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Long-Term Oil and Gas Structure Installation and Removal Forecasting in the Gulf of Mexico: A Decision- and Resource-Based Approach

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ABSTRACT

The platform forecasting procedures employed by the Resource Evaluation Analysis (REA) Unit of the U.S. Minerals Management Service (MMS) is evaluated and quantified in a formal analytic framework. The assumptions employed in the REA/MMS methodology, the uncertainty associated with the modeling procedures, and the primary consequences of the assumption set are examined. Ten recommendations are suggested to clarify and maintain the consistency of the approach, and an alternative model is described which incorporates the suggestions for improvement. The analytic framework of the alternative model is presented and compared to the REA/MMS procedure.

A long-term infrastructure forecast in the Gulf of Mexico is developed in a disaggregated decision- and resource-based environment. Models for the installation and removal rates of structures are performed across five water

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CHAPTER 1: AN ASSESSMENT OF THE INFRASTRUCTURE FORECAST METHODOLOGY OF THE U.S. MINERALS MANAGEMENT SERVICE

1.1. Introduction

The Resource and Economic Analysis (REA) Unit of the U.S. Minerals Management Service (MMS) performs infrastructure forecasting in support of economic and environmental impact studies in the Gulf of Mexico (GOM) (Coffman *et al*., 2001). The MMS performs a number of forecasts related to GOM infrastructure, including but not necessarily limited to,

Number of exploratory wells,
Number of delineation wells,
Number of development wells,
Number of production wells,
Number of workovers,
Number of structures installed,
Number of structures removed,
Number of subsea completions, and
Miles pipeline.

Infrastructure forecast is an important input element to decision making at the MMS, and because of the scale of activities involved, drilling activity and structure installations are closely watched and used as a general guide on resource levels and development expectations.

The purpose of exploration is to discover the presence of oil and gas, and the number of exploratory wells provides a gauge of interest in the region and the level of development activity expected in the future. If hydrocarbons are discovered, delineation wells may be drilled to establish the amount of recoverable oil, production mechanism, and structure type. The number of wells required to develop reserves depends on a trade-off between risked capital and expected production. Development wells are drilled to produce the hydrocarbon resources discovered, and production wells are defined (aptly enough) as those wells that are currently in production. Development and production wells are tied into structures such as caissons, well protectors, and both fixed and floating platforms. If the wellhead control values (Christmas tree, Blow Out Preventer, etc.) are located on the seabed, the well is referred to as a subsea completion. Workovers are carried out periodically to ensure the continued productivity of the wells. The number of structures installed is an important statistic since platforms support production, must be manufactured prior to development, installed, serviced during production, and finally removed after decommissioning. The economic, environmental, and socioeconomic impact of structure installations is a significant contribution to the economic vitality of Gulf Coast communities and is evaluated and assessed with every five year lease program on offer.

Infrastructure forecasting is an uncertain and difficult endeavor due to the confluence of a number of interrelated factors, such as the uncertainty of the resource base and its future development; the uncertain economic and regulatory environment; and the large number of operator- and site-specific variables that drive activity trends. To help minimize the forecast uncertainty and ensure the accuracy and reliability of input-output models, it is important to maintain forecasting procedures that are well documented and established on a solid quantitative foundation.

There is only a limited amount of documentation supporting the REA/MMS forecast models, however, and so the first task of this paper is to formalize the REA/MMS procedure in a quantitative framework. The REA's platform forecasting procedure is analyzed in an effort to add operational insight into the methodology and to provide support for refinements to the approach. The primary purpose of this paper is thus three-fold:

(1) To document and specify the procedures currently employed by the REA in the construction of a platform forecast in the Gulf of Mexico,

(2) To analyze the assumption set employed in the REA forecast and to critique the procedure, and

(3) To use the assessment as a guide to develop an alternative methodology for platform forecasting.

The outline of Chapter 1 is as follows. In Chapter 1.2, a description of the REA/MMS platform forecast procedure is detailed. The general methodology is presented in Chapter 1.2.1 followed by important background information in Chapter 1.2.2 on the definition of resource categories. The production profile forecast is described in Chapter 1.2.3 and the infrastructure requirements forecast is described in Chapter 1.2.4. A critique of the REA methodology is discussed in Chapter 1.3 and a series of procedural recommendations are presented in Chapter 1.4. In Chapter 1.5, the analytic framework for an alternative infrastructure forecast is presented. The methodology is outlined in Chapter 1.5.1, followed in Chapter 1.5.2 and Chapter 1.5.3 by a description of the cumulative production profile and the derivation for the expression of the number of active platforms. The alternative approach is formalized in Chapter 1.5.4 and compared to the REA approach in Chapter 1.5.5. Conclusions are presented in Chapter 1.6.

1.2. The MMS Infrastructure Forecast Methodology

1.2.1. The REA/MMS Infrastructure Forecasting Procedure: Platform forecasting was initiated at the REA/MMS in the early 1990's and has evolved to a sophisticated

Step 2. Annual production per active platform is forecast per water depth and planning area category.

Step 3. The number of active platforms required to meet the annual production projections (from *Step 1*) is determined using the annual production to active platform ratio forecast (from *Step 2*).

Step 4. Platform installation and removal rates are estimated to achieve the number of active platforms computed in *Step 3*.

The hydrocarbon production profile outlined in *Step 1* will be discussed Chapter 1.2.3 after the resource categories are defined. The infrastructure forecast outlined in *Steps 2-4* will be examined in Chapter 1.2.4.

1.2.2. Resource Category Definition: The MMS is required by legislative mandate to provide assessments of Outer Continental Shelf (OCS) undiscovered oil and gas. Reserve estimates are performed frequently – normally every year or so – while undiscovered oil and gas assessments are performed every four years or so.

Reserves are those quantities of hydrocarbon that are anticipated to be commercially recoverable from known accumulations. Proved reserves can be thought of as inventory in the ground already paid for with investment dollars. The inventory is known with high confidence (“reasonable certainty”) and is specified in terms of a given reserves amount. Proved reserves are known with reasonable certainty because the field has been defined by appraisal wells, and while developed reserves can be produced from existing wells and existing infrastructure, undeveloped reserves will have to be produced from wells that have not yet been drilled or from existing wells that are “beyond the pipe.” Proved reserves are *not* fixed, but rather, depend upon the amount of exploration undertaken, technology, and economic conditions, and thus can vary as a result of changes in the external position of these factors; e.g., proved reserves increase with successful exploration and decrease by the amount of production.

Unproven reserves are calculated similar to proven reserves, but because of technical, contractual, economic, or regulatory uncertainty, their production is not as certain as proven reserves. Unproven reserves are producible and economically recoverable, but their presence is based more on geologic interpretation than on physical evidence, and hence, the quantities are less certain than proved reserves.

Reserves appreciation refers to the *expected* increase in estimates of proven reserves as a consequence of the extension of known pools or discovery of new pools within existing fields. Reserves appreciation, or reserves growth, represents the expected increase in the estimates of original proved reserves of an oil and gas field. Field growth can result from several factors such as improvements in recovery, physical expansion of the field, better understanding of the reservoir, data re-evaluation, extension drilling, and changes in economic parameters. Changes in reserve estimates may be negative as well as positive, but on average reserve estimates have grown over time. Field growth is most rapid the first few years after a field is discovered, and later tend to level out at a smaller increment.

Statistical growth curves based on historic data are commonly used to estimate reserves appreciation, and this is the method employed by the MMS (Lore *et al*., 2001).

Unproved reserves and reserves appreciation are not quite the same as proved reserves because for unproved reserves and appreciation we are forecasting how to build inventory, and of course, we don't know the required investment or the future prices that will induce such investment. Hence, unproved reserves and reserves appreciation are more uncertain than remaining proved reserves, but are generally considered reliable and more certain than undiscovered resources.

Undiscovered conventionally recoverable resources (or, ultimately recoverable reserves) is oil and gas which has not yet been physically discovered but for which there is “some certainty” that it exists and can be extracted with, by definition, conventional technology[1]. Undiscovered resources are those resources outside of known fields that is postulated to exist based on broad geologic knowledge. Undiscovered resources come in two forms – conventionally recoverable and economically recoverable. Conventionally recoverable resources are that portion of the hydrocarbon potential that is producible, using present or reasonably foreseeable technology, without any consideration of economic feasibility. Undiscovered conventionally recoverable resources (UCRR) are primary located outside of known fields, but undiscovered pools within known fields are also included to the extent that they occur within separate plays. The portion of UCRR that is economically recoverable under imposed economic and technologic conditions[2] is referred to as undiscovered economically recoverable resources (UERR). Resource appraisals are based on group assessments and the application of subjective probability estimates of various parameters. Undiscovered resources have significant uncertainty associated with its expected magnitude and development.

The following notation is established. Proved reserves located within the Western and Central GOM planning area P_i, i=1,2, are denoted by $R_1(P_i)$, unproved reserves by $R_2(P_i)$, reserves appreciation by $R_3(P_i)$, undiscovered conventionally recoverable resources by $R_4(P_i)$, and undiscovered economically recoverable resources by $R_5(P_i)$. The magnitude of $\{R_1(P_i),\ R_2(P_i),\ R_3(P_i),\ R_4(P_i),\ R_5(P_i)\}$ depend upon a number of uncertain economic, geologic, and technologic parameters, and are considered stochastic quantities; e.g., although the estimate of the magnitude of $R_1(P_i)$ is fairly certain, $R_5(P_i)$ is highly variable, and the uncertainty associated with $R_2(P_i)$, $R_3(P_i)$, and $R_4(P_i)$ fall in

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[1] While unconventional oil deposits (e.g., tar sand, oil shale) have thus far contributed little to domestic U.S. production, unconventional natural gas

between these two classifications. Resource estimates based on the 2000 National Assessment data are depicted in Table A.1[3].

The elements $\{R_1(P_i),\ R_2(P_i),\ R_3(P_i)\}$ are assessed as point estimates in the 2000 National Assessment and represent average (or expected) values, while $\{R_4(P_i),\ R_5(P_i)\}$ are estimated relative to a "low" (pessimistic) and "high" (optimistic) case scenario corresponding to a "pessimistic" and "optimistic" economic environment[4]. For $R_4(P_i)$, the low and high estimates are referred to as F5 (5th percentile) and F95 (95th percentile), respectively, while the average estimate is referred to as F50 (50th percentile). The F5 estimate reflects the resource quantity having a five percent probability that the ultimate resource, when found, will equal or exceed the estimated quantity. The F50 and F95 estimates have similar interpretations. For $R_5(P_i)$, the low and high estimates represent the mean resources at $18/bbl oil, $2.11/Mcf and $30/bbl oil, $3.52/Mcf.

<u>1.2.3. The Production Profile Forecast:</u> The Resource and Economic Analysis Unit of the MMS performs a 40-year production profile forecast for oil and natural gas for each planning area of the Gulf of Mexico. The REA constructs production profiles by specifying annual production rates to recover the resource base within each resource category over the time horizon of the forecast. If

$q_{(o,g)}^{[L,H]}(P_i,t,K_i) =$ Annual production rate of (oil, gas) = (*o*, *g*) under a [low, high] = [*L*, *H*] case economic scenario corresponding to planning area P_i at time *t* and resource category K_i,

then the construction of the supply curve follows by specifying $q_{(o,g)}^{[L,H]}(P_i,t,K_i)$ each year over the range (*τ*, *τ*+40] subject to the following conditions:

$$\sum_{t=\tau}^{\tau+40} q_{(o,g)}^{[L,H]}(P_i,t,K_1) = p_1^{[L,H]}K_1,$$
$$\sum_{t=\tau}^{\tau+40} q_{(o,g)}^{[L,H]}(P_i,t,K_2) = p_2^{[L,H]}K_2, \qquad (1)$$

where *τ* represents the current time; $K_1 = \{R_1(P_i) + R_2(P_i) + R_3(P_i)\}$; $K_2 = \{R_5(P_i)\}$; and $0 < p_i^{[L,H]} \le 1, i=1,2$. Resource category K_1 is reserves and appreciation while K_2 is undiscovered resources. If $p_i^{[L,H]} = 1$, full recovery of the resource category is specified, while $p_i^{[L,H]} < 1$ indicates only partial recovery. The value of $p_i^{[L,H]}$ can be viewed as a

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[3] The Eastern GOM planning area is not considered due to its low production and activity levels and historic restrictions on leasing sales.

[4] The pessimistic economic scenario corresponds to $18/bbl oil and $2.11/Mcf gas, while the optimistic economic scenario corresponds to $30/bbl oil and $3.52/Mcf gas.

decision variable, and in the present context is inferred from the production profiles established by the REA.

After the production profiles

$$q_{(o,g)}^{[L,H]}(P_i, t, K_j)\,,\ \ i\!=\!1,\,2;\ \ j\!=\!1,\!2,$$

are constructed for each resource class K_j, the total hydrocarbon annual production within planning area P_i at time t, $q_{(o,g)}^{[L,H]}(P_i, t)$

2. (a) To recover undiscovered economically recoverable resources, the REA/MMS employs a procedure where the production profiles used to recover $R_5(P_1)$ are decomposed into a "proposed" and "future" sales category which begins recovery within three and four years, respectively, of the current time. Proposed sales represents approximately 7% of the estimated total oil resources and 8% of the estimated natural gas resources within the category.

   (b) The recovery curves $q_{(o,g)}^{[L,H]}(P_i, t, K_2)$ are smooth and bell-shaped reaching their maximum recovery rates near the year 2030 for both oil and gas. The production profiles for the low and high case scenario are approximately scaled versions of one another; i.e.,

$$q_{(o,g)}^{H}(P_i, t, K_2) \approx \alpha\, q_{(o,g)}^{L}(P_i, t, K_2), \text{ for } \alpha > 1.$$

   (c) The REA hydrocarbon production forecast recovers a fraction of the undiscovered resource base in the WGOM. More precisely, (31%, 35%) of the oil resources and (46%, 58%) of the gas resources in the K_2 category are recovered over the time horizon of the forecast. The recovery rates of K_3 are slightly higher in the CGOM region: (41%, 54%) for oil and (62%, 91%) for gas. Refer to Table A.1.

3. (a) The REA allocates (41%, 45%) of the total oil resources and (66%, 73%) of the total gas resources within the WGOM over a 40-year horizon. In the CGOM, (61%, 64%) of the total oil resources and (83%, 95%) of the total gas resources are recovered. Oil recovery is underestimated relative to gas resources, and gas recovery percentages exhibit a larger spread. In terms of BOE recovery rates, the percentage values are a weighted average of the oil and gas recovery rates and converge in value: (56%, 60%) of the WGOM resources are recovered and (73%, 85%) of the CGOM resources are recovered.

   (b) The cumulative curves for the WGOM imply that the REA "implicit" forecasts is that between 63% (low) to 50% (high) of the oil resources, and between 57% (low) to 52% (high) of the gas resources, will be recovered within 20 years[5].

Production profiles constructed for oil and natural gas can be compared to other industry supply forecasts, such as those performed by the Gas Research Institute, National Petroleum Council, American Gas Association, and U.S. Department of Energy. A direct comparison of production forecasts should be approached cautiously, however, since the estimates of the resource base and underlying assumptions of the various models are not likely to be compatible; e.g., industry forecast generally tend to be "optimistic" relative to government assessments, although even government forecast have occasionally been criticized as being too optimistic (e.g., see (Attanasi, 2001)).

1.2.4. The Infrastructure Forecast: The hydrocarbon production profile is one of three forecasts required to drive the platform infrastructure requirements. Two additional forecasts are required to determine the number of structures installed and removed. In reference to the four-step procedure outlined in Chapter 1.2.1, we now focus on *Steps 2-4*:

The total annual production profile in planning area P_i in year t is denoted by $q(P_i, t)$ and the number of active platforms is designated by $A(P_i, t)$. A forecast is denoted by a superscript *, so that for instance,

$q(P_i,t)*$ = Forecast of the annual production profile in P_i

$\left(\dfrac{q(P_i,t)}{A(P_i,t)}\right)^*$ = Forecast of the annual production per active platform ratio in P_i .

The REA employs the forecast $q(P_i,t)*$ and $\left(\dfrac{q(P_i,t)}{A(P_i,t)}\right)^*$ to determine the number of active platforms that are required to meet the production projection. The number of active platforms is established by multiplication:

$$q(P_i,t)*\left(\frac{q(P_i,t)}{A(P_i,t)}\right)^* = A(P_i,t)*, \qquad (4)$$

and using the forecasted number of active platforms, $A(P_i,t)*$, and a conjectured relation on the ratio of installed-to-removed platforms, $i(P_i,t):r(P_i,t)$, to satisfy the relation

$$A(P_i,t)* = A(P_i,t-1)* + r(P_i,t)* - i(P_i,t)*. \qquad (5)$$

The annual number of installed and removed platforms required to achieve balance is estimated based on historic installed-removed ratio patterns and life-cycle analysis.

1.3. Critique of the MMS Methodology

1.3.1. A Critique of the Production Profile Forecast: Production forecasts are notoriously difficult to perform regardless of the individual, agency, or organization. A production forecast is based upon the best information available at the time and must be considered under the economic conditions projected for the future, including assumptions regarding inflation and technological improvements. It is important to carefully delineate all assumptions and decision parameters in a forecasting procedure. Based on REA/MMS methodology, the following observations are provided.

1. (a) The National Assessment of the remaining proved reserves in the WGOM is stated as a point estimate of 0.495 Bbbl oil and 7.393 Tcf gas (see Table A.1).

The REA bounds these values through the selection of a low and high case scenario which is not compatible with the manner in which the data is reported. To employ the point estimates it is suggested that appropriate assumptions be specified.

(b) For the estimated proved reserves, bounds on the recovery rate (not on the magnitude) of $R_1(P_1)$ and $R_2(P_1)$ may be desirable; e.g., the form of the low and high case profiles $q^H_{(o,g)}(P_1, t, K_1)$ should not necessarily be scaled versions of one other; i.e.,

$$q^H_{(o,g)}(P_1, t, K_1) \qquad\qquad (\quad , \; , \quad)$$

constructed over a planning area basis cannot drive a forecast through depth categories unless appropriately disaggregated.

2. (a) The annual production per active platfo

Ten recommendations follow.

1. The notion of being able to recover a fixed resource "bundle" (e.g., $R_1(P_1)+R_2(P_2)+R_3(P_2)$) at a given rate (e.g., $q_o^L(P_1,t,K_1)$) beginning at a specific time is entirely hypothetical. Resources flow between and within categories in ways that are not predictable or quantifiable. Reality is better explained in a dynamic manner

5. The construction of the REA supply profiles can be simplified in terms of a 2-parameter decision model where the decision maker specifies the amount of $R_T(P_i)$ that is expected to be recovered (the first parameter) within a particular time frame (the second parameter). This will help to clarify the exposition and simplify the forecast across multiple water depth categories; the downside of the approach is erosion of the link between

1.5. The CES Infrastructure Forecast Methodology

1.5.1. The CES Infrastructure Forecasting Procedure: The infrastructure forecast methodology proposed by the CES/LSU is a four-step procedure based in part on the structure of the REA/MMS approach. A formal treatment of the methodology is described as follows:

Step 1. Construct cumulative hydrocarbon production profiles on a BOE basis per water depth and planning area category over a 40-year time horizon

Step 2. The cumulative number of major and nonmajor structures installed and removed per cumulative BOE production on a water depth and planning area basis is forecast over a 40-year time horizon.

Step 3. The cumulative number of structures installed and removed over each water depth and planning area category is determined by the product of the profiles determined in *Step 1* and *Step 2*.

Step 4. The annual number of major and nonmajor structures installed and removed are derived from the cumulative forecast in *Step 3*.

1.5.2. The Cumulative Production Profile: To perform a resource-based infrastructure forecast on a water depth and planning area basis requires the user to construct a production profile forecast over a similar water depth and planning area basis. The REA currently performs a supply profile forecast over three planning areas; in the CES approach this is replaced by nine supply forecasts (one for each planning area and water depth category: 0-200m, 201-800m, 800+m). The CES approach employs a decision-oriented construction, requesting the user provide the following information:

What percentage of $R_T(\Gamma_{i,j})$ will be recovered within the time horizon τ?

The recovery of the remaining conventionally recoverable resources is thus based on the *belief* of the decision maker. Two input parameters are required: the percentage of $R_T(\Gamma_{i,j})$ to be recovered (the first parameter) within the time horizon τ (the second parameter). The application of a 2-parameter supply profile not only simplifies the construction of the profiles, but also creates a framework to perform sensitivity analysis.

1.5.3. Expression for the Number of Active Platforms: The number of active platforms operating in the water depth and planning area region $\Gamma_{i,j}$ at time t is denoted $A(\Gamma_{i,j},t)$. The number of active platforms is a dynamic quantity and is computed on an annual basis in terms of the relation

$$A(\Gamma_{i,j},t) = A(\Gamma_{i,j},t-1) + i(\Gamma_{i,j},t) - r(\Gamma_{i,j},t)\,, \tag{8}$$

where $i(\Gamma_{i,j},t)$ and $r(\Gamma_{i,j},t)$ represent the annual number of platforms installed and removed in region $\Gamma_{i,j}$ over the time interval (t-1,t]. In words, relation (8) indicates that the number of platforms active at time t, $A(\Gamma_{i,j},t)$, is equal to the number of platforms active in the previous year, $A(\Gamma_{i,j},t$ -1), plus the number of platforms installed minus the number of platforms that were removed over the past year (t-1, t], $i(\Gamma_{i,j},t)$ and $r($ *ts*

In words, relation (14) expresses the number of active platforms in region $\Gamma_{i,j}$ at time *t*, $A(\Gamma_{i,j},t)$, as the difference in the cumulative number of platforms installed and removed through time *t*, $I(\Gamma_{i,j},t)$ and $R(\Gamma_{i,j},t)$.

1.5.4. The CES Methodology: The REA approach to infrastructure forecasting employs the number of active platforms to annual production ratio,

$$\frac{A(\Gamma_{i,j},t)}{q(\Gamma_{i,j},t)}, \tag{15}$$

to determine the number of active platforms required to recover the anticipated production. Using relation (14), the ratio (15) is written equivalently as

$$\frac{q(P_i,t)}{A(P_i,t)}, \tag{23}$$

while the CES approach applies the cumulative number of (major, nonmajor) structures installed and removed over the cumulative production in region $\Gamma_{i,j}$:

$$\frac{I^{[m,n]}(\Gamma_{i,j},t)}{Q(\Gamma_{i,j},t)},\quad \frac{R^{[m,n]}(\Gamma_{i,j},t)}{Q(\Gamma_{i,j},t)}. \tag{24}$$

- The REA forecasts $q(P_i, t)^*$ and the ratio

$$\left(\frac{q(P_i,t)}{A(P_i,t)}\right)^*, \tag{25}$$

while the CES approach forecasts each of the functionals

$$\left(\frac{I^{[m,n]}(\Gamma_{i,j},t)}{Q(\Gamma_{i,j},t)}\right)^*,\quad \left(\frac{R^{[m,n]}(\Gamma_{i,j},t)}{Q(\Gamma_{i,j},t)}\right)^*. \tag{26}$$

separately.

- The REA forecasts the number of active platforms to support a given production profile by multiplying a forecast of the annual production, $q(P_i, t)^*$, by (the inverse of) the forecasted ratio $(q(P_i, t)/A(P_i, t))^*$, to yield the number of active platforms:

$$q(P_i, t)^* \cdot \left(\frac{A(\Gamma_{i,j},t)}{q(\Gamma_{i,j},t)}\right)^* = A(P_i, t)^*. \tag{27}$$

The CES approach forecasts the cumulative supply curve $Q(P_i, t)^*$ over the water depth and planning area category $\Gamma_{i,j}$, and then multiplies the cumulative profile by a forecast of the infrastructure requirements ratio:

$$Q(\Gamma_{i,j}, t)^* \cdot \left(\frac{I^{[m,n]}(\Gamma_{i,j},t)}{Q(\Gamma_{i,j},t)}\right)^* = I^{[m,n]}(\Gamma_{i,j},t)^*, \tag{28}$$

$$Q(\Gamma_{i,j},\, t)^{*} \cdot \left(\frac{R^{[m,n]}(\Gamma_{i,j}, t)}{Q(\Gamma_{i,j}, t)} \right)^{*} = R^{[m,n]}(\Gamma_{i,j}, t)^{*},$$

to yield the cumulative number of major and nonmajor structures installed and removed over $\Gamma_{i,j}$, ${}^{[\ ,\ ]}_{\text{removed over}}$

and promulgating the GOM platform forecast, and as discussed in this paper, the main criticism is aimed at refining the methodology, explicitly enumerating the assumption set, and ensuring that the solution methodology is consistent within the model framework. A set of recommendations was described addressing these concerns.

The methodology suggested in Chapter 1 is an adaptation of the REA approach that formalizes the framework in a consistent manner, modifies some key elements of the methodology, and incorporates decision parameters within the procedure. A formal development of the proposed methodology was presented and compared with the REA approach. Comparison of the two approaches illustrates that the REA and CES procedures represent a trade-off between the preferences of the user and the assumptions of the methodology. It is suggested that the two procedures evolve into an automated "best practice" model.

CHAPTER 2: A DECISION- AND RESOURCE-BASED APPROACH TO LONG-TERM INFRASTRUCTURE FORECASTING IN THE GULF OF MEXICO

2.1. Introduction

Platforms and pipelines are the primary infrastructure used to develop and transport hydrocarbons in the Gulf of Mexico (GOM). Platforms represent the visible signatures of production with pipelines their invisible partner. A wide variety of platforms, or more generally, structures, are used in gulf waters to support the equipment used for drilling wells, processing hydrocarbon production, or housing offshore personnel. Offshore structures are designed under specific environmental conditions and operator loads, and although it is difficult to classify all configurations, most structures may be characterized as caissons, well-protector jackets, conventionally piled fixed platforms, and floating structures. Knowledge of the number of structures expected to be installed and removed in offshore waters is of primary importance in forecasting methodology is described, followed by a description in Chapters 2.4.2 and 2.4.3 of the two key steps of the forecast, namely, constructing the supply profile and forecasting the infrastructure requirements ratio. Model results and a general interpretation of the procedure are presented in Chapter 2.4.4. Limitations of the analysis and suggestions for further research are presented in Chapter 2.5. In Chapter 2.6, conclusions complete the paper.

2.2. Background Information

2.2.1. The Demand for Infrastructure in the Gulf of Mexico: The oil and gas industry has operated along the Gulf Coast for nearly 100 years, beginning with overwater drilling at Caddo Lake, Louisiana, in 1905. To be able to drill and produce without direct contact to the land, construction engineers at Caddo Lake drove pilings into the bottom of the lake bed to provide support for the platforms. Barges transported drilling equipment and supplies to the drill site, and underwater pipeline connected the producing wells to gathering stations on the lake (Pratt *et al*., 1997). The first offshore platform was installed in the Gulf of Mexico in 1947 in about 5m of water (Kerr-McGee, Ship Shoal Block 32), while today, drilling and production companies are moving into the ultradeepwaters of the gulf in depths approaching 3,000m (Baud *et al*., 2000).

Platforms and pipelines are the primary infrastructure required to develop and transport hydrocarbons. Platforms either stand on the sea bottom or float on the sea surface, and hold the equipment required to treat and process the produced fluids, including drilling equipment, cranes, compressors, power generators, etc. Structures provide the foundation for surface facilities and serves as the “ground” in offshore development, while pipelines are used in gathering systems, moving fluids between facilities within and between fields, and for final transport away from the field to market[8]. In deep waters well platforms are connected by pipeline to a facilities platform where processing takes place. Wells, facilities, and quarters are kept on separate platforms, if possible, for safety reasons, but as the water gets deeper and platform jackets become more expensive, well, facility, and quarters’ platforms are normally combined into a single super structure. Platform costs escalate with increasing water depth and shift the economics away from wells with individual jackets toward multiple wells drilled from a single platform and subsea wells tied back to a host facility (Conaway, 1999).

Platform and pipeline infrastructure development in the offshore Gulf of Mexico is closely associated with field development but the correlation depends on a complex array of factors which are not readily quantified. The shallow waters of the GOM is a mature offshore region with the most highly developed infrastructure in the world, while deep water development is still considered a frontier region with virtually no supporting infrastructure (Baud *et al*., 2000). The dynamics of deepwater development are also quite different than shallow water fields, both in terms of production characteristics, development costs, cash flow streams, development time, and technology applications. While shallow water wells are commonly associated with individual structures, deepwater

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[8] All the natural gas in the GOM, and practically all the oil, is transported via pipeline to shore.

platforms are normally developed as a “hub” to serve several wells, and increasingly, more than one field. The number of producing wells per active platform as shown in Table B.1 is one measure that captures this trend. Recent reservoir management that act to reduce the number of new structures that need to be installed.

2.2.2. The Need to Forecast Infrastructure: Platform forecasting in the GOM is used as a guide to activity levels and as input to economic and environmental impact studies of oil and gas development (Coffman *et al*., 2001; Olatubi and Dismukes, 2002; Skolnik and Holleyman, 2002; USDOI, MMS, 2001). The need to forecast infrastructure development is thus primarily viewed in terms of its economic and environmental impact. In terms of economic development, platforms need to be constructed, delivered, installed, and equipped prior to production, operated and serviced during production, and then eventually decommissioned and removed after production. Each of these activities has both a direct and indirect impact on the communities in which the service facilities and manufacturing operations are located, and hence induce a "spill-over" effect on the economic growth and vitality of the regions which serve the development; e.g., see (Olatubi and Dismukes, 2002; Skolnik and Holleyman, 2002). An entire industry has been built in the GOM around installing production equipment and structures, servicing those structures (maintenance, repairs, supply), and then removing the structures when production ceases. In terms of environmental impact, the installation of application of a water depth categorization partitions configuration type to some extent, but

REM_t = Number of structures removed at time t,

CFZ_t = Cumulative field size at time t, and

P_t = Crude oil price at time t.

These relations were then combined with a drilling and discovery process model to forecast the number of structures through the year 2023. The impact of crude oil price variations on the number of active structures was also investigated through price scenarios supported by an EIA forecast. The reader can consult (Pulsipher *et al*., 2001) for a description of the procedures and discussion of the model results.

The MMS also performs platform forecasting (Desselles, 2001a and b) in support of economic and environmental impact studies and other regulatory concerns as described in (Coffman *et al*., 2001). The MMS forecasting procedure is a "resource-based" approach, meaning that the platform requirements necessary to develop the hydrocarbon resources are estimated using hypothetical production profiles that recover an estimated resource base. A "master" hydrocarbon production schedule is conjectured and the infrastructure trends required to support the production are then estimated using historic data and extrapolation techniques. The platform forecast performed by the MMS is at a lower aggregation level than the CES study, occurring over separate water depths and planning regions in the GOM, but as in the CES approach, the MMS does not aggregate the data elements into category types (e.g., major and nonmajor structures).

A review of the advantages, disadvantages, and assumptions of each approach is useful to guide and inform the current methodology. Regression-based models as employed previously in the CES study develop their relationship based on econometric fundamentals and historic data. These relationships are typically determined at a high level of aggregation and attempt to incorporate exogenous factors that influence the installation and removal rates of platforms. By employing data that does not distinguish between geographic location or structure type, however, it is difficult to categorize the model output in terms that are directly relevant for impact studies. In essence, the high level of aggregation destroys the information content of the data since heterogeneous entities are grouped and forecast as similar elements. The data aggregation schemes are easy to revise by constructing regression models over appropriate data subcategories, but the "slicing and dicing" needs to be performed carefully. The application of a discovery process model is also a standard approach to incorporate new field discoveries, but the uncertainty associated with discovery models performed over a large geographic region generally limits their usefulness in practice (Lynch, 2002; National Academy of Sciences, 1991).

The MMS approach drives the infrastructure forecast with a production profile which serves as a substitute for the discovery model. Production profiles are constructed over a planning area and are based on recovering the reserve and resource estimates provided in the National Assessment (Lore *et al*., 2001). Production profiles are relatively easy to construct, but there is also a high degree of uncertainty in the profiles which is not explicitly taken into account. The MMS performs the infrastructure forecast over a lower aggregation level than the CES study, employing planning area and water depth categories, but the production profiles themselves are not performed across the same water depth categories leading to an inconsistent formulation. Recovering the resource base along a production curve also limits the application of some exogenous variables – notably price and technological change – since the inclusion of such factors would not be logically consistent with the form of the resource data[10]. There is also no attempt to distinguish between the type of structures upon which the forecast is based. Since the platform forecast is used as input to economic impact studies which rely upon class demarcation more than merely a "count" of structures, the disaggregation of structures into type is considered essential.

The purpose of this paper is to combine and refine the CES and MMS approaches to platform forecasting to develop a framework that is logically coherent and sensitive to the needs of the user. An infrastructure forecast model is developed for major and nonmajor structures aggregated over a water depth and planning area category and driven production profiles determined in a user decision framework. The impact of technological change is considered a user defined parameter incorporated within the decision parameters of the model. The MMS approach of driving the forecast with a production profile is maintained and careful structure classification allow more meaningful inferences of the model results to be made. The development and exposition of a structured forecasting model serves as the primary task of this paper.

2.3. General Methodological Issues

2.3.1. Selecting the Appropriate Level of Disaggregation: The primary reason to aggregate data is based on modeling philosophy. If processes, activities, or entities (such as discovery rates, formation structures, production profiles, platforms, etc.) are not reasonably uniform within their category of analysis, it is generally agreed that the classification category should be subdivided to create more uniform subcategories in the belief that the categorization will reduce bias in the analysis[11]. The classification scheme employed in this analysis is based on structure type, water depth, and planning area.

The categorization of structure types ensures that the data is properly ba, w since the integrating effects of large data sets are lost. It is generally agreed, however, that the imposition of structure through classification schemes – when the classification is meaningful – improves understanding and helps to identify the limitations of the analysis. In the case of infrastructure forecasting, it is not only logical but necessary to aggregate structures according to water depth and configuration type to accurately account for the nature of installation and removal rates and to better understand the dynamics of development.

2.3.2. Categorization and System Constraints: Aggregation imposes a tight burden on the model structure and the data requirements of the problem. If a forecast is to be performed at a given level of aggregation then the system data must also be available at the same level of aggregation. Unfortunately, this does not usually occur for a variety of reasons.

are not explicit parameters, but are incorporated indirectly in terms of how fast the resource base is estimated to be recovered. This will be discussed in more detail in Chapter 2.4.2.

2.3.3. Modeling Principles: An infrastructure forecast is developed guided by the following criteria:

- The forecast should be based on a clearly defined structure.
- The forecast should be supported by a set of explicit assumptions.
- The forecast should be performed at a meaningful level of aggregation.
- The model structure and assumptions should be subject to parametric analysis.
- The model should be easy to calibrate and update, and preferably, performed in a step-by-step manner that is easy to understand and modify.
- Uncertainty should be accounted for based on the form of the data and user-defined parameters.
- The process should be transparent and well-documented.
- Short-term and medium-term forecast should be performed separately and calibrated against the long-term forecast.

The philosophy adopted to satisfy these criteria is to maintain simplicity of form and to extrapolate historical experience to predict future trends. To a large extent the current REA model satisfies most of these objectives, but it is deficient in specifying the model uncertainty and allowing user-defined parameters to be incorporated within the procedure. It is for these and other reasons (Lore and Batchelder, 1995) that the REA structure is maintained but structured to ensure a consistent assumption set to allow decision parameters to be applied with scenario analysis. The structural aspects of the proposed model should also help to deflect criticism of the methodology since the results are subject to an explicit assumption set rather than perceived as absolute in nature.

2.3.4. General Methodology: The general methodology is presented in four stages: 1. *Pre-Processing*, 2. *Forecasting*, 3. *Post-Processing*, and 4. *Scenario Analysis*. The stages are described as follows:

1. *Pre-Processing.* Develop historic trends of hydrocarbon production and infrastructure requirements on a water depth and planning area basis $\Gamma_{i,j}$.

   1.1. Report reserves (proved, unproved, appreciation) and resource (undiscovered conventionally recoverable, undiscovered economically recoverable) data over the category $\Gamma_{i,j}$, $R_k(\Gamma_{i,j})$, $k = 1,\ldots, 5$.

1.2. Aggregate historic production profiles for oil and natural gas over $\Gamma_{i,j}$, combine production in terms of a BOE basis, and report a cumulative production profile per category $\Gamma_{i,j}$, $Q(\Gamma_{i,j}, t)$.

1.3. Compute the cumulative number of major (m) and nonmajor (n) structures installed and removed in category $\Gamma_{i,j}$ through time t, $I^{[m,n]}(\Gamma_{i,j}, t)$ and $R^{[m,n]}(\Gamma_{i,j}, t)$.

1.4. Compute the ratio of cumulative stm

4. *Scenario Analysis.* Determine the number of structures installed and removed under scenarios that incorporate variation in resource magnitude, development profiles, and technological improvements.

   4.1. The average values of $i^{[m,n]}(\Gamma_{i,j}, t)$ and $r^{[m,n]}(\Gamma_{i,j}, t)$ are assessed over the time horizon θ through resource magnitude and development profile scenarios incorporated through the parameters (p, θ) in *Step 2.1*.

   4.2. The values of $i^{[m,n]}(\Gamma_{i,j}, t)$ and $r^{[m,n]}(\Gamma_{i,j}, t)$ are assessed through technological improvement scenarios by bounding the magnitude of the infrastructure requirements forecast in *Step 2.2*.

2.4. A Decision- and Resource-Based Model

2.4.1. The Infrastructure Forecasting Methodology: The infrastructure forecast methodology proposed is a four-step procedure that is similar in structure to the REA/MMS approach, but differs in the level and type of categorization employed and development of the functionals implemented. To maintain contact with the baseline model, the REA/MMS approach is highlighted in the discussion that follows.

The methodology is described as follows:

Step 1. Construct cumulative hydrocarbon production profiles on a BOE basis per water depth and planning area category over a 40-year time horizon.

Step 2. Forecast the cumulative number of major and nonmajor structures installed and removed per cumulative BOE production on a water depth and planning area basis over a 40-year time horizon.

Step 3. The cumulative number of structures installed and removed over each water depth and planning area category is determined by the product of the profiles determined in *Step 1* and *Step 2*.

Step 4. The annual number of major and nonmajor structures installed and removed are derived from the cumulative forecast in *Step 3*.

The infrastructure forecast is dependent upon the construction of the hydrocarbon production profile (*Step 1*) and forecast of the infrastructure requirements ratio (*Step 2*) across categories specified on a water depth and planning area basis. The hydrocarbon production profile forecast,

$$Q(\Gamma_{i,j}, t)^*,$$

and the infrastructure requirements ratio forecast,

$$\left(\frac{I^{[m,n]}(\Gamma_{i,j},t)}{Q(\Gamma_{i,j},t)} \right)^{*} = \gamma_I^{[m,n]}(\Gamma_{i,j},t)^{*},$$

$$\left(\frac{R^{[m,n]}(\Gamma_{i,j},t)}{Q(\Gamma_{i,j},t)} \right)^{*} = \gamma_R^{[m,n]}(\Gamma_{i,j},t)^{*},$$

represent the key input parameters to the model.

Unfortunately, over a long-term horizon no one knows – or should pretend to know for that matter – the production profile, $Q(\Gamma_{i,j},\ t)^*$, but since this is a required element in all resource-based forecasts, uncertainty should be accounted for in some manner. Uncertainty can be made explicit through the use of decision parameters which allow the user to express in a simple manner their expectations for future production, price, the impact of technological change, etc. The infrastructure requirements ratio forecast, $\gamma_I^{[m,n]}(\Gamma_{i,j},t)^*$ and $\gamma_R^{[m,n]}(\Gamma_{i,j},t)^*$, is less uncertain due to the integrating nature of the functional. Hence, there is a greater degree of confidence in extrapolating these trends in the future where sufficient data exists to reasonably allow such trending. It is also possible to incorporate a decision parameter in the infrastructure ratio to account for technological change specific to well productivity per platform, but this was not pursued since it can be incorporated within the previous decision parameter.

The product of the functionals

$$Q(\Gamma_{i,j},\ t)^* \cdot \gamma_I^{[m,n]}(\Gamma_{i,j},t)^* = I^{[m,n]}(\Gamma_{i,j},\ t),$$

$$Q(\Gamma_{i,j},\ t)^* \cdot \gamma_R^{[m,n]}(\Gamma_{i,j},t)^* = R^{[m,n]}(\Gamma_{i,j},\ t),$$

yields a forecast of the cumulative number of structures installed and removed through time *t*.

The annual number of structures installed and removed over the time horizon, $i^{[m,n]}(\Gamma_{i,j},\ t)^*$ and $r^{[m,n]}(\Gamma_{i,j},\ t)^*$, is then derived from the cumulative forecast, and the number of active platforms, $A^{[m,n]}(\Gamma_{i,j},\ t)$, is calculated from a recursive relation using the annual installation and removal rates and a boundary condition on the number of active platforms:

$$i^{[m,n]}(\Gamma_{i,j},\ t)^* = I^{[m,n]}(\Gamma_{i,j},\ t)^* - I^{[m,n]}(\Gamma_{i,j},\ t-1)^*,$$

$$r^{[m,n]}(\Gamma_{i,j},\ t)^* = R^{[m,n]}(\Gamma_{i,j},\ t)^* - R^{[m,n]}(\Gamma_{i,j},\ t-1)^*,$$

$$A^{[m,n]}(\Gamma_{i,j},\ t)^* = A^{[m,n]}(\Gamma_{i,j},\ t-1)^* + i^{[m,n]}(\Gamma^*_{i,j},\ t) - r^{[m,n]}(\Gamma_{i,j},\ t)^*.$$

The output functionals, $I^{[m,n]}(\Gamma_{i,j}, t,$

conventionally recoverable resources, $R_T(\Gamma_{i,j})$, according to the *belief* of the decision maker; i.e., the decision maker must address the following question:

> *What percentage of* $R_T(\Gamma_{i,j})$ *will be recovered within the time horizon θ?*

The specification of *p* and *θ* is user-defined and accounts for the decision makers understanding of resource recovery, including the nature of technological change, development timing, lease specific conditions, oil price, and supply/demand conditions. It is possible to try to account for these variables in separate models, but this was considered outside the scope of the project. The supply model is referred to as a 2-parameter recovery model since two parameters – *p* and *θ* – need to be specified to recover the resource.

The remaining conventionally recoverable resources of region $\Gamma_{i,j}$, $R_T(\Gamma_{i,j})$, represents the volume of all conventionally recoverable resources that has not yet been produced and includes remaining proved reserves $(R_1(\Gamma_{i,j}))$, unproved reserves $(R_2(\Gamma_{i,j}))$, reserves appreciation $(R_3(\Gamma_{i,j}))$, and undiscovered economically recoverable resources $(R_5(\Gamma_{i,j}))$:

$$R_T(\Gamma_{i,j}) = R_1(\Gamma_{i,j}) + R_2(\Gamma_{i,j}) + R_3(\Gamma_{i,j}) + R_5(\Gamma_{i,j})\,.$$

For a detailed definition of each resource category, see (Crawford *et al*., 2000; Lore *3*

Step 1. Plot the historic cumulative production curve $Q_h(\Gamma_{i,j}, t)$, $t \le \tau$.

Step 2. The cumulative production forecast $Q_h(\Gamma_{i,j}, t)^*$, $t > \tau$, is extrapolated in a linear fashion to recover 100*p*-percentage of $R_T = R_T(\Gamma_{i,j})$ within θ years, and all the resources within the 40-year time horizon. The cumulative production curve is written analytically as

$$Q(\Gamma_{i,j},t)^* = \begin{cases} Q_h(\Gamma_{i,j},t), & t \le \tau \\ \dfrac{pR_T}{\theta}(t-\tau) + Q_h(\Gamma_{i,j},t), & \tau \le t \le \tau+\theta \\ \dfrac{(1-p)\,pR_T}{40-\theta}(t-\tau-\theta) + pR_T + Q_h(\Gamma_{i,j},t), & \tau+\theta \le t \le \tau+40. \end{cases}$$

The value of $R_T = R_T(\Gamma_{i,j})$ can be selected as the F5, F50, or F95 estimate. The model is simple to use, which is its main attraction, and one can argue that the uncertainty involved with estimating future production profiles and the impact of technological change is such that structurally simple models capture the essence of the forecast in a manner analogous to more sophisticated models. Through the selection of p and θ the user can dictate a wide variety of scenarios that reflect trends and technological conditions within specific regions of the GOM.

2.4.3. The Infrastructure Ratio Forecast: The MMS approach requires three forecast to predict platform installation and removal rates:

- $q(\Gamma_{i,j}, t)^*$
- $\left(\dfrac{q(\Gamma_{i,j},t)}{A(\Gamma_{i,j},t)}\right)^*$, and
- $i(\Gamma_{i,j}, t)^* : r(\Gamma_{i,j}, t)^*$.

The CES approach also requires three forecast:

- $Q(\Gamma_{i,j}, t)^*$
- $\gamma_I^{[m,n]}(\Gamma_{i,j}, t)^*$, and
- $\gamma_R^{[m,n]}(\Gamma_{i,j}, t)^*$.

The MMS application of the annual production forecast $q($

installation and removal rates, while in the CES approach application of the cumulative infrastructure ratio eliminates the need to forecast the installation and removal ratio. The CES methodology incorporates expert judgment in the determination of $Q(\Gamma_{i,j}, t)^*$, and although it is not difficult to structure the procedure to allow user-defined input on the selection of the ratio forecast, $\gamma_I^{[m,n]}(\Gamma_{i,j}, t)^*$ and $\gamma_R^{[m,n]}(\Gamma_{i,j}, t)^*$, the current methodology does not develop this approach. The MMS employs expert judgment to determine the infrastructure forecast ratio, and while there are some benefits for a decision maker to provide such input, there are also disadvantages since the inclusion of too many parameters can confound the analysis.

The forecast $\gamma_I^{[m,n]}(\Gamma_{i,j}, t)^*$ and $\gamma_R^{[m,n]}(\Gamma_{i,j}, t)^*$ are based on linear extrapolation of historic data within category $\Gamma_{i,j}$, and in the event that the category $\Gamma_{i,j}$ does not have sufficient data on which to base a trend, a constant value is assumed based on the ratio at the current time τ; i.e., $\gamma_I^m(\Gamma_{i,j}, t)^* = \gamma_I^m(\Gamma_{i,j}, \tau)$ for $t \geq \tau$.

2.4.4. Model Results and Interpretation: After the historic data on offshore structures has been categorized according to water depth, planning area, and configuration type, and after the appropriate resource data has been compiled and tabulated, it is then a matter of providing a forecast for

$$Q(\Gamma_{i,j}, t)^*,$$

and

$$\gamma_I^{[m,n]}(\Gamma_{i,j}, t)^* = \left(\frac{I^{[m,n]}(\Gamma_{i,j},t)}{Q(\Gamma_{i,j},t)}\right)^*, \quad \gamma_R^{[m,n]}(\Gamma_{i,j}, t)^* = \left(\frac{R^{[m,n]}(\Gamma_{i,j},t)}{Q(\Gamma_{i,j},t)}\right)^*,$$

to drive the model output. The form of the supply forecast is tied to the decision maker, in the selection of the parameter values p and θ, while the infrastructure forecast is automated based on linear extrapolation. The product of the functionals yields the cumulative number of installed and removed structures which is then processed to determine the annual installation and removal rates for the major and nonmajor categories.

The forecast of the average annual number of major and nonmajor structures installed and removed in the CGOM and WGOM is provided in Tables B.3 and Tables B.4. The annual installation and removal rates over the time horizon of the forecast are reported in terms of an annual average rate over θ which is denoted by

$$\langle i^{[m,n]}(\Gamma_{i,j}, t)^* \rangle$$

$$\langle r^{[m,n]}(\Gamma_{i,j}, t)^* \rangle .$$

Average annual rates are normally non-integer, so that for instance if $\langle i^{[m,n]}(\Gamma_{i,j}, t)^* \rangle$ = 0.5, then one nonmajor structure will be installed in $\Gamma_{i,j}$ every two years.

To interpret the model output, the user selects the time frame and resource recovery parameters that he/she believes will reflect the nature of resource recovery, supply/demand conditions, and technological change in the future. For instance, if 75% of the hydrocarbon resources within 0-200m in the CGOM are believed to be recoverable by 2020, then from Table B.3.2 with $p = 0.75$ the average annual number of major and nonmajor structure installations are (10.9, 56.3) with (54.5, 95.3) annual major and nonmajor structure removals. The decision maker may have reason to assess the 201-800m and 800+ m categories on a different time horizon and recovery rate; e.g., if 50% of the resources within the deepwater categories are believed to be recoverable through 2030, then from Table B.3.3 with $p = 0.50$ an expected (1.3, 0.2) major and nonmajor structure installations are expected in 201-800m and (3.1, 1.5) installations are expected within 800+ m. No major or nonmajor structures are expected to be removed during this time.

The annualized forecast values in Tables B.3 and Tables B.4 can be compared against the average short-term historic installation and removal rates shown in Table B.5. For example, using Table B.3.1 and the short-term historic average values shown in Table B.5, the model forecast can be calibrated by comparing the 0-200m values for major and nonmajor installations and removals, (32, 78) and (37, 69), respectively, with the closest approximation in Table B.3.1. In this case the installation rate corresponds to $p \approx 0.5$ while the removal rate corresponds to $p \approx 0.25$.

In principle, the tables can be used one of two ways:

I. The user determines the values of p and θ per water depth and planning area category, $\Gamma_{i,j}$, and then employs the table to forecast expected average installation and removal rates, $\langle i^{[m,n]}(\Gamma_{i,j}, t) \rangle$ and $\langle r^{[m,n]}(\Gamma_{i,j}, t) \rangle$.

II. The user specifies the expected average installation and removal rates per category $\Gamma_{i,j}$, $\langle i^{[m,n]}(\Gamma_{i,j}, t)^* \rangle$ and $\langle r^{[m,n]}(\Gamma_{i,j}, t)^* \rangle$, and then using the table, determines the value of p and θ that correspond to these rates.

The selection of p and θ is considered independent across water depth categories.

The results of the model reveal expected behavior. For instance, recovering a greater percentage of the available resources within a short time horizon (should) impose greater infrastructure requirements; i.e., if a data entry in the table is denoted by $f(\Gamma_{i,j}, p, \theta)$, then

$$f(\Gamma_{i,j}, p, \theta) \le f(\Gamma_{i,j}, p, \theta') \text{ if } \theta' > \theta,$$

$$f(\Gamma_{i,j}, p, \theta) \le f(\Gamma_{i,j}, p', \theta) \text{ if } p' > p.$$

(4) Infrastructure Requirement Ratio Forecast

A variety of techniques can be employed to forecast infrastructure requirements, and it is difficult to gauge the accuracy of one technique over another. It is therefore essential that the user of a particular approach understand the limitations and implicit assumptions of the model and uncertainty inherent to the methodology. Scenario analysis is a useful tool to explore some of this uncertainty as proposed in the 2-parameter supply model, and it may be desirable to incorporate additional decision parameters to control the infrastructure ratio forecast.

(5) Application of BOE

A barrel of oil has about 5.6 times the heat value of one thousand cubic feet of gas, and so it is popular to express gas in terms of barrels of “oil equivalent.” This was necessary in the forecast model since both oil and gas contribute to the need for infrastructure. Unfortunately, since neither the price nor the in-ground value of oil and gas track each

2.6. Conclusions

The task of Chapter 2 was to develop a unified approach to infrastructure forecasting in the Gulf of Mexico and to forecast the number of structures expected to be installed and removed per water depth and planning area category over a long-term horizon. The consistency of the methodology, the application of a discrete assumption set, and the inclusion of a decision-oriented framework within the model represent the central tenants of the procedure. The model results should be interpreted as a first-order approximation to a very complex reality, and as such, should serve as a guide to infrastructure forecast requirements.

The need to properly select and specify aggregation categories is a critical ingredient in any forecast strategy, and the decomposition of the data into appropriate categories is an important aspect of pre-processing to ensure that the methodology is consistent and the procedure is sufficiently structured. No matter how fine the infrastructure data is decomposed and disaggregated within various categories, however, the forecasting procedures employed in Chapter 2 rely upon other forecast and judgmental adjustments which can differ enormously in scope and magnitude. The uncertainty in these adjustments should be understood and clearly communicated to the user group. One of the principal tasks of this Chapter was to identify this uncertainty and to employ decision-oriented parameters as a means to explore the sensitivity of the model results.

The infrastructure forecast developed is a decision- and resource-based model similar to the methodology employed by the MMS but more broadly defined and executed within an analytic and computational framework. The output of the model is derived from the forecast of a supply curve and an infrastructure requirement ratio. A decision-oriented framework is employed to construct the supply curve which incorporates the beliefs of the user and variables such as technology change. The results of the forecast were presented under various assumptions on recovery rate and development timing.

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APPENDIX A

CHAPTER 1 TABLES

Table A.1

Western and Central GOM National Assessment Resource Estimates and REA/MMS Allocation Quantities

Category[2]	Notation[3, 4]	Western Gulf of Mexico					
		National Assessment[1,5]		MMS Allocation[6]		Percent Recovery[7]	
		Oil (Bbbl)	Gas (Tcf)	Oil (Bbbl)	Gas (Tcf)	Oil (%)	Gas (%)
	Q_h	0.559	23.800	0.557	23.4	100	100
	R_1	0.495	7.393				
	R_2	0.067	0.603				
	R_3	1.091	17.881				
K_1	$R_1+R_2+R_3$	1.653	25.877	(1.37, 1.669)	(24.88, 26.6)	(83, 101)	(96, 103)
	R_4	(12.11, 14.22)	(70.19, 80.36)				
K_2	R_5	(6.46, 9.87)	(38.49, 54.10)	(1.98, 3.47)	(17.7,31.6)	(31, 35)	(46, 58)
Total (K_1+K_2)	R_T	(8.11, 11.52)	(64.37, 79.98)	(3.35, 5.14)	(42.6,58.2)	(41, 45)	(66, 73)
		Central Gulf of Mexico					
		National Assessment		MMS Allocation		Percent Recovery[6]	
	Q_h	10.4	108.9	10.36	109.3	100	100
	R_1	2.9	22.6				
	R_2	0.9	3.8				
	R_3	6.6	49.6				
K_1	$R_1+R_2+R_3$	10.4	76	(8.15, 8.26)	(74.4, 76.0)	(78, 79)	(98, 100)
	R_4	(18.5, 23.8)	(99.4, 114.0)				
K_2	R_5	(9.51, 15.37)	(54.73, 77.47)	(3.90, 8.30)	(33.90, 70.3)	(41, 54)	(62, 91)
Total (K_1+K_2)	R_T	(19.91, 25.77)	(130.73,153.47)	(12.05, 16.56)	(108.3,146.3)	(61, 64)	(83, 95)

Footnote:

(1) The National Assessment data is current as of January 1, 1999, and the MMS data is adjusted to correspond to this date; i.e., the cumulative production represented by Q_h is taken through the year 1998.
(2) Resource category K_1 denotes assessed reserves and appreciation. Resource category K_2 denotes assessed undiscovered economic resources.
(3) The resource estimates are designated as remaining proved reserves R_1 unproved reserves R_2, reserves appreciation R_3, undiscovered conventionally recoverable resources R_4, and undiscovered economically recoverable resources R_5. R_T denotes the remaining conven

Table A.2

A Summary of Measures Implied by the REA/MMS Forecast

Measure	WGOM	CGOM	GOM[3]
Total Resource Recovery[1]			
Oil	(41%, 44%)	(59%, 64%)	(54%, 58%)
Gas	(67%, 73%)	(83%, 95%)	(77%, 88%)
BOE	(55%, 60%)	(72%, 75%)	(61%, 73%)
Implied Recovery[1]			
Oil	(63%, 50%)	(65%, 73%)	(64%, 73%)
Gas	(57%, 52%)	(77%, 93%)	(64%, 81%)
BOE	(59%, 51%)	(72%, 85%)	(64%, 73%)

Footnote:

(1) The total resource recovery percentage is defined as the MMS allocation divided by the National Assessment estimates. The values are summarized from Table A.1.

(2) Implied recovery is determined by plotting the cumulative production profile and then computing how much of the resource estimate is recovered θ years from the present time, where for convenience, θ is selected as 20 years. The National Assessment estimates and MMS allocation are given under a (low, high) case scenario and are computed with respect to this classification. Note that (x, y) does not necessarily require $x<y$ since the low and high case calculations are independent estimates of resource and recovery rates.

(3) The Gulf of Mexico resource estimates include only the Western and Central planning areas.

APPENDIX B

CHAPTER 2 TABLES

Table B.1

Offshore Statistics by Water Depth

Water Depth (m)	Active Platforms	Production Wells	$\frac{\text{Producing Well}}{\text{Active Platform}}$
0-200	3,489	3,840	1.1
201-400	455	1,873	4.1
401-800	49	285	5.8
801-1000	4	50	12.5
1000+	22	309	14.0

Table B.2

National Assessment Results for the Western and Central Planning Area in the Gulf of Mexico, BOE (Bbbl)

Water Depth (m)	R_1[a]	R_2	R_3	R_4[b]		R_5		R_T	
				F95	F5	F95	F5	F95	F5
Western									
0-200	1.16	0.00	2.72	4.32	5.43	3.12	3.63	7.00	7.51
201-800	0.23	0.02	0.43	3.37	4.47	2.94	3.24	3.62	3.92
801-1600	0.42	0.15	1.12	7.57	9.42	4.76	6.73	6.45	8.42
1601-2400	0.00	0.00	0.00	6.54	8.38	1.99	4.66	1.99	4.66
2400+	0.00	0.00	0.00	1.73	2.65	0.54	1.29	0.54	1.29
Total[c]									

Table B.3.1

Table B.3.3

Forecast of the Annual Number of Major and Nonmajor Structures Installed and Removed in the CGOM Through 2030 as a Function of Water Depth and Supply Curve Parameter *p*

Water Depth (m)	*p*	Major Installed	Nonmajor Installed	Major Removed	Nonmajor Removed
0-200	0.25	1.1	4.0	35.2	58.1
	0.50	1.4	18.3	42.4	71.4
	0.75	2.5	32.7	49.6	84.8
	1.00	6.1	47.0	56.9	98.1
201-800	0.25	0.6	0.1	-	-
	0.50	1.3	0.2	0.1	-
	0.75	1.9	0.4	0.1	-
	1.00	2.6	0.5	0.2	-
800+	0.25	1.5	0.8	-	-
	0.50	3.1	1.5	-	-
	0.75	4.6	2.3	-	-
	1.00	6.1	3.1	-	-

Table B.3.4

Forecast of the Annual Number of Major and Nonmajor Structures Installed and Removed in the CGOM Through 2040 as a Function of Water Depth and Supply Curve Parameter *p*

Water Depth (m)	*p*	Major Installed	Nonmajor Installed	Major Removed	Nonmajor Removed
0-200	0.25	0.2	0.2	34.2	56.1
	0.50	0.2	10.5	40.7	67.8
	0.75	0.6	20.8	47.2	79.5
	1.00	1.5	31.2	53.7	91.2
201-800	0.25	0.5	0.1	-	-
	0.50	1.0	0.2	0.1	-
	0.75	1.4	0.3	0.1	-
	1.00	1.9	0.4	0.1	-
800+	0.25	1.1	0.6	-	-
	0.50	2.3	1.1	-	-
	0.75	3.4	1.7	-	-
	1.00	4.6	2.3	-	-

Table B.4.1

Forecast of the Annual Number of Major and Nonmajor Structures Installed and Removed in the WGOM Through 2010 as a Function of Water Depth and Supply Curve Parameter *p*

Water Depth

Table B.4.3

Forecast of the Annual Number of Major and Nonmajor Structures Installed and Removed in the WGOM Through 2030 as a Function of Water Depth and Supply Curve Parameter *p*

Water Depth (m)	*p*	Major Installed	Nonmajor Installed	Major Removed	Nonmajor Removed
0-200	0.25	3.2	2.7	11.8	12.5
	0.50	8.8	6.7	16.3	17.5
	0.75	14.7	10.7	20.9	22.5
	1.00	17.3	14.7	25.4	27.6
201-800	0.25	1.0	0.3	0.1	0.1
	0.50	2.0	0.6	0.2	0.2
	0.75	3.0	0.8	0.3	0.3
	1.00	4.1	1.1	0.4	0.4
800+	0.25	0.4	0.4	-	-
	0.50	0.8	0.8	-	-
	0.75	1.2	1.2	-	-
	1.00	1.6	1.6	-	-

Table B.4.4

Forecast of the Annual Number of Major and Nonmajor Structures Installed and Removed in the WGOM Through 2040 as a Function of Water Depth and Supply Curve Parameter *p*

Water Depth (m)	*p*	Major Installed	Nonmajor Installed	Major Removed	Nonmajor Removed
0-200	0.25	1.1	1.5	11.3	11.9
	0.50	5.4	4.4	15.4	16.5
	0.75	10.1	7.3	19.5	20.9
	1.00	14.4	10.2	23.7	25.4

201-800 1.00 14.4 10.2 23.7515.46 548.2.66

Table B.5

The Average Annual Number of Major and Nonmajor Structures Installed and Removed in the Western and Central Gulf of Mexico via Water Depth Category (1996-2000)

Water Depth (m)	Major Structures		Nonmajor Structures		All Structures	
	Installed	Removed	Installed	Removed	Installed	Removed
Western						
0-60	(5, 3.9)	(9.2, 3.3)	(13, 3.1)	(11.4, 6.4)	(18, 5.2)	(20.6, 7.1)
61-200	(2, 0.7)	(1.2, 0.8)	(1.6, 1.1)	(0.2, 0.5)	(3.6, 5.1)	(1.4, 1.1)

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