for leases with one active structure (1-lease), 773 of the 944 leases hold no idle iron, 118 leases hold one idle structure, 29 leases hold two idle structures, and so on (refer to the first row one in Table A.4). A total of 291 idle structures exist on all 1-leases:

$$291 = 773(0) + 118(1) + 29(2) + 8(3) + 6(4) + 3(5) + 3(6) + 2(7) + 2(10).$$

The average number of idle structures on *k*-leases increases as the number of active structures increases, from 0.31 = 291/944 (1-lease) to 0.58 (2-lease), 1.1 (3-lease), 2.4 (4-lease), 6.0 (5-lease). Only a handful of leases maintain significant quantities of idle iron. Specifically, two 4-leases hold 13 and 14 idle structures and six 5-leases hold 14, 17, 19, 23, 44 and 55 idle structures. Over 30% of the total number of idle structures is contained in 48 leases, with four of the 44 leases holding over half of the subtotal.

The number of active, idle, and auxiliary structures by lease type is shown in Table A.5. More than one-half of the producing structures in the GOM exist on leases with one or more active structure.

The number of inactive leases with *l* inactive structures is shown in Table A.6. There are 273 inactive leases with 248 of these leases once-producing and 25 leases never-producing. Most inactive leases contain one inactive structure and over half of the number of idle structures on inactive leases can be found on 30 leases. The average idle time per structure is roughly five years across lease categorization, which is consistent with our previous discussion regarding the average idle age of structures on inactive leases.

1.7.5. Production Statistics: At the end of 2003, 319 working interest owners were reported in the GOM. The collection of owners and asset holdings are constantly in flux, and so it is important to realize that the data reported represents a "snapshot" of conditions that exist relative to the year 2003. The vast majority of companies in the GOM are small, independent firms, but the majority of production is held by 21 companies were responsible for over 80% of 2003 annual production (Table A.7, Figure A.5). Four majors are responsible for over 40% total hydrocarbon production. Thirty companies hold 80% of all the structures in the GOM (Table A.8).

1.7.6. Ownership Patterns: The number of idle structures that a company owns is roughly proportional to its total number of structures. If *NS* denotes the total number of structures owned by a company, then based on data from all companies that hold working interest ownership, we obtain

$$NS = 3.33NI + 1.71,\ R^2 = 0.92,$$

indicating that for every idle structure that a company owns, the company will hold on average about three active structures (Figure A.6). Ownership patterns of total idle age and total age of structures are shown in Table A.9. The total age and total idle age owned by companies is also roughly proportional to the number of structures and idle structures:

$$T = 24.28NS - 30.95,\ R^2 = 0.97,$$

$$I = 10.80NI + 1.41,\ R^2 = 0.93.$$

Refer to Figure A.7 and Figure A.8.

1.8. Conclusions

Federal regulations require that all oil and gas wells be permanently plugged and abandoned and platforms be removed from a lease within one year after the lease terminates. Typically, leases are terminated when production stops, but other circumstances may allow inactive leases to be held for a period of time before decommissioning. Idle iron is a natural characteristic of field development and depends upon the regulatory structure that governs decommissioning and operator preference. At the end of 2003, there were 2,175 active structures, 898 idle structures, and 440 auxiliary structures on 1,356 active leases; and 329 idle structures and 65 auxiliary structures on 273 inactive leases. A total of 2,175 active structures, 1,227 idle structures, and 505 auxiliary structures, or 3,907 total structures, reside in the GOM. The 1,227 idle structures on active leases represent about one-third of all structures in the GOM, but only 329 structures –

about 10% of all existent structures – are idle on inactive leases. Idle iron does not appear to be a significant issue in the GOM, but leases identified to contain abnormally high number of idle structures should be reviewed on a case-by-case basis.

CHAPTER 2: MODELING REGULATORY POLICIES ASSOCIATED WITH OFFSHORE STRUCTURE REMOVAL REQUIREMENTS IN THE GULF OF MEXICO

2.1. Introduction

Federal regulations specify the manner in which structures are removed after production from a lease ceases. In recent years, the MMS has begun to encourage operators to remove idle iron on producing leases that serve no "useful economic purpose" or are no longer "economically viable." Changes in the regulation or re-interpretation of removal requirements will change the nature of decommissioning services in the GOM, changing the number of inputs (i.e., amount of service equipment and personnel, timing of services, etc.) used in decommissioning, which will impact the overall cost of the operation and the removal patterns.

The purpose of this chapter is to examine the federal requirements for structure removal and to estimate the impact of alternative regulatory schemes on removal patterns in the GOM. The general modeling framework is first presented, followed by a description of various regulatory policy alternatives. The structure of the regulatory models is then compared, and the system metrics and removal policies are illustrated on a generic example. The model parameterization is presented and representative results summarized.

2.2. Model Framework

<u>2.2.1. Methodology:</u> To determine when a producing structure will be removed from service requires the use of geologic, regulatory, and operator information. The general procedure to model the removal of a structure follows a five-step approach. For structure s, time t, and policy P:

Step 1. Forecast production profile, $Q(s, t)$,
Step 2. Forecast revenue profile, $R(s, t)$,
Step 3. Estimate abandonment time, $t_a(s)$,
Step 4. Estimate removal time, $t_r(s, P)$, and
Step 5. Estimate removal cost, $C(s, P)$.

<u>2.2.2. Production Model:</u> Hydrocarbon production profiles are generated using the iterative function,

$$Q(s, t + \alpha(s)) = (Q(s, t + \alpha(s) - 1) + \beta(s))\,[1 - d(s, t + \alpha(s))],$$

where $d(s, t)$ represents the decline parameter for structure s and time t selected from a Normal distribution with mean, $DEC(s)$, and standard deviation, σ_{DEC}. For structures that have already reached peak production, $\alpha(s) = \beta(s) = 0$; for structures that have not yet achieved peak production, $\alpha(s)$ and $\beta(s)$ are used to adjust the profile to the expected peak production time and rate. The values of $DEC(s)$, σ_{DEC}, $\alpha(s)$, and $\beta(s)$ are derived from historical data of structures that have previously been removed in the GOM.

2.2.3. Revenue Model: The gross revenue stream is determined from the relation,

$$R(s, t) = g(s)P(t)Q(s, t),$$

where the conversion factor, $g(s)$, depends on the gravity and sulfur content of oil and the amount of impurities, condensate, and hydrogen sulfide of natural gas. The hydrocarbon price, $P(t)$, is based on a reference benchmark determined from historical data and adjusted for inflation.

2.2.4. Abandonment Time: A structure is assumed to be abandoned when its economic limit is reached, that is, when the production or revenue stream of the structure converges to a threshold level that cannot sustain commercial operation:

$$t_{a,Q}(s) = \min\{t \mid Q(s,t) = \varepsilon_Q(s)\},$$

$$t_{a,R}(s) = \min\{t \mid R(s,t) = \varepsilon_R(s)\}.$$

The abandonment time, $t_{a,Q}(s)$, is associated with the production threshold level, $\varepsilon_Q(s)$; the abandonment time, $t_{a,R}(s)$, is associated with the revenue threshold level, $\varepsilon_R(s)$. Threshold levels are empirically derived measures and vary with characteristics such as water depth, structure type, hydrocarbon production, and the number of structures on the lease.

2.2.5. Removal Time: The time a structure is removed after its economic limit is reached is dependent on factors specific to the operator, time of operation, regulatory policy, and enforcement practices. If a structure exists on a lease with no other producing structures, then the structure is required to be removed within one year after production ceases unless special circumstances arise. If a structure exists on a lease with other producing infrastructure, then the structure may sit idle for a period of time before being removed (Kaiser, 2006). In the later case, operator preference and regulatory policy will play a determining role in the timing decision of removal.

The approach taken in this paper is to determine removal time according to rule-based policy alternatives, and to impose behavioral aspects on the regulatory models to capture operator preferences which are generally unobservable. The removal time of structure s is modeled as a real-valued function of the structure s and policy P:

$$t_r : s, P \rightarrow t_r(s, P).$$

In general terms, it is clear that policies that provide operators minimal flexibility will have better defined output characteristics (less uncertainty) than regulatory rules that are broad based or subject to interpretation. If a policy is broadly defined, operator preferences will have a greater impact on removal decisions and a stochastic element will be added to the model output. Operator preferences depend on factors which are unobservable and generally impossible to predict, because they involve a confluence of variables such as decommission schedules, vessel and equipment supply-demand conditions, strategic opportunities, etc. that are site- and time-specific.

2.2.6. Removal Cost: The cost to remove structure s at time $t_r(s,P)$ is determined as the present value of the removal cost,

$$C(s,P) = \frac{C(s)}{(1+d)^{t_r(s,P)-\tau}},$$

where $C(s)$ denotes the decommissioning cost of the structure; d is the discount rate, $0 < d < 1$; τ is the observation time; and $t_r(s,P)$ is the removal time. The decommissioning cost is described through empirically derived functions which are assumed constant over time (Kaiser and Pulsipher, 2005). Potential cost savings associated with scale economies are not considered, and since decommissioning is generally a low technology, low-margin operation, with no significant barriers to entry, technological progress is not expected to have a significant impact on future cost. Interest and inflation rates are variable, and if the interest rate exceeds inflation, structure removals may be delayed; otherwise, removing structures early may be preferred.

2.3. Regulatory Policy Alternatives

Five policies are modeled which encompasses the full spectrum of available regulatory options, from the latest possible removal under current federal regulations (Models I) to the earliest conceivable removal requirements (Model II), and various options bounded between these extremes: delayed early removals under deterministic criteria (Models III), delayed early removals under stochastic criteria (Model IV), and constrained early removal (Model V). A summary description of the models is presented in Table B.1.

2.3.1. Latest Possible Removal: Federal regulations currently require that all structures on a lease be removed within one year after production on the lease ceases. In Model (I), we exclude the possibility that idle structures will be removed earlier than required by law, and as such, construct a latest possible removal scenario.

If structures $\{s_1, \cdots, s_k\}$ exist on lease l and are held until production from the last structure ceases, then the time in which all the structures on the lease are removed is determined from the relation:

$$t_r(s_i) = \max_{i=1,\ldots,k}\{t_a(s_i)\} + 1,\ i = 1,\ldots,k;$$

e.g., if one structure exists on the lease, $s \in l$, then

$$t_r(s) = t_a(s) + 1,$$

while if two structures exist on the lease, $\{s_1, s_2\} \in l$, then

$$t_r(s_1) = t_r(s_2) = \max\{\, t_a(s_1), t_a(s_2)\} + 1\,,$$

and so on, for three or more structures.

A lease can "hold" structures idle without violating federal regulations as long as the lease remains producing. Operators may remove idle structures on producing leases early, and indeed, depending upon decommissioning schedules or other conditions, it may be economic for operators to remove idle iron, but these provisions are not considered in this formulation.

2.3.2. Earliest Feasible Removal: The most demanding regulatory framework is to require operators to remove structures one year after the structure ceases production without regard to the activity of the lease on which it resides. In this case, the removal decision rule for Model (II) is defined by

$$t_r(s_i) = t_a(s_i) + 1\,,\ i = 1,\ldots, k.$$

A structure is required to be removed one year after it ceases production, regardless of the nature of lease production. Model (II) denotes the earliest feasible removal scenario.

2.3.3. Delayed Early Removal – Deterministic: Regulations that require an operator to remove a structure within $m \geq 1$ years of last production relax the one-year specification of Model (II). The delayed early removal Model (III-m) is denoted by the decision rule:

$$t_r(s_i) \leq t_a(s_i) + m\,,\ \ i = 1,\ \ldots,\ k.$$

If the operator removes idle structures at the latest time permitted by regulation, then equality will hold in the above relation. Note that in this case Model (III-1) = Model (II). Federal regulations must still be enforced, however, to ensure that the removal does not violate the requirement that all structures be removed within one year after the lease on which it resides ceases production. The final decision rule is denoted:

$$t_r(s_i) = \min\{t_a(s_i) + m,\ \max_{i=1,\ldots,k}[t_a(s_i)] + 1\},\ \mathrm{m} \geq 1,\ i = 1,\ \ldots,\ k.$$

Model (III) denotes a delayed early removal scenario using a fixed time shift.

2.3.4. Delayed Early Removal – Stochastic: When a structure stops producing, it may sit idle until the lease on which it is located ceases production, or depending upon operator preferences and other circumstances, may be removed prior to the time lease production ceases. Operators may remove idle structures early if the structure is to be reused in another field development, or if savings from scale economies are expected to exceed the value of delaying removal. These conditions cannot be specified on an individual basis, however, and so aggregate probabilistic criteria applied across the set of all structures are used to capture the unobservable conditions.

The possibility that an idle structure will be removed early is incorporated within the model framework by introducing a probability of early removal. Let $p(s_i|x)$ denote the probability that structure s_i will be removed x years after the structure ceases production at $t_a(s_i)$. Since the structure has to be removed at some point in time between the time when the structure reaches its economic limit, $t_a(s_i)$, and the time the lease ceases production, $\max_{i=1,\ldots,k}\{t_a(s_i)+1\}$, it is clear that

$$\sum_{x=0}^{K} p(s_i\,|x) = 1,$$

where x takes the values $\{0,1,\ldots, K = \max_{i=1,\ldots,k}\{t_a(s_i)+1\} - t_a(s_i)\}$.

The value of $\{p(s_i|x),\ x = 0,\ldots, K\}$ is a complicated function that depends on a number of variables such as structure type, water depth, operator, number of structures on the leasehold, idle age, and time until lease abandonment. In theory, the value of the probability function can be derived empirically based on the historic removal record of structures, but the effort involved in computing the probability matrix is believed to far exceed the value derived from unproved model output. The probability function is thus postulated rather than derived empirically.

The final decision rule for Model (IV) is denoted

$$t_r(s_i) = \min\{\, t_a(s_i) + \widetilde{m},\ \max_{i=1,\ldots,k}[t_a(s_i)]+1\},\ i = 1,\ldots, k,$$

where the value of $\widetilde{m}$ is drawn from the set $\{0,1,\ldots, K\}$ with probability $\{p(s_i|0),\ p(s_i|1),\ldots, p(s_i|K)\}$. Model (IV) denotes a delayed early removal as in Model (III), but in place of a fixed time shift to induce structure removals, stochastic criteria is employed to determine the time of removal.

2.3.5. Constrained Early Removal: Removal requirements can also be "designed" in various ways based on conditions specific to the operator and lease. Let $\chi = \chi(l, t)$ represent a function that assigns to lease l at time t a real number that characterizes the lease; e.g., χ can denote the number of idle structures on the lease, the total idle age of the lease, etc. Let $\alpha(\chi)$ represent a positive integer and denote the set of idle structures on lease l at time t by $I(l, t) = \{s_i \in l \mid Q(s_i,t) = 0\}$. Denote t^* as the time χ first exceeds the trigger value $\alpha(\chi)$:

$$t^* = \min_{t}\{\, t|\ \chi \geq \alpha(\chi)\}.$$

The constrained early removal decision rule specifies that all the idle structures in the set $I(l, t^*)$ must be removed within m years from the time the trigger value is exceeded. Assuming that the operator will remove the idle structure set $I(l, t^*)$ at the latest possible time, structures in the set $I(l, t^*)$ will be removed at time $t^* + m$ unless federal requirements are violated. The removal time relation is determined as

$$t_r(s_i) = \min\{t^* + m,\ \max_{i=1,\ldots,k}[t_a(s_i)]+1\},\ \ s_i \in I(l,t^*).$$

Application of the removal relation is applied sequentially, and after the idle set is cleared, the lease is free of idle iron and the function χ is recalibrated. Probabilistic formulations of this model can be constructed by allowing *m* to be determined through a probability distribution or by allowing elements in the set $I(l, t^*)$ to be removed at discrete times.

2.4. Model Comparison

2.4.1. Model Statistics: The number of structures removed in year *t* under category Γ and policy *P* are denoted as $NR(\Gamma, P, t)$, with the time variable running from the observation year, $t = \tau$, until the year the last structure in Γ is removed, $t = T$:

$$NR(\Gamma, P) = (NR(\Gamma, P, \tau), NR(\Gamma, P, \tau+1), \cdots, NR(\Gamma, P, T)) .$$

Typical categorization levels may involve structure type, production type, water depth, planning area, and block type. $NR(\Gamma, P)$ is a random process with expected value and variance denoted by $E[NR(\Gamma, P)]$ and $VAR[NR(\Gamma, P)]$; e.g., for $\tau \le t \le x$,

$$E[NR(\Gamma, P)] = \frac{\sum_{t=\tau}^{x} NR(\Gamma, P, t)}{x - \tau} .$$

The idle age of structure s_i, $IA(s_i, t)$, depends on the time of observation relative to the abandonment and removal time:

$$IA(s_i, t) = \begin{cases} 0, t \le t_a(s_i) \\ t - t_a(s_i),\ t_a(s_i) < t \le t_r(s_i) \\ 0, t > t_r(s_i). \end{cases}$$

The present value of the removal operations under policy *P*, *P* = {I, II, …, V}, is denoted:

$$C(\Gamma, P) = \sum_{s \in \Gamma} C(s, P) = \sum_{s \in \Gamma} \frac{C(s)}{(1+d)^{t_r(s,P)-\tau}} .$$

Note that the total (undiscounted) cost to remove all the structures in category Γ is constant and does not depend upon the policy under consideration:

$$C(\Gamma) = \sum_{s \in \Gamma} C(s) ;$$

i.e., $C(\Gamma)$ is policy-invariant.

2.4.2. Limiting Cases – Model (I) and Model (II): The latest possible and earliest feasible removal models bound the system metrics for the five models considered. This is intuitively obvious since Model (I) concentrates structure removal in the last year of lease production, providing the operator the greatest flexibility and maximum amount of time in scheduling removals, whereas in Model (II), each structure is removed one year after production on the structure ceases, requiring an accelerated removal schedule and no opportunity to achieve scale economies.

The cumulative number of structures removed under Model (II) for $\tau \le t \le x < T$ will dominate the removed structures of Model (I):

$$\sum_{t=\tau}^{x} NR(\Gamma, \mathrm{II}, t) > \sum_{t=\tau}^{x} NR(\Gamma, \mathrm{I}, t).$$

Equality will hold in this relation when all the structures are removed from inventory. The cost of Model (II) will exceed the cost of Model (I) if discounting is applied:

$$C(\Gamma, \mathrm{I}) < C(\Gamma, \mathrm{II}).$$

In Model (I), the idle age of each structure is determined as $IA(s_i, t) = t - t_a(s_i)$, $t > t_a(s_i)$, until the lease ceases production at time $\max_{i=1,\ldots,k}\{t_a(s_i)\} + 1$. In Model (II), the idle age of structure s_i is simply

$$IA(s_i, t) = t_r(s_i) - t_a(s_i) = t_a(s_i) + 1 - t_a(s_i) = 1,\ i = 1, \ldots, k,$$

at time $t_a(s_i) + 1$, and zero otherwise; i.e.,

$$IA(s_i, t) = \begin{cases} 1, & t = t_a(s_i) + 1 \\ 0, & t \neq t_a(s_i) + 1. \end{cases}$$

2.4.3. Deterministic Generalization – Model (III): Model (III) generalizes the latest possible and earliest feasible removal models, and in the limit will transform into these formulations.

(i) For large m, $m \to \infty$,

$$t_a(s_i) + m \ge \max_{i=1,\ldots,k}\{t_a(s_i)\} + 1,$$

and so the latest possible removal relation will determine the removal time:

$$\lim_{m\to\infty} \text{Model (III - m)} \to \text{Model (I)}.$$

(ii) For small m, $m \to 1$,

$$t_a(s_i) + m < \max_{i=1,\ldots,k}\{t_a(s_i)\} + 1,$$

and the earliest feasible relation defines the removal time:

$$\lim_{m \to 1} \text{Model (III - m)} \to \text{Model (II)}.$$

(iii) For $1 < m < \infty$, the cumulative number of removals of Model (III-m) will dominate Model (I),

$$\sum_{t=\tau}^{x} NR(\Gamma, \text{II}, t) \geq \sum_{t=\tau}^{x} NR(\Gamma, \text{III-m}, t) \geq \sum_{t=\tau}^{x} NR(\Gamma, \text{I}, t),$$

for x = 1,2, …., while the removal cost relation will be ordered as follows:

$$C(\Gamma, \text{I}) < C(\Gamma, \text{III-m}) < C(\Gamma, \text{II}).$$

2.4.4. Stochastic Generalization – Model (IV): Model (IV) allows idle structures on a lease to be removed early in accord with operator preference. Model (IV) generalizes Model (III) by allowing the value of m to be a random variable drawn from the set $\{0,1,\ldots, K\}$ with probability $\{p(s_i|0), p(s_i|1),\ldots, p(s_i|K)\}$. The expected removal time of structure s_i is determined by

$$\text{E}[t_r(s_i)] = \sum_{x=0}^{K} p(s_i \mid x) \cdot [t_a(s_i) + x].$$

The relationship between Model (IV) and Model (III-m) depends on the value of m relative to the expected value of $\tilde{m}$, E[$\tilde{m}$],

$$\text{E}[\tilde{m}] = \sum_{x=0}^{K} x p(s_i \mid x);$$

e.g., if E[$\tilde{m}$] < m, we would suspect that

$$C(\Gamma, \text{I}) < C(\Gamma, \text{III-m}) < \text{E}[C(\Gamma, \text{IV})] < C(\Gamma, \text{II}),$$

while if E[$\tilde{m}$] > m,

$$C(\Gamma, \text{I}) < \text{E}[C(\Gamma, \text{IV})] < C(\Gamma, \text{III-m}) < C(\Gamma, \text{II}).$$

2.4.5. Complex Regulatory Policy – Model (V): Regulations that attempt to "manage" idle structures based on lease-specific conditions are too complicated and obtuse to work as viable policy alternatives, but modeling the various possibilities that can arise provide some insight into the system dynamics. In Model (V), a constrained early removal model is constructed for the functional χ and trigger level $\alpha(\chi)$. Recall that the trigger time t^* is defined by $t^* = \min_t\{t \mid \chi \geq \alpha(\chi)\}$. For $\alpha(\chi)$ small, the trigger will prompt early removal of idle set elements.

As $\alpha(\chi)$ increases, χ is less likely to exceed $\alpha(\chi)$, and in the limit as $\alpha(\chi) \to \infty$, Model (V) transforms into Model (I):

$$\lim_{\alpha(\chi)\to\infty} \text{Model (V)} \to \text{Model (I)}.$$

The choice of m, χ and $\alpha(\chi)$ impact the timing of removal, the magnitude of the cost metric, and related system measures.

It is easy to postulate and model more sophisticated regulatory alternatives, either through the construction of additional trigger functionals χ_i, i=1,…, n; through the selection of more complex timing schedules; e.g.,

$$t^* = \min\{t | \chi_i \geq \alpha(\chi_i), \text{ for any } i=1,\ldots, n\}, \quad t^* = \min\{t | \chi_i \geq \alpha(\chi_i), i=1,\ldots, n\};$$

or combinations thereof, but as previously described, such models are not practical alternatives. The manner in which regulatory alternatives can be developed remains primarily of interest from a pedagogical perspective.

2.5. Illustrative Example

2.5.1. Model Scenario: Policy P determines the manner in which idle structures are removed from a lease, and subsequently, the number of idle structures at any point in time, their idle age, active age, removal cost, and related system metrics. Consider a lease with three structures $\{s_1, s_2, s_3\}$ installed in 1985, 1993, and 1987, respectively, and which are expected to achieve last production in $t_a(s_1)$ = 2007, $t_a(s_2)$ = 2009, and $t_a(s_3)$ = 2015. The cost of decommissioning for each structure is estimated to be $C(s_1)$ = \$500,000, $C(s_2)$ = \$200,000, and $C(s_3)$ = \$1,300,000.

2.5.2. Output Statistics: For each structure s, the output statistics computed include the structure age ($A(s, t)$), active age ($AA(s, t)$), and idle age ($IA(s, t)$), at time t. The age of a structure is the difference between the observation year and the year of installation, and coincides with the active age until production on the structure stops. Idle age is the time between the observation year and the year of last production. The cost to decommission structure s is denoted as $C(s)$, and the present value of the cost under policy P and discount rate d, $0 < d < 1$, is denoted $C(s, P)$. Lease statistics include the age ($A(l, t)$), active age ($AA(l, t)$), and idle age ($IA(l, t)$); number of active structures on a lease, $NA(l, t)$; number of idle structures ($NI(l, t)$); number of structures ($NS(l, t)$); number of structures removed ($NR(l, t)$); and present value of the total removal cost,

$$C(l, P) = \sum_{s \in l} C(s, P).$$

2.5.3. Latest Possible Removal Model: In Model (I), operators remove all idle structures one year after production on the lease ceases. As each structure reaches its economic limit, it will be abandoned and held idle on the producing lease. The number of idle structures on the lease will increase until the last structure on the lease ceases production (Table B.2). Structure removal time is defined by

$$t_r(s_1, \text{I}) = t_r(s_2, \text{I}) = t_r(s_3, \text{I}) = \max_{i=1,\ldots,k}\{t_a(s_i)\} + 1 = 2016,$$

and the removal vector is denoted

$$NR(l, \text{I}) = (0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 3),$$

where the elements of $NR(l, \text{I})$ are defined sequentially with the first component referenced with respect to the year 2004.

The age, active age, and idle age is shown on a structure and lease basis in the fifth, sixth, and seventh column, respectively. In 2004, the structure age $A(s_1, 2004) = 19$, $A(s_2, 2004) = 11$, $A(s_3, 2004) = 17$, and the lease active age is $A(l, 2004) = A(s_1, 2004) + A(s_2, 2004) + A(s_3, 2004) = 47$.

Idle structures are not removed early, and so the idle age statistics will be increasing functions of time across all categorization levels. The average number of idle structures on the lease over the time horizon of production is

$$\overline{NI}(l, \text{I}) = \frac{\sum_{s \in l} \sum_{t=2004}^{2016} NI(s,t)}{2016 - 2004} = 1.4,$$

indicating that through the year 2016, 1.4 idle structures on average exist on the lease in any given year. The age and idle age of the lease is maximum at the end of the lease life cycle:

$$\max_t A(l, t) = A(l, T), \quad \max_t IA(l, t) = IA(l, T).$$

The present value of the cost of decommissioning under Model (I) is computed as

$$C(l, \text{I}) = \frac{\$2{,}000{,}000}{(1+d)^{12}};$$

and for $d = 10\%$, $C(l, \text{I}) = \$637{,}262$.

2.5.4. Earliest Feasible Removal Model: In Model (II), idle structures are removed one year after they cease production. Idle iron cannot accumulate, however, since structures are removed immediately after production ceases, and so the idle age statistics and average metrics are zero, or nearly zero, depending upon the formulation of the idle age metric (Table B.3). The structure removal vector is denoted

$$NR(l, \text{II}) = (0, 0, 0, 0, 1, 0, 1, 0, 0, 0, 0, 0, 1),$$

which induces the decommissioning cost expression:

$$C(l, \text{II}) = \frac{\$500{,}000}{(1+d)^4} + \frac{\$200{,}000}{(1+d)^6} + \frac{\$1{,}300{,}000}{(1+d)^{12}}.$$

For d = 10%, $C(l$, II) = \$868,620 > \$637,262 = $C(l$, I). The average number of idle structures on the lease over the production time horizon is $\overline{NI}\,(l$, II) = 0.25.

2.5.5. Delayed Early Removal – Deterministic Model: In Model (III-m), idle structures are removed m years after they cease production as long as the federal regulations on latest removal are not violated. Delaying removal allows idle structures on the lease to accumulate. If m = 5, then $t_r(s_1$, III-5) = $t_r(s_1$, II) + 5 = 2013, $t_r(s_2$, III-5) = $t_r(s_2$, II) + 5 = 2015, and $t_r(s_3$, III-5) = $t_r(s_3$, II) = 2016. The shift operator impacts system metrics in a nonlinear fashion, and so the lease idle age is not necessarily an increasing function of time (Table B.4). The structure removal vector yields:

$$NR(l, \text{III-5}) = (0, 0, 0, 0, 0, 0, 0, 0, 0, 1, 0, 1, 1),$$

inducing the removal cost,

$$C(l, \text{III-5}) = \frac{\$500{,}000}{(1+d)^9} + \frac{\$200{,}000}{(1+d)^{11}} + \frac{\$1{,}300{,}000}{(1+d)^{12}};$$

and at d = 10%, $C(l$, III-5) = \$696,368. Also, $\overline{NI}\,(l$, III-5) = 1.2. Note that $C(l$, I) < $C(l$, III-5) < $C(l$, II) and $\overline{NI}\,(l$, II) < $\overline{NI}\,(l$, III-5) < $\overline{NI}\,(l$, I).

2.5.6. Delayed Early Removal – Stochastic Model: In Model (IV), each idle structure has a probability of early removal defined by $p(s_i|x)$, x = 0,…, K, where K denotes the time between lease abandonment and the year the structure ceases production. Structure s_1 is expected to be abandoned in 2007, and eight years hence the lease is expected to cease production. Associated with s_1 is a discrete probability function that characterizes early removal, which for illustrative purposes, is assumed to be given by:

$$\{p\,(s_1|0)\,, p\,(s_1|1), \ldots, p(s_1|8)\} = \{0.02, 0.05, 0.05, 0.07, 0.08, 0.08, 0.20, 0.45\}.$$

Structure s_2 is abandoned in 2009 and in 2015 the lease will cease production. Associated with s_2 is the probability distribution:

$$\{p(s_2|0)\,, p\,(s_2|1), \ldots, p(s_2|6)\} = \{0.083, 0.083, 0.083, 0.125, 0.25, 0.375\}.$$

Removal times are defined in a probabilistic manner, and so the system metrics are stochastic and need to be computed through simulation, using the removal policy and probability functionals to compute the expected values, such as E[$C(l$, IV)] and E[$\overline{NI}\,(l$, IV)]. One possible realization of Model (IV) is shown in Table B.5, where s_1 is removed in 2010, and s_2 and s_3 are removed in 2016. The structure removal vector is

$$NR(l, \text{IV}) = (0, 0, 0, 0, 0, 0, 1, 0, 0, 0, 0, 0, 2),$$

which induces the removal cost,

$$C(l,\,\text{IV}) = \frac{\$500{,}000}{(1+d)^6} + \frac{\$1{,}500{,}000}{(1+d)^{12}}\,.$$

At d = 10%, $C(l$, IV) = \$760,183 and $\overline{NI}$ (l, IV) = 1.0.

2.5.7. Constrained Early Removal Model: In Model (V), idle structures are removed after specific lease conditions are triggered. The definition of the lease condition(s) χ, $\alpha(\chi)$, and m are user-defined. For illustration, let the functional $\chi = IA(l, t)$, the trigger level $\alpha(\chi) = 10$, and the shift parameter $m = 2$. In Table B.6, the lease idle age column represents χ, and in the year 2013, $IA(l, 2013) = 10$, triggering the removal of all idle structures in the set $I(l, 2013)$; i.e., s_1 and s_2 are required to be removed in the year 2015, two years after the lease idle age reached 10 years. The structure removal vector is denoted as

$$NR(l,\,\text{V}) = (0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 0, 2, 1),$$

which induces the removal cost,

$$C(l,\,\text{V}) = \frac{\$700{,}000}{(1+d)^{11}} + \frac{\$1{,}300{,}000}{(1+d)^{12}}\,.$$

For d = 10%, $C(l$, V) = \$659,566 and $\overline{NI}$ (l, V) = 1.1. The ordering

$$C(l,\,\text{I}) < C(l,\,\text{V}) < C(l,\,\text{III-5}) < C(l,\,\text{II}),$$
$$NI(l,\,\text{II}) < NI(l,\,\text{V}) < NI(l,\,\text{III-5}) < NI(l,\,\text{I}),$$

arises from the specification of the model parameters $\{\chi = IA(l, t), \alpha(\chi) = 10, m = 2\}$. Any changes in the function formulation or threshold levels will impact the system metrics and relative ordering.

2.6. Model Parameterization

2.6.1. Initialization: At the end of 2003, the GOM contained over 1,356 active leases and 273 inactive leases. On active leases, there were 898 idle structures, while on inactive leases, there were 329 idle and 65 auxiliary structures (Table B.7). Structures on inactive leases form an inventory that is expected to be removed in the near future unless they serve a useful economic purpose or other special circumstances apply. Inactive lease structures are excluded in the forecast that follows. Further, the 440 auxiliary structures on active leases are assumed to be removed when production on the lease on which they reside ceases. This is believed to be a reasonable assumption, but one which cannot be fully justified due to a lack of additional information. The remaining 2,175 active structures and 898 idle structures are removed according to the policy P = {I, II, III, IV}. Model (V) was not implemented.

2.6.2. Production Model: For each producing structure in the GOM, the decline parameter, $d(s, t)$, is sampled annually from the Normal distribution, N($DEC(s)$, σ_{DEC}), to forecast the production profile. The value of $DEC(s)$ is computed through various empirical relations derived from historic rates of production decline:

$$DEC(s) = -14.8 - 0.035ST - 0.019GORV - 0.0104NW + 0.0017O/G + 0.00771VINT,$$

where ST = structure type (ST = 0, caisson; ST = 1, otherwise), $GORV$ = gas-oil ratio variation, NW = number of wells, O/G = oil/gas structure (O/G = 0, oil; O/G = 1, gas), and $VINT$ = vintage (year structure installed). The values of σ_{DEC}, $\alpha(s)$, and $\beta(s)$ are estimated from historical data.

2.6.3. Revenue Model: The quality and sulfur content of the hydrocarbon stream is field and time dependent, and although the MMS collects field data on API gravity, the correlation between gravity and sulfur content is weak, and so a quality-adjusted hydrocarbon price is believed not to contribute significantly to the reliability of price forecasting. Using netback values to account for the pipeline transportation cost would further refine the revenue model, but this was not pursued.

2.6.4. Abandonment Time: A structure is abandoned when the production and revenue profile converges to the threshold level (i.e., economic limit) of the structure. Threshold levels vary with numerous interacting factors, including water depth, structure type, operator size, production level, and number of structures on the lease. By examining the characteristics of structures that have been removed near the time of their abandonment, historical values can be used to guide and predict future levels. In Table B.8, summary data of threshold levels are presented which were applied in the analysis. Observe that threshold levels generally increase with water depth and structure type and depend whether oil or gas is being produced. Economies of scale are also frequently present, so that thresholds tend to be slightly lower on average if more than one producing structure exists on a lease; e.g., structures that exist on leases with no other infrastructure at the time of removal (lease category I) exhibit an average annual production and revenue threshold of 57,000 BOE and $734,000; for leases with more than one producing structure at the time of removal (lease category II), the average production and revenue thresholds are 33,000 BOE and $423,000.

2.6.5. Decommissioning Cost: The total cost to decommission a structure is decomposed according to three cost categories – plugging and abandonment ($C_1(s)$), structure removal ($C_2(s)$), and site clearance and verification ($C_3(s)$). Functional expressions for each cost component are derived based on survey data collected from operations in the Gulf of Mexico. Representative values from (Kaiser, 2006) follow:

$C_1(s)$ = \$150,000/well,
$C_2(s)$ = \$506.9 + 579.1ST – 0.24WD – 262.5$REEF$ + 53.1CF,
$C_3(s)$ = \$1,061+ 66WD + 17,752ST + 405AGE +8,919G,

where WD = water depth (in feet), ST = structure type (ST = 0, caisson; ST = 1, otherwise), $REEF$ = reefing option ($REEF$ = 0, structure not reefed; $REEF$ = 1, structure reefed), CF =

complexity factor (unitless), AGE = age upon removal (in years), G = Gorilla net application (G = 0, Gorilla net not applied; G = 1, Gorilla net applied). The complexity factor is defined as the total number of piles and wells associated with the structure. $C_2(s)$ needs to be scaled by a factor of 1,000. The reefing option is considered a random variable that depends upon water depth and planning area. Application of the Gorilla net is assumed to occur in 1-in-4 site clearance and verification operations.

2.6.6. User-Defined Parameters: There are no user-defined parameters in Models (I) and (II), since the regulatory policies are defined entirely through rule-based mechanisms. Model (III-m) admits a one-dimensional parameterization through the integer variable *m*. In Model (IV), the probability of early removal is defined by distributing 25% of the probability weight equally across each year of the first-half of the time horizon defined by *K*, and 75% of the probability to the second-half of the time horizon in a uniformly increasing manner, defined by

$$p(s \mid x) = \begin{cases} \dfrac{0.25}{\left\lceil \frac{K+1}{2} \right\rceil} & \text{if } x < \left\lceil \dfrac{K+1}{2} \right\rceil \\ \left(x - \left\lfloor \dfrac{K}{2} \right\rfloor \right) \left(\dfrac{1.5}{\left\lfloor \frac{K+1}{2} \right\rfloor \left(\left\lfloor \frac{K+1}{2} \right\rfloor + 1 \right)} \right) & \text{if } x \geq \left\lceil \dfrac{K+1}{2} \right\rceil \end{cases}$$

e.g., for K = 5, $\{p(s|0), \ldots, p(s|5)\} = \{\frac{0.25}{3}, \frac{0.25}{3}, \frac{0.25}{3}, 0.125, 0.25, 0.375\}$. As mentioned previously, empirical expressions for the probability can be derived based on historic data, but for the present study specification of $p(s_i|x)$ was hypothesized.

2.7. Model Results and Limitations

The number of structures expected to be removed in the Central GOM (CGOM) according to Model (I) and Model (II) is computed using the revenue threshold data and the parameterization specified in Section 2.6. In Model I (Figure B.1), structures are removed one year after production on the lease ceases, while in Model II (Figure B.2), operators are required to remove structures one year after the structure ceases production. These two model outputs bound the regulatory options, representing a latest possible removal (Model 1) and an early removal scenario (Model II).

The total cost to decommission the current inventory of shallow water structures in the CGOM is estimated at $5.2 billion. The net present value of the total cost using a 10% discount factor is computed to range between $2.4 billion (Model I) and $2.8 billion (Model II). See Figure B.3.

In Figure B.4, the number of idle structures is compared under the two model scenarios, while in Figure B.5, the total idle age of the inventory is depicted. The number of idle structures in Model I dominates the Model II inventory due to the regulatory specification described. The total idle age is a composite statistic that reflects the total age of structures in inventory under the different regulatory guidelines.

In Table B.9, Model (III-*m*) structure forecasts are depicted as a function of the index *m*. As *m* increases, the net present value of decommissioning will decrease, from \$2.72 billion (m = 2) to \$2.47 billion (m = 5) to \$2.40 billion (m = 9). As *m* increases, the net present value of the decommissioning cost and the removal forecast of Model (III-*m*) converge to Model (I).

Model (IV) structure removal forecast and valuation is shown in Table B.9 in the last column. In this case, each idle structure has a probability of early removal which acts to "average" the lagged forecast in accord with the hypothesized probability function. The removal forecast and decommissioning cost fall between the values depicted in the table, as expected.

The operating environment in the GOM is modeled based upon the assumptions and parameterizations employed. The model output is the most useful when used in a comparative assessment, between the various regulatory proposals, rather than as an absolute indicator of removal trends. Since we are modeling the variation that is expected to occur in removing the current structure inventory under various regulatory frameworks, and as such, we do not consider structures to be installed in the future. Further, we are concerned primarily with structures that exist in 400 ft water depth or less, and do not account for the decommissioning cost of deepwater facilities. We also do not consider the impact of extreme events (e.g., hurricanes) upon removal trends, although in theory, this would be easy to adjust. Only private removal costs are considered. The social costs and benefits associated with different regulatory alternatives is a potential area of future research. As with any forecast model, the output should be viewed as the expected outcome as opposed to the actual (realized) results. A number of uncertainties associated with the model parameters may influence the model results.

CHAPTER 3: SCRAP AND STORAGE MARKETS FOR OFFSHORE STRUCTURES IN THE GULF OF MEXICO

3.1. Introduction

The origin of offshore drilling can be traced to Summerland, California, in the late 19^{th} century. Henry Williams noticed that the most prolific wells of an onshore drilling boom occurred along the coast line, and he surmised that the play extended offshore. Eleven wooden piers were constructed to extend the land operation over water, and by 1897, 20 derricks were drilling 500 ft from the shore in 35 ft water depth (Graff, 1981).

Following the end of the Second World War, companies began to explore new frontiers in their search for oil and gas (Pratt et al., 1997; Veldman and Lagers, 1997). The continental shelves surrounding the world's land masses had always been regarded as potentially rich in hydrocarbon reserves, and an increasing world demand stimulated companies to explore in progressively deeper waters. Kerr-McGee drilled the first well beyond the sight of land at the Ship Shoal block 32 discovery in 1947 in 18 ft of water, ten miles from the Louisiana coastline. By 1972, wells were being drilled in 1,000 ft water depth, while today, the water depth record for drilling currently stands at 10,011 ft.

When an operator determines that a facility will be decommissioned, removal options and various disposal and reuse alternatives are compared as part of the overall assessment. The basic idea is to maximize the value of the waste stream by reducing the structure according to a generally accepted disposal hierarchy: refurbish and reuse, scrap and recycle, dispose in a designated landfill. In practice, a combination of methods is employed.

A significant number of structures in the GOM are maintained (stored) on producing leases as "idle iron". A structure that no longer produces may be maintained on a lease as long as the lease continues to produce. It has been estimated that approximately 1-in-3 structures in the GOM exist as idle iron (Kaiser and Mesyanzhinov, 2004). At the end of the producing life of a lease, when the lease production ceases, all[5] the structures on the lease will be decommissioned and removed. Typically, the structures are removed to shore for storage, refurbishment and recycling, but structures may also be reefed – either voluntarily or by acts of nature (hurricanes, explosions) – to provide habitat for marine life or as destinations for recreational diving and fishing.

The purpose of this chapter is to review the scrap markets in the GOM associated with the offshore industry. Very little has been written about the scrap industry related to the oil and gas industry, and thus, we aim to provide a general perspective on the topic. We begin with a general description of the U.S. scrap steel market and then focus discussion on the Gulf of Mexico. The design requirements of offshore infrastructure are briefly reviewed, followed by a description of the stages of decommissioning that generate waste product. Typical component pathways for the main elements of offshore structures are outlined. Storage and scrap markets are described, and general industry characteristics, inventory dynamics, scrap operations, and factors that influence

[5] Unless special circumstances hold. For example, if the operator is pursuing drilling activity on the lease or an adjacent lease, or an active pipeline crosses the lease, then conditions may warrant an extension of the lease termination. These conditions do not occur frequently.

competitiveness are reviewed. We conclude the chapter by developing conceptual economic models to provide insight into the financial criteria and strategic factors that play a role in decision making.

3.2. U.S. Scrap Steel Market

3.2.1. Scrap Metal Classification: Scrap metal is any primary metal (such as iron, copper, aluminum, lead) or alloy (steel, brass, bronze, tin) that has been used and then recovered for reprocessing and subsequent reuse (Hess et al., 2001). All metals are classified as either ferrous or nonferrous. The main element of a ferrous metal is iron, and metal is ferrous if it contains more iron than any other metal. Scrap iron, steel, and various steel alloys are ferrous metals. Automobiles, farm and rig equipment, household appliances, beams, pipes, platforms, and ships are primarily composed of ferrous metals. A metal is nonferrous if it contains less iron than any other metal (USDT, IRS, 1999).

Scrap metal is also characterized by how it is created. Home scrap is generated at the mill, refinery, or foundry where it was created, and is generally remelted and reused at the same plant. Industrial plants are the source of prompt (industrial) scrap. Obsolete scrap is created from discarded objects like automobiles and appliances. Offshore platforms, rigs, oil tankers, and Navy vessels that have been decommissioned and are no longer in use are examples of obsolete scrap.

3.2.2. Steel Scrap Life Cycle: After iron ore is extracted from the ground, it is shipped to a mill where it is made into different forms. The steel is then shipped to a buyer to be fabricated, and eventually, assembled in various products. During fabrication and at the end of the steel product's useful life, scrap metal is produced (Figure C.1). A purchaser and seller transact and the obsolete product enters the recycling system. After processing the scrap metal, the scrap processor will sell the processed scrap to a mill or foundry that will use the metal to make new products.

3.2.3. Supply, Demand, Stock Levels: The United States is the world's largest producer of scrap steel. In 2005, the domestic steel industry recycled about 67 million metric tons (mt) of scrap iron and steel in the form of appliances, automobiles, cans, construction materials, and other steel products (Table C.1). Forty-nine percent of recycled scrap was obsolete scrap, 26% prompt scrap, and 25% home scrap. The primary source of obsolete steel is the automobile, of which 14 million mt was recovered and recycled in 2005, representing a recycling rate[6] of 102%. About 3 million mt of steel was recovered from appliances. The total value of domestic purchases and exports in 2005 was estimated to be $12.6 billion (Fenton, 2006). Manufacturers of pig iron, raw steel, and steel castings accounted for 87% of scrap consumption.

Iron and steel scrap supply and consumption levels for the Gulf Coast region is shown in Table C.2 and Table C.3. Consumer stocks of iron and scrap steel on December 31, 2004, are shown in Table C.4. Recycled iron and steel scrap is an important raw material for the production of new

[6] A recycling rate greater than 100% indicates that the steel industry recycled more steel from automobiles than was used in the domestic production of new vehicles.

steel and cast iron products, and plays an important role in conservation because remelting scrap requires significantly less energy than the production of iron or steel products from iron ore.

3.2.4. Imports and Exports: The U.S. exported 11,800 thousand mt of iron and steel scrap in 2004, at an estimated value of $2.9 billion, up from 10,800 thousand mt in 2003 and an estimated value of $1.9 billion. The primary export countries were China (25%), Canada (18%), South Korea (16%), Mexico (13%), Thailand (6%), and Turkey (6%). The top four export centers for iron and steel scrap was New York (19%), San Francisco (10%), Boston (6%), and Seattle (5%). Several Gulf Coast cities export iron and steep scrap, but at considerably smaller levels: Tampa (4%), Laredo (3%), and New Orleans (3%); Miami, Houston, Galveston, and El Paso each had less than 1% of the total export tonnage (USGS, 2005). The U.S. imported 4,660 thousand mt of iron and steel scrap in 2004, primarily from Canada and the U.K., and arriving through Detroit (26%), Charleston (24%), and New Orleans (16%).

3.2.5. Scrap Metal Prices: Market prices for steel scrap vary depending on the organization that performs the assessment. The most common grade is No. 1 heavy melting scrap, defined by the Institute of Scrap Recycling Industries (ISRI) as wrought iron and steel scrap that is at least ¼ inch thick with individual pieces no larger than 5 ft by 24 inches. The most common market price for scrap is established by the American Metal Market, which lists the consumer buying prices of 25 different grades in 12 U.S. cities (Birmingham, Carolinas, Chicago, Cleveland, Detroit, Houston, New York, Philadelphia, Pittsburgh, Seattle/Portland, St Louis, Youngstown) and two Canadian regions (Hamilton, Montreal). The prices are collated through contact with producers, traders, purchasers, and are meant to represent an approximate evaluation based on current dealings. Recycler's World uses the average prices of mixed scrap iron and steel, while Intermet uses scrap brokers in 11 U.S. cities to determine market price. Iron Age and Scrap Price Bulletin and MSA are additional sources of price data.

Over the past five years, the annual average price for No. 1 heavy melting scrap for sales at Pittsburgh, Philadelphia, and Chicago has ranged between $74 and $205 per ton (Figure C.2), with significant monthly variations (Figure C.3). Transaction prices reflect quantities, grades and qualities, credit terms, and many other parameters.

3.2.6. Price Factors: Scrap steel is a commodity, and as with all commodities, price is determined by the intersection of supply and demand curves and adjusted for various additional factors, such as steel price, the scrap class of the metal, the location the scrap is traded, exchange rates, purchase agreements, inventory levels, import-export balance, and local capacity constraints.

Supply and Demand

The main factor in determining scrap steel prices is supply and demand. The majority of scrap iron and steel available in the U.S. is from industrial and construction scrap, generated from sheet metal and car bodies, plate and shape accumulated from industrial scrap, or miscellaneous material such as engine blocks and other forged and cast items. Ships, offshore structures, rigs, and other vessels make a contribution to supply quantities, but relative to total production and other scrap sources, are estimated to contribute less than 5% total supply. In regional markets such as the Gulf Coast, offshore structures and vessels play a somewhat larger role in scrap supplies, but are still considered marginal.

Demand for scrap steel depends on economic activity and the needs of local industry, reflected through the steel and foundry industries[7] which are the primary users of recycle scrap. Foundries require a particular quantity of ferrous scrap regardless of price fluctuations. When more scrap is available, prices tend to drop to encourage foundries to buy more than their usual stock, but as specific grades become scarce, dealers increase prices because they have to pay more for the supply. As scrap steels prices rise, it is a good indication[8] that manufacturing demand is rising and the economy is picking up. Steel scrap is exported when netback prices exceed domestic prices.

Scrap Class

More than 100 classes of ferrous scrap are defined based on size and thickness, material preparation, the source of the steel, and other factors (Table C.5). The formal codification of scrap specifications began in 1926 under the U.S. Department of Commerce, and has been revised several times over the years to conform to the needs of consumers and suppliers. Common classes include No. 1 heavy melt scrap, a grade that includes old appliances and flattened cars, and No. 2 heavy melting steel, which has a minimum thickness of 1/4 inch and a maximum size of 5 feet by 18 inches. Mini-mills favor a scrap called No. 1 busheling, which is black and/or galvanized steel scrap not exceeding 12 inches in any dimension.

Each foundry has its own grade specifications with respect to environmental materials, size, density, and other factors. Different grades of scrap work better in various types of furnaces. Cupolas for example can accept a wide range of scrap grades, including obsolete scrap. Coreless induction methods are restricted to prompt scrap because of its smaller size and cleaner properties. All material must be free of dirt, nonferrous metals, foreign material, and excessive rust and corrosion.

A "typical" offshore platform will contain anywhere from 50-70% plate and structural steel, 20-40% No. 1 and No. 2 heavy melting scrap, 5-10% nonferrous metal, and 5% or less piping.

Steel Prices

Scrap steel prices generally follow standard grade steel, which is determined by iron ore and coke prices and labor cost, and tends to follow business cycles. If there is a downturn in standard grade prices, then this usually results in scrap famines, because scrap merchants who bought in high do not want to sell low and take a loss. Scrap merchants will hold onto their stocks in storage until base prices improve.

[7] Over the past two decades, the U.S. iron and steel industry has not added significant capacity, shifting from blast furnace operations, which process iron ore, to electric furnaces and mini-mills, whose feedstock is scrap.
[8] The price of No. 1 heavy melt scrap is one of Alan Greenspan's favorite economic indicators.

Delivery Method and Quantity

The price of scrap depends on whether the scrap is delivered to a broker or directly to a mill or foundry. Scrap delivered to a mill in many ton lots will bring a higher price than delivering to the yard of a broker or exporter on a piecemeal basis.

Location

The price of scrap steel varies within the U.S. on a regional basis and depends on the city in which the scrap is traded and the cities proximity to the mills in which the scrap is processed. Scrap delivered to Pittsburgh, Philadelphia, and Chicago mills will generally command a higher price than scrap delivered to Seattle or Houston, as illustrated in Table C.6. Access to cheap barge and rail transportation also impacts price differentials.

3.2.7. Transportation: Truck, rail, and barge are common means of transportation, with barges probably the most often used for transporting scrap and steel products (Broughton, 2001). River-transportation is generally the most fuel-efficient means to transport scrap, since large volumes can be shipped in one unit[9] at one time. Transportation of material is a significant cost for both scrap processors and steel mills. Historically, steel mills were located on the Great Lakes or close to sources of coal. Today, mini-mills and scrap yards are geographically dispersed along river systems to realize scale economies in transportation.

3.2.8. Industry Structure: The top 20 ferrous and nonferrous scrap processors in the U.S. are ranked in Table C.7. The ranking is based on industry surveys of scrap volumes processed, and as common throughout the industry, data transparency is an issue. Observe that scrap volumes or yard capacity are not provided. This is because scrap volumes provide a rough indicator of revenue and market position, which in the scrap business, is carefully guarded information.

Most scrap processors are privately (closely) held and trace their roots to small business origins. As companies grow, they may acquire facilities in or adjacent to regional markets, and then consolidate through corporate mergers. Hugo Neu is considered the single largest exporter and importer of scrap metal in the United States. Simsmetal America is the only scrap processor owned by an overseas holding company.

The majority of scrap processors are located in the manufacturing regions of the U.S., especially in the Midwest, where there is access to a steady supply of scrap from the automobile industry. Many yards throughout Indiana, Michigan, and Pennsylvania take advantage of strategic partnerships with steel mills. Three Gulf Coast companies are in the top 20 scrap processors: Commercial Metals (TX), Southern Scrap Recycling (LA), and TXI Chaparral (TX).

The scrap business is generally considered a marginal and risky play. Companies seem to go in and out of bankruptcy proceedings and frequently open/close yards with changes in the business cycle, fluctuations in the commodity price and scrap supply, and other factors (Guegel, 2004; Marley, 2006). The success of the companies that stay in business is difficult to gauge because of the lack of transparency and public shareholder reporting. Several companies have diversified

[9] The typical capacity of a barge is 1,500-1,700 tons, compared to 100 tons for a railcar, and 26 tons for a truck.

operations and provide services beyond handling, such as slag processing, brokering, smelter and mini-mill operations, rebar fabrication, etc., which complicates isolating the scrap processing aspects of the business.

3.3. Offshore Infrastructure

3.3.1. Design Requirements: Development schemes for offshore oil and gas vary widely across the world, and even in different areas within the same region, depending upon the size, shape, depth, and productivity of the reservoirs; the time of development; logistical considerations in moving the production to market, strategic decisions of operators; and the lead time required to acquire or design and construct structures, rigs, production facilities, pipelines, and other downstream facilities.

The general design requirements for an offshore structure are similar to any industrial facility (Graff, 1981; Gerwick, 2000; Mather, 2000). The first step is to develop a conceptual model based on its functional requirements, environmental constraints, and method of construction. The primary function of an offshore structure is to provide a secure working platform to support a specific operation in a hostile and dangerous environment. The basic requirements of a structure are to withstand all loads during fabrication, transportation, and installation; to withstand loads resulting from severe storms and hurricane events; and to function safely relative to its requirements.

3.3.2. Structure Components: Offshore structures in the GOM in water depths less than 1,000 ft consist of three main elements:

- A tubular steel structure, called the template or jacket, which extends from the seafloor to above the waterline and is used to support the deck and topsides equipment;
- Steel pipe piling driven through the jacket legs into the seafloor to provide the platform foundation; and
- One or more deck sections placed on top of the jacket to hold the drilling and processing equipment, heliport, quarters, and related infrastructure.

In addition to these three basic elements, offshore structures may also contain, depending on the function of the structure:

- Conductors, which are used to conduct the oil and gas to the surface;
- Topsides equipment, such as compressors, cranes, drills, heat exchangers, power generation units, pumps, separators, scrubbers, tanks, etc.; and
- Bottomsides equipment, such as cable, manifolds, pipelines, flowlines, risers, umbilicals, wellheads, etc.

The facilities for drilling and production operations, often called the topsides, define the function of the structure. The support substructure and foundation defines the platform type.

3.3.3. Removal Trends: The removal trends of oil and gas structures are shown in Figure A.1. Caissons are the simplest offshore structure and are just a big pipe driven into the ground to protect the well. Well protectors and fixed platforms are jacket structures that provide a protective layer around the conductors and a deck area to support the topsides equipment and processing facilities. Fixed platforms comprise slightly more than half of the 3,922 GOM structures (as of March 2005). Most of the offshore infrastructure removed to date has been simple structures, such as caissons and well protectors in shallow waters, and roughly speaking, for every major structure decommissioned two nonmajor structures have been removed. The number and type of structures removed vary considerably from year-to-year. Over the past decade, the number of structures removed has ranged from a low of 68 to a high of 188, and this range continues to serve as a good indicator on the bounds of decommissioning activity expected in the future.

3.3.4. Buying and Selling: Offshore structures may be purchased by yards for refurbishment, salvage companies for scrapping, or by speculators who act as intermediaries, buying the jacket and/or deck for cash, holding it in storage, and then waiting for the market to cycle to resell the unit at a premium, either for refurbishment or scrap. Sales are usually handled by a broker, who keeps records of recent sales and, because they are in the market, they know who is buying at any point in time. Brokers provide liquidity to the market by taking positions or bringing buyer and seller together. Brokers do not readily divulge "market information," however, since a transparent flow of information will likely act to reduce their margins and market power.

Rigs and ships trade in the international market, where the final buyers are the demolition and refurbishment yards located throughout the world. Platform and offshore support vessels trade in local markets, since the structures generally do not provide sufficient economies to allow international breakers to compete after the cost of transportation is included in the assessment. Nearly all large ships in the world (commercial and military) are broken in international yards in China, India, and Bangladesh, while local markets exist to handle smaller vessels and offshore structures.

Prices are determined by negotiation and depend on the market price, local demand for scrap metal, availability of scrapping facilities, and other factors. When scrap arrives at site, the scale operator weighs the scrap and creates a cash slip/weight ticket, identifying the type of metal, total weight, price per pound, total amount to be paid, and the name of the individual/business selling the scrap. Guidelines for scrap metal transactions followed by industry are outlined in ISRI *Scrap Specifications Circular 2001, Guidelines for Metals Transactions*.

Purchasers of scrap metal include foundries, mills, mini-mills, brokers, peddlers, and scrap processors (USDT, IRS, 1999). Scrap processors (also known as dealers or recyclers) collect, sort, process, store, and eventually sell the scrap metal to foundries, mills, mini-mills, and other purchasers. A scrap peddler is usually a sole proprietorship that purchases scrap metal and resells it to the scrap processor. A peddler is different from a processor because he does not process or store the scrap metal, merely transporting the scrap from the seller to buyer. Brokers act as the agent or intermediary for others in negotiating contracts, purchases or sale.

3.4. Stages of Decommissioning

Different government bodies regulate the decommissioning and abandonment of offshore structures. State agencies are responsible for structures located in state waters, while the Minerals Management Service (MMS) is responsible for structures in federal waters. The main stages of decommissioning and the equipment involved in the operation are shown in Figures C.4 through C.9. For additional reference to the literature, see also (National Research Council, 1985 and 1996; Kaiser et al., 2003; Schroeder and Love, 2004).

After all wells are plugged and abandoned, the structure is prepared for removal by flushing and cleaning all piping and equipment that contained hydrocarbons.

In accord with MMS regulations, a pipeline may be abandoned in place if it does not constitute a hazard to navigation, commercial fishing operations, or unduly interferes with other uses in the OCS. Pipelines abandoned in place need to be flushed, filled with seawater, and plugged with the ends buried at least 3 feet below the mudline. Pipelines are cut by divers or remotely operated vehicles and typically abandoned in place according to federal regulations.

The most common removal method in the GOM is to cut the deck from the jacket using torches and then lift and place the deck on a materials barge (Figure C.4) for removal to shore or an artificial reef site (Figure C.5).

The interior of the piling is then cleared using water jets to remove the mud from within the platform legs so that the explosives (or other cutting device) can be lowered 15 feet below the mudline. The explosives technician prepares and loads the charges into the legs and conductors, and then the derrick barge is backed off a safe distance and the explosives are detonated in accord with federal regulations (Figure C.6).

Piling and conductors are pulled using the derrick barge crane and placed on a cargo barge (Figure C.7), and then the jacket is lifted out of the water and welded to the materials barge for transport to shore or a reef site (Figure C.8).

The last stage in decommissioning is site clearance and verification, which is the process of eliminating or otherwise addressing potentially adverse impacts from debris and seafloor disturbances. The most common method is to trawl the area with specialized, heavy-duty trawling gear with reinforced mesh (Figure C.9).

3.5. Decommissioning Wastes

There are many environmental wastes that occur throughout the various stages of decommissioning, ranging from air pollution, water pollutants, and solid wastes. Air and water pollutants arise from the equipment (boats, tugs, equipment, etc.) required in the operation, while solid and liquid wastes arise from the actual operation (Table C.8). Waste streams are manageable and are considered to present a reasonably small impact on the surrounding environment.

Hazardous Waste

In plugging and abandonment, the wastes of the operation include drilling muds and cement for the plugs, production tubing and casing which may be NORM (Naturally Occurring Radioactive Material) contaminated, and other wastes. In preparation, topsides equipment and vessel are cleaned resulting in tank bottoms, heavy metal sludge, PCB fluids, halon gas and asbestos (Prasthofer, 1997). Vessels, tanks, and piping will be flushed to remove residual hydrocarbons in the preparation of cutting and other activity. Removal eliminates the potential for release of hydrocarbons or pollutants into the marine environment. Some heavy metals (e.g., lead, zinc, cadmium, mercury) may be present, but they are predominantly in metallic form and not directly or easily available in the food chain.

Equipment

Platforms will contain a combination of facilities, including oil, condensate, and gas production/processing; hydrocarbon pumping/loading; water reinjection; gas reinjection; power generation; drilling; accommodation and support. Each of these facilities will have specific requirements for decommissioning. Topsides equipment will normally have hydrocarbons or potentially hazardous chemicals contained in transformers, coolers, scrubbers, separators, heat exchangers, batteries, pumps, engines, generators, sumps, tanks, and hydraulic systems.

Bulk Steel

Bulk steel consists of piping, valves, instruments, electrical and instrument cable, fireproofing, firewalls, and miscellaneous support steel which needs to be cleaned to remove hydrocarbon residues.

Industrial Wastes

Industrial wastes are not unique to offshore facilities and typically include construction debris, packaging, paint, lubrication, pipe thread, etc. Light bulky material that is typically removed includes life boats, life jackets, thermal insulation, panels, and module fittings.

3.6. Waste Disposal Hierarchy

When an operator determines that a facility will be decommissioned, disposal and reuse options are made as part of the overall assessment. Disposal options are place, time and component specific with decision making determined by economic, technological, and regulatory conditions. The basic idea is to maximize the value of the waste stream by reducing the structure according to a generally accepted disposal hierarchy (Bossink and Brouwers, 1996; Chun et al., 1994; Teo and Loosemore, 2001; Schultmann and Rentz, 2002):

- Refurbish and reuse,
- Scrap and recycle, and
- Dispose in designated landfills.

In practice, a combination of these methods is likely to be employed. Thus, to the extent that equipment can be refurbished and reused, and demand exists, this will be the first method utilized. Material and equipment that cannot be refurbished or resold will be sold for scrap and recycling, except for those elements that cannot be scrapped and recycled which will need to be disposed in designated landfills (Prasthofer, 1997).

The extent to which a component can be refurbished and reused depends on factors such as its age, supply/demand conditions, regulatory restrictions, cost of refurbishment, vintage, and technical specifications. Components that cannot be reused are stored, sold for scrap and recycled, or disposed in a designated landfill.

There are five basic avenues for material generated from decommissioning: storage, refurbishment and reuse, scrap and recycle, reefing, and landfill disposal (Figure C.10). Equipment, piles and conductors follow on-shore pathways exclusively, while deck and jacket components may also follow offshore pathways. Piping is almost always left in place. Reefing, recycling and disposal are terminal states, while reuse and storage are intermediate (transient) stages. Components that enter into the reuse or storage states will eventually, given sufficient time, transition into a terminal state.

3.7. Disposal Alternatives and Component Pathways

<u>3.7.1. Title Retention and Transfer:</u> The owner of the structure may retain title to the facilities during abandonment or transfer title to the contracting (removal) company. The nature of ownership is specified in the service contract. If the owner retains title, the contractor executing the operations will be relieved of liabilities relating to the facilities and remain liable only for third party risks and the risks associated with their own equipment and personnel. Titles which are transferred on site transfers the liability risk at this place and time.

<u>3.7.2. Piles and Conductors:</u> Piling and conductors are typically broken down and recycled, cut into smaller pieces, and if NORM contaminated, will require special handling and disposal (Figure C.11). If conductors and piling are grouted, the cement needs to be broken out and disposed prior to scrapping the steel, or if the cost is prohibitive – which it typically is - the entire component will be stored on site or disposed in a landfill. In some cases, piles may be refurbished and reused; conductors are almost always cut into smaller pieces and sold as scrap.

<u>3.7.3. Decks:</u> Decks are usually fabricated of solid steel plate over wide flange beams, and because of their simple configuration and shape, are relatively easy to break into smaller components for recycling (Figure C.12). See Culwell (1997). A small percentage of decks, probably about 10 to 20%, are refurbished and reused, while a smaller number are used in reef construction, estimated at less than 5% of the annual number of reefed structures. Decks sit above the water and usually are not subject to significant corrosion loss for the first 20-25 years of their life, although after this time corrosion on bulk material is quite common. Decks are not permitted for reef construction unless completely clean of hydrocarbons.

<u>3.7.4. Topsides Facilities:</u> Topsides vary greatly in functionality and complexity, from large integrated drilling/production platforms with accommodation for 200-300 workers, to processing-only (manned or unmanned), drilling-only, quarters-only, gas compression, or various combinations (Figure C.13).

Topsides steel arises from

- Equipment required for the production operations, support utilities, drilling, and power generation;
- Bulks consist of piping, valves, instruments, electrical and instrument cable, fireproofing, firewalls, and miscellaneous support steel; and
- Structural steel used to support equipment, stairwells, walkways, etc.

Processing equipment is cleaned and all prohibited substances removed in accordance with regulations. Opportunities for large scale or wholesale reuse of topsides or equipment are limited by strict technical standards and the fact that many components are designed for a specific set of functional requirements. Unless an operator has or knows of an upcoming field development whose parameters approximately match the facility to be decommissioned, reuse is not likely to be successful. Subsea wellheads, production manifolds, and equipment designed to high specification and deployed for a short production life (e.g., 10 years or less) are the best candidates for re-use and/or sale.

Stored equipment may be salvaged for parts and will eventually be broken down into scrap metal components and recycled or disposed in a landfill. Material such as braces, bridges, heliports, and miscellaneous steel are typically stored on-shore, cut up and scrapped, and then sent to a smelter/mini-mill for recycling. In some cases, structural components may also be refurbished and reused.

3.7.5. Jackets: Water depth and structure type determine the relative proportion of jacket and deck steel. Jackets are stored both onshore and offshore, and are also used as artificial reef material.

Offshore Storage

About 1-in-3 structures in the GOM are inactive (non-producing) and held by lease production (Table C.9). Because federal regulations only require structures to be removed one year after a lease stops producing (*Federal Register*, 2002), a lease may contain anywhere from one to a dozen or more idle structures (Kaiser and Mesyanzhinov, 2004).

Onshore Storage

Structures that are decommissioned eventually end up in storage onshore, awaiting a reuse opportunity, or until the price of scrap steel achieves a minimum economic threshold to recycle (Figure C.14).

Reuse

A small number of jackets, about 10 to 20% of the structures removed, are refurbished and reused. Exact data is unavailable since reliable statistics are not tracked in the area. Jackets that are stored offshore can be towed directly to a new installation site if refurbishment is not required, while jackets stored onshore incur the risk of damage and the cost of storage. Since jackets sit in a salt water environment throughout their life, they are subject to steel thickness loss due to corrosion and structural fatigue due to the impact of wave, current, and hurricane forces.

Reefing

About 10% of the total number of structures removed in the GOM in any given year is reefed[10], but the percentages increase significantly with increasing water depth (Table C.10). "Rigs to reefs" is an established practice in the GOM where operators tow their decommissioned steel jackets to designated sites (or topple the structure in place) to enhance the bottom-structure and to provide a habitat and breeding ground for fish and other marine fauna (Dauterive, 2001; Pinkham, 1995; Reggio, 1987). Jackets make ideal artificial reefs because they are environmentally safe and are constructed of a highly durable and stable material that withstands displacement and breakup. Reefing is usually less expensive than onshore removal, but distance is a determining factor. If a structure is a large distance from an approved reef site, then reefing will likely be a more expensive option than onshore removal.

3.8. Gulf Coast Scrap Market

3.8.1. Industry Structure: Scrap processors in the Gulf Coast receive scrap metal from a variety of sources, and generally do not rely on platforms and other offshore infrastructure as a source of supply. The reasons for this are twofold – the quantity of structures available to the market are both small and uncertain, and thus, unreliable. Whenever offshore structures do become available, either from storage or directly offshore they are eagerly sought because of their high-quality steel properties.

Scrap metal operations in the Gulf Coast are abundant and include several small, family owned businesses having between 10-100 employees, as well as a handful of publicly held corporations with 500 or more employees (Table C.11)[11]. Scrap processors exhibit a wide diversity in operations. Companies may store and break, store and refurbish, store only, break only, or refurbish only. Breaking may be a significant or minor revenue generator for the company.

---

[10] All Gulf coastal states maintain active reef programs, but only Louisiana and Texas have programs specifically targeted for offshore structures (Kaiser and Pulsipher, 2005). The Louisiana Artificial Reef Program started in 1984, and the Texas Artificial Reef Program began accepting platforms in 1986.

[11] The list of companies shown in Table C.11 is not exhaustive, and several companies that were contacted were unable to provide information or reasonable estimates. Due to the reluctance of some companies to provide information, they may be omitted from the list, or the table entries will appear blank. Scrap processors and storage yards that are not directly involved with offshore structures are also excluded.

The main structure breaking companies in the Gulf Coast include Alison Marine, Bisso Marine, Horizon Offshore, Southern Scrap, and Unifab. These organizations scrap between 5-15 structures a year on average, with fluctuations that vary widely. Smaller firm such as Acadian Contractors, Manson Gulf, and Partech generally scrap five structures a year or less. Structures that are not broken and recycled are stored at various yards throughout the region, for example: at Amfels, Alabama State Port, Allen Process System, Bay Offshore, Dynamic Topside, Euromex, Houma Industries, McDermott, Nabors Industries, Offshore Specialties, Twin Brothers Marine, and other facilities. Large contractors typically have several yards throughout the region, while medium and small contractors have between one to three yards. Refurbishment service providers are generally not involved with scrapping.

The main ship breaking companies in the Gulf Coast are International Shipbreaking and ESCO Marine in Brownsville, Texas, which provide dismantling and recycling services to the U.S. Navy and other commercial maritime vessels. Ship breaking companies have diversified service offerings, and are also involved with recycling rail cars, oil tankers, barges, and tugs. These companies have the capacity to scrap platforms, but they are generally not involved with these services. Southern Scrap Material, Commercial Metals, and PSC Metals are large industrial waste recycling facilities that scrap barges, crew boats, and other smaller offshore vessels. A number of small private companies dismantle barges, shrimp boats, and tugs such as Bayou Concessions, Cross Equipment, P&D Steel, and Modern American Recycle.

Scrap processors offer full and specialized services. A full-service facility will take metals from both industrial and obsolete scrap suppliers, and ship to nearby steel mills or export. The facilities that cut offshore structures, however, tend to offer specialized services, while the ship breakers are similar to the large platform fabrication facilities in the Gulf (McDermott, Gulf Island Fabrication, LeTourneau, etc.), which are large, integrated yards that include various services, from jacket and deck fabrication to floating platforms and production facilities. Unlike GOM fabrication yards (Kaiser et al., 2004), storage and scrap yards are family-owned and relatively homogenous. Their main purpose is to cut steel and recycle structures, and they serve local markets and a small number of customers. The business operations of the firms do not require a high degree of dependency with other service providers.

3.8.2. Inventory Dynamics: The number of decks and jackets held in inventory is a dynamic quantity, best viewed in terms of a "pool," with both additions and reductions occurring over time. The structures that are stored may be owned by the company, the storage yard, or an independent broker. Storage times may range for any length of time, from 1 month to 10 years or more. Structures held in inventory may be reduced in number by cutting and recycling, or through sales agreements, while increases in inventory occur through purchase or barter agreements as new structures arrive from decommissioning activities. The size of the pool changes over time depending upon many different factors, such as the price of scrap steel, the availability of labor, and the strategic decisions of companies and brokers. The strategic decision of firms is the most important factor, but it is intractable and generally unobservable, which makes its application difficult to incorporate in modeling studies.

Information is difficult to track since there does not exist a central repository of data. A company will sell its vessels through an auction or broker, to one or more parties, who may utilize, upgrade, or refurbish the vessels, resale, change usage or sell to a scrap yard. After a sale, the company will not track the final destination of the vessel. Brokers in the market transact sales, but because knowledge about prices provide the margins for their business activity, brokers are secretive (and at times, deceptive) players since their livelihood requires maintaining a non-transparent price environment.

3.8.3. Storage Cost: Jackets are stored in the vertical (upright) position, but are scrapped lying horizontally. Yards do not need a large or specialized area for storage, and just a few acres would be sufficient to store several dozen structures. Storage costs vary with ownership. Land along the Gulf Coast is cheap and plentiful, and so for a yard that breaks, fabricates, or refurbishes structures, the storage and insurance costs for one or more structures are effectively zero. For a broker or company that does not have access to a storage yard, storage cost may range from $500-1000 per structure per month, $0.5-1.00 per square foot per day, or $1,000-1,500 per acre per month.

3.8.4. Process Work Flow: Cutting structures is probably one of the least sophisticated services offered along the Gulf Coast. The following outline presents the basic steps followed in all scrap operations.

Site Preparation

A site is prepared suitable for the receipt, handling, storage, demolition, and scrap processing.

Deck, Jacket, Piling, and Conductor Offloading

- Labor and equipment are used to receive, offload, and let go barges after delivering the deck, jacket, piling, and conductors.
- Framing and rigging for crane operations are installed and connected.
- Topsides, deck, jacket, piling and conductors are transported to storage, preparation, or the demolition site.

Structure Preparation and Inspection

- A material investigation of each unit is performed for hazardous materials, non-ferrous metals, re-usable machinery, equipment, and safety hazards.
- Clean and decontaminate deck, jacket, and piling.
- Inspect structure to perform optimal work flow.

Scrapping Deck

- Remove/dispose of asbestos, PCB's, and other hazardous material.
- Remove non-ferrous materials for recycling.
- Remove machinery and equipment items appropriate for resale.
- Process deck steel to a suitable grade for steel mill recycling.

Scrapping Jacket

- Install, position and adjust support structures in the storage location.
- Remove marine growth.
- Design rigging and cutting scheme to reduce jacket section for delivery to scrap processing operations.
- Remove and dispose of grout installed between piling and jacket compartments.
- Process jacket steel to a suitable grade for steel mill recycling.

Scrapping Pile/Conductor

- Test for NORM contamination.
- Remove marine growth.
- Remove and dispose of attached grout.

3.8.5. Scrap Operation: Obsolete structures are stored and scrapped outdoors. The primary operations are cutting and disassembly. The typical scrap yard is sparse in its requirements. A lift and various cranes are required, and access to a navigable channel, from a large canal or wet dock, is common. Other equipment requirements include torches of various kinds, saws, and related machines.

Cutting is a low-technology, "dirty" business, employing minimum wage labor and an immigrant work force. The operation is manual, in sometimes awkward and dangerous positions, and there is little economic incentive to mechanize the process. Working conditions are noisy and potentially hazardous, varying in complexity depending on the structure or vessel to be recycled. Deck and jacket components are relatively straightforward to break, although because of the dimensions of a jacket, are more cumbersome than decks. Jackets also have a lower steel density than decks and thus a lower scrap value. Drilling rigs, support vessels, and tankers are more complex, and thus more costly to break; military vessels and warships are the most complex to scrap (Table C.12).

For a complex structure, such as an oil tanker or Navy vessel, with many internal subdivisions, hazardous wastes, and irregular shapes, cutting is best performed on a manual basis. For a flat, small piece of steel, such as a deck or hull structure, cutting could be mechanized to increase productivity, but the large capital expenditures required for the specialized equipment is rarely justified given the small margins and high risk exposure of the industry.

The equipment utilized to process scrap metal varies with the type and volume of scrap the processor purchases. Most processors will have a crane, large magnets or grapples to lift and move ferrous scrap, baling press, various shears, and possibly shredders. Other equipment utilized includes scales, conveyers, crushers, and containers.

Decommissioning has been active in the GOM region for the better part of two decades. Sites with major graving docks or dry docks are best placed to handle de-constructed elements such as jackets, module support frames, and deck structures. Topsides modules are readily scrapped, stored, or refurbished at the many smaller fabrication yards that populate the region.

<u>3.8.6. Competitiveness Factors:</u> The main factors which determine an area's attractiveness as a breaking facility, include the availability of cheap labor, access to water, government subsidies, weak environmental and labor laws, and local demand for steel and other products. Ship breaking is often subsidized by developing nations in much the same way ship construction is subsidized by developed nations. Ship breaking allows a country to develop an industrial base, and thus, many developing countries actively promote the industry and turn a blind eye to environmental hazards. Safety practices, insurance costs, litigation costs, and the degree of mechanization are additional factors which determine the relative competitiveness of the industry. In ship breaking, these factors drive the industry structure and regional concentration that is observed. For offshore structures and small ships, the advantages of scale economies are less pronounced and small local players dominate the market.

3.9. Conceptual Economic Models

Many decisions are made throughout the life cycle of every field: Should the owner produce, sell the asset, or abandon production? Should the owner decommission and remove a structure after it stops producing or let it sit idle on an active lease? When a structure is decommissioned and removed from service, should it be reefed or disposed on shore? The contractor that performs the removal operation typically takes title to the structure at the time/point of removal. Should the contractor sell the structure to the highest bidder once ashore or hold the structure in storage, waiting to get a better price or perhaps refurbish the unit for resale? For each of these options, simple conceptual economic models are developed to provide additional insight into the financial criteria that often plays a major role in decision-making (Table C.13).

<u>3.9.1. Produce or Shut-In:</u> The decision to maintain production or cease operations are in most cases one of basic economics and strategic opportunity (Lohrenz, 1991). If the revenue from a structure's production exceeds the cost of operation, then the structure will likely continue to produce. When the production revenue is equal to or falls below operating cost, however, then a decision to stop production or make additional investment is made. Investment may be used to enhance recovery, through gas lift water injection or similar technique, or additional drilling may be undertaken through sidetract lateral wells to increase production rates. If the investment required is expected to result in an increase in production that has an incremental positive discounted present value, or achieves a threshold level on risked rate of return, then the investment is likely to be undertaken. This has to be balanced by the additional maintenance costs, which will be incurred as equipment ages, and the structure requires corrosion protection. An asset that appears uneconomic in isolation may create opportunities enabling the owner to undertake other investments or field developments in the future. It is also possible that the owner will maintain the facility to keep open the option of reuse at another field.

If the annual net revenue of a structure derived from hydrocarbon production is denoted by *NR* and the operating cost is *OPEX*, then a simple economic criteria will determine the production decision:

$$\begin{cases} \text{If } NR > OPEX\text{, then continue to produce} \\ \text{If } NR < OPEX\text{, then stop production.} \end{cases}$$

This is only an approximate, order-of-magnitude criteria, however, since many other factors will likely play a role in decision making.

3.9.2. Offshore Storage or Decommission: Federal regulations in the OCS of the GOM require that all structures on a lease be removed within one year after the lease is terminated. Typically, a lease is terminated when production on the lease ceases, but if the structure is being used to process production from another lease, the operator intends to re-work well(s) or is pursuing drilling activity on the lease, or the lease contains an active pipeline, conditions may warrant to grant an extension of the lease termination. MMS rules require the leaseholder to "demonstrate a firm commitment to develop and produce the proven reserves that have been discovered by wellbore penetration." MMS expects leaseholders to support any suspension request with a reasonable schedule of measurable milestones.

Several structures are usually contained on a lease, and so it is only when production from the *last* structure on the lease ceases that *all* the structures are required to be removed. Operators typically plug and abandon non-producing wells and may remove isolated structures, such as caissons and storage facilities on a productive lease early, but it is only *after* the lease is terminated that all the structures are required to be removed.

Operators have incentives to remove their structures in a timely manner to avoid environmental and operational hazards; to reduce their insurance premiums and liability, inspection[12] and maintenance[13] requirements; and to maintain good working relations with the MMS. The MMS requires operators to post bonding requirements if certain financial criteria is not satisfied, and recently, have begun to "encourage" operators to remove structures that are no longer "economically viable." On the other hand, operators also have a desire to maintain structures in place to defer the cost of removal; to increase the opportunity for resale; to reduce the risk and expense of storing platforms in a fabrication yard; and to reduce the cost of decommissioning through scale economies, scheduling, and shared mobilization costs. A tradeoff thus exists between several competing factors that are resolved by each company and their specific needs.

3.9.3. Reef or Onshore Removal: The location of the structure is a major factor in evaluating the options for disposal. The distance to shore, proximity to the nearest reef site, water depth, and planning area are all important factors in removal and reefing decisions because they directly impact the cost of the operation. All Gulf coast states maintain artificial reef programs, and to date, approximately 200 offshore structures have been donated and converted to reefs, primarily

---

[12] Platforms must be maintained to assure the structural integrity of the platform as a workbase and are inspected periodically in accord with the provisions of API RP 2A, Section 14, Surveys. A report must be submitted annually stating which platforms have been inspected, the extent and area of inspection, and the type of inspection employed; i.e., visual, magnetic particle, ultrasonic testing, etc. Use of an inspection interval which exceeds 5 years requires approval by the MMS Regional Supervisor. Inspection enforcement encourage operators to remove idle iron in a timely fashion if the Regional Supervisor does not grant an extension on the 5-year inspection schedule.

[13] Since jackets are made of steel and sit in salt water throughout their life, the submerged parts of the structure are subject to loss due to corrosion and structural fatigue. The "splash" zone is usually subject to more significant corrosion than structural components that reside within the water column (submerged zone) or above the splash zone (atmospheric zone). Decks and equipment, which sit above the water, are subject to atmospheric corrosion from salt water and spillage from production fluids and other chemicals.

offshore Louisiana and Texas, with about two dozen oil and gas structures scattered across Alabama, Mississippi, and Florida (Kaiser and Pulsipher, 2005).

Louisiana has designated nine approved sites for the disposition of artificial reefs. If a structure is located within an approved reef site, then it is likely that it will be reefed in place or in close proximity to its current location. If a structure is not located close to an approved reef site, then it will have to be towed for placement. Texas uses an exclusion approach under which any area is assumed to be an appropriate site unless excluded because of alternative uses such as navigation or pipeline lanes.

The decision to reef a structure is made within the context of alternative decommissioning options. Cost is a primary driver of decision making, so that if alternative X is expected to have cost C(X), then alternative A will be preferred to alternative B if $C(\mathrm{A}) < C(\mathrm{B})$. If the costs of the alternatives are approximately equal, the operator may be indifferent between the two alternatives with factors such as the duration of the operation, risk, and preferences playing a determining role. The decision to reef a structure is a function of several variables, many of which are unobservable.

A simplified model of the reefing versus onshore removal option is idealized as follows. Denote by P, S, and R as the location of the service port, offshore structure, and proposed reef location, respectively. The distance between X and Y is denoted as $d(\mathrm{X}, \mathrm{Y})$, so that

$d(P, S)$ = distance from port to structure (miles),

$d(S, R)$ = distance from structure to reef planning area (miles), and

$d(R, P)$ = distance from reef planning area to port (miles).

The time function associated with decommissioning operations is denoted as $\tau(\cdot)$:

$\tau(P)$ = time at port to offload structure (days),

$\tau(S)$ = time at structure site to perform operation (days),

$\tau(R)$ = time at reef site to lay reef (days),

$\tau(P, S)$ = transportation time from port to site (days),

$\tau(S, R)$ =transportation time from site to reef (days), and

$\tau(R, P)$ = transportation time from reef to port (days).

The time function depends upon the option specified and can be considered roughly proportional to cost (under dayrate contracts). If the structure is removed to shore, for instance, then $\tau(P)$ will include the time to unload the structure at the port; $\tau(S)$ will include the time to cut, lift, and load the structure on a barge for transport to shore or reef site; and $\tau(R)$ is the time to prepare the reef, placement, buoy, etc.

Assume that the structure will be stored at the port site and the construction vessel will return to port after the operation. Further, assume that the cutting regulatory costs for onshore removal and reefing are comparable (even though reefing involves more permits and state agencies, and complete removal will typically involve more cutting).

The cost of complete (onshore) removal CR versus reefing RF is computed as follows.

$$CR = 2d(P, S) + \tau(S) + \tau(P) + C_1 + C_2 - \sum p_i V_i$$
$$RF = d(P, S) + d(S, R) + d(R, P) + \tau(S) + \tau(R),$$

where C_1 = annual storage cost, C_2 = annual insurance cost, V_1 = deck value, V_2 = jacket value, V_3 = pile/conductor value.

The transportation (mobilization) time from port to site, and the demobilization time from site to port, is assumed to be proportional to the distance traveled. For simplicity, assume $d(P, S) = \tau(P, S) = \tau(S, P)$, and similarly, $d(S, R) = \tau(S, R)$, and $d(R, P) = \tau(R, P)$. The values of the time elements may be difficult to estimate.

Many special cases exist; e.g.,

- If the operator maintains ownership of the structure, then storage and insurance cost will be incurred ($C_1 \neq 0$, $C_2 \neq 0$).
- If the operator transfers title of the structure to a contractor, then $C_1 = C_2 = 0$, and since $\sum p_i V_i > 0$, the removal cost will be reduced.
- If the structure is located at the reef site ($S = R$) or in close proximity ($S \approx R$) then $d(S, R) = 0$ and $RF = 2d(P, S) + \tau(S)$, which is usually less than the complete removal option.

<u>3.9.4. Refurbish or Newbuild:</u> The characteristics of oil and gas fields differ over a wide range of parameters, such as the gas-oil ratio, flow rate, specific gravity, sour gas content, etc. Unless an operator has or knows of an upcoming field development whose parameters approximately match the facility to be decommissioned, immediate reuse of the deck and/or jacket structure is not likely to be successful. Old structures and equipment are much less likely to be reused because refurbishment cost is likely to exceed replacement cost and specifications may not match available opportunities. Timing and scheduling is a major complicating factor for the reuse of structural components. Subsea wellheads, production manifolds, and equipment designed to high specification and deployed for a short production life (e.g., 10 years or less) are usually the best candidates for re-use. “Gas” structures comprise the majority of reuse opportunities since gas fields are frequently depleted 5-10 years after installation.

The resale market varies with the component elements, liquidity and ease of reuse, generally with equipment the most liquid, followed in decreasing order by decks, jackets, piles, and conductors. If the cost of refurbishment, selling price, and risk premium associated with a used structure is less than the cost of a newbuild plus the delay cost associated with the fabrication process, then the operator will be inclined to reuse. Online markets exist for equipment, deck, and jacket components.

3.9.5. Scrap or Store: Land throughout the Gulf Coast is abundant, cheap, and sparsely populated, and so storage facilities for equipment and structural components are numerous throughout the region. The contractor who removed the deck and jacket may take title to the structure once it is aboard the cargo barge, or depending on the contract specifications, the operator may maintain ownership. A storage facility, shipyard, or independent broker may acquire the structure at port or at a later point in time. The removal contractor may hold the structure in storage at their facility or another shipyard, and once in storage, will await a resale opportunity, or if the price of steel rises sufficiently above the breaking cost, the structure will be broken and sold to a mini-mill for recycle or export.

From the broker's perspective, the decision to hold equipment and structural components to create a market also involves cost and opportunity. Let bp_i denote the price paid for the component. Holding a structure in storage involves the cost of storage (s_i), insurance cost (i_i), and the interest on capital (int_i). One or more of these terms may be zero; e.g., if the owner of the structure is a construction yard which specializes in fabrication, then $s_i = 0$, and if the structure was provided at no cost, then $int_i = 0$. If a broker bought the structure from the operator and is storing it in a yard, then $s_i > 0$, $i_i > 0$, and $int_i > 0$.

Let the component have a resale value V_i with probability q_i and denote the price of steel as P and the breaking cost b_i. The decision to hold versus scrap is determined by the relation
$bp_i + s_i + i_i + int_i \sim \max(q_i V_i,\ P - b_i)$.

The price paid for the component is a sunk cost, while all the other elements are time dependent: The decision to sell or scrap the structure will occur at the point τ such that the present value of holding falls below the present value of the opportunity.

Expectations of the market will influence storage and scrap decisions, since if the structure owner believes scrap prices will increase in the future, then they may delay breaking the structure if the expected incremental increase is greater than the holding cost. Alternatively, if current scrap prices are too low to cover the cost of breaking, then the structure will be held in storage. At any point in time, brokers may buy, sell, or exchange structures with other brokers, shipyards, or companies.

Figures C.15 through C.24 show typical deck and jacket structures stored at Unifab's Gulf Coast facilities.

CHAPTER 4: A REVIEW OF SHIP BREAKING AND RIG SCRAPPING IN THE GULF OF MEXICO

4.1. Introduction

A wide variety of vessels have been developed over the past century in support of the offshore energy industry. Most are designed to meet specific needs and have evolved to perform specific functions, such as transporting oil, handling anchors, or laying pipeline. Offshore vessels are typically categorized according to function and the stage of operation in which the vessel is involved (Table D.1). The oil and gas industry utilize mobile offshore drilling units (jackups and floating structures such as semisubmersibles and drillships) to explore for and develop reserves. A variety of small vessels service these rigs, bringing crew and supplies back and forth.

Ships and drilling rigs pass through many stages throughout their lives, from birth (newbuild) through death (cannibalization, demolition, or destruction), and various transition states in between (maintenance, upgrading, storage, conversion). At the end of their useful life, units are scrapped in a labor intensive, low technology operation in breaking yards across the world. Work conditions in breaking yards are uniformly difficult, dangerous, and potentially hazardous. Developed countries with high levels of labor costs, environmental requirements, and limited government support cannot compete with countries with cheap labor, weak worker safety and environmental laws, and government interest in supporting the industry.

The purpose of this paper is to review the ship breaking and rig scrapping markets in the Gulf of Mexico. We begin with an overview of the market structure and outline industry characteristics. Disposal alternatives, inventory statistics, and cost data are examined for each market. We conclude with a brief review of environmental protection and worker safety statutes.

4.2. Market Structure

Ships, service and supply vessels, and drilling rigs each trade in four separate markets (Stopford, 1997): newbuild market, service and supply market, sale and purchase market, and scrap market.

4.2.1. Newbuild Market: In the newbuild market, steel and other material is transformed into hulls, rigs, and related infrastructure using capital and labor. The decision to build depends on market fundamentals and the strategic decisions of firms. If the demand for ships or rigs is high or expected to remain high for a period of time, charter and dayrates will increase to the point where contractors, investors, shipyards, or operators determine that it will be profitable to build a new unit to take advantage of the strong rates. Units can be built on a speculative basis (without a contract in hand) or on a firm basis (with a contract).

4.2.2. Service and Supply Market: The service and supply market is the primary mechanism that drives the activities of investors in the other markets and may be converging or diverging across time and location. In the shipping industry, the market is referred to as the freight market; in the drilling industry, the rig market; in the service and supply market, the service market. Charter and day rates provide signals that indicate supply and demand conditions and that guide investor decision making. Ships are not often used as an inventory of spare parts or equipment, due to the high storage cost and other factors, but may be converted to alternative uses. Rig owners regularly upgrade their units, modifying existing equipment with new generation technologies and expanding the capacity of bottleneck equipment.

4.2.3. Sale and Purchase (Second-Hand) Market: The sale and purchase (second-hand) market involves transactions between owners and investors. Second-hand ships, vessels, and rigs are offered for sale to operating companies, service companies, speculators, scrap yards, and other participants. Several factors influence the decision to offer a ship or rig to the market and the purchase decision of investors. For example, a company may have a policy to replace its fleet at a given average age, a ship may no longer be suitable for operations, or the contract which held the unit may have expired and the company wants to exit the business. Government regulations may require scrapping a ship at a specific age[14], a drilling company may consider a rig technologically obsolete, financial exigency may force an asset sale to raise funds, or business commitments may require a unit not in the current fleet (e.g., LNG carrier, deep gas, harsh environment).

4.2.4. Storage and Scrap Market: In the scrap and storage market, old or obsolete vessels and rigs are stored for possible reuse or sale, cannibalization, and dismantling. Dismantling is the process by which a vessel or rig is "broken" down and recycled into salvageable components. Ships are "laid up" when not in active service, and may be converted to an alternative use depending on the condition and age of the vessel, through "jumboizing" or reduction. The world average scrapping age for ships is about 20-25 years, while in protected trades such as the U.S. domestic[15] market, the average scrapping age is about 35 years. Rigs are "stacked" when not in service and are frequently cannibalized for parts when idle longer than 3-5 years. Drilling rigs typically remain in service for 30 years or longer. Owners place a premium on resale and reuse options and a low priority on scrapping because of the significant residual value in marine units.

4.2.5. Market Cycle: The market cycle is driven by the cash flows between each of the four markets and global economic conditions. At the start of a cycle, contract rates rise and cash flows into the sale and purchase and newbuild markets. Second-hand units are transferred quickly, after minor technical upgrades and maintenance, while for newbuilds, there is an 1-3 year delay before the units arrive on the market. Investors may build with a contract in-hand or on a speculative basis depending on their risk profile and expectations of the future. As additional units enter the market, supply will increase and day rates will become depressed if demand conditions remain unchanged. Falling rates lead to a decline in cash inflow, and financially weak owners may be required to sell on the second-hand market, store, or scrap units to service their debt requirements. As units are stacked and scrapping increases, supply falls, rates are bid up, and the process starts again.

[14] For example, OPA-90 regulations mandate a phase-out of old, 10,000+ dead weight ton single-hull barges from operating in U.S. petroleum trade. Since 1994, 25 barges have been removed from service, at an average age of 28 years (U.S. Coast Guard, 1994). The smaller segment of the single-hull fleet will be affected by the regulation in 2015. In Europe, the International Maritime Organization controls the phase out of ships. All single hull tankers in Europe, for example, were phased out in 2005, with higher category tankers required to be phased out by 2010.

[15] Ships operating in fresh water such as the Great Lakes or inland rivers corrode at a much slower rate than steel exposed to a humid, salt-laden environment.

4.3. Investment Decision Making

Shipyards, brokers, construction companies, and other market participants acquire marine vessels and rigs for the purpose of refurbishment, storage, resale, or salvage. Units may be purchased directly by yards and salvage companies, or by speculators who act as intermediaries, buying the units for cash and selling them for demolition. Sales are usually handled by a broker. The purchaser takes delivery of the unit, and if he is an intermediary, makes arrangements for delivering the unit to the demolition yard.

The investment decisions of companies depend upon the strategic opportunities of the firm, the supply and demand conditions in the market, and the companies' expectations of the future. Age, market forces, and regulation are primary drivers. If a vessel is not expected to return to active service, it will be declared impaired for accounting purposes and a buyer sought. Another investor will buy the unit at a price which he believes he can make a profit. A seller may require a guarantee that the vessel will not re-enter the fleet as competition; e.g., towing and supply vessels may be sold for short sea shipping, hauling or container vessel companies. If no owner thinks they can make a profit, the scrap dealer will likely be the winning bid. As ships and rigs age and decline in value, they eventually all enter the demolition market.

4.4. Industry Characteristics

4.4.1. Breaking Is a Labor-Intensive, Low-Technology Activity: Cutting steel is a dirty, noisy, and potentially dangerous job. Most activities are performed by workers earning low wages and given little training. Working conditions are generally difficult, performed outdoors in open yards year round, involving bending, lifting, and cutting in hot, enclosed and often dark conditions such as inside the hulls of ships. To cut steel, propane-oxygen and acetylene welding guns, saws and other pneumatic devices are employed. Various types of hazardous material and toxic waste are found in equipment and machinery, including Polychlorinated Biphenyls (PCBs), asbestos, petroleum products, mercury, and ozone depleting substances. Worker productivity can be increased using mechanized methods, but low cost labor will discourage capital intensive investments. In the past, shipyards in Northern Europe and elsewhere became highly automated and efficient, but because of fluctuating markets and government decisions to support the industry, most of these investments were eventually lost. European companies are reported to be trying to bring back ship breaking to their shores (*Economist*, 2005), but the economic conditions and low margins will ultimately determine the success of this endeavor.

4.4.2. Working Conditions Range from Poor to Bad: In developing countries, workers are exposed to extremely hazardous conditions with high accident rates and long-term health and environmental consequences that are well documented; e.g., Bailey 2000a, Bailey 2000b, Gohre 2000, Rahmam and Ullah 1999. Insurance costs, workers compensation, and other social benefits are usually nonexistent; accidents, injuries, and deaths go unreported; and there is usually no recourse for worker compensation. Trade unions are nonexistent, and training is provided sporadically, if at all. In the Gulf Coast region, working conditions are less harsh but still difficult. The majority of the labor force in breaking yards along the Gulf Coast is migrant workers, primarily from Latin America (Mexico) and South East Asia (Vietnam, Cambodia, Laos).

4.4.3. Ship Breaking Is a Mobile and International Industry: Ship breaking is a mobile industry that gravitates towards countries with low labor costs, minimal health, safety, and environmental (HSE) regulations, and strong local demand for steel and scrap products. The demand for low-cost steel for manufacturing is one of the principal reasons the governments of developing countries actively support scrapping industries despite its negative environmental impacts.

In the 1960s and 70s, ship breaking in the U.S. was an active industry, conducted in over 30 shipyards on both coasts and the Gulf of Mexico (Maritime Administration, 2005). Ship breaking was also active throughout many developed countries during this time. As the U.S. and world economy grew and labor cost and environmental regulations increased, ship breaking became less attractive to industrialized nations and breaking facilities went out of business and/or exited the industry. Low cost regions such as India, Pakistan, China, Taiwan, and Korea began to dominate the market, and by the mid-1980s, almost three-quarters of the ship breaking industry was located in Taiwan, China, and South Korea (Table D.2, Figure D.1). By 1990, Pakistan, India, and Bangladesh comprised over 80% of the business; Taiwan and South Korea left the industry; and China's decline was only temporary (attributed to the introduction of stricter environmental laws). Today, China, India, and Bangladesh are the primary ship breaking countries in the world.

4.4.4. U.S. Ship Breaking Requires Government Subsidies to Maintain Profitability: The U.S. ship breaking industry depends upon the availability of guaranteed price contracts for survival. In theory, a shipyard that has the capacity to construct and repair a vessel also has the capability to break it down and recycle it, since the process is similar to fabrication but in reverse. Many shipbuilding and repair yards in the U.S. have the technical capability to scrap ships, with experienced workers' HSE programs to address hazardous materials abatement, handling, and disposal (U.S. Department of Labor, 2005); worker compensation programs (Rhodes, 2001); cranes and other heavy equipment necessary to handle scrap metal, etc. In practice, however, most U.S. shipyards prefer not to deal with scrapping operations because of low margins and the cyclic nature of the business. Intense international competition and differences in environmental regulations/enforcement means that U.S. scrap yards will likely remain a marginal player reliant on the domestic supply of government-owned military ships and guaranteed price contracts to maintain capacity and profitability.

4.4.5. U.S. Breaking Capacity: There are currently six qualified ship breaking facilities in the U.S. capable of handling U.S. military vessels – four firms in the Gulf Coast (International Shipbreaking, ESCO Marine, Marine Metals, All Star Metals) and two along the East Coast (Metro Machine and North American Ship Recycling) (Table D.3). The number of domestic ship breaking companies is continuously in flux[16], changing with the availability of supply, scrap steel prices and other factors.

4.4.6. Successful Ship Breaking Companies Tend to be Diversified: Successful ship breaking companies tend to be diversified in their service offerings, involved with recycling platforms,

[16] In recent years, several companies have either filed for bankruptcy or are no longer active in ship recycling; e.g., Baltimore Marine Industries (MD), D&D Steel (TX), Ship Dismantlement and Recycling Joint Venture (CA). Other facilities have closed yards for lack of work or cash flow problems (Guegel, 2004; Marley, 2006).

rigs, rail cars, oil tankers, and other vessels. Sourcing supply from a variety of sources allow a steady stream of units to dispose to maintain equipment and labor capacity. International Shipbreaking, Ltd., for example, has recycled and scrapped tankers, troop carriers, cargo carriers, cruisers, destroyers, ice breakers, crane barges, tugs, and various other ships (Figure D.2).

4.4.7. Labor Rates: Labor is a major factor in the cost to scrap a unit, and depending on the type and complexity of the unit, may account for 50-90% of the total breaking cost. The labor force of major ship breaking companies is generally less than 200-250 employees. Regular workers include skilled labor such as supervisors, cutters, and crane operators, while temporary workers include semi-skilled and unskilled workers such as truck drivers, helpers, and loaders. Regular employees are paid wages, while temporary employees are paid on a daily basis and as work commitments require. Small family owned yards compete in local markets for smaller ships and rigs and typically serve a small number of customers. The sizes of these firms generally range from 10-20 employees, or less. The average labor rate of private shipyards in the U.S. ranges from $38 to $53 per hour, while for demolition yards, the rate tends to range between $7 to $25 per hour, depending on qualifications and experience.

4.4.8. Statutory and Regulatory Requirements: The U.S. has strict worker safety statutes described by the Occupational Safety and Health Act of 1970 that provide protection to workers engaged in ship and rig scrapping with rules governing asbestos handling, the use of personal protective equipment, and working within confined and enclosed spaces. The Resource Conservation and Recovery Act of 1976 and the Toxic Substances and Control Act of 1986 govern the handling, management, transport, and disposal of hazardous and solid wastes in the United States.

4.4.9. Many Factors Impact Breaking and Disposal Cost: The cost to break and recycle a ship or rig depends upon factors such as the vessel class (tanker, bulk cargo, container cargo, military) and rig type (submersible, jackup, semisubmersible, drill ship); the amount and type of material used in construction (ferrous, nonferrous, hazardous material); unit size, complexity, and general condition; scrapping location (beach, sheltered waters, wet dock, dry dock); labor costs; the availability of certified abatement facilities; price of scrap metal; level of domestic and foreign competition; technical capability of the yard; contract specifications (turnkey, fixed price, single or multiple awards); and health, safety, and environmental regulations and enforcement.

Vessel and Rig Specification

Marine vessels vary widely in terms of their complexity, construction material[17], and hazardous substances. Merchant vessels and tankers are comprised of large open spaces designed for cargo carriage, whereas warships and other military vessels are highly compartmentalized for damage control and security. Different configurations lead to different breaking cost.

Rigs are made out of tubular members and rectangular beams which must be processed before being sold. The dimensions of rigs pose unique cutting requirements, and a low steel density usually contributes to weak scrap prices. Rigs also tow slower than ships, and so transportation costs tend to be higher (Colledge, 1994).

Complexity

Structures with many internal subdivisions, hazardous wastes, and irregular shapes are more expensive to break than flat, small pieces of steel, such as a deck or hull structure. The cost to break a jacket in the GOM usually ranges between $50-60 per ton, while for a military vessel, breaking cost may fall anywhere from $100-900 per ton. The cost to cut a deck may be as low as $10-20 per ton; empty ship hulls from $40-50 per ton; semisubmersibles between $60-200 per ton. Typical demolition prices for bulk carriers and tankers are summarized in Table D.4.

Hazardous Material

Military ships contain a substantial amount of hazardous material, estimated to account for about 25% of the total cost of disposal (Ahluwalia and Sibal, 2002). Cargo vessels, tankers, rigs, and other support vessels also contain hazardous wastes, but they are usually of substantially smaller quantity and concentrated in specific areas which can be removed by removing the modules that contain the substance.

Competition

Differences in labor cost, productivity, local demand, and government subsidies mean that developed countries are not competitive compared to countries with cheap labor, weak worker safety and environmental laws, and government interest in subsidizing the industry. Competition within a region means better bids and a lower disposal cost. The number of units per dismantling contract also typically results in scale economies that lead to lower disposal cost.

---

[17] The primary component of maritime vessels and rigs is steel, representing approximately 90-95% of a ship's total weight. Tankers typically have more ferrous material that can be recycled as re-roll plate, while steam powered vessels have more material containing asbestos than diesel-powered vessels. Marine vessels are composed of grades ISRI 232 and 236 plate and structural steel, which are sized into 3 ft. and under or 5 ft. and under pieces, and flat thick pieces, which may be processed to re-roll plate. Heavy melt No. 1 and No. 2 are processed into 3 ft. or 5 ft. and under pieces. Cast iron, unbundled miscellaneous sheet metal, plating, pig iron, and other thick ferrous products are also processed. Nonferrous scrap includes aluminum, copper, brass, and lead, and may be found in propellers, wire, engine rooms, and fire lines. Nonferrous material is usually considerably more valuable than ferrous products by weight. Materials containing asbestos, PCB solids and liquids, and other nonmetallics have no value and cost money to dispose.

Equipment Value

The machinery and equipment on ships, tankers, and rigs may or may not have a credit value. In U.S. markets, the residual value of equipment often has marginal value because of changing technical standards and high refurbishment costs. In developing countries, there is usually a large and liquid market for diesel engines, generators, deck cranes, furniture, etc. Mats of submersibles and jackups, for example, have been converted to barges and small dry docks in developing countries.

4.5. U.S. Ship Breaking Industry

4.5.1. Pulitzer Prize Winning Articles Focus Attention on Industry: Throughout the 1990s, the U.S. government sold their obsolete vessels to the highest bidder. The new owners then moved the ships to developing countries for dismantling. In May 1997, the Baltimore Sun published a series of Pulitzer Prize winning articles depicting the environmental and worker safety and health conditions in domestic and foreign scrapping facilities (Cohn and Englund, 1997a,b, and c). The articles also raised policy issues regarding the appropriateness of the U.S. and other nations putting workers and the environment at risk in less developed countries where most scrapping occurs. As a result of the articles and other activity at the time, both national and international attention began to focus on ship scrapping. The Under Secretary of Defense established an interagency panel on ship scrapping, and in 1998, overseas scrapping was suspended. The Maritime Administration (MARAD) was charged with investigating ways to ensure that U.S. government-owned vessels were disposed in an environmentally sound and economically feasible manner.

4.5.2. National Defense Reserve Fleet (NDRF) Inventory: The MARAD and U.S. Navy manage the disposal of inactive[18] government-owned vessels through various authorization and appropriations acts[19]. The acts require MARAD and the Secretary of the Navy to report on a regular basis the obsolete vessels designated for disposal, the condition of the vessels, the method of disposal, and the disposal costs. The Floyd Spence National Defense Act required that by September 30, 2006, all vessels in the National Defense Reserve Fleet (NDRF) be disposed, but by the end of 2005, the NDRF inventory contained 113 vessels not under contract for disposal.

MARAD has three sites for obsolete ships awaiting disposal – the James River Reserves Fleet (JRRF) in Virginia (Figure D.3), the Suisun Bay Reserves Fleet (SBRF) in California, and the Beaumont Reserves Fleet (BRF) in Texas. Ships held at these sites are classified in terms of high, moderate, and low priority risks, and are scheduled for dismantling according to budgetary restrictions and rank classification. High priority vessels have hulls that are in an advanced stage of corrosion, while moderate priority ships are managed to prevent them from becoming a high

[18] A ship or service craft that has been taken out of commission or out of service for retention as a mobilization asset or for pending disposal is referred to as inactive. Navy assets are stricken from the Naval Vessel Register before they are disposed.
[19] The Floyd D. Spence National Defense Authorization Act for Fiscal Year 2001 (Pub. L. 106-398, §3502, 114 Stat. 1654), the Bob Stump National Defense Authorization Act for Fiscal Year 2003 (Pub. L. 107-314, §3504, 116 Stat. 2458, 2471), and the Independent Agencies Appropriations Act, 2006 (Pub. L. 109-115, 119 Stat. 2396).

risk vessel. Currently, 20 moderate priority vessels not under contract are moored in the SBRF, 11 in the BRF and 7 in the JRRF.

4.5.3. Disposal Options: MARAD pursues several options to dispose of U.S. government-owned ships (Table D.5):

Foreign Recycling

Foreign recycling is considered the most cost effective of all the available methods, but several obstacles, including continued legal challenges and statutory impediments associated with the export of vessels containing high levels of toxic substances (EPA, 1998), make this option difficult to pursue.

Domestic Recycling

Domestic recycling is the most expensive disposal option available for ship scrapping. Limited domestic ship recycling facilities and budgetary constraints make this option feasible only for the removal of a small number of ships on price-fixed contracts. Historically, 17-22 vessels per year are recycled domestically (Maritime Administration, 2000 and 2005; USGAO, 2004).

Artificial Reefing

MARAD's artificial reef program is required to be at no cost to the Federal Government. The State must take custody of the vessel "as is, where is," meaning that the State is responsible for the costs of towing and preparation for scuttling, including the removal of all petroleum products and debris. Significant cost advantages can be realized with reefing, but this option has a relatively low capacity (since there is only a limited demand by coastal states) and involves a long lead time (to prepare the environmental review).

Federal and State permits are required to create an artificial reef. The process of obtaining a ship involves coordination with various Government agencies, such as the U.S. Army Corps of Engineers, the U.S. Coast Guard, and EPA. In 2000, the EPA established requirements for the mandatory removal of all PCBs and asbestos-containing material in areas that could be disturbed by setting off explosives (Hynes et al., 2004). For a related discourse on the federal role in the identification, protection and maintenance of ship wrecks, see (Helton, 2004).

Vessel Sale

Vessel sale is a low revenue to no-cost option for ship disposal, but relatively few ships are sold each year, if any, and foreign sales (for scrap) are not currently viable.

Vessel Donation

Vessels are occasionally donated to non-profit historical preservationist and humanitarian groups at zero cost. This option remains extremely limited and has not significantly impacted the number of vessels in inventory.

Deep Sinking

The Navy's Sinking Exercise Program (SINKEX) serves as a weapons development testing and fleet training exercises on ship sinking. SINKEX is administrated under a permit issued by the EPA under the Marine Protection, Research, and Sanctuaries Act. There is no limit to the number of ships that can be sunk in SINKEX, and on average, around 3-7 ships are employed in training exercises each year (Maritime Administration, 2005). The vessels are prepared in accordance with procedures that protect the environment, similar to the artificial reefing alternative, and the costs of deep sinking are comparable to the reefing option.

4.5.4. U.S. Military Breaking Cost Statistics: The number of ships scrapped by MARAD and the disposal cost per ton are shown[20] in Tables D.6 and D.7. Several variables affect the rate of disposal, including market conditions; the number, condition, and location of obsolete ships; disposal alternatives; industry capacity; capability and production throughput of disposal facilities; and budgetary resources. The number of companies that win disposal bids depends upon the location of the ships to be scrapped as well as the number of companies qualified to bid. The disposal[21] cost per ship and unit cost have exhibited a decreasing trend over time. The degree to which the decrease is due to the condition of the vessels, increased competition, learning economies, contract execution, or other conditions is not hypothesized. Ship disposal statistics for the Gulf Coast are shown in Table D.8.

4.5.5. World Ship Breaking Statistics: Ship breaking statistics for marine vessels (e.g., tanker, bulk cargo, container) are tracked on an annual basis from various commercial data vendors. MARAD is required to report public data on the government-owned fleet of vessels, while the Department of Transportation reports on coastal tank barges and other vessels. As ship size becomes smaller, information on scrap rates and costs becomes increasingly inaccessible and unreliable. Public companies frequently make reference to write downs on annual statements, but tracking individual vessels from this data is not recommended. Buyers and sellers usually consider sales information proprietary.

Information is difficult to track throughout small markets since there does not exist a central source for disposition. Reported data is usually ambiguous or imprecise. A company will sell its vessels through an auction or broker, who may utilize, upgrade, or refurbish the vessels, change usage or sell to a scrap yard. After a sale, companies do not track the final destination of the vessel. Brokers in the market transact sales, but because knowledge regarding price information about prices provide the margins for their operation, are typically the most secretive (and at times, deceptive) players since a non-transparent price environment allows brokers to maintain a greater margin.

---

[20] For data prior to 1999, see (Hess et al., 2001).

[21] Breaking cost involves the direct cost for labor; consumables and expendables; ship purchase; personal protection; rigging and staging; asbestos removal; PCB disposal; tank and bilge cleaning; non-PCB disposal; and cutting materials. Indirect costs include benefits (Medicare, worker's compensation, leave); overhead; general and administrative, bid and proposal. Environmental and safety costs typically account for about half the total cost of breaking, followed by labor and benefits at 30%. Materials (10-20%) and overhead (10%) account for the remaining costs (Creese and Sibal, 2001).

Privately-owned ships and rigs do not have the same restrictions as U.S. government vessels and may be recycled overseas. Commercial ship and rig scrapping occurs primarily in foreign facilities, although niche markets for small vessels such as coastal barges, support vessels, and offshore structures exist in the U.S. Ships, rigs, and offshore platforms may be stored in inventory for an indefinite period of time prior to scrapping, and a portion of this inventory may be converted to alternative uses, depending on the vessel/structure type, condition, and market environment.

4.6. U.S. Rig Scrapping Industry

4.6.1. Rig Tracking: Drilling rigs are closely tracked throughout their lives. From birth (new-build) through death (cannibalization, demolition, or destruction), and various transition states in between (maintenance, upgrading, storage, conversion), rigs are tracked at a detailed level because oil and gas companies require knowledge of the precise location of all rigs at all times for negotiation and planning purposes. Contract conditions are also closely tracked. The widespread availability and dissemination of rig data provides a market that is transparent, competitive, and quickly reactive to changes in supply and demand conditions.

4.6.2. Rig Status: An active rig is under contract, while an inactive (idle, or ready stacked) rig is not under contract, but is available for service quickly (hot stacked), with minor preparation (warm stacked), or major preparation (cold stacked). Refer to Table D.9. Dead stacked rigs have been in storage for many years and are permanently out of service.

Hot and warm stacked rigs are ready for use. A hot stacked rig is fully staffed and ready for immediate work. A warm stacked rig requires minor preparation and the rehiring of semi-skilled workers. Cold stacked (mothballed) units are stored in a wet dock and require both investment and time to return to working condition. Cold stacked rigs are maintained using inhibitive chemicals, and depending on the length of inactivity and value of the unit, doors may be welded shut and guards may be placed on duty to protect from vandalism. To bring back a cold stacked rig into operational mode, a series of inspection and testing procedures are required, including power, load, and pressure testing; blow out preventer certification; riser and tensioner inspection; and a host of other service checks (Aird, 2001). A rig that is several years old and cold stacked usually has no debt obligation, and so a firm contract is usually sufficient to cover the expenses to bring a stacked unit out of storage. Reactivation expenses typically range between $10-20 million for semisubmersibles and between $5-10 million for jackups.

Rigs stacked more than 3 years are rarely brought back into service and are referred to as dead stacked. Dead stacked rigs are permanently out of service and usually have their access stairs and ladders removed to prevent theft and vandalism. Dead stacked rigs are not maintained and frequently serve as a source of spare parts for the active fleet. Eventually, all dead stacked rigs are sold[22] for scrap metal or converted into an alternative use[23], depending on the condition of the rig. Rigs that have accidents (e.g., due to an explosion, blowout, or environmental forces) are usually dead stacked or demolished immediately.

[22] For the delays and attendant problems associated with the sale of six dead stacked rigs, see Colledge (1994).
[23] Many of the floating Production Storage Offloading vessels that are in operation around the world were converted from old tankers. Many semisubmersible production units were converted from drilling rigs.

4.6.3. Transition States: Active rigs transition to inactive status when their drilling contract (work obligation) expires. A drilling contract may be for one well and expire after the completion of the well, which is typical in the GOM, or a rig may be committed to a specific company for several years, which is common in deepwater and frontier basins. A rig will transition between inactive states many times throughout its life, and as a rig ages, it will likely spend an increasing portion of its time cold stacked. Cold stacked rigs that are moved out of the U.S. may be for service or scrap purposes.

4.6.4. Maintenance Requirements: A properly maintained and operated rig can remain in service for more than 30 years before wearing out structurally, and so rigs are maintained on a regular basis to ensure their marketability and asset value. Drilling rigs are often refurbished/upgraded every 7-10 years, and depending on the extent of the upgrade, can cost anywhere between $10-50 million or more. Improvements in drilling technology can usually be incorporated without altering the structure of the platform. It is common to associate a rig with a given finite amount of fatigue life. A rig that lives through a particularly bad hurricane or drills in harsh environmental conditions will usually use up a significant amount of its fatigue life.

4.6.5. Cold Stacked Units, Age Profile, and Attrition: The rig fleet that exists today consists of a wide variety of vessels conceived and built over the past three decades. As of April 2006, there were about 670 mobile offshore drilling rigs worldwide: 390 jackups, 163 semisubmersibles, 38 drillships, 46 barges, 25 tenders, and 3 Arctic rigs. Only 14% of the current fleet was built after 1994. The youngest fleet segments are the deepwater floaters and harsh environment jackups with 63% and 50% of the rigs built after 1994 (Figure D.4). As of April 2006, there are confirmed orders for 62 jackups, 21 semisubmersibles, and 5 drillships, plus several options for additional rigs.

The number of offshore drilling rigs as a function of time and region is shown in Figure D.5. The number of rigs varies over time and place as new rigs are built or assembled from components, cold rigs are reactivated from service, rigs move into or out of a region, and as rigs are upgraded, stacked, or scrapped. The number of cold stacked units has historically been reasonably constant, but in recent years, a significant portion of this inventory has been brought back into service, and worldwide utilization rates is currently close to 100%. A snapshot of the number of cold stacked units (as of October 2006) is shown in Table D.10. In 2004, there were 18 jackups, 20 semisubmersibles, and 9 drillships cold stacked. Historically, the worldwide attrition rate of rigs is about 3% of the fleet size per annum. Over the past 20 years, the fleet has lost on average 11 rigs per year (6 jackups, 3 semisubmersibles, and 2 drillships), but over the last ten years, the average was just six per year (Kellock, 2006). See Figures D.6-D.8.

4.6.6. U.S. Fleet Dynamics: Offshore rigs are tracked by ODS-Petrodata, Schlumberger ReedHycalog, Baker Hughes, Smith Tool, *Oil and Gas Journal*, R.S. Platou, Rig Data, and several other sources. Detailed information is provided on location, contractor, contract duration, and day rate for the U.S. and international fleet. Variations across data sources exist, since every census and survey counts and classifies in a slightly different ways and uses different methods for data collection, but for the most part, data is consistent across the major data providers.

Schlumberger ReedHycalog perform an annual census for the U.S. rig fleet, counting a rig as active if it has "turned to the right" any time during a defined 45-day period (May 5-June 18). A rig drilling one day during the period is counted as utilized (Table D.11).
Reductions to the fleet are reported in five categories:

- Rigs auctioned for parts or cannibalized;
- Land rigs requiring capital expenditures of more than $100,000 and offshore rigs needing more than $1 million;
- Rigs moved out of the U.S.;
- Rigs stacked for more than three years; and
- Rigs destroyed.

Rigs auctioned for parts, or cannibalized to support other units, are typically one of the largest categories of deletions. Census rules exclude rigs that require significant capital expenditures to be operable. Rigs leaving the country are primarily offshore rigs moving out of the Gulf of Mexico.

Additions to the fleet are reported in four categories:

- Rigs assembled from components;
- Newly manufactured rigs;
- Rigs brought back into service after being inactive; and
- Rigs moved into the U.S.

Land units are regularly assembled from rig components, and depending on market conditions, newbuilds will also increase the available fleet. As drilling conditions improve, cold stacked units are reactivated and put back into service. Rigs may also be brought into the U.S. from other countries.

4.7. Scrapping Economics

4.7.1. Storage and Scrapping Sites: Land along the Gulf Coast is plentiful and cheap, and yard capacity with water access is essentially unconstrained, and so companies can store any type of offshore vessel at zero (or near-zero) cost indefinitely. Rigs are stacked at various sites throughout the Gulf Coast at locations that vary with each contractor; e.g., Atwood Oceanics has storage yards at Fourchon, Sabine River, Galveston, and Pascagoula; Diamond Offshore has storage yards at Sabine River and Galveston. Rig scrapping does not require any specialized equipment or facilities and can be performed wherever a shipyard is located. Drilling companies do not perform scrap or refurbishment operations.

4.7.2. Scrap Valuation: Offshore infrastructure is made primarily out of steel, which over time, due to fatigue, wear, and corrosion needs to be upgraded, replaced, or scrapped. The scrap value of a unit is evaluated periodically, based upon market conditions; upgrades performed on the unit; the cost to break the unit and dispose of hazardous material; and the value of scrap metal and salvaged equipment. Both internal and external data are reviewed. If the price of scrap steel is $300 per ton and the breaking cost is $150 per ton, then the scrap value of a 40,000 lightweight[24] ton (LWT) vessel would be \$6 million. If the price of scrap steel falls to \$200 per ton and no local yards are willing to break the ship, then a foreign facility with smaller breaking cost, may bid for and capture the unit. The salvage value of jackup rigs typically ranges from \$0.5-3 million per rig. Semisubmersibles and drillships range from \$1-5 million per rig.

4.7.3. Scrap and Refurbishment Decision Making: The economics of scrap and refurbishment decision making is illustrated for a jackup rig built in 1985 at a cost of $\$X$ million. If the rig depreciates at p% per year on a straight-line basis, then after T years, the book value of the rig would be worth $\$X/Tp$. If the price of materials, labor, and equipment have increased by q% per year, the expected replacement cost after T years would be $\$(X/Tp)(1+q)^T$. When the replacement cost of the rig falls below the value of the rig as scrap, it is likely that the rig will be stored or sold. A typical rate of return calculation for a contractor deciding to refurbish a cold stacked rig for \$50 million and a 1 well firm and a 1 well plus option contract is shown in Table D.12.

4.8. Environmental Protection and Worker Safety Statutes

4.8.1. Hazardous Materials: Various types of hazardous material are found in ship and rig components and systems. The primary hazardous materials include:

- Polychlorinated Biphenyls (PCBs) – for fire resistant and insulation in electrical cables and system components, rubber and ventilation duck gaskets, adhesives, paint and insulation materials.
- Asbestos – for insulation in bulkheads, floor and ceiling tiles, pipe, electrical cables, machinery, seals, and gaskets, especially for ships and rigs built before 1970.
- Petroleum products – fuels (No. 6 and No. 2 fuel oil) and lubricants in storage tanks, double-bottom tanks, fuel oil settling tanks, tanks designated for the carriage of fuel as cargo, the sumps of machinery, and lubricating gears.
- Surface coatings –older ships and rigs may contain lead, chromium, and other metals as surface protection.
- Sodium Chromate – used on older ships and rigs as a corrosion inhibitor.
- Mercury – found in temperature sensors, heat detectors, gauges, and fluorescent light bulbs.
- Ozone depleting substances and chlorofluorocarbons used as refrigerant.
- Waste water – generated during the dismantling process from rainwater and other water often contains metal particulates, paint chips, oil and miscellaneous materials.

4.8.2. U.S. Statutory and Regulatory Requirements: U.S. laws and regulations exist to protect worker safety and the environment during the process of handling and disposing of hazardous materials and the occupational hazards inherent in scrapping. Fatal incidents usually result from explosions due to flammable substances and/or gas pockets, and falling objects from improperly secured components.

[24] A ship lightweight is the weight of the vessel as built, including hull, machinery, and equipment. The deadweight of a ship measures the total weight of cargo that the vessel can carry when loaded down, including the weight of fuel, stores, water ballast, fresh water, crew, passengers, and baggage.

Scrapping facilities in the U.S. are responsible for compliance with U.S. statutory and regulatory requirements, including the:

- Toxic Substance Control Act of 1976, 15 U.S.C. §§2601-2629 (Act of October 11, 1976, 90 Stat. 2003) [TSCA];
- Resource Conservation and Recovery Act of 1976, 42 U.S.C. §§6901-6992k (Act of October 21, 1976, 90 Stat. 2795, as amended) [RCRA];
- Occupational Safety and Health Act of 1970, (29 U.S.C. §§651-678) Act of December 29, 1970, 84 Stat. 1590, as amended) [OSHA]; and
- International laws, treaties, conventions and agreements, as appropriate.

The OSHA governs workplace worker health and safety protections, and provides policies and procedures to reduce and eliminate work place hazards associated with ship breaking (U.S. Department of Labor, 2005). The primary rules for shipyard facilities include those governing asbestos, confined and enclosed spaces, and personal protective equipment.

RCRA regulations govern the handling, management, transport, and disposal of hazardous and solid wastes. RCRA prohibits the export of hazardous waste before the exported: (1) notifies the importing country; (2) receives the importing country's consent to accept the waste; (3) attaches a copy of the importing country's written consent to the shipment; (4) meets with EPA's reporting requirements; and (5) where a valid international agreement regarding hazardous waste exports exists between the U.S. and the receiving country, the shipments must conform with the terms of that agreement.

TSCA governs activities related to specific toxic substances. TSCA and EPA's implementing regulations prohibit the processing or distribution in commerce (including export from the U.S.) of PCBs equal to or greater than 50 parts per million. Vessels and rigs built before 1975 often contain PCBs at or above allowable levels for export. To export vessels, three options exist: (1) remove all regulated PCBs from the vessels, (2) exercise EPA's enforcement discretion, or (3) modify TSCA or otherwise provide MARAD an exemption with respect to current law.

4.8.3. Multilateral and Bilateral Treaties: Numerous multilateral and bilateral treaties on hazardous materials, hazardous wastes, and trade exist, including: The Basel Convention; North American Free Trade Agreement's Environmental Side Agreement; The Organization for Economic Cooperation and Development's 1988 Decision of the Council Concerning the Control of Transfrontier Movements of Wastes; London Convention, 1972 – Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter; Agreement Between the Government of the United States of America and the Government of the Canada Concerning the Transboundary Movement of Hazardous Waste; and Agreement Between the Government of the United States of America and United Mexican States on Cooperation for the Protection and Improvement of the Environment in Border Area.

4.8.4. International Policy Considerations: The International Maritime Organization, the Conference of the Parties to the Basel Convention, and the International Labour Organization (ILO) have addressed ship scrapping over the past several years (UN General Assembly, 2000). The Basel Convention prohibits the export of certain wastes from Organization for Economic

Cooperation and Development (OECD) signatories to non-OECD countries. While the Convention does not list ships as hazardous wastes, many of the hazardous materials on the vessels are listed. The main regulatory mechanisms of Basel are: notice[25], consent, and either reshipment to the exporter or proper on-site disposal of waste paid for by the exporter when so requested by the country of import.

[25] Notice and consent consists of a mechanism whereby transboundary movements of hazardous wastes or other wastes can take place only upon prior written notification by the State of export to the competent authorities of the States of import and transit.

CHAPTER 5: STEEL WASTE STREAMS ASSOCIATED WITH DECOMMISSIONING OFFSHORE STRUCTURES IN THE GULF OF MEXICO

5.1. Introduction

The first oil and gas operations over water occurred in Summerland, California, in 1896, where wells were drilled from piers extending from shore (Graff, 1981). In 1910, wells were drilled in Ferry Lake, Louisiana, from a wood deck erected on a platform supported by cypress trunks driven as piling (Lee, 1968). The oil industry in the United States moved into the marsh and swamp lands of south Louisiana using timber structures, and by the mid-1940s, exploration was being conducted in the open seas of the Gulf of Mexico, where the lateral forces from waves, wind, and current required a stronger structure than provided by wood (Veldman and Lagers, 1997). In 1947, the first steel jacket structure was installed at Ship Shoal block 32 in 18 feet of water, 10 miles from the Louisiana coastline, and became the standard design for fixed platforms throughout the world (Drawe, 1986; Drawe and Reifel, 1986; Austin et al., 2004).

Steel is the material of choice in the construction of offshore structures because of its strength, durability, corrosion and stress resistance, and ability to be formed into various shapes, machined, and joined by welding. Steel is generally classified into groups based on strength (related to design stress), chemistry (related to weldability), and toughness (related to brittle fracture). Two grades of steel are typically used in offshore construction: low-carbon steel for structural elements such as jackets, decks, railing, stairs, walkways, and deck plating; and high-strength, low-alloy steel for critical components and extreme climate conditions such as tubular joint and spanning nodes (Marshall, 1986). The American Petroleum Institute's Recommended Practices for Planning, Design, and Constructing Offshore Platforms lists a number of structural steel and pipe specifications which are suitable for general use in offshore structures (API, 2000; API, 1978).

The purpose of this chapter is to describe how development options impact the weight of offshore structures and derive algorithms to estimate deck, jacket, pile, and conductor weights based on structure type, production capacity, footprint, water depth, and other factors. We illustrate the application of the weight algorithms and provide order-of-magnitude estimates of the amount of structural steel removed in decommissioning. We begin with an overview of field development strategies, and describe the factors that influence the selection and weight of topside facilities. The infrastructure used in shallow and deepwater field developments is then outlined, followed by a general description of the components and weight distribution of fixed structures. Weight algorithms are developed for floating and fixed structures in the GOM, based on survey techniques, power relations, and regression modeling. The amount of structural steel removed in the GOM in 2003 is estimated.

5.2. Field Development Strategies

Development schemes vary widely across the world, and even in different areas within the same region, depending upon the size, shape, depth, and productivity of the reservoir; the time of development and proximity to infrastructure; logistical considerations in moving the production to market; operating conditions such as well interventions; economic considerations; strategic decisions such as an operators interest in establishing a production hub for the area; and the lead time required to acquire or design and construct structures, rigs, production facilities, pipelines, and other downstream facilities.

The optimal development of an oil and gas asset is a complex and difficult problem, involving multiple trade-offs and numerous uncertain, unobservable, and intractable variables. The theoretical framework of asset development involves a nonlinear, stochastic, multidimensional, and mixed[26] problem formulation. Many feasible development options and design permutations exist, and numerous technical, operational, strategic, and financial constraints govern the development. Operators make decisions regarding investment, production rates, development plans and scheduling, which impact hydrocarbon recovery, and ultimately, the economic performance of the asset. Design decisions involve selecting the topsides facilities, the type of platform, the number and timing of wells to be drilled, and a myriad of other factors. Operational decisions typically involve production rates and setting reservoir pressure profiles.

5.3. Topsides Facilities

Topsides facilities ("topsides" or "deck") define the function of the structure and refer to the deck supporting substructure, the plant for drilling, processing and export of oil and/or gas, and the utilities, accommodation and life support facilities. The requirements for topsides are determined by the reservoir fluid properties, production rate, product quality, and product disposition.

5.3.1. Gas-Oil Ratio: As oil passes from the reservoir to the surface, gas will come out of solution. The amount of gas in solution may be as little as 10 cubic feet per barrel, but typically, it is in the range of 500-600 cubic feet per barrel. At the surface, the gas bubbles out of solution and is used for fuel, sold, flared, or reinjected back into the reservoir. It is also possible that gas from a gas cap will be pulled down (coning) into the well and flow along with the produced oil.

The ratio of the produced gas to produced oil is referred to as the gas-oil ratio (GOR) and provides an indication of the type of well ("oil" or "gas"), hydrocarbon type (heavy oil, light oil), and reservoir drive (dissolved gas, gas cap, water drive). The GOR in a well changes during production with changes in the reservoir conditions.

The producing GOR is an important parameter in production management decisions. For a GOR < 2,000 scf/STB, the fluid is a dark, heavy, black oil, with gravity typically less than 45°. Fields that produce crude with gravity less than 25° often have low reservoir pressure, low GOR, and experience high water cuts later in field life. Volatile oils are lighter oils and have GORs in the range from 2,000 to 3,300, while retrograde gas has GORs from 3,300 to 50,000 with gravity ranging from 40° to 60°. High GOR streams require choke wells to limit drawdown and sand production, and require more separation stages (Bothamley, 2004). A GOR > 50,000 defines a wet gas well, while a dry gas well will have no liquid hydrocarbons formed. High producing GORs will increase the size and cost of gas-handling equipment, particularly compression.

[26] Involving discrete and continuous decision variables.

In an “oil” well, gas is dissolved in the oil in the reservoir and when extracted, will bubble out of the liquid at the surface and then be separated in production facilities. Water is also present in oil which must be separated. A GOR < 300 will usually satisfy offshore fuel usage but will be insufficient to warrant pipeline installation. A GOR > 300 generally requires conservation, either for sale to a pipeline or for reinjection back into the reservoir. In a “gas” well, gas in the reservoir is at a high pressure and temperature, and as it rises to the surface, a portion of the heavy hydrocarbons in the stream condenses into liquid, forming condensates, while the light components remain gas. For sales gas, the gas is dehydrated[27] prior to being transported through a pipeline.

5.3.2. Reservoir Pressure: A reservoir is pressurized because of its location, characteristics of the trap and rock, and other factors. When a well is drilled into the reservoir, the reservoir pressure is an important determinant of the flow rate. The driving force for the production of oil is the pressure difference between the reservoir and the bottom of the well. As oil is produced, the reservoir pressure decreases, leading to a drop in the driving force and oil production. As pressure declines and eventually dissipates, oil will no longer flow to the surface naturally, and must be pumped using “artificial lift.” After time, “secondary” and “tertiary” production methods are required, such as waterflooding, CO2 flood, and other enhanced oil recovery methods. A well is usually capped when the GOR exceeds a certain threshold limit or when the pressure in the reservoir is lower than a minimum pressure. Reservoir pressure may be maintained by injecting filtered deaerated seawater or gas, but relatively few shelf fields in the GOM use water injection for pressure maintenance. For fields that require injection systems, topsides facility dry weight may increase by 50-60% (Graff, 1981).

5.3.3. Production Capability: The production rate of a facility varies with the characteristics of the reservoir, the number of wells drilled, and design philosophy. A facility must be able to process the crude oil and gas that flows from the well, but the design criteria determines the “robustness” of capability. Facility design range from “minimal” to “robust,” depending on the level of capability, reliability, operability, flexibility, and constructability (Ellis and Shirley, 2005).

A system that is able to meet substantial variations in hydrocarbon composition, flow rates and physical properties, while providing allowances for future capacity expansion and tiebacks is a robust system. Reliability is determined by capability and the amount of redundancy, spare equipment, and process configuration complexity. Operability issues focus on the layout and physical arrangements of equipment, while constructability is determined by the manner the facility is constructed. Production facilities for example can be integrated into the structure at the construction site, or skid modules can be fabricated separately and shipped to the yard for hookup. The modular approach is common in the GOM, but this approach tends to add weight to the structure (Anderson and Boulanger, 2004).

5.3.4. Environment: The primary function of a structure is to provide a secure working platform to support a specific operation in a hostile and dangerous environment (Landes, 1986). The basic requirements of a structure are to withstand all loads during fabrication, transportation,

[27] Only a few platforms in the GOM employ additional gas processing, such as dewpoint control, natural gas liquid recovery, or fractionation columns.

and installation; to withstand loads resulting from environmental forces (e.g., severe storms, ice, hurricane events), and to function safely relative to its requirements.

In shallow water, the field configuration and the functional requirements generally dictate the form of the structure. In deepwater, the water depth and environmental criteria play a significant role in design, since structures must be designed for the environmental conditions; in this case, functional requirements have less impact on the configuration. In mild climates, topside loads are minimally affected by environmental conditions, while in harsh environments topside facilities will require a greater amount of steel support and more robust design (Landes, 1986).

Severe Weather

The re-supply period for extreme weather conditions determines the size of storage facilities and deck area to handle the event. In the North Sea and GOM, the re-supply period is usually taken as 3-5 days, while in extreme environments such as Sakhalin Island in the Sea of Okhotsk, the re-supply period is designed for 2 weeks (Clarke et al., 2005).

Winterization

Structures in the GOM are freely ventilated, while in severe climate regions compartments are enclosed, insulated, and temperature controlled, all of which contribute to a greater load from ducking, HVAC equipment requirements, and safety precautions (Mather, 2000).

Seismic Conditions

Structures are designed for strength and stiffness to ensure that no structural damage occurs from an earthquake that has a reasonable likelihood of being exceeded. Offshore structures that are installed in earthquake prone areas, such as the Pacific Coast, Alaska, Sakhalin, and New Zealand are designed for additional strength.

5.3.5. Design Optimization: Complex tradeoffs are involved with all design issues, and the ability to optimize systems and subsystems is a complicated and difficult problem. Because so many interdependent factors play a role in design, it is impossible to isolate one factor (e.g., weight) and trace its role or dependency through the process. Process optimization involves designing and selecting the equipment, processes, and flows to process the crude oil using the optimal number of separation trains, storage facilities, etc. to reduce area, weight, and cost. Some of the conditions can be controlled and are well understood, while other factors cannot be controlled or are less understood. It has been estimated that for each ton of topsides weight reduction, anywhere from 0.2-0.4 ton of jacket steel may be saved (Drawe, 1986). The savings in deepwater facilities are even more pronounced, where the cost of hull and mooring systems ranges from $5,000-10,000 per ton of topsides payload (Shivers et al., 2001). A 100 ton reduction in topsides payload would result in a $500,000 - $1 million cost reduction.

5.4. Offshore Infrastructure

5.4.1.Shallow Water Structures:

Caisson

If a reservoir is small or isolated, it will normally be completed with a “minimal” structure – a caisson, well protector, or subsea completion – with flowlines tied back to shore or an accompanying fixed platform. A caisson is a cylindrical or tapered pipe through which a well is drilled (Figure E.1). Caissons may be installed before the well is drilled or may be set over an existing well. A small deck is sometimes provided above the wellhead to support navigational aides, gas compression, meter equipment, or a crane.

Well Protector

A well protector (or well jacket) is an open lattice truss template consisting of a welded frame of tubular members extending from the mudline to above the water surface. Most well protectors in the GOM are 3- or 4-piled structures with minimum decks and production facilities in water depths less than 200 feet (Figure E.2). Jackets consist of large-diameter tubular legs framed together by a number of smaller tubular braces, and are large, heavy structures, supported by horizontal bracing to stabilize the frame and conductors. The jacket protects the wells while supporting the deck and topsides facilities. Piling is driven through each leg of the jacket and into the seabed to secure the structure from lateral forces. The configuration of a jacket is related to the number of pilings required and whether it is to be launched. The number and size of pilings is related to the magnitude of gravity, environmental loads, and foundation soil strength (Graff, 1981).

There are 1,524 caissons and well protectors in the GOM, representing about 39% of the 3,922 structures, as of May 25, 2005. The remaining 2,367 structures comprise drilling, production, drilling/production, and auxiliary platforms.

Drilling Platform

A drilling platform supports drilling operations and contains the derrick, equipment, and material required to drill wells. After the wells have been drilled, the drilling equipment is often removed and production equipment installed, including a Christmas tree, manifold, and treatment facilities (Figure E.3). Drilling platforms frequently exist in a transitory and temporary mode, during which the wells are drilled, but afterwards transforms into a production platform for the majority of its lifetime.

Production Platform

Production platforms process the liquid and gaseous hydrocarbons, and separate the produced water, sand, and other materials prior to transport, disposal, or reinjection. Oil is "stabilized" within pipeline specifications and gas is "dehydrated" for export requirements[28].

The basic system collects production from each well or zone through an individual flowline. The flowlines are manifolded together and production from the combined well streams goes to the bulk separator. Liquid hydrocarbons are collected and sent to an oil treater, where it is sometimes necessary to heat the oil to facilitate oil-gas-water separation and to stabilize the crude for pipeline specification (Bothamley, 2004). Heating is also required in glycol regeneration and other processes. Process cooling systems is necessary on some processes to cool the export crude to temperatures below 140°F to limit expansion and stress on the riser and pipeline. Heavy, waxy, and emulsified oils are more difficult to segregate from water, and require larger vessels with greater retention volume and increased operating weights.

Produced water is treated to remove the latent oil and gas and is then injected back into the reservoir or deposited[29] into the ocean. Production platforms contain metering and shipping equipment, depending on the hydrocarbon production, and may also contain sump tanks, pumps, meters, storage tanks for gas to be flared, fuel gas storage tanks, crude oil storage tanks, and sometimes, flare towers.

Drilling/Production Platform

Drilling/production platforms support both drilling and production operations (Figure E.4). Drilling/production platforms are large, usually with multiple decks to support the drilling rig with its equipment and crew quarters, as well as the buildings, treatment facilities, compressors, pumps, and storage tanks for production. For deepwater structures, the quarters are an integrated part of the system; for shallow water structures, quarters are usually separated from the drilling and production facilities.

Auxiliary Platforms

Auxiliary platforms do not drill, produce, or process hydrocarbons, but provide support for operations, typically as pumping and compressor stations, flare towers, oil storage, and quarters.

5.4.2. Deepwater Structures: Fixed platforms have been used in the GOM in water depths up to 1,500 feet, but beyond this limit[30], due to the cost of fabrication and installation constraints, floating structures are required. The objective of a deepwater unit is the same as structures fixed

---

[28] Sales specifications for oil is determined by vapor pressure, basic sediment and water content (1% bs&w), and salt specification (10-20 lbs/1000 bbl). Allowable water content for gas ranges from 2.5-7 lb/MMscf, depending on the pipeline or sales contract, or hydrate avoidance requirements.

[29] Oil-in-water specifications to discharge usually range from 40-50 ppm by weight. In the GOM, the maximum oil-in-water specification is 42 ppm, with an average maximum of 29 ppm.

[30] Shell's Bullwinkle platform in Green Canyon block 65 in 1,350 feet water depth stands 1,617 feet tall and is one of the largest fixed structures in the world.

to the seabed, namely, to provide a safe, cost-effective, and stable platform for operations. Topsides facilities on shelf and deepwater fields are similar except for scale.

The types of deepwater systems in use across the world vary widely and include: compliant tower, floating production storage offloading vessel, floating storage offloading system, floating production system, semisubmersible, tension leg platform, deep draft column vessel (also known as a spar), and subsea system. Recall Figure A.2. The number of deepwater systems in use in the GOM is summarized in Table E.1.

Compliant Tower

A compliant tower consists of a narrow tower and a piled foundation laterally braced with wires attached to the seabed. Configurations are typically slender, tubular steel, space frames with relatively constant cross-section dimensions over the height of the structure. Compliant towers extend traditional fixed platform capability and can withstand larger lateral forces. Three compliant towers have been installed in the GOM in the 1000 - 2000 ft water depth range.

Floating Production System

A Floating Production System (FPS) consists of a large deck connected to submerged pontoons by widely space columns, similar to the design configuration of semisubmersible drilling vessels. The vessel is moored with a catenary system of anchors, chain, and wire rope. Wells are subsea completed and tied back using flexible, buoyant risers.

Floating Production Storage Offloading

A Floating Production Storage Offloading (FPSO) vessel is a tanker-based system capable of producing, storing, and offloading crude oil directly to a shuttle tanker or via Single Point Mooring. The FPSO hull is usually a converted tanker, although newbuild vessels are also used, depending on the expected field life. Newbuild FPSOs are generally designed for a field life of 20-25 years, while a converted tanker is designed for a field life of 10-15 years. For harsh environments, FPSOs tend to be newbuilds.

Floating production systems have been utilized for over 30 years in a wide variety of water depths, weather conditions, and field types, and remain the most flexible and widely used system for developing offshore fields. FPSOs can be used on a short-term basis for extended well testing (before export facilities are available), early production systems (before production infrastructure is installed), and can be relocated for reuse.

Field development in deepwater and in areas with little or no existing offshore infrastructure have given floating production systems a dominant position in the development of new fields. There are over 100 FPSO installations worldwide, and more units operating than semisubmersibles, tension leg platforms, and spars combined. FPSOs and FSOs are used throughout Southeast Asia, the North Sea[31], West Africa, Brazil, Australia, and elsewhere (e.g.,

[31] The North Sea is the most active region in the world, with about half of the total FPSO installations worldwide.

Italy, Spain, Thailand, and Egypt). No FPSOs or FSOs are currently in use in the GOM because of the extensive pipeline infrastructure in the region.

Tension Leg Platform

A Tension Leg Platform (TLP) is a vertically moored compliant system which uses buoyant components to maintain tension in the mooring system. The platform is floated over the wellhead area and tethered at each corner by tubular members that are attached to piles. The first TLP used as a drilling and production platform was installed in the North Sea in 1984. The deepest TLP in the world is the Magnolia field in the GOM in 4,674 ft of water.

Semisubmersible

The semisubmersible (semi) was developed for offshore drilling in the 1960s, and by 1980, several of the units were converted for use as floating production vessels. A semi is a floating system that is moored using either suction piles or embedded plate anchors, depending on the soil conditions and installation logistics. A semi consists of pontoons, columns, and a large deck, and may have drilling capability. The pontoons and columns provide buoyancy to the system and vessel movements permit the use of rigid risers and dry trees. Three semisubmersible production units currently operate in the GOM (NaKika, Thunderhorse, Gomez).

Spar

A spar is a vessel with a circular cross-section that sits vertically in the water and is supported by buoyancy chambers (hard tanks) at the top, a flooded mid section structure hanging from the hard tanks, and a stabilizing keel section at the bottom (French et al., 2006). The hull uses standard ship-type plate and stiffener construction and contains an open centerwell (moonpool) for drilling. Stationkeeping is provided by lateral, catenary anchor lines which are attached to the hull near its center of pitch.

Three generations of spar designs have developed in the GOM: classic spar, truss spar, and cell spar. The first generation of spars was made of one cylindrical hull that extended to the bottom of the structure. The first classic spar installed in the GOM was at the Neptune field (1,935 ft) in 1996 (Vardeman et al., 1997). The truss spar is the second generation of spar design. In a truss spar, a truss structure (similar to a fixed platform) replaces the lower portion of the cylindrical hull, reducing the construction cost (and weight) and providing additional flexibility for drilling and topsides facilities. The first truss spar was installed at Nansen field (3,680 ft) in 2001 (Thibodeaux et al., 2002; Mitchell et al., 2004). The third generation of spar design is the cell spar, made up of several identically sized cylinders surrounding a center cylinder. Cell spars are the easiest and cheapest of the three designs to fabricate, but because they have no center opening for surface wellheads, only subsea production is possible (Lamey et al., 2005).

Subsea Completion

Subsea systems are multi-component seafloor facilities that allow the production of hydrocarbons from marginal fields or water depths that are currently precluded by conventional systems. The seafloor equipment will typically include subsea wells, manifolds, control umbilicals, and flowlines. Surface components of subsea systems includes the control system and other production equipment.

5.5. Platform Components and Weight Distribution

5.5.1. Jacket: Jackets have been designed and constructed in many shapes and sizes. The tube diameters of early jackets were limited in size, and so many legs and a multiplicity of horizontal and diagonal braces were required to obtain sufficient soil support (Graff, 1981). As tubular members became larger, the number of legs required for support decreased, and today, the majority of jacket structures are 4-pile and 8-pile platforms. Depending on design and construction requirements, platform legs in the GOM can be as small as 24 inches or as large as 96 inches; in Cook Inlet, Alaska, leg diameters range from 14-17 ft.

5.5.2. Piling and Conductors: Large plates of high strength steel up to 2.5 inches thick are rolled or formed into tubular shapes and welded longitudinally to form piles. In most offshore structures, piles range from 24 to 60 inches in diameter and extend through the water column, 30-50 ft above the water line, and 200-400 ft into the seabed. Piles are fabricated in pieces and assembled in the field. The length of a pile section depends on the lifting capacity and working height of the derrick barge that will lift the pieces into place. Piles are driven with high-energy impact hammers. As the water depth or the environmental forces increase, or the soil conditions at the site worsen, the number or size of the piles that provide lateral support and fix the jacket to the seabed will increase. In deepwater, skirt piles are used to increase the capacity of the structure to lateral forces or to lessen the pile penetration required.

A conductor provides structural strength and guides drilling and casing strings into the hole. The conductor string supports the wellhead, the Christmas tree, and subsequent casing strings (PETEX, 2005). Conductors are vertical tubes between 24 to 48 inches in diameter and are driven into the seabed 100-200 ft below the mudline. Conductor and piling is specified by its outside diameter and thickness, weight per unit length, grade of steel, type of construction, and length of joint. The mechanical and physical properties of casing are dependent on the chemical composition of the steel and the heat treatment it receives during manufacture.

5.5.3. Deck and Topsides: The deck sits on top of the jacket structure and is welded to the pile ends. The loads of the deck and topsides equipment are transferred to the jacket and piles via the system of deck floor beams, girders, and substructure trusses. Wind, waves and extreme weather load brought about by the decks and equipment are also conveyed to the jacket column. A deck may contain one or more levels and plan size varies depending on the number of jacket legs and the functional requirements of the platform. The lower level is designed to be high enough above the water so that the crest of storm waves clears the trusswork by a specified amount. Upper decks are placed above the lower deck to provide operating clearance for equipment.

The most sophisticated drilling and production platforms include production and utility equipment; bulk material (piping, electrical, instrumentation); drilling equipment; module, deck, and finishing steel; living quarters and helideck; flare booms and cranes. The total weight of drilling equipment usually ranges between 3,000-4,000 kips (1 kip = 0.45 ton[32]). A general rule of thumb is that topsides weight accounts for 500 pounds per square foot of deck area, so that a 1000 square foot deck space will weigh 500*1000 = 500,000 pounds (250 tons).

5.5.4. Weight Distribution: The distribution of jacket and deck weight for a typical 8-pile drilling/production platform in 300 ft water depth is shown in Table E.2 and Table E.3.

5.6. Floater Weight Functionals

5.6.1. Data Source: The 40 deepwater structures in the GOM are widely reported in the trade press, conference proceedings, and company literature, and thus, a complete enumeration of the structural specifications is feasible. Since spars and TLPs are the most prevalent deepwater structure in the GOM, we focus exclusively on these two structure classes.

5.6.2. Factor Description: The factor variables include topsides weight (*TOPSIDES*, ton), payload weight (*PAYLOAD*, ton), dry hull weight (*DRYHULL*, ton), hull diameter (*DIAM*, ft), total deck area (*DECK*, ft^2), hull volume (*VOL*, ft^3), production capacity (*CAP*, MBOE), and water depth (*WD*, ft).

The hull is characterized by its diameter and length and is designed using standard ship-type plate and stiffener construction. Dry hull weight is the weight of the hull without topsides facilities, and the hull volume is induced by its diameter and length. The size of the hull is usually proportional to the topside payload and the production throughout. Production capacity is determined by the specification of the processing equipment or the oil and gas maximum production, and is described in terms of barrels of oil equivalent (BOE)[33].

5.6.3. Spar Weight Algorithms: Spar weight characteristics are summarized in Table E.4 and one variable relations are graphed in Figures E.5 through E.7: topsides weight as a function of total deck area (Figure E.5), payload weight as a function of hull diameter (Figure E.6), and payload weight as a function of hull volume (Figure E.7). In Figure E.8, the correlation between the dry hull weight and topsides weight is shown. The one-variable factor relations are summarized in Table E.5. Multidimensional weight algorithms derived using a linear specification is presented in Table E.6.

5.6.4. TLP Weight Algorithms: Weight characteristics of TLPs in the GOM are summarized in Table E.7. In Figure E.9, topsides weight as a function of volume is depicted, and in Figure E.10, in terms of production capacity. The one-variable factor relations are summarized in Table E.5. In Table E.8, TLP weight algorithms are derived for a multivariable factor set.

5.7. Fixed Platform Weight Functionals

5.7.1. Data Source: Over the past half century, over 6,500 structures have been installed in the GOM. These structures have evolved with changes in design practices and regulatory standards

[32] 1 ton = 1 short ton = 2,000 lb.
[33] Since oil is described in barrels (bbl) and gas in cubic feet (cf), the "barrels of oil equivalent" heat conversion 6 Mcf gas = 1 bbl oil is used to transform the production capacity into a BOE-equivalent stream.

(Mangiavacchi et al., 2005), and in 2006, there are about 3,000 structures that are active. Before a structure is installed in the GOM, the operator submits an application to the MMS in accordance with 30 CFR 250.901, describing the design loadings, size and thickness of structural members, jacket and deck weights, and other specifications. For nonstandard designs, third party and Certified Verification Agents review and approve the blueprints. The jacket and deck weight data from these specifications is not recorded or stored in the MMS TIMS database, and so there does not exist a public, central repository of weight data. Fabrication facilities maintain specifications for projects in which they are involved, but these are closely guarded by the industry and not available for analysis.

Weight data collected from the decommissioning project management firm Twachtman, Synder, and Bryd, Inc. (TSB) were used to develop weight algorithms for structures in water depth less than 500 ft. TSB maintains a public database on structures available for sale in a Platform Listing Service (www.tsboffshore.com). Structure data was reviewed over a three-year period, filtered, and processed. About 60 structures were acceptable for analysis. The weight data was supplemented with additional data collected through the trade press and various other sources.

For platforms in water depth 500-1000 ft, Pacific Coast structures were used to proxy for the GOM. There are only two dozen Pacific Coast structures, and because they have reliable and complete weight data (Gebauer et al., 2004), the processing is straightforward. The disadvantage of using Pacific Coast structures is that the environmental and design criteria are different than the GOM, which will bias the correspondence.

5.7.2. Factor Description: Fixed platform structures are classified according to type and function. Structure type is defined by caisson, well protector, and fixed platform. Structure function is defined by drilling platform, production platform, drilling/production platform, and auxiliary platform. Structures are composed of a jacket (*j*), deck (*d*), piles (*p*), conductors (*c*), and topside equipment (*e*). The weight in tons associated with each element is described by W_j, W_d, W_p, W_c, and W_e, respectively.

Variables that potentially impact weight include water depth (*WD*, ft), deck area (*DECK*, ft^2), footprint[34] (*FOOT*, acre), production capacity (*CAP*, MBOE), pile diameter (D_p, in), conductor diameter (D_c, in), pile length (L_p, ft), conductor length (L_c, ft), number of conductors (*NC*), and number of piles (*NP*). Complexity factors (CF_i, i= 1, 2, 3) can also be specified if additional data[35] is available.

5.7.3. Function Specification: The weight of each structure component is a function of one or more factors. Piles and conductors are tubular elements and the weight of any tubular element can be determined (precisely) by its diameter, length, thickness, and material density. Jacket, deck, and topsides components have more complex geometry and depend on numerous

[34] Footprint is the mat area at the seabed formed by the jacket.

[35] For example, if the production capacity is known or can be estimated, this will serve as a potential explanatory variable for topsides weight. Variables such as the number of trains, number of dry trees, quarters size, generation capacity, rig type, etc. may also be useful in the formulation of a composite complexity index for deck weight. Jacket weight may include information such as the inclusion of skirt piles and other factors.

interdependent and unobservable factors. The hypothesized functional relations are specified as follows:

$$W_p = W_p(D_p, L_p),$$
$$W_c = W_c(D_c, L_c),$$
$$W_j = W_j(WD, DECK, W_d, NP, CF_1),$$
$$W_d = W_d(DECK, CF_2), \text{ and}$$
$$W_e = W_e(SF, W_d, CF_3).$$

Pile/Conductors

The weight of steel pipe is expressed in weight per foot according to the formula:

$$w = 10.69(D - t)t,$$

where w = weight of steel pipe (lb/ft), D = outside (nominal) diameter of pipe (in), and t = wall thickness of pipe (in). This formula is based on the density of steel assumed to be 0.2836 pounds per cubic inch.

The total weight of steel pipe is determined as

$$W_i = w_i L_i,$$

for piling ($i = p$) and conductors ($i = c$), where L_i = total weight of steel pipe (lbs), w_i = unit weight of steel pipe (lb/ft), and L_i = total length of steel pipe (ft).

Diameter, thickness, and length for a given tubular element may or may not be known. Pile diameter typically ranges between 24 to 96 inches and conductor diameter between 24 to 60 inches. Pile diameter may be approximated by leg diameter if available. The thickness of pipe is often not reported, and so it is necessary to assume a value for thickness, 1 to 2 inches being a reasonable assumption.

The length of a tubular member is computed as $L = WD + AWL + BML$, where AWL = above water line height (ft) and BML = below mud line depth (ft). Piles, conductors, and skirt piles are typically driven into the seabed, anywhere from 200-400 ft, depending on soil conditions[36], water depth, and other factors, and extend above the water line anywhere between 30-50 ft. Water depth is a widely reported statistic for GOM structures, but AWL and BML variables will need to be estimated. Skirt piles do not extend through the water column and their length is determined by L = BML.

[36] In soft soil regions, more skirt piling, deeper piles, and thicker steel are required. These conditions are independent of water depth.

Jacket

A jacket extends from the seabed, through the water column, and above the water line. The size of the jacket and dimensions determines the amount of steel used in its construction. Jackets taper out as they approach the seabed depending on the water depth at the site. Leg batter for structures in water depth less than 500 ft is typically in the range of 1:5 to 1:8 (horizontal: vertical). For deepwater structures, leg batter is often reduced to 1:16-20 (Drawe, 1986). If the deck area and water depth is known, then the footprint can be estimated using a suitable leg batter ratio, and vice versa; if the mat footprint and water depth is known, then under a given leg batter ratio we can estimate deck area. Jacket weight depends upon the function of the structure, and more specifically, deck weight, and may also be correlated with age; e.g., older structures are expected to be more robust/heavier than recent installations, and other (unobservable) characteristics; e.g., design philosophy, soil conditions, environmental requirements.

Deck and Topsides Facilities

The weight of the deck is proportional to the total deck area, the number of levels, substructure complexity, and structure function. Deck weight should not depend on water depth. The topsides dry weight is a function of the hydrocarbon production rate and field type, and includes major equipment (production and utility equipment, drilling equipment, crane, flare boom), bulk material (piping, valves, instrumentation, fireproofing, cladding, miscellaneous support), and topsides structural steel (stairways, walkways, etc.). Weight data for fixed platforms are frequently reported in aggregate, as $W_d + W_e$, but only for simple structures will the deck and topsides weight approximately equal the deck weight. Deck structure and piping usually make up 70-80% of the total weight, with equipment comprising the remaining weight.

5.7.4. Fixed Platform Weight Algorithms:

0 - 500 ft Water Depth

Weight data for structures that have been decommissioned over the past 5-10 years serve as our data source, and thus our sample is composed primarily of older structures, mostly from 20-40 years of age. For caissons and well protectors, aggregate statistics indicate that one square foot of deck area correspond on average to 15 tons and 25 tons deck weight, while for drilling and production platforms, the average deck weight was 20 tons/ft^2. The deck weight for caissons and well protectors as a function of deck area is shown in Figure E.11. In Figure E.12, the jacket weight for well protectors and fixed platforms as a function of water depth is shown. Table E.9 summarizes the one-dimensional relations. Table E.10 depicts representative multidimensional weight algorithms.

501 - 1000 ft Water Depth

Weight characteristics of the Pacific Coast infrastructure are summarized in Table E.11. Jacket weight and total weight is depicted as a function of water depth in Figure E.13, where the total weight of the structure includes the deck, jacket, piling, and conductors. Piling and conductor weight also exhibit a well-defined relation with water depth. Deck weight as a function of footprint is shown in Figure E.14. A summary of the power relations is provided in Table E.12. In Table E.13, representative weight algorithms are derived for a multivariable factor set.

5.8. Steel Tonnage Decommissioned in 2003

The amount of steel decommissioned in the GOM in 2003 is estimated. In 2003, there were 73 caissons, 25 well protectors, and 70 fixed platforms decommissioned in the federal offshore waters of the GOM (Table E.14). Twenty structures were reefed in the Central and Western Gulf of Mexico during the year.

All caissons are disposed onshore, but reefing will reduce the amount of deck and jacket tonnage. None of the decommissioned structures was reused (towed directly to site) for another field development. For each structure, the weight algorithms previously developed are used to estimate the amount of caisson, piling, deck and jacket steel brought to shore (Tables E.15 and E.16).

The location (block) of a structure will determine its likely geographic destination, but gross approximations can also be used, since tracking the destination of individual structures on an aggregate basis is difficult at best. For the geographic destination, we assume that the structures are disposed (stored or scrapped) in the general proximity of there planning area in accord with the proportion of structures decommissioned in the region.

Pile and conductor weight is computed based on the previous unit weight algorithm assuming a one inch tubular thickness, AML = 30 ft, BML = 15 ft, an average conductor diameter of 30 m, and an average pile diameter of 48 in. Well protector and fixed platform weight is computed according to the weight algorithms based on available public data associated with each structure. Conductor and pile diameter are assumed as before unless better data is available.

REFERENCES

Aird, D. 2001. Rig Acceptance Guidelines. Kingdom Drilling, RAG01. Internet website: http://www.kingdomdrilling.co.uk/engine/adobe/RAG01.pdf.

Ahluwalia, R.S. and P. Sibal. 2002. "Dismantling of obsolete vessels." *AACE International Transactions.* 1-6.

American Metal Market. 2006. AMM.com – The World Metals Information Network. Internet Website: http://www.amm.com/.

American Petroleum Institute. 1978. *Specifications for Carbon Manganese Steel for Offshore Platform Tubular Joints*. 2nd Ed. API Spec 2H. Washington, D.C.

American Petroleum Institute. 2000. *Recommended Practice for Planning, Designing, and Constructing Fixed Offshore Platforms*. 21st Ed., API RP 2A. Washington D.C.

Anderson, R. and A. Boulanger. 2004. "Lean energy management–7: Knowledge management and computational learning for lean energy management." *Oil and Gas Journal*. 102(44):36-40.

Austin, D., B. Carriker, T. McGuire, J. Pratt, T. Priest, and A.G. Pulsipher. 2004. *History of the offshore oil and gas industry in Southern Louisiana: Interim report; Volume I: Papers on the evolving offshore industry*. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-049. 98 pp.

Bailey, P.J. 2000a. "Is there a decent way to break up ship?" Sectoral Activities Programme Discussion Paper, International Labour Organization, Geneva.

Bailey, P.J. 2000b. "The social and labour impact of globalization in the manufacture of transport equipment." International Labour Organization, Geneva.

Baker Hughes. 2006. Baker Hughes Incorporated Oilfield Services. Internet Website: http://www.bakerhughes.com/bakerhughes/.

Baud, R.D., R.H. Peterson, C.E. Richardson, L.S. French, J. Regg, T. Montgomery, T.S. Williams, C. Doyle, and M. Dorner. 2002. *Deepwater Gulf of Mexico 2002: America's expanding frontier*. 2002. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Report MMS 2002-021. 133 pp.

Berkman, S. and T. Stokes. 2006. "53rd ReedHycalog rig census: Record number of newbuilds joins the rig fleet." *World Oil*. 227(10):69-82.

Bossink, B.A.G. and H.J.H. Brouwers. 1996. "Construction waste: quantification and source evaluation." *ASCE Journal of Construction Engineering and Management.* 122(1):55-60.

Bothamley, M. 2004. "Offshore processing options vary widely." *Oil and Gas Journal*. 102(45): 47-55.

Broughton, A.C. 2001. "Scrap by barge." *Recycling Today.* July.

Chun, L.P., K.R. Grosskopt, and C.J. Ribert. 1994. "Construction waste management and recycling strategies in the United States." In: Kibert, C.J., ed. *Sustainable Construction*. Center for Construction and Environment, Gainsville, FL. Pp. 689-696.

Clarke, C.S.J., C. Shaw, and R. Buchanon. 2005. "Extreme forces of nature." Global Offshore Report, August 2005, pp. 72-76.

Cohn G. and W. Englund. 1997a. "Scrapping ships, sacrificing men." *The Baltimore Sun*, December 7. Internet website: http://www.pulitzer.org/year/1998/investigative-reporting/works/day1/1.html.

Cohn G. and W. Englund. 1997b. "The curious captains of a reckless industry." *The Baltimore Sun*, December 8. Internet website: http://www.pulitzer.org/year/1998/investigative-reporting/works/day2/1.html.

Cohn G. and W. Englund. 1997c. "A third world dump for America's ships?" *The Baltimore Sun*, December 9. Internet website: http://www.pulitzer.org/year/1998/investigative-reporting/works/day3/1.html.

Colledge, K.G. 1994. "The scrap sale of six long term stacked MODU's." IADC/SPE Drilling Conference in Dallas, TX, Feb. SPE Paper 27442.

Creese, R.C. and P. Sibal. 2001. "Ship dismantling cost review." *2001 AACE International Transactions*. Pp. 33-37.

Culwell, A.S. 1997. "Removal and disposal of deck and jacket structures." In: Manago, F. and B. Williamson, eds. *Proceedings: Public workshop, decommissioning and removal of oil and gas facilities offshore California: Recent experiences and future deepwater challenges, September 1997*. U.S. Dept. of the Interior, Pacific OCS Region, Camarillo, CA. OCS Study MMS 98-0023. Pp. 48-65.

Dauterive, L. 2001. *Rigs-to-reefs, policy, progress, and perspective*. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Report MMS 2000-073. 8 pp.

DEMEX. 2004. DEMEX International, Inc. Internet Website: http://www.demex.us/.

Drawe, W.J. 1986. "Conceptual development." In: McClelland, B. and M.D. Reifel, eds. *Planning and Design of Fixed Offshore Platforms*. Van Nostrand Reinhold Company, New York. Pp. 519-545.

Drawe, W.J. and M.D. Reifel. 1986. "Platform function and types." In: McClelland, B. and M.D. Reifel, eds. *Planning and Design of Fixed Offshore Platforms*. Van Nostrand Reinhold Company, New York. Pp.11-23.

The Economist. 2005. "Breaking up is hard to do." *The Economist: Technology Quarterly*. 377(8456):10-12.

Ellis, J. and R. Shirley. 2005. "A weighty issue." *Offshore Engineer*. April. Pp. 125-128.

Federal Register. 2002. Dept. of the Interior, Minerals Management Service, 30 CFR Parts 250, 256, Oil and Gas and Sulphur Operations in the Outer Continental Shelf – Decommissioning Activities; Final Rule. 67(96): 35398-35412.

Fenton, M.D. 2006. "Iron and steel scrap." *Mineral Commodity Summaries*. U.S. Geological Survey, January.

French, L.S., G.E. Richardson, E.G. Kazanis, C.M. Bohannon, and M.P. Gravois. 2006. *Deepwater Gulf of Mexico: 2006: America's expanding frontier*. U.S. Dept. of the Interior, Minerals Management Services, Gulf of Mexico OCS Region, New Orleans, LA. OCS Report MMS 2006-022. 144 pp.

Gebauer, D., C. Hoffman, E.L. Lim, M. Mitchell, G. Shackell, J. Smith, and F.L. White. 2004. *Offshore facility decommissioning costs*. U.S. Dept. of the Interior, Minerals Management Service, Pacific OCS Region, Camarillo, CA.

Gerwick, B.C., 2000. *Construction of Marine and Offshore Structures*. 2nd Edition. CRC Press, Boca Raton, FL.

Gohre, S. 2000. "Globalization's downside – from shipyard to graveyard: Is there a decent way to break ships." *World of Work*. International Labor Organization, Geneva. No. 37, December.

Graff, W.J. 1981. *Introduction to Offshore Structures*. Gulf Publishing Company, Houston, TX.

Guegel, A. 2004. "Unifab needs a new cash boost." *Upstream*. April 16. P. 18.

Helton, D. 2004. *Wreck removal: A federal perspective*. Office of Response and Restoration, National Oceanic and Atmosphere Administration, Seattle, WA.

Hess, R., D. Rushworth, M.V. Hynes, and J.E. Peters. 2001. *Disposal options for ships*. RAND National Defense Research Institute. MR-1377-NAVY.

Hyne, N.J. 1995. *Nontechnical Guide to Petroleum Geology, Exploration, Drilling, and Production*. PennWell Books, Tulsa, OK.

Hynes, M.V., J.E. Peters, and D. Rushworth. 2004. *Artifical reefs – a disposal option for Navy and MARAD ships*. RAND National Defense Research Institute. DB-391-NAVY.

Institute of Scrap Recycling Industries. 2001a. *Scrap Specifications Circular 2001, Guidelines for Metals Transactions*. Washington, D.C.

Institute of Scrap Recycling Industries. 2001b. *Scrap Specifications Circular 2001, Guidelines for Ferrous Scrap FS-01*. Washington, D.C.

International ShipBreaking, Ltd. 2005. International ShipRecycling Limited. Internet Website: http://www.shiprecycling.com/.

Kaiser, M.J. 2006. "Offshore decommissioning cost estimation in the Gulf of Mexico." *Journal of Construction Engineering and Management*. 132(3):249-258.

Kaiser, M.J. and D.V. Mesyanzhinov. 2004. "A note on idle oil and gas platforms (idle iron) in the Gulf of Mexico." *Ocean Development and International Law*. 35(4):377-389.

Kaiser, M.J., D.V. Mesyanzhinov, and A.G. Pulsipher. 2004. *Long-term oil and gas structure installation and removal forecasting in the Gulf of Mexico: A decision- and resource-based approach*. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Study MMS 2004-009. 56 pp.

Kaiser, M.J. and A.G. Pulsipher. 2005. "Rigs-to-reef programs in the Gulf of Mexico." *Ocean Development and International Law*. 36(2):119-134.

Kaiser, M.J., A.G. Pulsipher, and R.C. Byrd. 2003. "Decommissioning cost functions in the Gulf of Mexico." *ASCE Journal of Waterways, Ports, Harbors, and Ocean Engineering*. 129(6):1-11.

Kaiser, M.J., A.G. Pulsipher, and J. Martin. 2005. "The cost of site clearance and verification operations in the Gulf of Mexico." *ASCE Journal of Construction Engineering and Management*. 131(1):117-126.

Kellock, T. 2006. "Offshore rig construction: Too much or too little." ODS-Petrodata, Houston, TX.

Lamey, M., P. Hawley, and J. Maher. 2005. "Red Hawk Project: overview and project management," Proceedings of Offshore Technology Conference, OTC 17213, Houston, TX, May 2-5.

Landes, S.H. 1986. "Operational loadings." In: McClelland, B. and M.D. Reifel eds. *Planning and Design of Fixed Offshore Platforms*. Van Nostrand Reinhold Company, New York. Pp. 27-45.

Lee, G.C. 1968. “Offshore structures: past, present, future, and design considerations.” *Offshore*. 28(6):44-55.

Lohrenz, J. 1991. “Shut-In and abandonment decision economics.” SPE Hydrocarbon Economics and Evaluation Symposium, Dallas, TX, April 11-12. SPE 20014.

Mangiavacchi, A., G. Rodenbusch, and D. Wisch. 2005. “API offshore structure standards: RP 2A and much more.” Offshore Technology Conference, Houston TX, May 2-5. OTC 17697.

Marley, M. 2006. “Metro machine ship dismantling facility closing for lack of work.” *American Metal Market*. May 30, 2006. P. 8.

Marshall, P.W. 1986. “Steel selection for fracture control.” In: McClelland, B. and M.D. Reifel eds. *Planning and Design of Fixed Offshore Platforms*. Van Nostrand Reinhold Company, New York. Pp. 692-719.

Mather, A. 2000. *Offshore Engineering: An Introduction*. 2nd Edition. Witherby & Company Ltd, London, UK.

McClelland, B. and M.D. Reifel, eds. 1986. *Planning and Design of Fixed Offshore Platforms*. Van Nostrand Reinhold Company, New York.

Mitchell, G.D., Y. Delepine, and S. Rasmussen. 2004. “Gunnison development: Project management & lessons learned.” Proceedings of Deepwater Offshore Technology Conference, DOT 168, November 30-December 2.

National Marine Fisheries Service–Galveston. 2004. NOAA Fisheries – National Marine Fisheries Service. Internet Website: http://www.nmfs.noaa.gov/.

National Research Council. 1985. *Disposal of Offshore Platforms*. National Academy Press, Washington, D.C.

National Research Council, Marine Board, Committee on Techniques for Removing Fixed Offshore Structures. 1996. *An Assessment of Techniques for Removing Offshore Structures*. National Academy Press, Washington, D.C.

ODS-Petrodata. 2006. ODS-Petrodata. Internet Website: http://www.ods-petrodata.com/Home?newURL=opd.

PETEX. 2005. *Offshore Well Construction*. University of Texas, Petroleum Extension Service, Austin, TX.

Pinkham, M. 1995. “The tide is rising fast in rig-to-reef programs – recycling technology.” *American Metal Market*. August.

Prasthofer, P. 1997. "Offshore production facilities: Decommissioning of topside production equipment." In: Manago, F. and B. Williamson, eds. *Proceedings: Public workshop, decommissioning and removal of oil and gas facilities offshore California: Recent experiences and future deepwater challenges, September 1997*. U.S. Dept. of the Interior, Pacific OCS Region, Camarillo, CA. OCS Study MMS 98-0023. Pp. 38-47.

Pratt, J.A., T. Priest, and C.J. Castaneda. 1997. *Offshore Pioneers Brown & Root and the History of Offshore Oil and Gas.* Gulf Publishing Company, Houston, TX.

Rahman, A. and T. Ullah. 1999. "Report on ship-breaking." Sectoral Activities International Labour Organization, Dhaka, October.

Reggio, Jr., V.C. 1987. *Rigs-to-reefs: The use of obsolete petroleum structures as artificial reefs*. U.S. Dept. of the Interior, Minerals Management Service, Gulf of Mexico OCS Region, New Orleans, LA. OCS Report MMS 87-0015. 17 pp.

Rhodes, D.P. 2001. *An investigation of the availability and affordability of workers' compensation insurance in the ship dismantling industry*. Indiana University of Pennsylvania National Environmental Education and Training Center, Indiana, PA.

Rose, P.R. 2001. *Risk Analysis and Management of Petroleum Exploration Ventures*. American Association of Petroleum Geologists, Tulsa, OK.

R.S. Platou Offshore. 2005. *Offshore Rig Market Status Report*. Oslo, Norway.

Schroeder, D.M. and M.S. Love. 2004. "Ecological and political issues surrounding decommissioning of offshore oil facilities in the Southern California Bight." *Ocean and Coastal Management*. 47(1-2):21-48.

Schultmann, F. and O. Rentz. 2002. "Scheduling of deconstruction projects under resource constraints." *Construction Management and Economics*. 20(5):391-401.

Seba, R.D. 2003. *Economics of Worldwide Petroleum Production*. OGCI and Petroskills Publications, Tulsa, OK.

Shivers, R.M., C.T. Skies, J.W. Chianis, R. Aggarwal, and D.E. Berner. 2001. "Cost effective dry tree field development in deepwater West Africa." Offshore Technology Conference, Houston, TX., April 30-May 3. OTC 12985.

Stopford, M. 1997. *Maritime Economics*. 2nd Edition, Routledge, London, UK.

Stopford, M. 2005. "Market outlook: Where now, where next?" Clarkson Dubai Seminar, Dubai, UAE, November 26.

Taylor, B. 2002. "Top 20 ferrous scrap processors in the United States." *Recycling Today*. March.

Taylor, B. 2003. "Top 20 nonferrous scrap processors." *Recycling Today*. April.

Teo, M.M.M. and M. Loosemore. 2001. "A theory of waste behavior in the construction industry." *Construction Management and Economics*. 19(7):741-751.

Thibodeaux, C.J., R.D. Vardeman, and C.E. Kindel. 2002. "Nansen/Boomvang projects: Overview and project management." Offshore Technology Conference, Houston, TX., May 6-9. OTC 14089.

Twachtman Snyder and Byrd, Inc. 2006. Platform Listing Service. Internet Website: http://pls.tsboffshore.com/sellindex.asp.

U.N. General Assembly. 2000. Oceans and Law of the Sea, Division for Ocean Affairs and the Law of the Sea, Reports of the Secretary-General, Doc. A/55/61. Internet Website: http://www.un.org/Depts/los/general_assembly/general_assembly_reports.htm.

U.S. Coast Guard. 1994. "Guidance for determination and documentation of the Oil Pollution Act of 1990 (OPA 90) phase-out schedule for existing single hull vessels carrying oil in bulk." *Navigation and Vessel Inspection Circular No. 10-94*. Washington, D.C., December 22.

U.S. Dept. of Labor. Occupational Safety & Health Administration. 2005. *OSHA's national emphasis program (NEP) on shipbreaking*. Washington, D.C. CPL 02-00-136.

U.S. Dept. of the Interior. Minerals Management Service. 2004. U.S. Dept. of the Interior. Minerals Management Service. Pacific OCS Region. Pacific OCS Platforms. Internet Website: http://www.mms.gov/omm/pacific/offshore/platforms/platformintro.htm.

U.S. Dept. of the Interior. Minerals Management Service. 2006. U.S. Dept. of the Interior. Minerals Management Service. Gulf of Mexico Region. Deepwater Information. Internet Website: http://www.gomr.mms.gov/homepg/offshore/deepwtr.html.

U.S. Dept. of the Treasury. Internal Revenue Service. 1999. *Market segment specialization program: Scrap metal industry*. U.S. Government Printing Office, Washington, D.C.

U.S. Dept. of Transportation. Maritime Administration. 2000. *Audit report on the program for scrapping obsolete vessels*. Office of Inspector General, Washington, D.C. Report No. MA-2000-67.

U.S. Dept. of Transportation. Maritime Administration. 2005. *Report to Congress on the progress of the vessel disposal program*. Washington, D.C.

U.S. Environmental Protection Agency. 1998. *Self-audit and inspection guide for facilities conducting ship scrapping*. Washington, D.C.

U.S. General Accounting Office. 2004. *Improved program management needed to address timely disposal of obsolete ships*. Washington, D.C. GAO-05-264.

U.S. Geological Survey. 2005. USGS Minerals Information: Iron and Steel Scrap. Internet Website: http://minerals.usgs.gov/minerals/pubs/commodity/iron_&_steel_scrap.

Vardeman, R.D., S. Richardson, and C.R. McCandless. 1997. "Neptune project: Overview and project management." Offshore Technology Conference, Houston, TX., May 5-8. OTC 8381.

Veldman, H., and G. Lagers. 1997. *50 Years Offshore*. Foundation for Offshore Structures, Delft, Holland.

APPENDIX A

CHAPTER 1 TABLES AND FIGURES

Table A.1

Gulf of Mexico Infrastructure (2003)

Water Depth	WGOM			CGOM			GOM
(ft)	CAIS	WP	FP	CAIS	WP	FP	Auxiliary
0-20	1	0	0	200	10	35	79
21-100	79	25	119	767	268	710	318
101-200	3	17	83	49	63	490	73
201-400	1	4	86	1	12	320	31
400+	0	0	13	0	3	43	4
TOTAL	84	46	301	1,017	356	1,598	505

Source: Kaiser et al., 2004

Table A.2

Number of Deepwater Production Facilities Installed in the Gulf of Mexico, Including Plans Through 2006

Development Strategies	Number
Fixed Platform	5
Compliant Tower	3
TLP	8
Small TLP	6
Spar	4
Truss Spar	8
Semi FPS	5
Subsea	164

Source: (MMS, 2006)

Table A.3

Active, Idle, and Auxiliary Structure Statistics – Active and Inactive Leases (2003)

Lease Type	Parameter	Caisson	Well Protector	Fixed Platform	Total
Active					
	Active structures	503	225	1,447	2,175
	Idle structures	484	136	278	898
	Auxiliary structures				440
	Total age – active (yr)	6,848	5,151	29,578	41,577
	Total idle age (yr)	4,021	946	2,089	7,056
	Total age – idle (yr)	11,892	4,071	7,622	23,578
	Idle age/Total age (%)	21	10	6	11
Inactive					
	Idle structures	114	41	174	329
	Auxiliary structures				65
	Total idle age (yr)	558	180	565	1,303
	Total age (yr)	1,916	833	3,358	6,107
	Idle age/Total age (%)	29	22	17	21
All					
	Active structures	503	225	1,447	2,175
	Idle structures	598	177	452	1,227
	Auxiliary structures				505
	Total age – active (yr)	6,848	5,151	29,578	41,577
	Total idle age (yr)	4,579	1,126	2,654	8,359
	Total age – idle (yr)	13,808	4,904	10,980	29,692
	Idle age/Total age (%)	22	11	7	12

Note: Auxiliary structures were not decomposed in terms of function type because this data was not available for analysis.

Table A.4

Distribution of Idle Structures on Active Leases (2003)

k	Number of active leases with k active structures	Number of k active leases with l idle structures										
		l = 0	1	2	3	4	5	6	7	8	9	10
1	944	773	118	29	8	6	3	3	2	0	0	2
2	245	171	40	20	7	1	2	3	0	1	0	0
3	84	36	26	12	5	1	0	1	3	0	0	0
4	35	12	9	4	5	0	1	1	0	0	0	0[a]
≥ 5	48	12	4	6	7	2	4	5	0	1	0	1[b]
Total	1,356			71	32	10	10	13	5	2	0	3

Footnote: a) One lease exists with 13 idle structures, 2 leases exist with 14 idle structures.
b) Six leases exist with 14, 17, 19, 23, 44, 55 idle structures.

Table A.5

Number of Active, Idle, and Auxiliary Structures on Active Leases (2003)

k	Number of active leases with k active structures	Number of active structures	Number of idle structures	Number of auxiliary structures
1	944	944	291	129
2	245	490	141	79
3	84	252	96	66
4	35	140	84	43
≥ 5	48	348	286	123
Total	1,356	2,175	898	440

Table A.6

Distribution of Idle Structures on Inactive Leases (2003)

l	Number of inactive leases with l inactive structures	Total number of idle structures	Average idle age (yr)
1	197	113	5.1
2	21	40	4.3
3	9	26	4.9
4	7	27	5.1
≥ 5	14	123	5.3
Total	248	329	5.1

Table A.7

GOM Production Statistics by Operator (2003)

Company	2003 Production (MMBOE)	Percentage (%)
Shell Offshore	139	14.3
ChevronTexaco	124	12.8
BP Exploration & Production	84	8.7
ExxonMobil	72	7.5
Apache	41	4.2
Kerr-McGee	30	3.1
El Paso	25	2.6
Union Oil	21	2.2
Marathon	21	2.2
Devon Louisiana	19	2.0
Newfield Exploration	18	1.9
Dominion E&P	18	1.9
Anadarko Petroleum	17	1.8
Forest Oil	16	1.7
Stone Energy	16	1.6
Devon Energy Production	15	1.6
Pogo Producing	15	1.5
Samedan Oil	14	1.4
BP America Production	12	1.3
W&T Offshore	10	1.1
Anadarko E&P	10	1.0
Conoco Phillips	10	1.0
Apache Clearwater	10	1.0
GOM Shelf	9	0.9
Nexen Petroleum Offshore	9	0.9

Table A.8

Number of Active, Auxiliary, and Idle Structures by Ownership in the GOM (2003)

Company	Active	Auxiliary	Idle	Total
ChevronTexaco	311	95	157	562
Apache	160	30	43	234
Union Oil	72	37	39	149
Forest Oil	81	18	36	136
Devon Louisiana	55	22	34	111
Samedan Oil	72	11	29	111
J.M. Huber	24	9	63	95
Energy Partners	41	8	45	94
Newfield Exploration	67	9	16	92
Stone Energy	58	8	21	87
Anadarko Petroleum	47	14	25	86
ExxonMobil	63	9	10	81
BP Exploration & Production	48	7	24	79
Devon Energy Production	42	8	23	73
Comstock Offshore	22	10	40	72
Kerr-McGee Oil & Gas	34	7	26	68
BP America	43	6	17	66
Murphy E&P	26	8	28	62
W&T Offshore	39	4	17	60
Energy Resource Technology	44	4	7	55
Nexen Petroleum Offshore	35	7	10	52
GOM Shelf	33	6	9	48
Anadarko E&P	34	3	8	45
Houston Exploration	31	1	11	43
El Paso Production	29	6	7	42
Apache Clearwater	27	1	4	32
SPN Resources	16	7	10	32
El Paso Production Oil & Gas	27	2	2	30
El Paso Production GOM	25	3	2	30
Shell Offshore	19	3	2	24
Maritech Resources	15	2	6	24
Hunt Oil	12	3	9	23
Dominion E&P	19	2	1	22
GOM Oil and Gas Properties	12	4	5	20

Table A.9

Total Idle Age and Total Age by Ownership in the GOM (2003)

Company	Total Idle Age (yr)	Total Active Age (yr)
Chevron Texaco	1,507	14,176
J.M. Huber	1,227	3,614
Apache	532	4,715
Devon Louisiana	458	2,830
Energy Partners	458	3,494
Forest Oil	420	2,882
Comstock Offshore	352	1,420
Union Oil	319	4,000
Samedan Oil	296	2,063
BP Exploration & Production	276	1,499
Murphy E&P	271	1,160
Kerr-McGee Oil & Gas	267	1,265
Stone Energy	229	1,847
Devon Energy Production	222	1,703
Anadarko Petroleum	210	1,595
Newfield Exploration	204	1,573
ExxonMobil	187	2,384
BP America Production	174	1,765
W&T Offshore	141	945
Energy Resource Tech.	114	1,107
SPN Resources	105	717
Anadarko E&P	102	699
Hunt Oil	102	553
El Paso Production	102	615

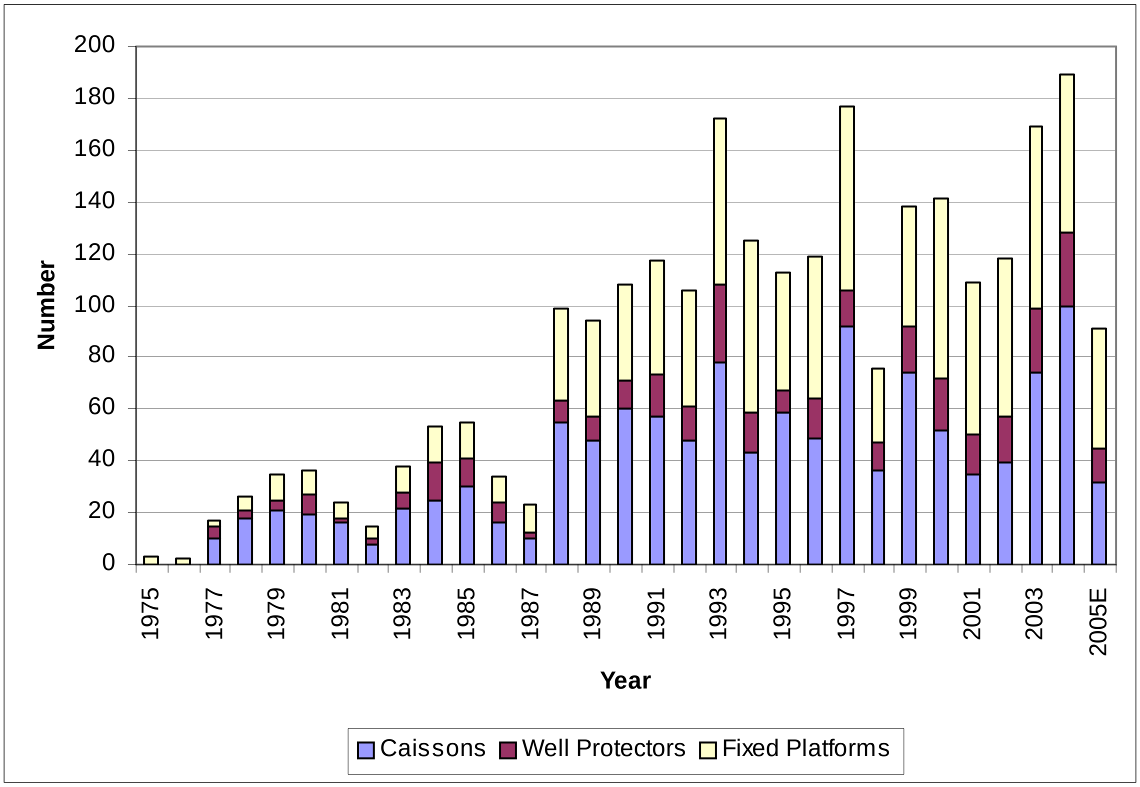

Figure A.1. Structures Removed in the Outer Continental Shelf of the Gulf of Mexico, 1973-2005 (Data for 2005 as Reported on March 3, 2006 and Indicated as 2005E).

Figure A.2. Caisson, Well Protector, and Fixed Platform Structures (Twachtman Snyder & Byrd, Inc., 2006).

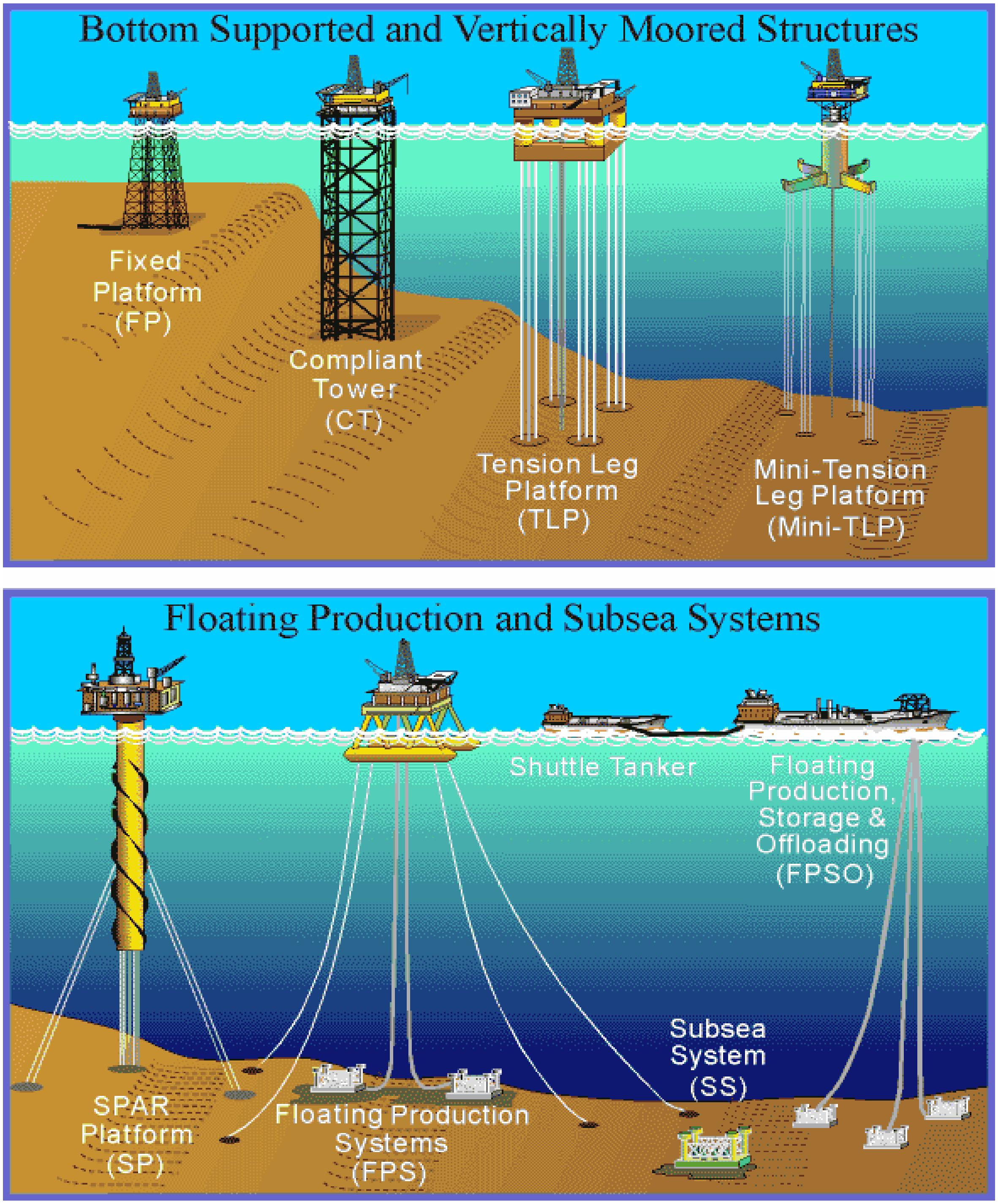

Figure A.3. Deepwater Development Strategies (French et al., 2006).

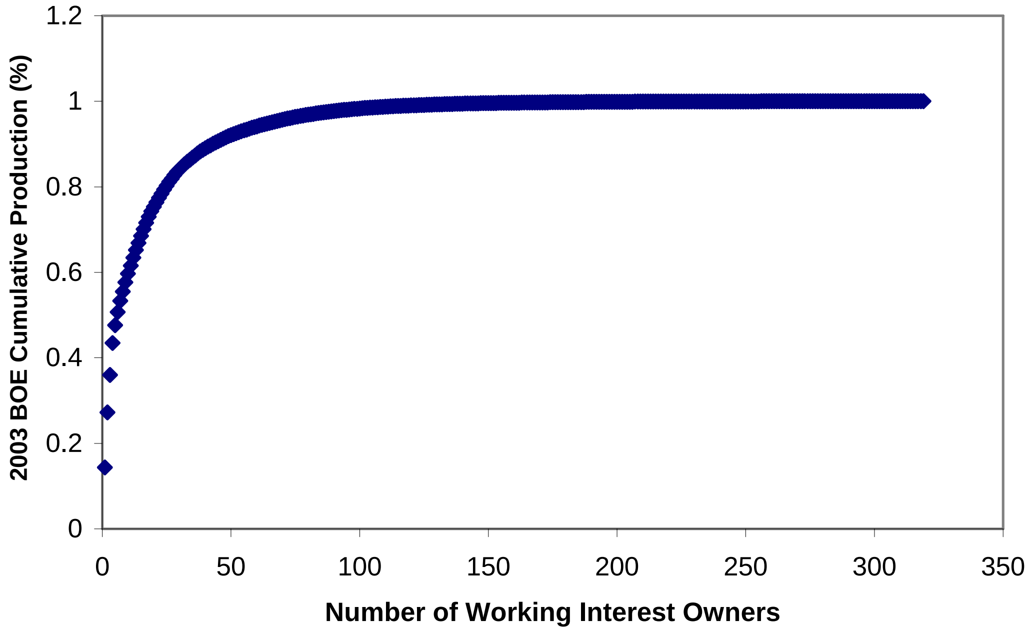

Figure A.4. 2003 Cumulative Production and the Number of Working Interest Owners.

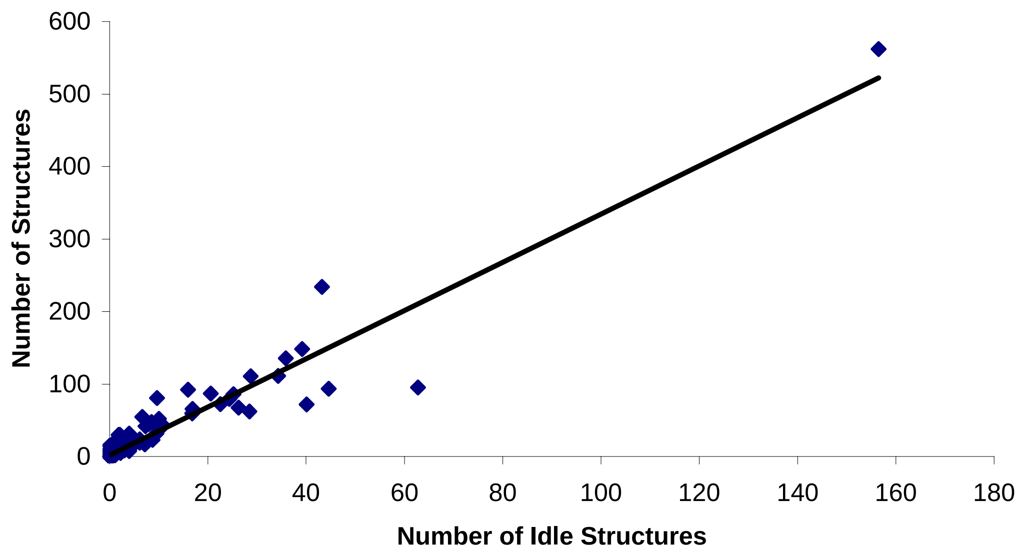

Figure A.5. Number of Structures and Idle Structures.

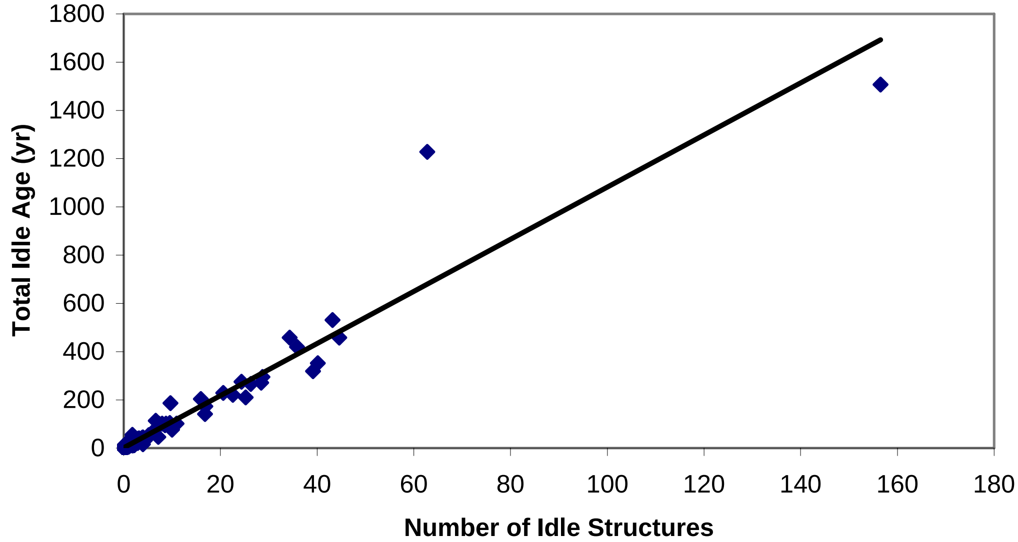

Figure A.6. Total Idle Age and Number of Idle Structures.

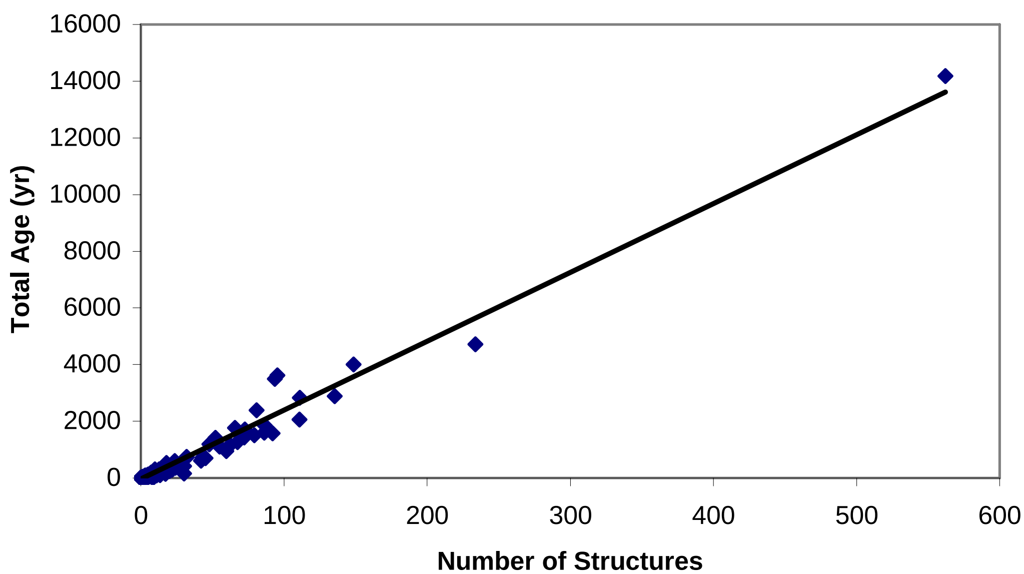

Figure A.7. Total Age and Number of Structures.

APPENDIX B

CHAPTER 2 TABLES AND FIGURES

Table B.1

Regulatory Scenarios for Removal Requirements, Analytic Formulation, and Descriptive Summary

Model	Name	Formulation	Comment
(I)	Latest possible removal	$t_r(s_i) = \max_{i=1,\ldots,k}\{t_a(s_i)\} + 1$, i=1,…, k	All idle structures are removed one year after lease production ceases.
(II)	Earliest feasible removal	$t_r(s_i) = t_a(s_i) + 1$, i=1,…, k	Each idle structure is removed one year after structure production ceases.
(III)	Delayed early removal - deterministic	$t_r(s_i) = \min\{t_a(s_i) + m,\ \max_{i=1,\ldots,k}[t_a(s_i)] + 1\}$, $m \geq 1$, i=1,…, k	Each idle structure is removed m years after structure production ceases.
(IV)	Delayed early removal - stochastic	$\text{E}[t_r(s_i)] = \sum_{x=0}^{K} p(s_i \mid x) \cdot (t_a(s_i) + x)$, $\sum_{x=0}^{K} p(s_i \mid x) = 1$, $K = \max_{i=1,\ldots,k}\{[t_a(s_i)] + 1\} - t_a(s_i)$	Each idle structure has a probability of early removal determined by $p(s_i \mid x)$.
(V)	Constrained early removal	$t_r(s_i) = \min\{t^* + m,\ \max_{i=1,\ldots,k}[t_a(s_i)] + 1\}$, $s_i \in I(l, t^*)$, $t^* = \min\{t \mid \chi \geq \alpha(\chi)\}$, $m \geq 1$, $\alpha(\chi) \geq 0$, i=1,…, k.	All idle structures within a specific set are removed m years after user-defined lease/operator conditions are triggered.

Table B.2

Summary Statistical Output – Latest Possible Removal Model (I)

	Number	Number	Number	Age (yr)				Active Age (yr)				Idle Age (yr)			
Year	Active	Idle	Removed	s_1	s_2	s_3	l	s_1	s_2	s_3	l	s_1	s_2	s_3	l
2004	3	0	0	19	11	17	47	19	11	17	47	0	0	0	0
2005	3	0	0	20	12	18	50	20	12	18	50	0	0	0	0
2006	3	0	0	21	13	19	53	21	13	19	53	0	0	0	0
2007	3	0	0	22	14	20	56	22	14	20	56	0	0	0	0
2008	2	1	0	23	15	21	59	0	15	21	36	1	0	0	1
2009	2	1	0	24	16	22	62	0	16	22	38	2	0	0	2
2010	1	2	0	25	17	23	65	0	0	23	23	3	1	0	4
2011	1	2	0	26	18	24	68	0	0	24	24	4	2	0	6
2012	1	2	0	27	19	25	71	0	0	25	25	5	3	0	8
2013	1	2	0	28	20	26	74	0	0	26	26	6	4	0	10
2014	1	2	0	29	21	27	77	0	0	27	27	7	5	0	12
2015	1	2	0	30	22	28	80	0	0	28	28	8	6	0	14
2016	0	3	3	31	23	29	83	0	0	0	0	9	7	1	17

Table B.3

Summary Statistical Output – Earliest Feasible Removal Model (II)

Year	Number Active	Number Idle	Number Removed	Idle Age (yr) s_1	s_2	s_3	l
2004	3	0	0	0	0	0	0
2005	3	0	0	0	0	0	0
2006	3	0	0	0	0	0	0
2007	3	0	0	0	0	0	0
2008	2	1	1	1	0	0	1
2009	2	0	0	0	0	0	0
2010	1	1	1	0	1	0	1
2011	1	0	0	0	0	0	0
2012	1	0	0	0	0	0	0
2013	1	0	0	0	0	0	0
2014	1	0	0	0	0	0	0
2015	1	0	0	0	0	0	0
2016	0	1	1	0	0	1	1

Table B.4

Statistical Output – Delayed Early Removal Model: Deterministic (III-5)

Year	Number Active	Number Idle	Number Removed	Idle Age (yr) s_1	s_2	s_3	l
2004	3	0	0	0	0	0	0
2005	3	0	0	0	0	0	0
2006	3	0	0	0	0	0	0
2007	3	0	0	0	0	0	0
2008	2	1	0	1	0	0	1
2009	2	1	0	2	0	0	2
2010	1	2	0	3	1	0	4
2011	1	2	0	4	2	0	6
2012	1	2	0	5	3	0	8
2013	1	2	1	0	4	0	4
2014	1	1	0	0	5	0	5
2015	1	1	1	0	0	0	0
2016	0	2	1	0	0	1	1

Table B.5

Statistical Output – Delayed Early Removal Model: Stochastic (IV)

	Number	Number	Number	Idle Age (yr)			
Year	Active	Idle	Removed	s_1	s_2	s_3	l
2004	3	0	0	0	0	0	0
2005	3	0	0	0	0	0	0
2006	3	0	0	0	0	0	0
2007	3	0	0	0	0	0	0
2008	2	1	0	1	0	0	1
2009	2	1	0	2	0	0	2
2010	1	2	0	3	1	0	4
2011	1	2	1	0	2	0	2
2012	1	1	0	0	3	0	3
2013	1	1	0	0	4	0	4
2014	1	1	0	0	5	0	5
2015	1	1	0	0	6	0	6
2016	0	2	2	0	7	1	8

Table B.6

Statistical Output – Constrained Early Removal Model (V)

	Number	Number	Number	Idle Age (yr)			
Year	Active	Idle	Removed	s_1	s_2	s_3	l
2004	3	0	0	0	0	0	0
2005	3	0	0	0	0	0	0
2006	3	0	0	0	0	0	0
2007	3	0	0	0	0	0	0
2008	2	1	0	1	0	0	1
2009	2	1	0	2	0	0	2
2010	1	2	0	3	1	0	4
2011	1	2	0	4	2	0	6
2012	1	2	0	5	3	0	8
2013	1	2	0	6	4	0	10
2014	1	2	0	7	5	0	12
2015	1	2	2	0	0	0	0
2016	0	1	1	0	1	1	1

Table B.7

Idle and Auxiliary Structures on Inactive Leases in the GOM (2003)

Water Depth	WGOM			CGOM		
(ft)	CAIS	WP	FP	CAIS	WP	FP
0-100	22	7	29	103	20	88
101-200	3	4	6	13	10	44
201-400	1	1	9		1	30
TOTAL	26	12	44	116	31	162

Table B.8

Normalized Annual Production and Revenue Threshold Levels in the GOM

Threshold	Lease Categorization	Hydrocarbon Production	Water Depth (ft)	CAIS (MBOE)	WP (MBOE)	FP (MBOE)
Production	I	Oil	0-100	18	21	33
			101-200	30	30	66
			201+			34
		Gas	0-100	41	41	45
			101-200	51	47	52
			201+			51
	II	Oil	0-100	14	17	23
			101-200	20	20	44
			201+			25
		Gas	0-100	42	34	29
			101-200	41	31	31
			201+			36
Threshold	**Lease Categorization**	**Hydrocarbon Production**	**Water Depth (ft)**	**CAIS ($1,000)**	**WP ($1000)**	**FP ($1,000)**
Revenue	I	Oil	0-100	287	300	540
			101-200	512	608	623
			201+			595
		Gas	0-100	534	518	578
			101-200	631	640	697
			201+			695
	II	Oil	0-100	221	231	361
			101-200	488	614	806
			201+			545
		Gas	0-100	516	374	403
			101-200	546	744	478
			201+			1,172

Table B.9

Central Gulf of Mexico Removal and Cost Forecast Model (III-m)

Year	Model (III-2)	Model (III-3)	Model (III-5)	Model (III-7)	Model (III-9)	Model IV
2005	1114	341	341	341	341	534
2006	367	218	218	218	218	248
2007	325	960	360	360	360	501
2008	373	515	539	539	539	480
2009	272	305	735	409	409	344
2010	175	197	267	263	263	300
2011	123	143	153	401	193	164
2012	94	119	129	169	169	102
2013	75	97	114	123	296	100
2014	57	67	85	95	118	87
2015	42	47	57	66	71	75
2016	35	39	44	51	56	63
2017	28	30	33	37	43	58
2018	23	24	26	27	31	55
2019	21	18	23	24	27	21
2020	17	16	20	20	21	15
Cost ($billion)	2.72	2.55	2.47	2.42	2.40	2.52

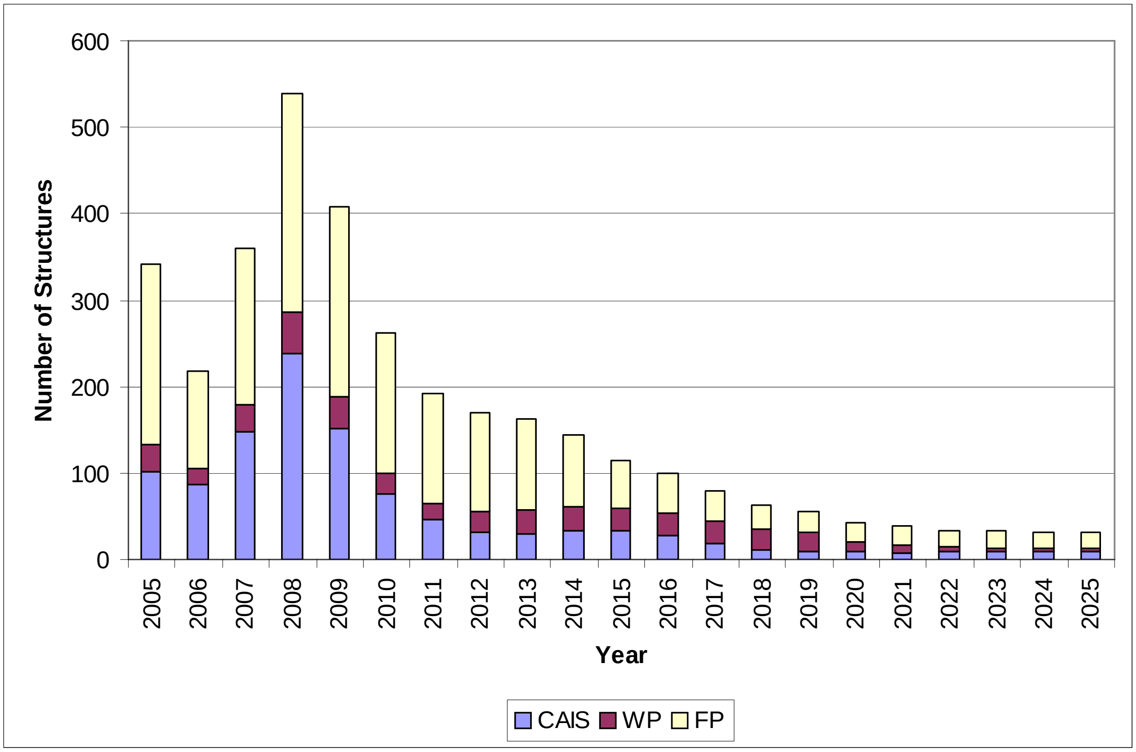

Figure B.1. Central GOM Structure Removal Model (I) Forecast.

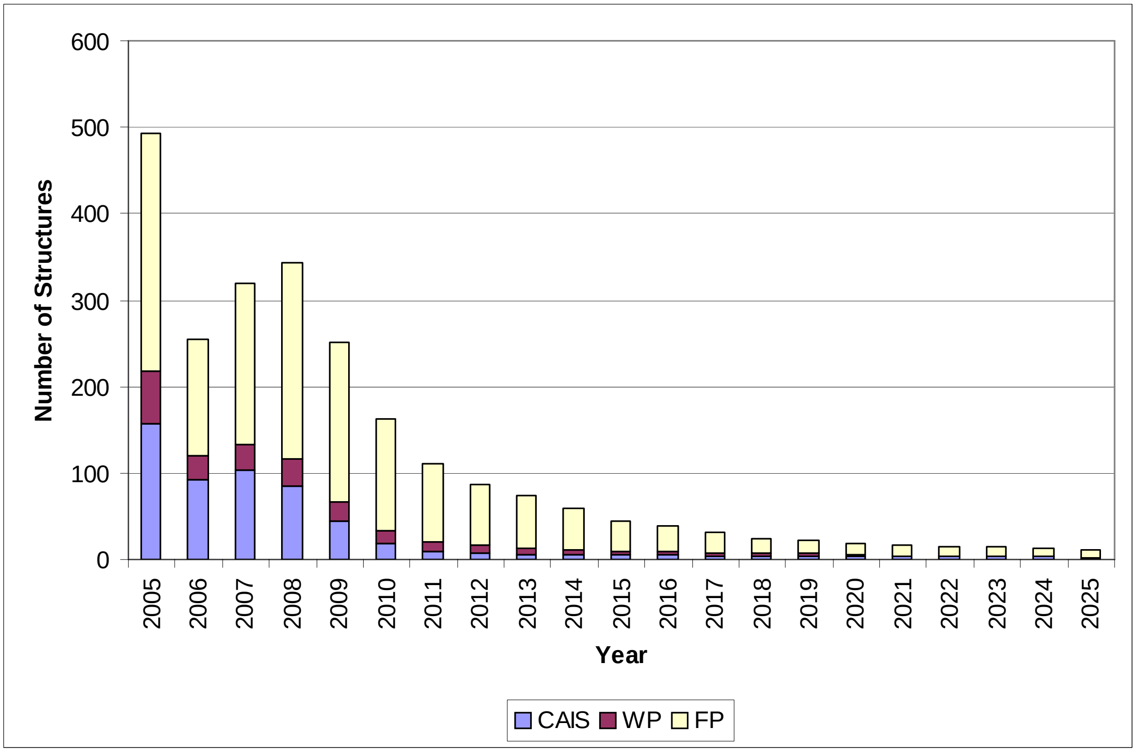

Figure B.2. Central GOM Structure Removal Model (II) Forecast.

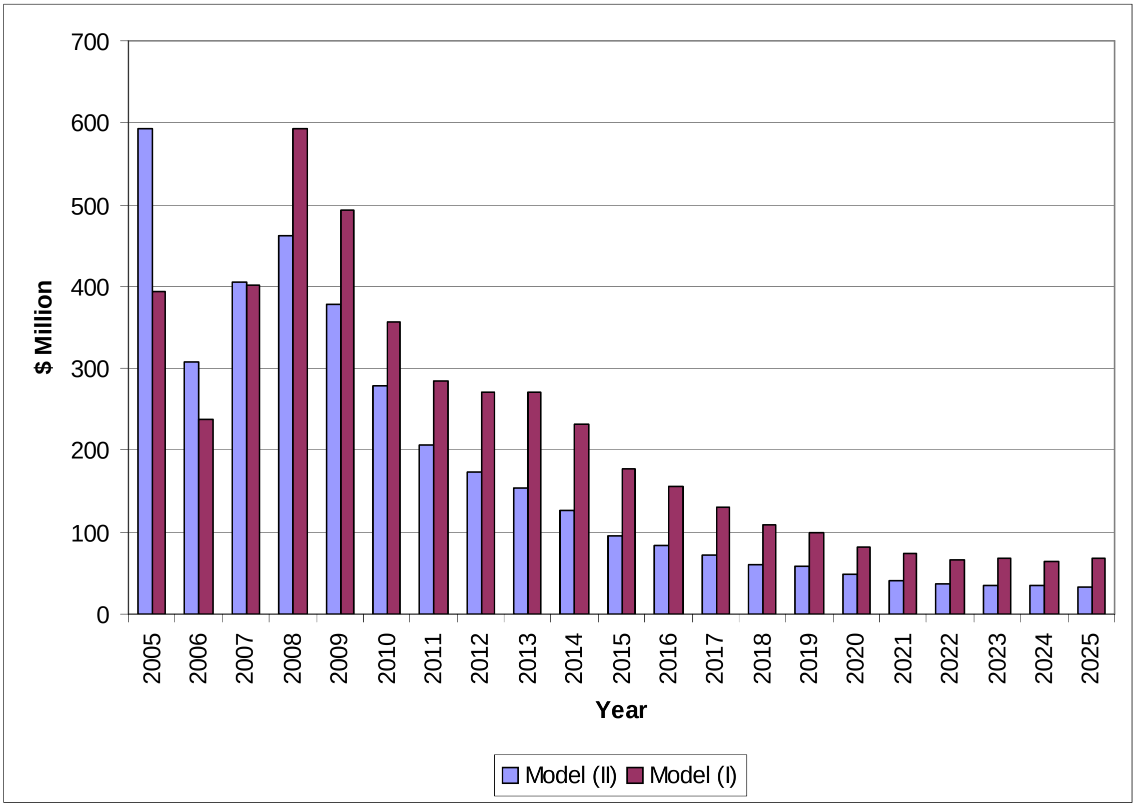

Figure B.3. Central GOM Removal Cost Model Comparison.

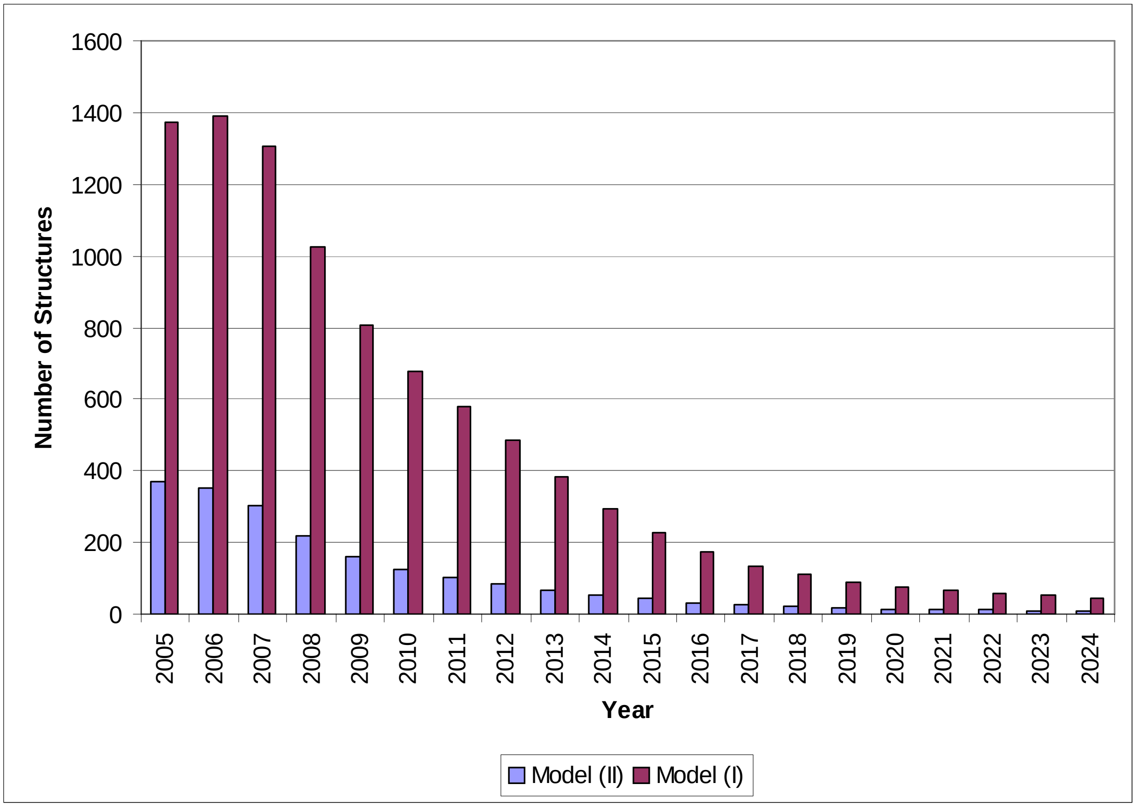

Figure B.4. Central GOM Idle Count Model Comparison.

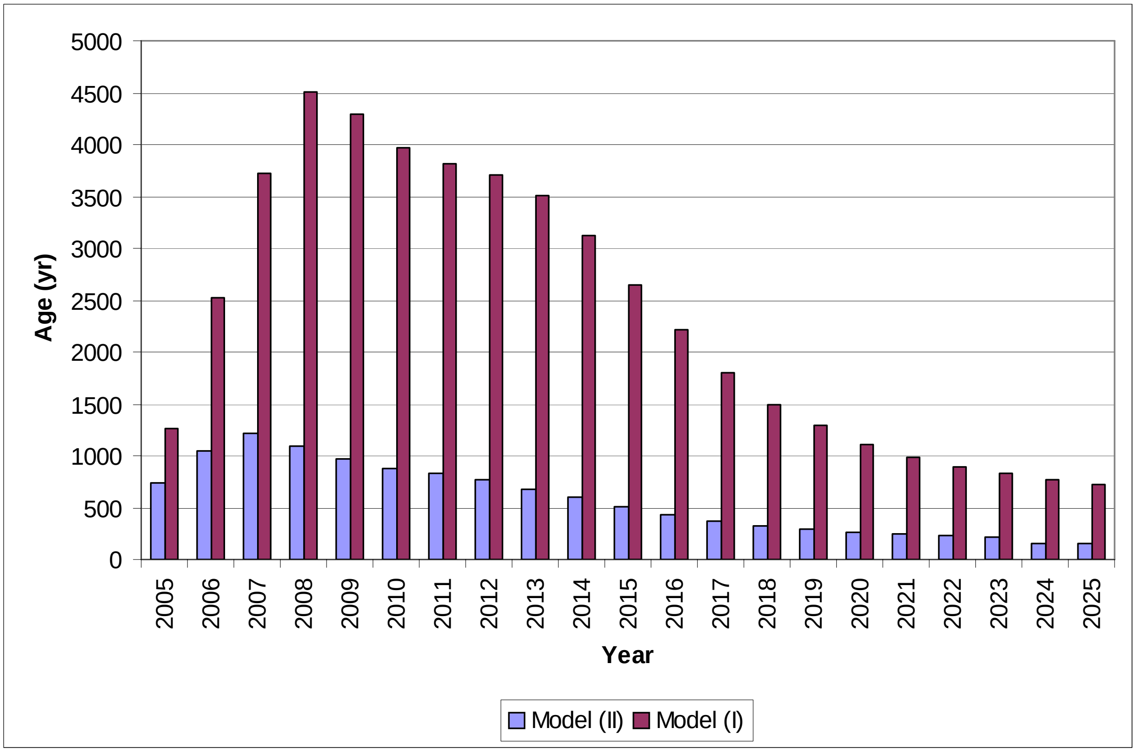

Figure B.5. Central GOM Idle Age Model Comparison.

APPENDIX C

CHAPTER 3 TABLES AND FIGURES

Table C.1

Iron and Steel Scrap Statistics (Million metric tons)

	1995	1996	1997	1998	1999	2001	2002	2003	2004	2005E
Production										
Home scrap[a]	20	20	20	20	21	18	17	17	14	14
Purchased scrap[b]	59	57	59	56	49	55	56	53	60	62
Imports[c]	2.3	2.9	3	3	6	3	3	4	5	4
Exports[d]	10.5	9.1	9	6	5	7	9	11	12	14
Consumption	72	71	73	73	68	71	69	61	67	67
Price[e], ($/mt)	131	126	126	104	87	74	88	108	205	175
Yearend stocks	4.2	5.2	5.5	5.2	4.4	4.9	5.1	4.4	5.4	4.5
Employment[f]	37,000	37,000	37,000	37,000	37,000	37,000	30,000	30,000	30,000	30,000

Footnote: a) Receipts – shipments by consumers + exports – imports.

b) Includes used rails for rerolling and other uses, and ships, boats, and other vessels for scrapping.

c) From 2001-2004, the import sources are Canada (60%), United Kingdom (20%), Sweden (7%), and Russia (3%).

d) In 2004, the primary export countries include China (25%), Canada (18%), South Korea (16%), Mexico (13%), Thailand (6%), and Turkey (6%).

e) No. 1 heavy melting average composite price computed at Pittsburgh, Philadelphia, and Chicago.

f) For 1995-2001, estimated from 1992 Census of Wholesale Trade; for 2002-2005, estimated from 2002 Census of Wholesale Trade.

Source: (USGS, 2005)

Table C.2

Iron and Steel Scrap Supply Available for Consumption in 2004 (Thousand metric tons)

	Receipts of scrap		Production of home scrap			
Region and State	From brokers, dealers, and other outside sources	From other own company plants	Recirculating scrap resulting from current operations	Obsolete scrap	Shipments of scrap	New supply available for consumption
Florida and Georgia	982	--	39	--	--	1,020
Alabama and Mississippi	4,850	W	744	W	21	5,580
Arkansas, Louisiana, Oklahoma	5,010	W	331	W	W	5,530
Texas	3,190	836	462	3	7	4,490
Gulf Coast Total	14,032	836	1,576	3	28	16,620
U.S. Total	52,000	2,390	14,000	288	1,590	67,100

Note: W = Withheld to avoid disclosing company proprietary data. -- Zero

Source: (USGS, 2005)

Table C.3

U.S. Consumption of Iron and Steel Scrap in 2004 (Thousand metric tons)

Region and State	Manufacturers of pig iron and raw steel and casting scrap	Manufacturers of steel casting	Iron foundries and miscellaneous users	Totals for all manufacturers types
Florida, Georgia, North/South Carolina	3,970	W	170	4,140
Alabama, Kentucky, Mississippi, Tennessee	6,440	83	1,630	8,150
Arkansas, Louisiana, Oklahoma	5,310	12	18	5,340
Texas	4,330	11	196	4,540
Gulf Coast Total	20,050	106	2,014	22,170
U.S. Total	56,700	1,330	8,490	66,500

Note: W = Withheld to avoid disclosing company proprietary data: included in "Total."

Source: (USGS, 2005)

Table C.4

U.S. Consumer Stocks of Iron and Steel Scrap, December 31, 2004 (Thousand metric tons)

Region and State	Carbon steel	Stainless steel	Alloy steel	Cast iron	Other grades of scrap	Total scrap
Florida, Georgia, North/South Carolina	318	--	W	19	5	342
Alabama, Kentucky, Mississippi, Tennessee	805	W	W	275	W	1,580
Arkansas, Louisiana, Oklahoma	547	W	W	2	W	550
Texas	271	W	W	6	W	277
Gulf Coast Total	1,941	51	W	302	5	2,749
U.S. Total	4,010	51	35	628	679	5,410

Note: W = Withheld to avoid disclosing company proprietary data: included in “Total.” -- Zero

Source: (USGS, 2005)

Table C.5

Selected Ferrous Scrap Specifications

ISRI No.	Item	Description	Dimension/Density
200	No. 1 heavy melting steel	Wrought iron and/or steel scrap	Greater than ¼ inch in thickness; individual pieces not over 5 ft x 24 inches
201	No. 1 heavy melting steel	Wrought iron and/or steel scrap	Greater than ¼ inch in thickness; individual pieces not over 3 ft x 24 inches
204	No. 2 heavy melting steel	Wrought iron and/or steel scrap, black and galvanized	Greater than ¼ inch in thickness; maximum size 5 ft x 18 inches
207	No. 1 busheling	Clean steel scrap, free of metal coated, limed, or vitreous enameled.	Maximum size 12 inches in any dimension
209	No. 2 bundles	Old black and galvanized steel sheet scrap	Minimum density 75 pounds per cubic foot; compressed to charge box size
211	Shredded scrap	Homogeneous iron and steel scrap magnetically separated	Average density 70 pounds per cubic foot; compressed to charge box size
231	Plate and structural steel	Clean open hearth steel plates, structural shapes, crop ends, shearings, or broken steel tires	Greater than ¼ inch thickness; individual pieces not over 5 ft x 18 inches
236	Cut structural and plate scrap	Clean open hearth steel plates, structural shapes, crop ends, shearings, or broken steel tires	Greater than ¼ inch thickness; individual pieces not over 3 ft x 18 inches

Source: (ISRI, 2001a and b)

Table C.6

Estimated Consumer Buying Prices for Selected Scrap Specifications for Different Regions of the U.S. ($ per gross ton delivered mill price on June 7, 2006)

Specification	Chicago	Houston	Pittsburgh	Seattle/ Portland
No. 1 heavy melt	248	225	250	126
No. 2 heavy melt	247	215	242	123
No. 1 bundles	342	315	330	-
No. 2 bundles	200	160	170	104
No. 1 busheling	342	320	345	-
Shredded auto scrap	278	260	278	148
Cut structural/plate, < 5 in	270	255	265	141
Cut structural/plate, < 3 in	-	265	275	-

Source: (American Metal Market, 2006)

Table C.7

Top 20 U.S. Ferrous and Nonferrous Scrap Processors

Rank	Ferrous Processor	State	Nonferrous Processor	State
1	Metal Management	IN	David J. Joseph	OH
2	OmniSource	IN	OmniSource	IN
3	Tube City	PA	Metal Management	IL
4	Philip Metals	IN	Hugo Neu	NY
5	Hugo Neu	NY	PSC Metals	TX
6	Ferrous Processing & Trading	MI	Commercial Metals	TX
7	Commercial Metals	TX	SLC Recycling	MI
8	David J. Joseph	OH	Simsmetal America	CA
9	Schnitzer Steel Products	OR	Northeast Metal Traders	PA
10	AMG Resources	PA	Admetco	IN
11	Miller Compressing	WI	Miller Compressing	WI
12	Simsmetal America	CA	Schnitzer Steel Products	OR
13	Southern Scrap Recycling	LA	Southern Scrap Recycling	LA
14	Alter Scrap Processing	MO	Alpert & Alpert Iron & Metal	CA
15	Samuel Recycling	WI	Alter Scrap Processing	MO
16	TXI Chaparral Steel	TX	Morris Recycling	MS
17	North Star Recycling	MN	Cohen Brothers	OH
18	Galamet	MO	Samuel Recycling	WI
19	Camden Iron & Metal	NJ	Ansam Metals	MD
20	Gershow Recycling	NY	Shine Brothers	IA

Source: (Taylor, 2002 and 2003).

Table C.8

Waste Streams Generated Across the Primary Stages of Decommissioning

Stage	Waste	Special Issues
Plug & Abandonment	Tubing, casing, wellhead, cement, fluids	NORM contamination
Preparation	Fluids, flowlines, cuttings, cable, umbilicals, braces, industrial	Asbestos, PCBs, hazardous materials
Removal	Equipment, deck, jacket, piling, conductors, manifolds, etc.	Human safety, marine mammal
Site Clearance & Verification	Debris, scrap metal, tires, cable, anchors, etc.	Human safety, marine mammal

Table C.9

Active, Idle, and Auxiliary Structures on Active Leases (2003)

k	Number of active leases with *k* active structures	Number of active structures	Number of idle structures	Number of auxiliary structures
1	944	944	291	129
2	245	490	141	79
3	84	252	96	66
4	35	140	84	43
≥ 5	48	348	286	123
Total	1,356	2,175	898	440

Source: (Kaiser and Mesyanzhinov, 2004)

Note: An active structure produces hydrocarbons, while an idle structure once produced hydrocarbons but is not currently producing. An auxiliary structure is a structure that has never produced hydrocarbons but serves in an auxiliary role, say as a quarters facility, flare tower, or storage platform.

Table C.10

Reefing Probability as a Function of Water Depth and Planning Area

Water Depth (ft)	WGOM (%)	CGOM (%)
0-20	0	0
21-100	11	1
101-200	65	27
201-400	82	63
Total	42	13

Source: (Kaiser and Pulsipher, 2005)

Note: WGOM = Western Gulf of Mexico; CGOM = Central Gulf of Mexico

Table C.11

Representative Gulf Coast Storage and Scrap Companies and Structure Inventory (2004)

Company	Location	Storage	Scrap	Deck	Jacket	Heliport	Employees
Acadian Contractors	Abbeville, LA	Yes	No	4	2		1
Alabama State Port Authority	Mobile, AL	Yes	No				60
Alison Marine	Amelia, LA	Yes	Yes	14	2	20	
Allen Process System	New Iberia, LA	Yes	Yes		2		
Amfels	Brownsville, TX	Yes	No	2	2		800
Bay Offshore	Belle Chasse, LA	Yes	No			1	75
Bisso Marine	Amelia, LA	Yes	Yes				
Brousard Brothers	Belle Chase, LA	Yes	No		6	2	45
Chey Morrison Contractors	Houma, LA	Yes	No		3		50
Dolphin Services	Houma, LA	Yes	No		2		350
Dynamic Topside	New Iberia, LA	Yes	No	6	6	2	30
Euromex	Loxley, AL	Yes	No		3		10
Horizon Offshore	New Iberia, LA	Yes	Yes				
Houma Industries	Harvey, LA	Yes	No		3		200
Kiewit Offshore	Ingleside, TX	Yes	No	2	2		1,000
McDermott	Gibson, LA	Yes	No		1		
Nabors Industries	New Iberia, LA	Yes	No		7		25
Offshore Specialties	Houma, LA	Yes	No	4	3		40
Omega Service Industries	New Iberia, LA	Yes	Yes	5	5		360
Partech	New Iberia, LA	Yes	No		5		50
Signal International	Pascagoula, MS	Yes	No				60
Southern Scrap	New Iberia, LA	Yes	Yes				400
Subsea7	New Iberia, LA	No	Yes				
Twin Brothers Marine	Louisa, LA	Yes	No				50
Unifab	New Iberia, LA	Yes	Yes	15	10		300

Table C.12

Typical Gulf Coast Breaking Cost ($/ton)

Barges, crew boats	40-60
Decks	40-60
Jackets	50-100
Drilling rigs	100-125
Ships	100-200
Navy vessels	200-400

Source: Industry Interviews.

Table C.13

Structure Status

Structure Status	State	Description
Active	Producing/Non-producing	Structure is either producing or serving in an active non-producing role
Inactive	Idle	Structure is no longer producing or serving a useful economic function, but because the lease is still producing, structure is not required to be removed
	Economic	Structure is no longer producing but serves an economic purpose or is expected to be used in future activities
Decommissioned	Removed	All wells of permanently plugged and abandoned, all platforms and other facilities removed, and the seafloor cleared of all obstructions

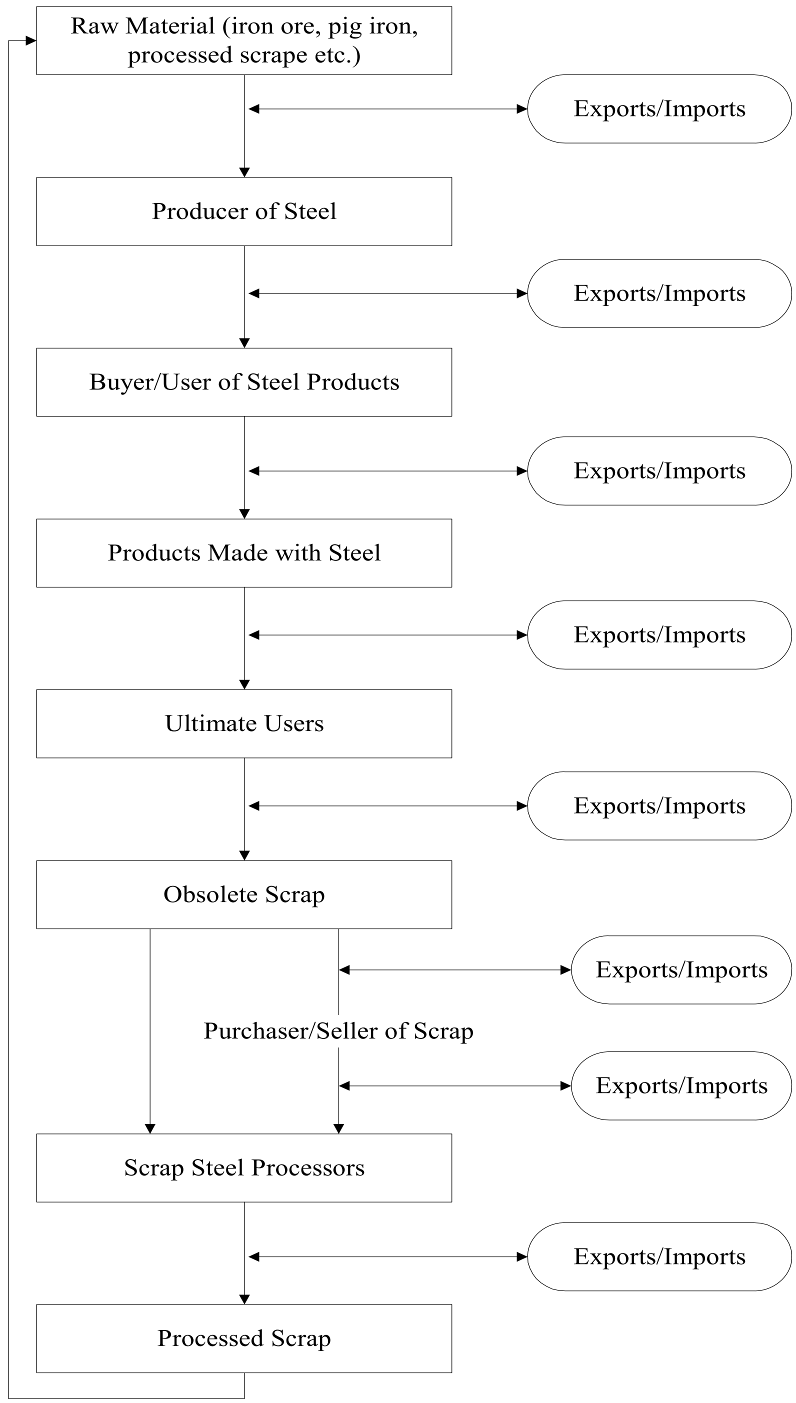

Figure C.1. Scrap Steel Life Cycle (USDT, IRS, 1999).

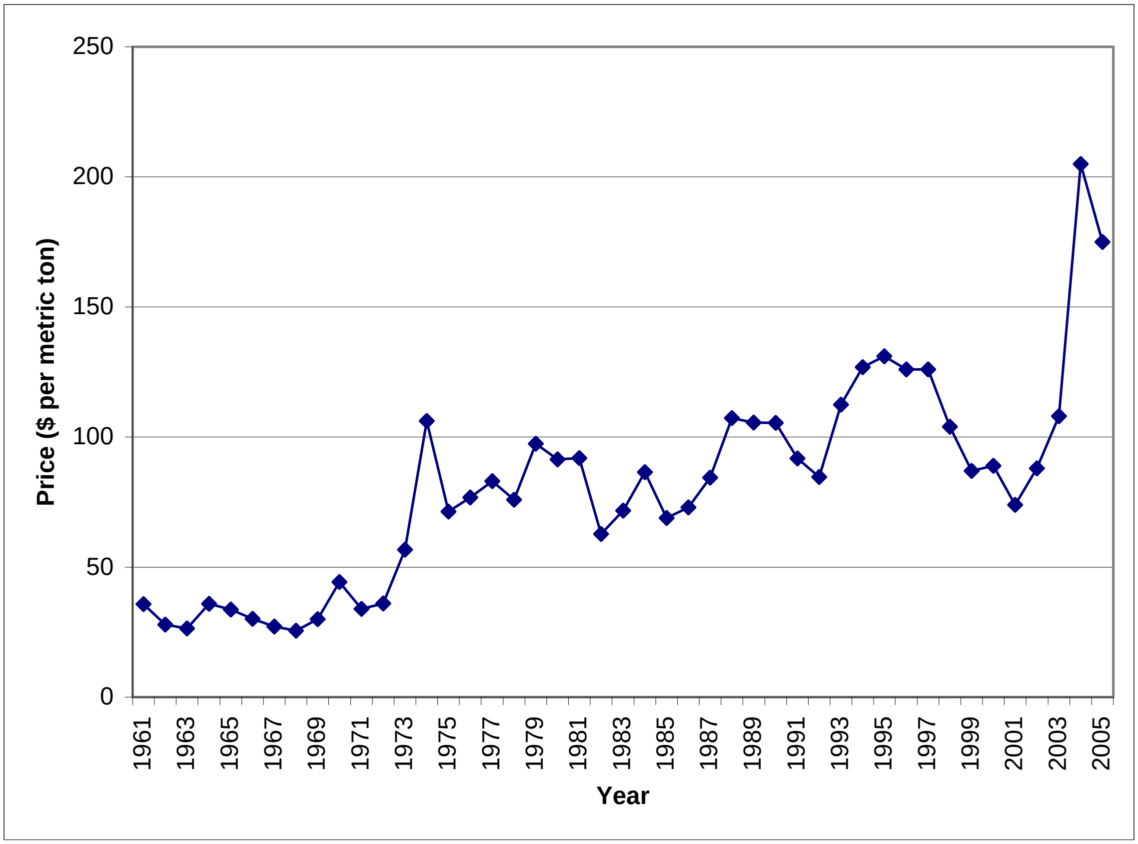

Figure C.2. Annual Average U.S. Scrap Steel Price, $ per metric ton (American Metal Market, 2006).

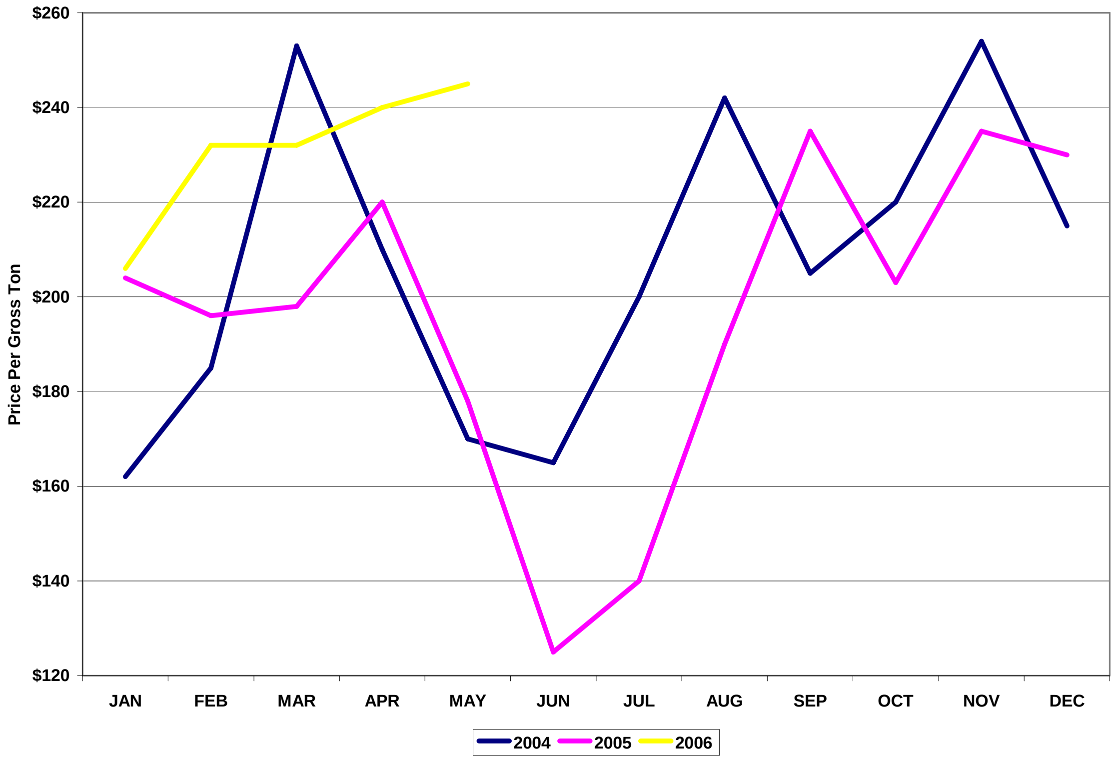

Figure C.3. Weekly No. 1 Heavy Melting Steel Scrap Price Composite (American Metal Market, 2006).

Figure C.4. Derrick Barge Arrives On-Site and Removes the Deck Module (National Marine Fisheries Service – Galveston, 2004).

Figure C.5. Deck Module and Heliport Transported to Shore (Twachtman Snyder & Byrd, Inc., 2006).

Figure C.6. Explosives Technicians Prepare and Load Charges into Conductors and Legs (National Marine Fisheries Service – Galveston, 2004).

Figure C.7. Severed Piles and Conductors Loaded Onto Derrick Barge (DEMEX, 2004).

Figure C.8. Jacket Lifted from Water and Transported to Shore or Artificial Reef Site (Twachtman Snyder & Byrd, Inc., 2006).

Figure C.9. Gorilla Net Application (Kaiser et al., 2005).

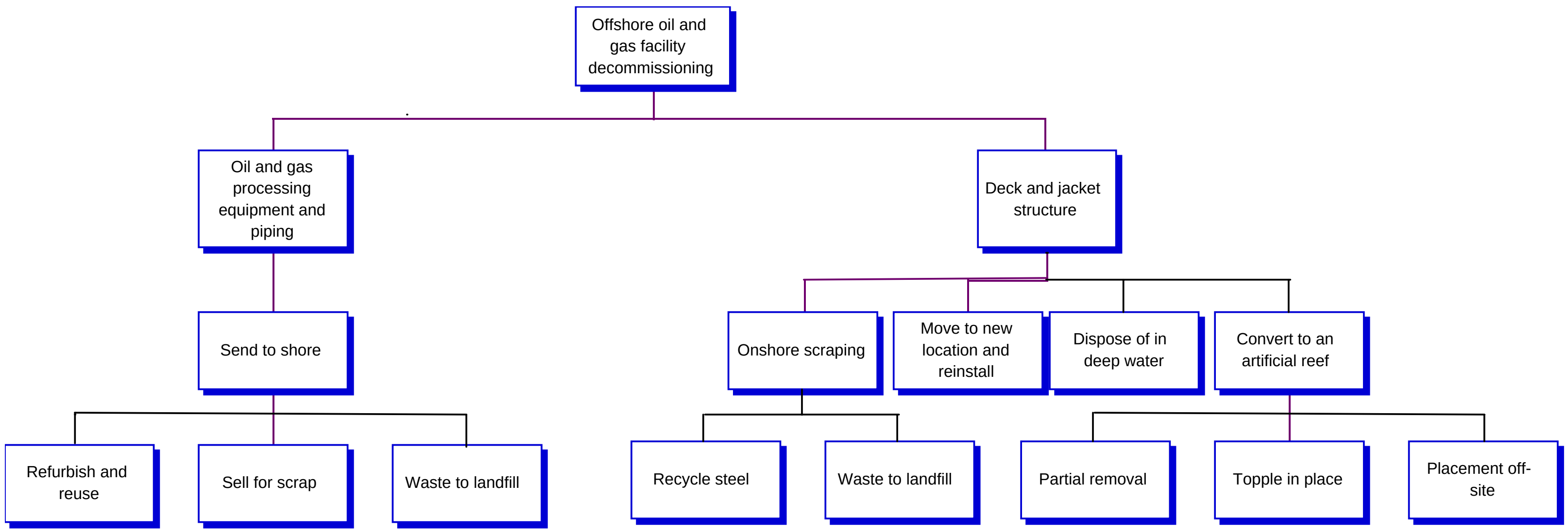

Figure C.10. Offshore Oil and Gas Facility Decommissioning Tree.

Figure C.11. Piling and Conductors Stored Onshore Awaiting Disposal or Reuse Opportunity.

Figure C.12. Deck Structures Stored Onshore Awaiting Disposal or Reuse Opportunity.

Figure C.13. Topsides Equipment Stored Onshore Awaiting Disposal or Reuse Opportunity.

Figure C.14. Jacket Structures Stored Onshore Awaiting Dismantlement or Reuse Opportunity.

Figure C.15. Jacket Structure in Storage at Unifab's Facility in New Iberia, Louisiana-I.

Figure C.16. Jacket Structure in Storage at Unifab's Facility in New Iberia, Louisiana-II.

Figure C.17. Jacket Structure in Storage at Unifab's Facility in New Iberia, Louisiana-III.

Figure C.18. Jacket Structure in Storage at Unifab's Facility in New Iberia, Louisiana-IV.

Figure C.19. Jacket Structure in Storage at Unifab's Facility in New Iberia, Louisiana-V.

Figure C.20. Jacket Structure in Storage at Unifab's Facility in New Iberia, Louisiana-VI.

Figure C.21. Jacket Structure in Storage at Unifab's Facility in New Iberia, Louisiana-VII.

Figure C.22. Jacket Structure in Storage at Unifab's Facility in New Iberia, Louisiana-VIII.

Figure C.23. Deck Structure in Storage at Unifab's Facility in New Iberia, Louisiana-I.

Figure C.24. Deck Structure in Storage at Unifab's Facility in New Iberia, Louisiana-II.

APPENDIX D

CHAPTER 4 TABLES AND FIGURES

Table D.1

Common Offshore Vessels and Their Function

Type	Purpose
Survey vessels	Locate drilling prospects
Drilling rigs	Drill wells to find hydrocarbons
Derrick barges	Transport and install infrastructure
Cargo barges	Transport infrastructure
Anchor handling towing supply vessels	Towing and anchor handling services
Pipelay barge	Install pipeline
Platform supply vessels	Service and supply offshore production
Tugs	Rig towage and construction support
Crewboats	Transport crews
Tankers	Transport oil

Table D.2

Percentage Distribution of Gross Tonnage Ship Breaking by Country, 1986-2004 (%)

Country	1986	1991	1995	2001	2004
Taiwan	38	2	0	0	0
China	23	7	9	20	37
S. Korea	13	0	0	0	0
Pakistan	4	19	20	14	5
Japan	4	3	2	0	0
India	3	29	33	29	35
Spain	3	1	0	0	0
Turkey	2	3	2	1	1
Italy	2	0	0	0	0
Bangladesh	1	22	30	34	19
Others	7	13	4	2	3

Source: (Lloyd's Register of Shipping)

Table D.3

Qualified Ship Breaking Facilities in the U.S. (2006)

Facility	Location
International Shipbreaking	Brownsville, TX
Esco Marine	Brownsville, TX
Marine Metals	Brownsville, TX
All Star Metals	Brownsville, TX
N. American Ship Recycling	Baltimore, MD
Metro Machine	Norfolk, VA

Table D.4

Demolition Prices for Bulk Carriers and Tankers ($/LWT)

Year	Bulk Carriers		Tankers	
	Subcontinent	Far East	Subcontinent	Far East
2005	410-415	350-370	425-450	360-400
2004	390-400	240-365	380-405	250-375
2003	190-200	190-200	200-210	200-210

Source: (R.S. Platou Offshore, 2005)

Table D.5

U.S. Government-Owned Ship Disposal Alternatives

Option	Advantages	Constraints	Comment
Foreign recycling	Competitive pricing, high capacity, high competition, high demand, expedient, previous success	Legal challenges, statutory requirements, environmental impediments	Not a commercially viable option in present legal environment
Domestic recycling	Reasonably expedient, environmentally sensitive, domestic jobs	High cost, limited capacity	Will continue to be used to dismantle a portion of NDRF inventory
Artificial reefing	Recreational opportunities for fishing and diving, marine habitat, lower cost than domestic recycling	Limited demand, state participation requires funding, long lead time	Not a significant disposal option in terms of numbers of ships
Vessel sales	Low revenue to no cost, high foreign demand	Limited domestic demand, legal impediments for foreign scrapping	Not a viable option for foreign scrapping under present legal environment
Vessel donation	No cost	Limited domestic demand, long lead time	Not a significant disposal option in terms of numbers of ships
Deep sinking	Lower cost than domestic recycling, military training	Limited domestic demand, cost similar to artificial reefing	Not a significant disposal option in terms of numbers of ships

Table D.6

Navy-Titled Obsolete Vessels in NDRF, 1999-2005

Award Date	Number of Ships Scrapped	Number of Companies[†]	Cost per ship[‡] ($M)	Cost per ton[‡] ($/ton)
1999	4	4	3.98	1,226
2000	6	4	3.04	830
2001	5	2	2.85	735
2002	4	3	2.78	531
2003	8	2	2.30	574
2004	3	2	2.16	495
2005	8	2	1.88	370

Note: [†] The number of companies that win disposal bids depends upon the location of the ships to be scrapped as well as the number of companies qualified to bid.

[‡] Cost per ship and cost per ton is a simple arithmetic average of the contract awards.

Source: (USDOT, Maritime Administration, 2005)

Table D.7

MARAD Ship Disposal in NDRF, 2000-2005

Award Date	Number of Ships Scrapped	Cost per ship[†] ($M)
2000	1	1.61
2001	4	1.38
2002	1	0.79
2003	3	0.84
2004	14	0.81
2005	17	0.72

Note: [†]Cost per ship is a simple arithmetic average of the contract awards.

Source: (USDOT, Maritime Administration, 2005)

Table D.8

Gulf Coast Ship Disposal Statistics, 2000-2006

Year	Contractor	Ship	Net Cost ($ million)	Cost per ton ($/ton)
2000	International Ship Breaking	Bagley	3.0	922
2000	International Ship Breaking	Cochrane	2.3	687
2002	International Ship Breaking	Hewitt	3.1	524
2003	International Ship Breaking	Francis Hammond	1.4	442
2003	International Ship Breaking	Halsey	2.9	500
2004	International Ship Breaking	England	1.1	187
2004	International Ship Breaking	Roarke	1.5	451
2005	International Ship Breaking	Gridley	1.9	399
2005	International Ship Breaking	Leahy	1.9	348
2005	International Ship Breaking	Sterrett	2.8	416
2006	ECSO Marine	Dahlgren	1.2	239
2006	International Ship Breaking	John Rodgers	1.9	283
2006	International Ship Breaking	Farragut	2.1	415
2006	ECSO Marine	Seattle	1.4	127
2006	ECSO Marine	Detroit	1.8	164
Average			1.9	400

Source: (USDOT, Maritime Administration, 2005)

Table D.9

Rig Life Cycle

State	Status	Description	Expected Reactivation Time/Cost	Description
Active	Working	In use	--	Under contract
Inactive	Hot stacked	Ready for immediate use	< 1 mo. < $20,000	Fully staffed and ready to work
Inactive	Warm stacked	Ready for use with minor preparation	1-2 mo. < $50,000	Semi-skilled workers need to be rehired; rig requires maintenance and refurbishment cost.
Inactive	Cold stacked	Not in use for a period of 1 year or less	2-6 mo. < $1million	Drilling crew needs to be assembled; requires maintenance; insurance required
		Not in use for a period of 1-3 years	5-10 mo. $1-3 million	Requires major maintenance; insurance required
		Not in use for a period of 3 years or more	10-18 mo. > $3 million	Requires extensive maintenance; insurance required
Dead	Dead stacked	Permanently out of service		Waiting to be scrapped; rig used for spare parts; insurance required

Note: A rig will transition within inactive states many times throughout its life, and as a rig ages, it will likely spend more time cold stacked. Once a rig is dead stacked, it will not return as a drilling rig, but will be cannibalized for parts, converted to an alternative use, or broken in a demolition yard and sold for scrap metal.

Table D.10

Mobile Offshore Drilling Units – Cold Stacked (October 2006)

Non-Contracted	Africa	Asia Pacific	Europe	Latin America	Middle East	North America	Total
Jack-ups	0	3	0	2	0	8	13
Semisubmersibles	0	3	1	0	0	0	4
Others	0	1	0	8	0	1	10
Total	0	7	1	10	0	9	27

Source: (ODS-Petrodata, 2006)

Table D.11

U.S. Rig Fleet Dynamics (1993-2006)

	2006	2005	2004	2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993
Previous year's fleet	2,026	1,988	1,719	1,722	1,722	1,636	1,644	1,705	1,665	1,649	1,729	1,841	1,853	1,996
Reductions to fleet														
Auctioned for parts*	-99	-141	-68	-59	n/a	-23	-24	-41	-22	-28	-36	-71	-51	-57
Large capital expenditure	n/a	n/a	n/a	-57	n/a	-36	-40	-46	-29	-58	-42	-62	-58	-126
Moved out of U.S.	-14	-29	-1	-45	n/a	-6	-4	-7	-10	-18	-24	-30	-21	-16
Stacked > 3 years	n/a	n/a	n/a	-7	n/a	-28	-12	-2	-8	-17	-36	-29	-13	-25
Destroyed	-6	-3	0	-4	n/a	-3	-2	-4	-3	-6	-3	-3	-5	-8
Subtotal, deletions	-119	-173	-69	-172	n/a	-96	-82	-100	-72	-127	-141	-195	-148	-232
Additions to fleet														
Assembled	53	58	79	74	n/a	105	34	9	62	57	24	35	42	13
Newly manufactured	238	23	32	48	n/a	9	6	6	7	2	3	0	2	1
Brought back into service	95	124	125	37	n/a	56	22	18	37	72	33	38	68	63
Moved into U.S.	5	6	7	10	n/a	12	12	6	6	12	1	10	24	12
Subtotal, additions	391	211	243	169	n/a	182	74	39	112	143	61	83	136	89
Net change	272	38	174	-3	n/a	86	-8	-61	40	16	-80	-112	-12	-143
Total available rigs	2,298	2,026	1,893	1,719	n/a	1,722	1,636	1,644	1,705	1,665	1,649	1,729	1,841	1,853

Source: (Berkman and Stokes, 2006)

Footnote: * Beginning in 2004, the categories "Auctioned for parts" and "Large capital expenditure" have been combined into the category "Removed from service" which is represented in this table by the category "Auctioned for parts."

Table D.12

Example Rate of Return Calculation for Reactivating a Cold Stacked Rig

	1 well plus option	1 well firm
Capital cost ($ million)	50	50
Daily operating cost ($/day)	50,000	50,000
Duration (days)	350	120
Annual operating expense ($million)	17.5	6
Dayrate ($/day)	75,000	75,000
Annual revenue ($ million)	26.3	9
Operating revenue ($ million)	8.8	3
Rate of return (%)	17.4	6.0

Table D.13

Comparison of Ship Breaking and Rig Scrapping Characteristics

Characteristic	Ship Breaking	Rig Scrapping
Job Specialization	High specialization	Low specialization
Yard Capacity	Limited domestic capacity; unlimited foreign capacity	Unlimited domestic and foreign capacity
Unit Inventory	Creates environmental risks and increases life cycle cost	Minimal environmental risks and option value of rig enhanced
Disposal Alternatives		
Domestic recycling	Yes	Yes
Foreign recycling	Yes – private vessels No – U.S. government vessels	Yes
Artificial reefing	Yes	No
Sales	Yes	Yes
Donation	Yes	No
Deep sinking	Yes	No
Storage	Yes	Yes
Environmental Impact	Manageable	Manageable
Worker Health & Safety	Poor/Acceptable	Acceptable
Constraints	Labor costs, environmental legislation, international competition	Labor costs, environmental legislations, international competition

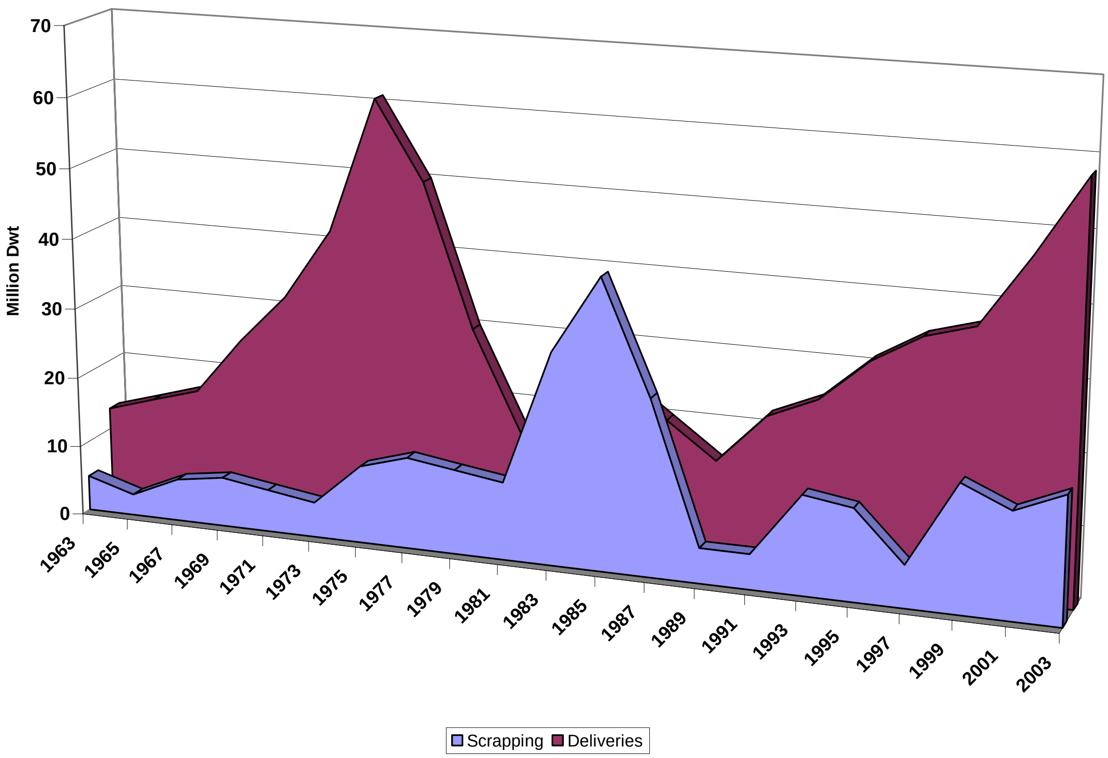

Figure D.1. Worldwide Ship Scrapping and Deliveries in Million Deadweight Tons (Stopford, 2005).

Figure D.2. Ship Breaking and Rig Scrapping in the Gulf Coast (International ShipBreaking, Ltd., 2005).

Figure D.3. U.S. Government-Owned Warships Stored at the James River Reserve Fleet in Virginia (USDOT, Maritime Administration, 2005).

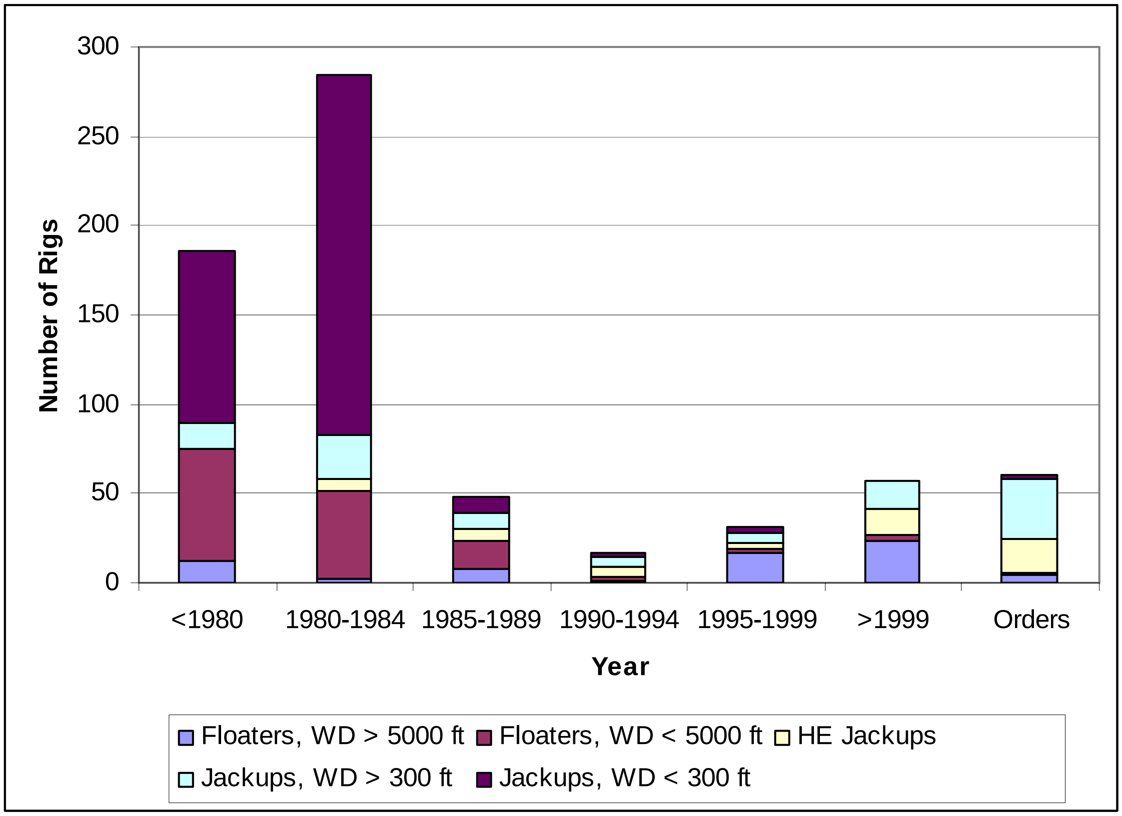

Figure D.4. Age Profile for Drilling Rig Fleet (ODS-Petrodata, 2006).

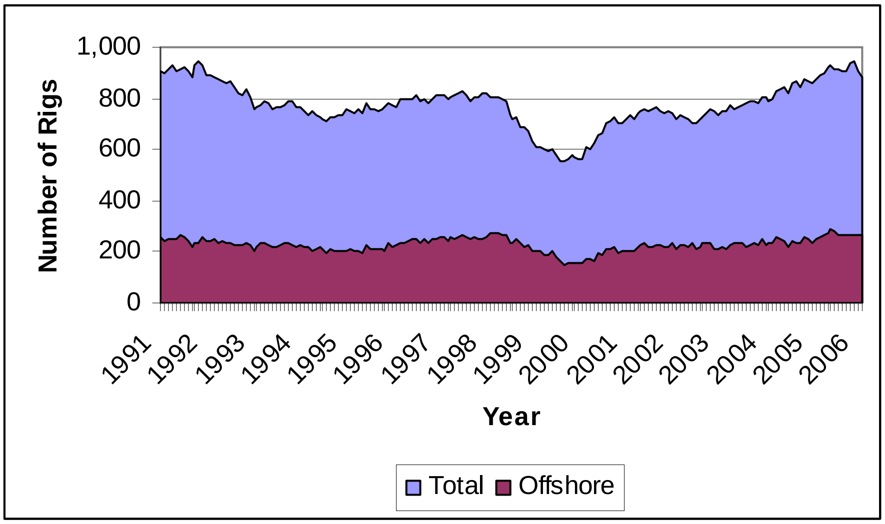

Figure D.5. Offshore Drilling Rigs (Baker Hughes, 2006).

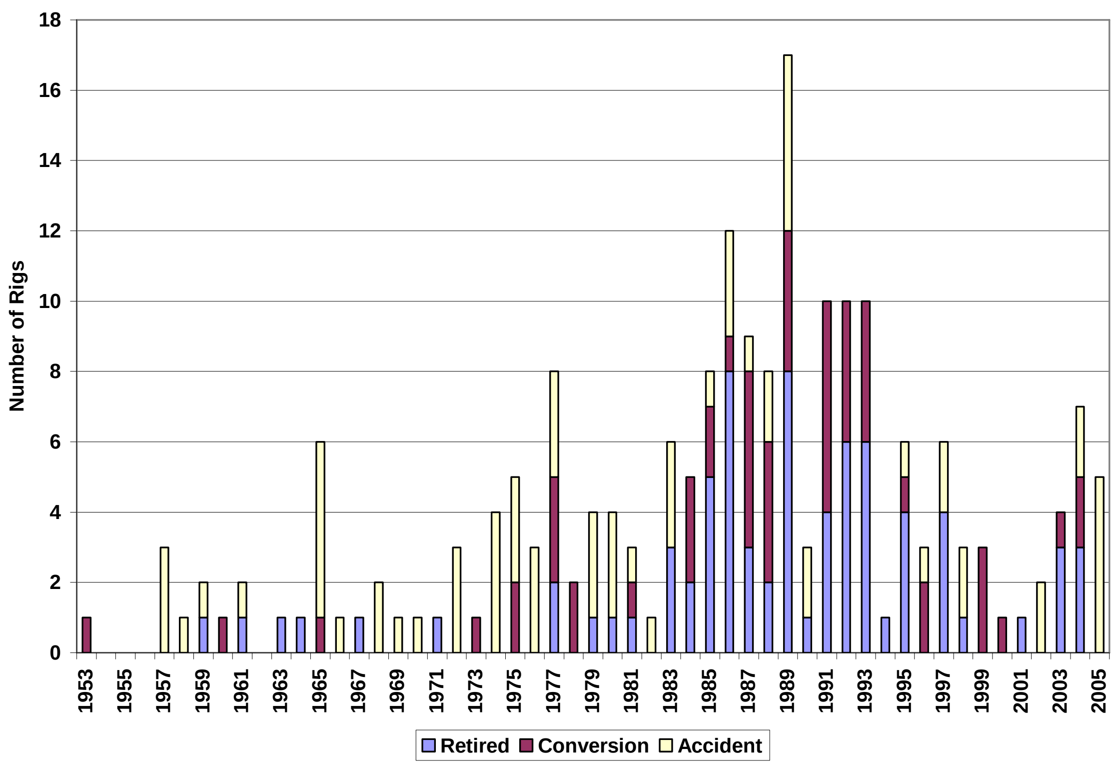

Figure D.6. Jackup Attrition Rates (Kellock, 2006).

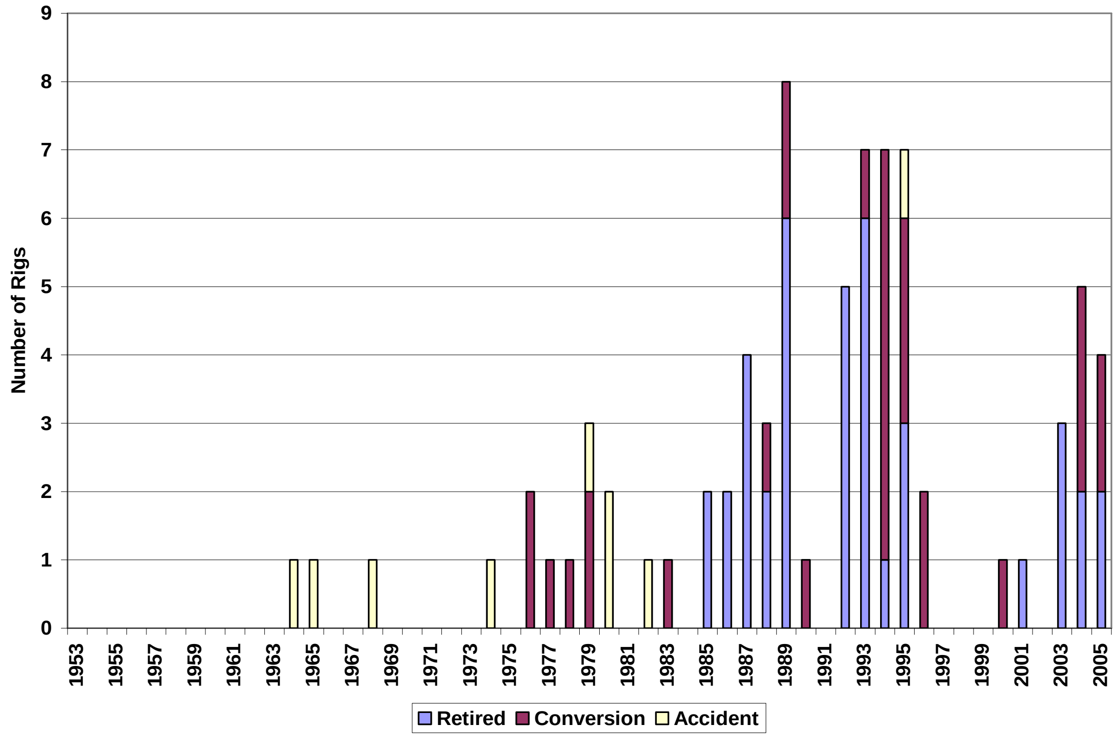

Figure D.7. Semisubmersible Attrition Rates (Kellock, 2006).

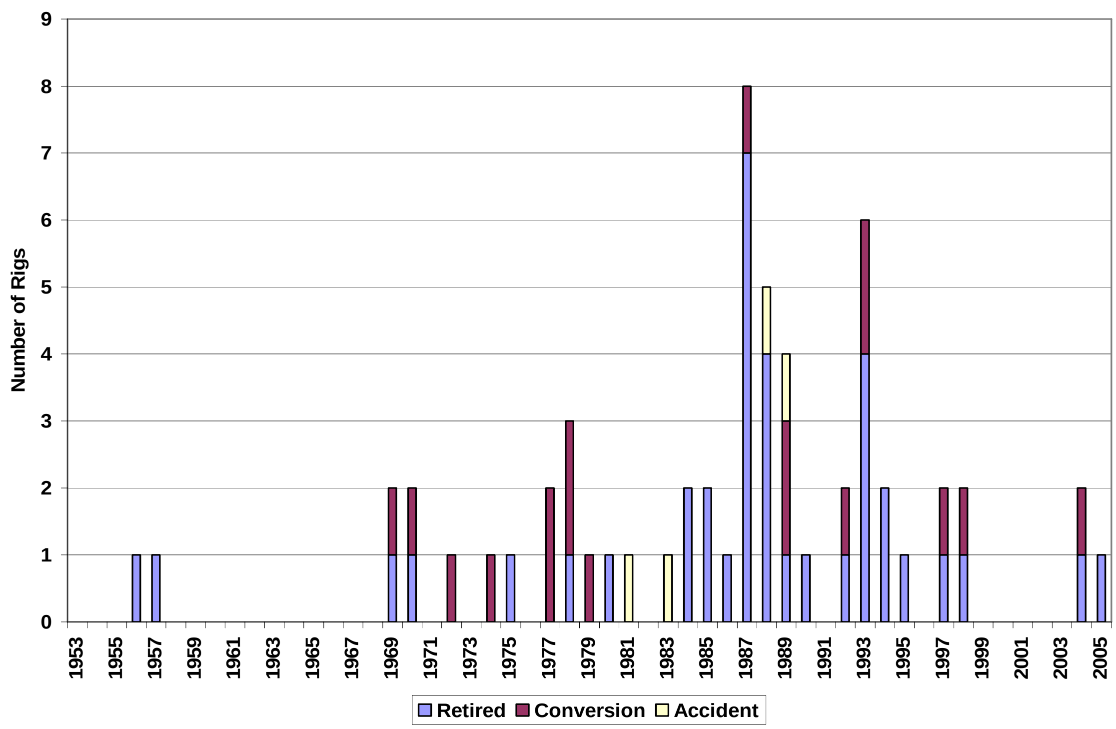

Figure D.8. Drillship Attrition Rates (Kellock, 2006).

APPENDIX E

CHAPTER 5 TABLES AND FIGURES

Table E.1

Deepwater Production Facilities in the Gulf of Mexico (2006)

Structure type	Number
Fixed Platform	6
Compliant Tower	3
TLP	8
Small TLP	6
Classic Spar	4
Truss Spar	8
Cell Spar	1
Semisubmersible	3
Subsea Completion	184

Source: (French et al., 2006)

Table E.2

Typical Topsides Weight Distribution for an 8-Pile Structure (300 ft Water Depth)

Component	Weight (tons)	Percent (%)
Drilling deck	84	10
Production deck	50	6
Deck beams	292	35
Plate girders/tubular trusses	191	23
Columns	150	18
Appurtenances†	70	8
Total	837	100

Note: † Includes rent stack, stairs, handrails, drains, subcellar, firewall, stiffeners.
Source: (Graff, 1981)

Table E.3

Typical Weight Distribution for an 8-Pile Drilling/Production Jacket Structure (300 ft Water Depth)

Component	Weight (tons)	Percent (%)
Legs	486	40
Braces	495	41
Other framing	114	9
Appurtenances†	116	10
Total	1215	100

Note: † Includes boat landing, corrosion anodes, walkways, lifting eyes.
Source: (Graff, 1981)

Table E.4

Weight Characteristics of Spars in the Gulf of Mexico

Field	Water depth (ft)	Hull diameter (ft)	Hull length (ft)	Topsides[†] weight (tons)	Payload weight (tons)	Dry hull weight (tons)
Neptune	1,930	72	705	3,200	6,600	12,895
Genesis	2,599	122	705	12,500	16,950	28,700
Hoover-Diana	4,800	122	705	17,210	26,500	35,831
Nansen	3,678	90	543	5,340	8,750	11,960
Boomvang	3,453	90	543	5,400	8,750	11,960
Horn Mountain	5,423	106	585	4,400	11,000	14,630
Medusa	2,223	94	586	6,000	9,800	12,897
Gunnison	3,150	98	549	5,700	10,770	13,354
Front Runner	3,330	94	587			14,093
Red Hawk	5,300	64	560	3,700	4,700	7,200
Mad Dog	4,420	128	555	18,000	24,500	23,376
Holstein	4,344	149	746	17,360	26,445	13,500
Devils Tower	5,610	94	586	3,810	8,500	12,600
Constitution	4,970	98	554	5,970	10,770	14,800

[†] Includes deck and facilities.

Table E.5

Weight Algorithms for Spar and TLP Floater Systems in the Gulf of Mexico

Class	*Y* (tons)	*X* (unit)	$Y = \alpha X^{\beta}$ α	β	R^2
Spar	*TOPSIDES*	*DECK* (ft^2)	0.045	1.07	0.68
	PAYLOAD	*DIAM* (ft)	0.398	2.24	0.91
	PAYLOAD	*VOL* (ft^2)	0.002	1.00	0.91
	DRYHULL	*TOPSIDES* (tons)	161.9	0.513	0.51
TLP	*TOPSIDES*	*VOL* (ft^3)	0.178	0.750	0.60
	TOPSIDES	*CAP* (MBOE)	130.2	0.912	0.51

Table E.6

Multidimensional Spar Weight Algorithms

Parameter (Unit)	*TOPSIDES* (tons)		*DRYHULL* (tons)	
	I	II	I	II
CONSTANT	-5244 (-3.9)	-4662 (-3.4)	1612.7 (2.3)	2547.6 (*)
CAP (MBOE)	65.04 (2.7)	41.62 (2.3)		
VOL (ft^3)	0.00199 (4.1)	0.00139 (6.4)	0.00111 (1.4)	0.00109 (*)
DECK (ft^2)	-0.074 (-1.4)			
WD (ft)				-0.250 (1.9)
TOPSIDES (tons)			1.256 (2.8)	1.277 (2.6)
R^2	0.94	0.93	0.96	0.95

Footnote: The t- statistics of the regression models are presented in parenthesis. (*) denotes t statistics less than 1

Table E.7

Weight Characteristics of TLPs in the Gulf of Mexico

Field	Water depth (ft)	Topsides† weight (tons)	Hull weight (tons)	Displacement weight (tons)
Jolliet	1,759	2,150	4,600	18,300
Auger	2,862	24,000	39,000	73,000
Mars	2,933	7,200	16,650	54,123
Ram/Powell	3,266		15,000	54,123
Morpeth	1,699	7,200	2,800	11,690
Ursa	3,800	22,400	28,680	97,500
Allegheny	3,350	3,065	2,600	11,690
Marlin	3,236	5,512	9,000	26,235
Typhoon	2,097		3,105	12,156
Brutus	2,985	22,000	14,500	54,700
Prince	1,472	4,000	3,500	14,437
Matterhorn	2,816	6,140	5,900	16,403
Marco Polo	4,300	13,779	5,750	27,500
Magnolia	4,674	15,230	11,023	
Neptune	4,250	5,516		

† Includes deck and facilities

‡ Includes tendons, foundation templates, and drilling templates.

Table E.8

Multidimensional TLP Weight Algorithms

Variable (Unit)	*TOPSIDES* (tons)	*DISPLACEMENT* (tons)
CONSTANT	1875.3 (*)	-5291.9 (*)
CAP (MBOE)	16.76 (*)	207.4 (2.9)
VOL (ft^3)	0.00314 (2.4)	0.00318 (*)
TOPSIDES (tons)		1.195 (1.6)
R^2	0.64	0.90

Footnote: The t- statistics of the regression models are presented in parenthesis. (*) denotes t statistics less than 1.

Table E.9

Weight Algorithms for Shallow Water Structures in the Gulf of Mexico

Structure Type	Y (tons)	X (unit)	$Y = \alpha X^{\beta}$		R^2
			α	β	
Caisson	W_d	$DECK$ (ft^2)	0.286	0.76	0.31
Well protector	W_d	$DECK$ (ft^2)	0.119	0.85	0.62
Fixed	W_d	$DECK$ (ft^2)	0.269	0.81	0.82
Well protector	W_j	WD (ft)	8.18	0.64	0.52
Fixed	W_j	WD (ft)	12.27	0.73	0.37

Table E.10

Shallow Water Jacket Weight Algorithms in the Gulf of Mexico

Parameter (Unit)	W_j (tons)	W_j (tons)
$CONSTANT$	-405.7 (-3.0)	-258.5 (-1.3)
$DECK$ (ft^2)	0.0298 (3.9)	
W_d (tons)	3.64 (6.5)	0.43 (2.6)
NP	38.6 (1.1)	117.8 (3.9)
WD (ft)		2.5 (4.1)
DP (in)		-5.4 (-1.6)
R^2	0.86	0.87

Footnote: The t- statistics of the regression models are presented in parenthesis.

Table E.11

Weight Characteristics of Fixed Platforms in the Pacific Coast

Platform	Water depth (ft)	Deck weight (tons)	Jacket weight (tons)	Pile weight (tons)	Conductor weight (tons)	Total weight (tons)
A	188	1,357	1,500	600	633	4,090
B	190	1,357	1,500	600	638	4,095
C	192	1,357	1,500	600	553	4,010
Edith	161	4,134	3,454	450	260	8,298
Ellen	265	5,300	3,200	1,100	1,700	11,300
Elly	255	4,700	3,300	1,400	0	9,400
Eureka	700	8,000	19,000	2,000	5,000	34,000
Gail	739	7,693	18,300	4,000	1,327	31,320
Gilda	205	3,792	3,220	1,030	1,300	9,342
Gina	95	447	434	125	96	1,102
Habitat	290	3,514	2,550	1,500	639	8,853
Harmony	1,198	9,826	42,900	12,350	4,831	69,920
Harvest	675	9,024	16,633	3,383	1,150	30,190
Henry	173	1,371	1,311	150	286	3,118
Heritage	1,075	9,839	32,420	13,950	4,360	60,556
Hermosa	603	7,830	17,000	2,500	802	28,131
Hildalgo	430	8,100	10,950	2,000	371	21,421
Hillhouse	190	1,200	1,500	400	638	3,738
Hogan	154	2,259	1,263	150	438	4,110
Hondo	842	8,450	12,200	2,900	3,700	27,250
Houchin	163	2,591	1,486	150	410	4,637
Irene	242	2,500	3,100	1,500	552	7,652

Source: (MMS, 2004)

Table E.12

Weight Algorithms for Fixed Platforms in the Pacific Coast

Weight (tons)	X (units)	$W = \alpha X^{\beta}$ α	β	R^2
W_j	WD (ft)	0.283	1.68	0.94
$W_{p,c}$	WD (ft)	0.432	1.47	0.89
W_d	$FOOT$ (acre)	5,218	1.16	0.82
W_{Total}	WD (ft)	2.849	1.43	0.92

Table E.13

Jacket Weight Algorithms in the Pacific Coast

Variable (Unit)	W_j (tons)	W_j (tons)
CONSTANT	-5,684 (6.3)	
FOOT (acre)	19,698 (11.0)	12,696 (3.0)
CAP (MMBOE)	-1.97 (-1.6)	-4.86 (-2.5)
W_d (tons)	-0.26 (*)	-1.37 (-2.7)
WD (ft)		21.5 (2.4)
R^2	0.97	0.93

Footnote: The t- statistics of the regression models are presented in parenthesis. (*) denotes t statistics less than 1.

Table E.14

Structures Decommissioned in the Gulf of Mexico in 2003

Water depth (ft)	Caisson	Well protector	Fixed platform	CGOM[†] reefed	WGOM reefed	Total[‡] onshore
0-50	50	9	13	0	0	22
51-100	17	7	25	4	0	28
101-150	4	2	13	0	1	14
151-200	2	1	7	3	5	0
201-250	0	6	7	1	3	9
251-300	0	0	3	1	2	0
301-400	0	0	2	0	0	2
Total	73	25	70	9	11	65

Footnote: [†]CGOM = Central Gulf of Mexico, WGOM = Western Gulf of Mexico
[‡]Total = well protector + fixed platform – CGOM reefed –WGOM reefed.

Table E.15

Caisson, Piling, and Conductor Steel Destined for GOM Storage and Scrap in 2003

State	Caisson[a] (tons)	Piling[b] (tons)		Conductor[c] (tons)	
		WP	FP	WP	FP
TX	208	337	2,050	69	633
LA	1,529	2,469	15,037	508	4,638
Total	1,737	2,806	17,087	577	5,271

Footnote: (a) Assumes an average 48" caisson diameter.
(b) Assumes a 3-pile WP and 6-pile FP with an average 48" diameter.
(c) Assumes one conductor per WP and three conductors per FP with an average 30" diameter.

Table E.16

Deck and Jacket Steel Destined for GOM Storage and Scrap in 2003

State	Deck (tons)		Jacket (tons)	
	WP	FP	WP	FP
TX	712	3,122	452	3,186
LA	5,223	22,895	3,313	23,367
Total	5,935	26,017	3,765	26,553

Figure E.1. Caisson Structure in the Gulf of Mexico (Twachtman Snyder and Byrd, Inc., 2006).

Figure E.2. Well Protector Structures in the Gulf of Mexico (Twachtman Snyder and Byrd, Inc., 2006).

Figure E.3. Production Platforms in the Gulf of Mexico (Twachtman Snyder and Byrd, Inc., 2006).

Figure E.4. Drilling and Production Platforms in the Pacific Coast (French et al., 2006).

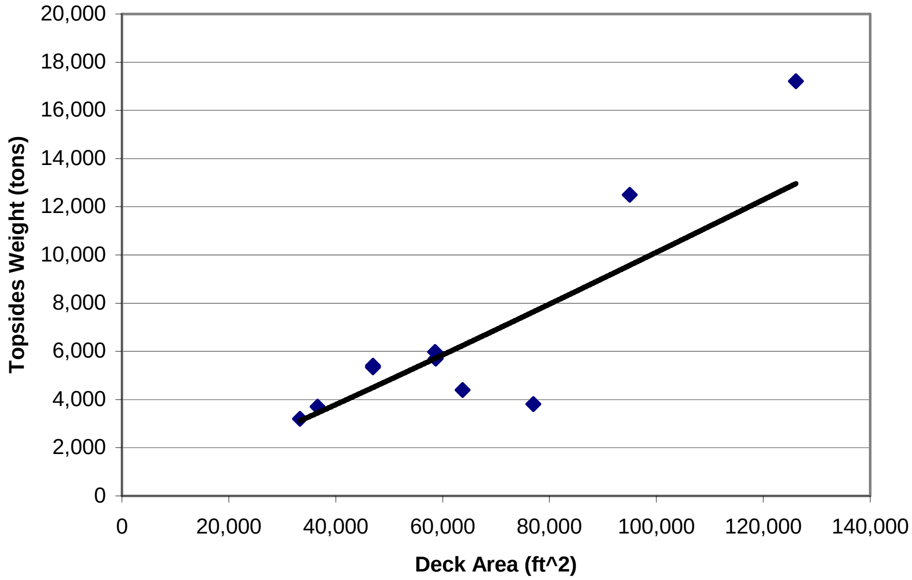

Figure E.5. Spars Topsides Weight as a Function of Deck Area.

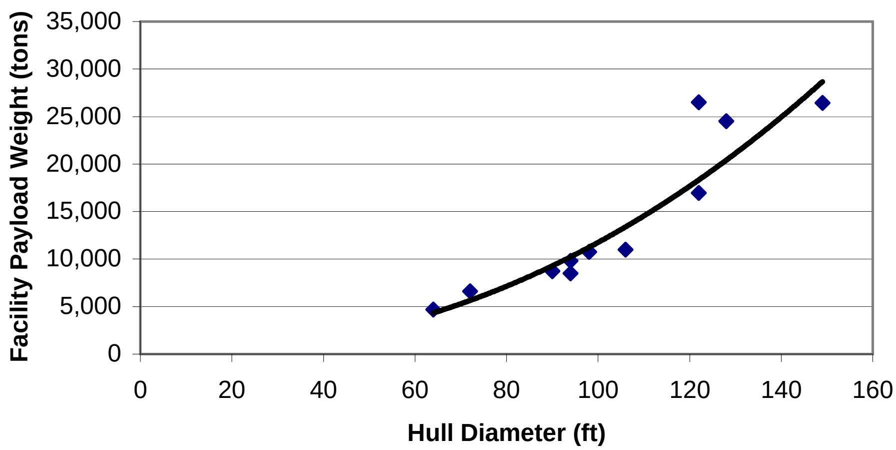

Figure E.6. Spars Facility Payload Weight as a Function of Hull Diameter.

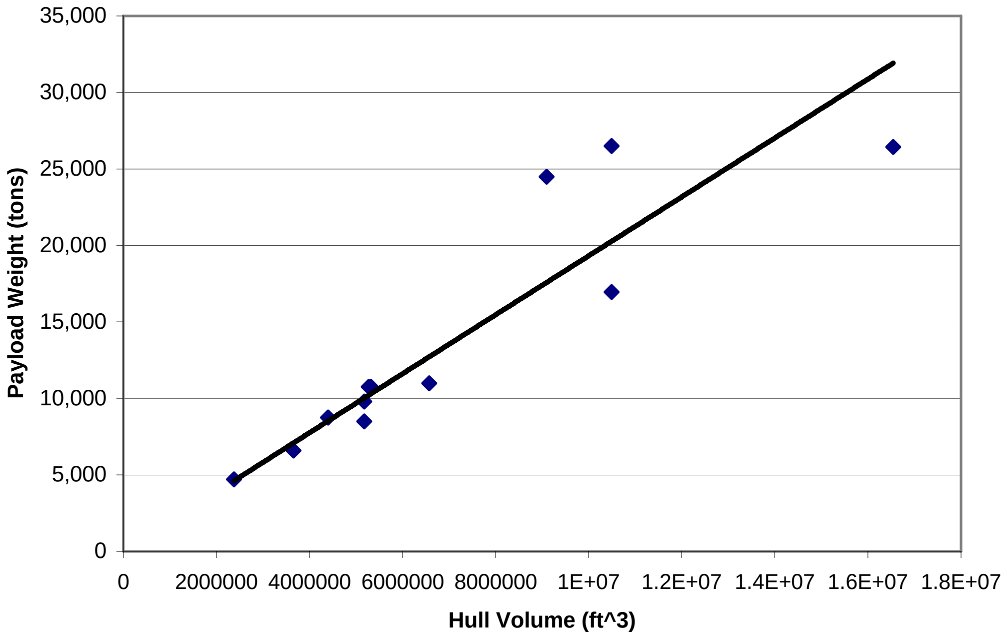

Figure E.7. Spars Payload Weight as a Function of Hull Volume.

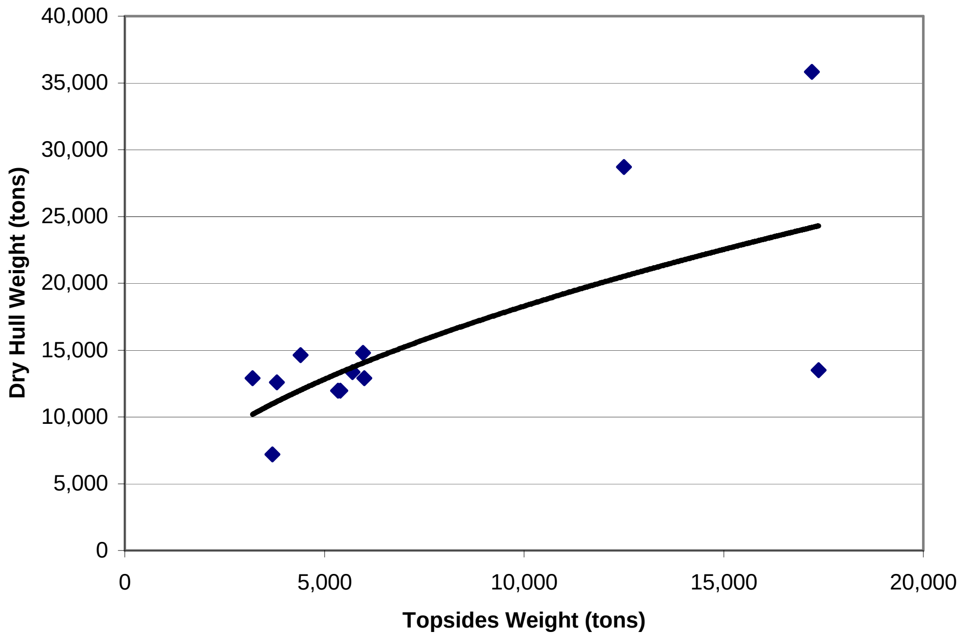

Figure E.8. Spars Dry Hull Weight as a Function of Topsides Weight.

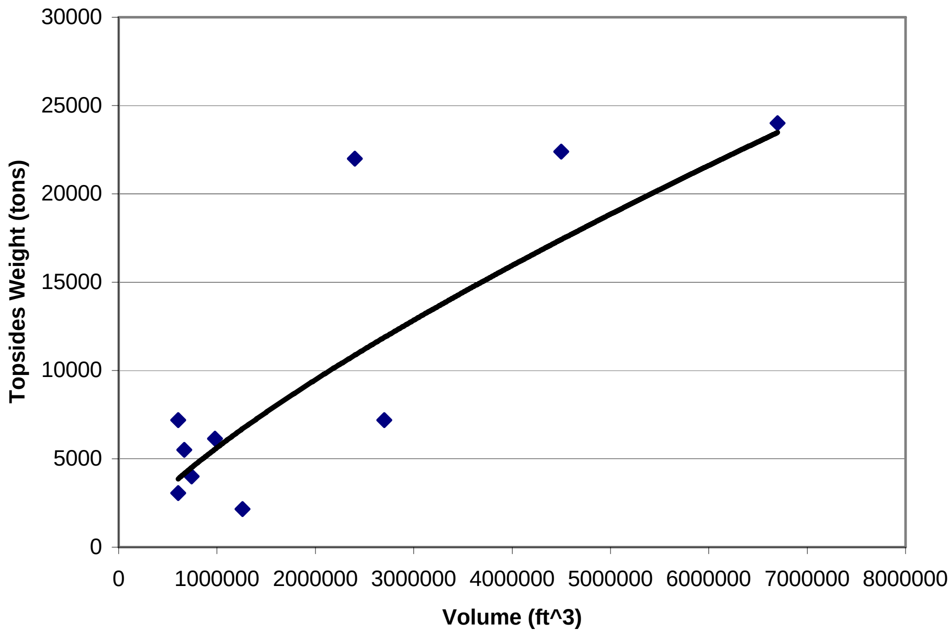

Figure E.9. TLPs Topsides Weight as a Function of Volume.

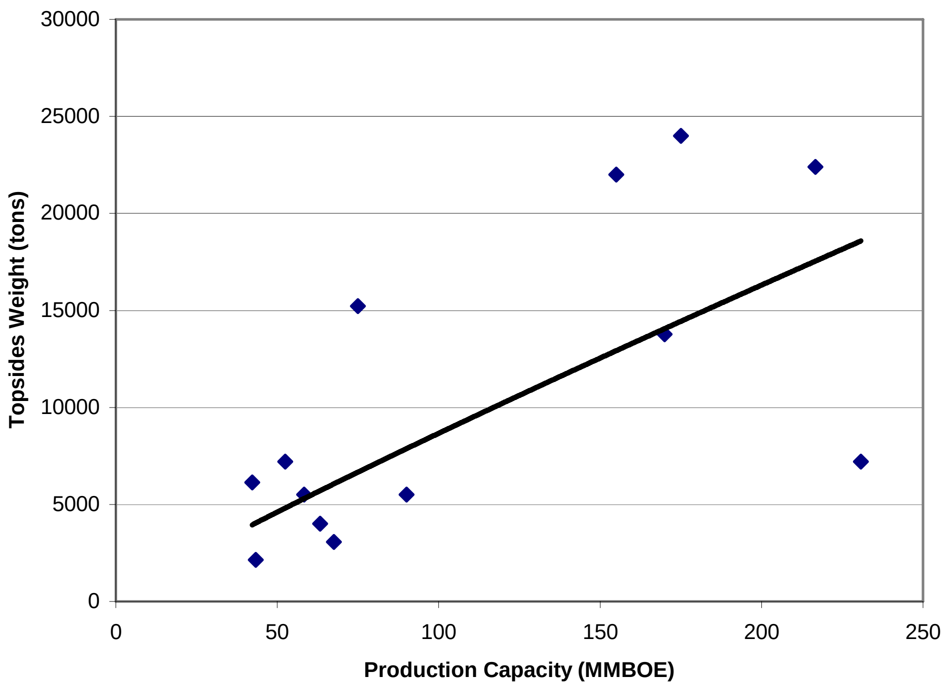

Figure E.10. TLPs Topsides Weight as a Function of Production Capacity.

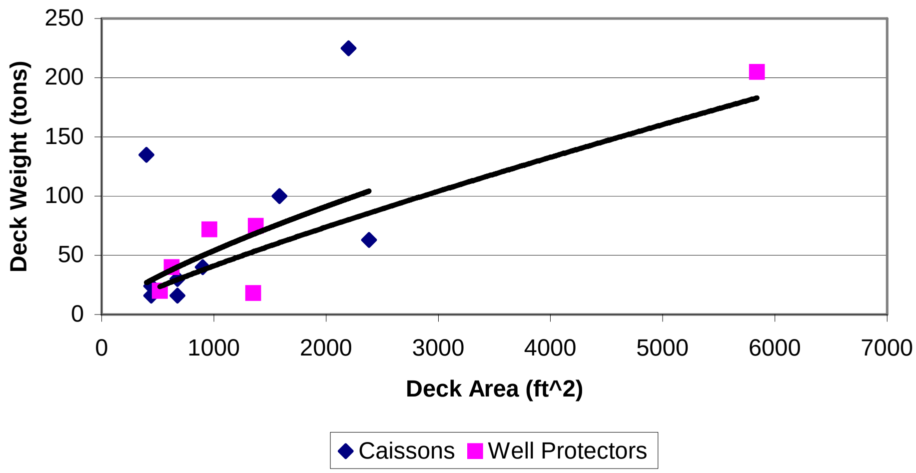

Figure E.11. Deck Weight as a Function of Deck Area (Caissons and Well Protectors).

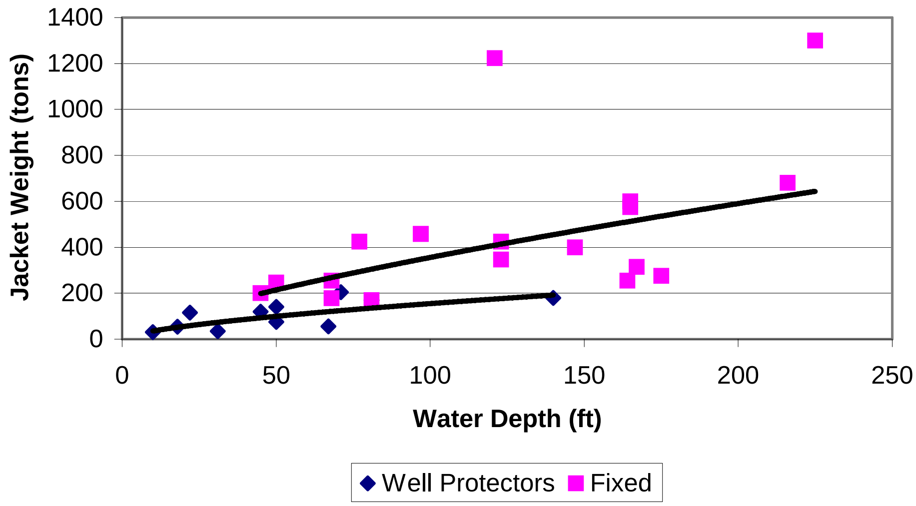

Figure E.12. Jacket Weight as a Function of Water Depth (Well Protectors and Fixed Platforms).

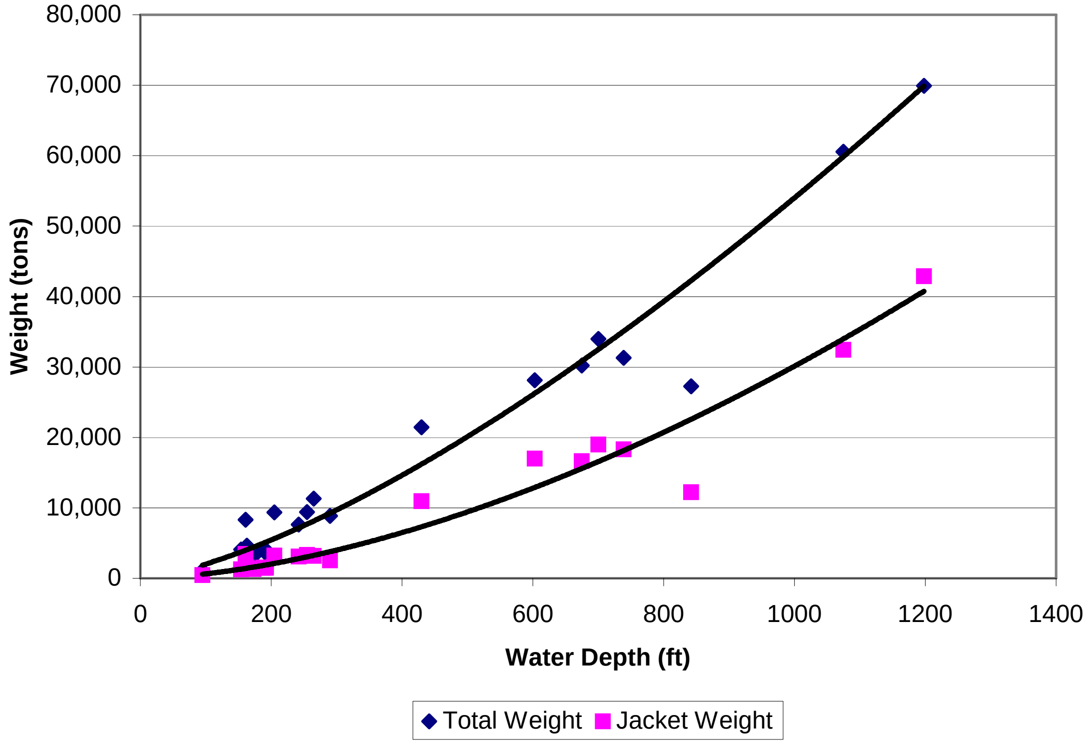

Figure E.13. Total Weight and Jacket Weight as a Function of Water Depth (Pacific Coast).

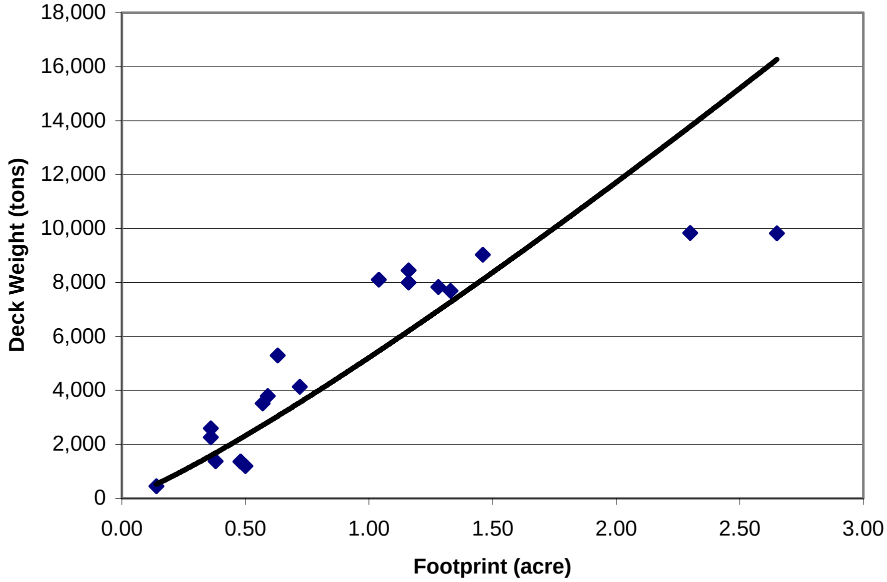

Figure E.14. Deck Weight as a Function of Jacket Footprint (Pacific Coast).

The Department of the Interior Mission

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

The Minerals Management Service Mission

As a bureau of the Department of the Interior, the Minerals Management Service's (MMS) primary responsibilities are to manage the mineral resources located on the Nation's Outer Continental Shelf (OCS), collect revenue from the Federal OCS and onshore Federal and Indian lands, and distribute those revenues.

Moreover, in working to meet its responsibilities, the **Offshore Minerals Management Program** administers the OCS competitive leasing program and oversees the safe and environmentally sound exploration and production of our Nation's offshore natural gas, oil and other mineral resources. The MMS **Minerals Revenue Management** meets its responsibilities by ensuring the efficient, timely and accurate collection and disbursement of revenue from mineral leasing and production due to Indian tribes and allottees, States and the U.S. Treasury.

The MMS strives to fulfill its responsibilities through the general guiding principles of: (1) being responsive to the public's concerns and interests by maintaining a dialogue with all potentially affected parties and (2) carrying out its programs with an emphasis on working to enhance the quality of life for all Americans by lending MMS assistance and expertise to economic development and environmental protection.