

Modeling Exploration, Development and Production in the Gulf of Mexico

Volume I: Summary



U.S. Department of the Interior
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Environmental Studies Program

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1. Introduction

1.1 Study Objectives

In late 2002, Innovation & Information Consultants, Inc. (IIC, Inc.) contracted with the Minerals Management Service (MMS) of the U.S. Department of the Interior to develop a computer model that would estimate oil and gas exploration and discovery, development, and production in the Gulf of Mexico (GoM). The model is to be used for a variety of purposes, including, but not limited to:

- providing inputs for the environmental impact statements associated with various MMS program documents and lease sale analyses, and
- informing policy evaluation studies such as those associated with changes in MMS royalty assessment and collection.

Environmental impact forecasts depend directly on activity projections, so the model development process included a substantial amount of data examination and statistical analysis to quantify relationships that would increase the information available to estimate environmental and social impacts. Because the second objective – policy analysis – is so broad, it was imperative that the model be flexible to permit addressing a wide range of problems. In addition, the model's projections must be sufficiently detailed by area, water depth, and well depth to be useful to these MMS objectives.

The contract left open whether IIC, Inc. would create a new model or adapt an existing model to MMS requirements. After reviewing several well-known model simulations that could address the GoM environment, it was clear that the most efficient course of action was a new development effort. The result was the IIC EDP Model.

1.2 Study Constraints

MMS representatives specified several requirements for the model that, in large part, led to our decision to construct a new computer model:

- The model should be a quick-to-iterate, portable computer program that could be easily adapted to a wide range of problems. Uncertainty in many of the variable inputs leads to the need to have a model that can be run quickly through a large number of sensitivity cases.
- Ease in changing inputs and data availability should be insured by depending heavily on data that MMS itself produces.

- The model must adhere to the MMS’s long-term forecasts for recoverable resources in the GoM. That is, the model should not produce oil and gas quantities that exceed MMS estimates of resources in place.
- The model should affect a smooth transition between history and model prediction. Since there have been more than 60 years of drilling, development, and production in the GoM, over 1,200 oil and gas fields have been discovered, most of which are in the development, delineation, or production stages. For those in production, many will soon reach the ends of their normal lives. Additionally, a substantial amount of infrastructure is already present and serving current activities. The effects that various regulatory and policy actions have on these fields and infrastructure in the future will be the focus of some of the more common uses of the model. Therefore, it should not only predict future field discoveries and their associated development and production, but also model the remaining lives of existing fields and major logistical assets.

Since we were undertaking a new model development, we were able to rely extensively on MMS data and involve MMS representatives in the details of the development to ensure compliance with these constraints. Finally, it is important to note and reiterate that this model was developed using data for the Gulf of Mexico only. Therefore it is intended to be used to model Gulf of Mexico exploration, development and production activity only. It should not be applied to other regions or planning areas.

2. Study Design and Tasks Performed

Research and data analysis consumed roughly two-thirds of the effort spent on this project. This period of study produced a series of findings and observations that then guided development of the model. IIC, Inc. senior staff met with MMS technical staff several times over the course of the project to ensure the model would meet MMS’s needs. Our study design included six technical tasks, described below, plus delivery of a report, user’s guide for the model, and a technical report on the mathematical detail of the model, analyses performed, and the data sources used in developing and implementing the model. The following sections summarize the technical tasks that were performed as part of this study design.

2.1 Task 1. Model Review

The objective of this task was to determine whether it would be easier to adapt an existing model to address MMS’s specific requirements, or to build a new model. We initially considered the following models, some of which were suggested by MMS:¹

- The Energy Information Administration (EIA) Oil and Gas Supply Model (Offshore Supply Module)

¹ See Appendix III-A for a more detailed review of these models.

- MMS's E & D Scenario Model
- MMS's IMODEL
- MMS's Gulf of Mexico Production and Development (PD) projections
- MMS RSVP Model
- American Gas Association (AGA) Model
- Margaret Walls' (1994) hybrid econometric approach as described in *Land Economics*.
- Department of Energy (Office of Fossil Energy) TORIS Model

Early in the model review task, we determined it would be more difficult to try to acquire, understand, and reprogram an existing model than to develop and program a new one. For example, at the time we reviewed its documentation, EIA's Offshore Model was coded in FORTRAN, considered to be outmoded by most contemporary programmers.² Additionally, its logic did not include a field discovery submodel, a component that MMS users recommended. Our approach quickly evolved to examining existing documentation of these models to draw on the theory and approach of others where we could, and still answer the broad requirements listed above.

We found the EIA's approach to be very useful in a number of areas, particularly for our cost submodel. The model developed under this contract would replace MMS's E & D Scenario Model, so we employed its output and some of its methods as guidelines for what we would develop. We elected to build an expected value simulation, so MMS's IMODEL structure was not applicable, but we found its approach useful toward understanding how MMS views the leasing process and results.³ Additionally, the model is very "user-friendly," so we designed a similar user interface structure.

We also studied closely Walls' modeling paper (1994), and, more importantly, traced her references back to the original U.S. Geological Service (USGS) papers, some of which were written almost 50 years ago. Despite their age, we found the theory applicable to the problem at hand in the Gulf of Mexico. After considerable data analysis, we independently arrived at discovery and exploratory well generation submodels that are similar in form to what Walls proposed based in part on the approaches found in these USGS papers. Finally, important elements of our review include noting strengths and shortcomings of the methods or models that were used in support of each effort (e.g., inability to distinguish by water or drilling depth, enough detail either geographically or geologically, inadequate data analysis, etc.).

² Since our initial consideration in the fall of 2002, the model apparently has been reprogrammed.

³ It is important to recognize that we are not attempting to model the leasing process itself.

2.2 Task 2. Defining and Analyzing Variables

This phase of the study encompassed identifying variables to be included in the model, performing a requirements analysis aimed at determining the MMS's primary uses of the model, and defining the inputs and outputs that are needed to support that use. The work statement generated a lengthy list of possible variables to consider. Variables that we considered included the following:

- the number of wells drilled by type and drilling depth (exploration, development, production),
- reserve additions,
- existing reserves,
- oil and gas production,
- platforms installed, added, and removed,
- miles of pipeline installed,
- oil and gas prices,
- royalty regimes,
- cost variables such as exploration and development drilling, platform costs, production drilling, other production and equipment costs, pipeline capital and operating costs, platform abandonment costs.

We also reviewed various MMS studies and decision documents such as the latest five-year leasing program EIS, a multi-sale EIS, and their supporting documents. An important part of our requirements review was a two-day, multi-session set of interviews with MMS staff members who would either be using the model or the output from it. The sessions began with MMS representatives presenting their current methodology, the E & D Scenario Model, and then evolved into detailed discussions with staff members who perform the EIS analyses for lease sales and five-year leasing programs. Broad issues addressed included:

- MMS's views on other models' shortcomings;
- what additional capability would MMS like to have;
- what types of output variables do the users need;
- MMS staff perspectives on the exploration, development and production process in the GoM that should be reflected in the model;

- computer and software issues such as programming language, operating system environment, input/output method preferences, and how many people will need to access the uncompiled version of the program.

IIC, Inc. staff also provided a small spreadsheet model of GoM exploration, development and production that aimed at focusing consideration of key technical areas. This was a useful tool because we received a number of more detailed suggestions than might otherwise be the case in a simple discussion forum. Following the meeting, we produced an eight-page detailed memorandum to the MMS staff that documented our understanding of MMS requirements and comments. This was our initial point of departure for developing the model. However, as noted above the development process over the next year or more was highly interactive.

2.3 Task 3. Data Collection

We submitted our first data request at the kickoff meeting and received a major portion of the data immediately. This request included 13 items from publicly available files (some were downloadable free, but others carried a purchase charge), 18 categories of data on which we sought MMS recommendations regarding sources, and 39 reports, some of which had multiple volumes and appendices, or multi-year issues. We also relied on data from a number of other sources including the Department of Energy, Energy Information Administration, *Oil and Gas Journal*, Rigzone, Baker Hughes, American Petroleum Institute, Platt's, and various technical and economic reports and articles.

The data we found most useful in the model development included (but were not limited to):

- Data files associated with the *2000 Assessment of Conventionally Recoverable Hydrocarbon Resources of the Gulf of Mexico and Atlantic OCS as of January 1, 1999* (Lore et al. 2001, often called the "National Assessment"). This was our primary source of data on discovered and undiscovered fields.
- The "well bore" or "borehole" file that can be downloaded from MMS's website. It lists 32 data elements on every well drilled in the GoM.
- Pipeline master database.
- MMS database extract files providing yearly reserve estimates for discovered fields. We used this to examine reserve growth, analyze production as a function of field reserves, and to update the discovered fields in the 2000 National Assessment.
- Platform data extracted from the MMS database.
- Monthly production data by field, by year, and by well extracted from the MMS database.

The last three data sets are not openly available to users outside the federal government. IIC, Inc. staff signed confidentiality statements to ensure protection of any proprietary information received through these data exchanges.

2.4 Task 4. Establish Linkage to MMS Environmental Models

This task was essentially a requirements review of the particular needs of the MMS environmental analysts who perform the EIS studies. Although most of that was accomplished in the two-day kick-off meeting, discussion of those requirements frequently took place throughout the study as model development proceeded. We interacted with MMS staff to ensure that outputs from the IIC EDP model would meet the needs of those at MMS performing environmental analyses and modeling exercises.

2.5 Task 5. Build Model Equations and Implement Model

Model equation development was scheduled for the last half of this project, but actually began prior to the kickoff meeting and continued throughout the effort. Although we studied other models' approaches to modeling various aspects of the exploration, discovery, development and production process, we relied on the data for the Gulf of Mexico to dictate the model's mathematical structure and detail. In the next section, we summarize the approach we determined best to model each aspect of the process and present an overview of the model itself. Details of the data, mathematics, and model flow are in the Technical Appendix (Volume III of the report) and the User's Guide (Volume II).

2.6 Task 6. Validate and Test Model

Most of the validation of the subcomponents of the IIC EDP Model occurred as they were being developed. For example, we fit discovery equations to actual field discoveries in the water depth and planning areas used to describe the GoM. A similar procedure was employed to construct the submodels that produced exploratory wells, reserves growth, and production as a function of known reserves at the field level. Cost equations and their results were verified based on historical cost information from various published sources. The model also draws on a substantial amount of historic data input as internal databases to insure that the "model years" simulated transition smoothly from the historic series.

Each model run actually begins by overlapping one or two history years. We began our "model year" simulation 2002, although the model was delivered to MMS in early 2004. That is because 2001 was the last year in which we had reasonable confidence that the field discovery data were current. This practice allows for two years of validation and calibration where data sources are current enough to make this possible.

Near the end of the development of the IIC EDP Model, IIC, Inc. staff met with MMS representatives to run the preliminary model and to receive other guidance MMS thought appropriate. This meeting also addressed model calibration and validation. In the process of

performing multiple test cases, we were able to validate the reasonableness of the model theory and algorithms, and confirmed that test case results were generally consistent with MMS expectations. The calibration effort allowed us to isolate certain areas where adjustments were needed. We addressed these and other issues with subsequent model modifications to ensure that the model accurately portrayed historical precedent.

2.7 MMS Guidance and Review

Although we frequently discussed data and methodology issues with the MMS staff, we held several more structured reviews to insure that the model development was on the right track. The first, described above, was the kickoff meeting. Three months after the kickoff meeting, we provided a detailed 15-page quarterly progress memorandum outlining our findings to date and highlighting problem areas, primarily in finding data to support certain aspects of the model development. Much of this report recounted our approaches to representing certain processes functionally (e.g., field discoveries as functions of exploratory wells, production versus field age and/or reserves remaining, etc.).

The project's midterm review in April 2003 at MMS offices in Herndon, Virginia took place over a two-day period. It was followed with a summary memorandum describing our understanding of the MMS guidance. At this point in the development, the approach was far enough along to begin talking about applications of the model, and how they might be addressed. Two key issues were the "single sale analysis" and deep gas exploration.

- The "single sale analysis" issue arose from MMS's historic approach to preparing an evaluation of future production and infrastructure activity that would come from a particular lease sale. The question comes from our earlier agreement to structure the model as an exploration-discovery-development-production model without explicitly modeling the leasing process. Therefore, wells drilled and fields found in any given model year could come from a number of lease sales in the past five to eight years. We decided that it would be necessary to impute the distribution of lease years associated with drilling in any given year to handle the problem this way similar to the way MMS has addressed it in the past.
- Deep gas exploration is more of a data definitional problem than a methodological problem. In practice, a lease holder could drill for deep gas within an existing lease, and the model could treat it as either reserves growth within an existing field, or discovery of new fields in an area. This issue was tabled for the time being because no one at the meeting could say how deep gas reserves would be treated in MMS's future reserves and resources estimates.

One additional issue that we addressed (which delayed the project completion) was that of field redefinition. After decades of specifying field sizes according to a certain lognormal classification, MMS had decided to change the base of the lognormal calculation in such a way that a one-to-one mapping of fields from old to new size classifications was not possible. Since we had developed all our test case data and equations on the old method, we were forced to revise all our analyses at about the mid-point of the project.

Our third quarterly review in July of 2003 covered some of the same issues as the midterm review: discovery model results, production well data and the method of modeling production and reserves, single sale modeling, and deep gas royalty relief. MMS proposed an acceptable method tying exploratory wells to lease sales, and we once again deferred the question of how best to model deep gas exploration. Much of the meeting centered on explaining and running the cost and net present value calculation submodel, which was already operational.

We met with MMS staff twice more before the February 2004 model delivery meeting in New Orleans: once for an informal progress report in October 2003, and then for two days in December to demonstrate the full model to the primary users. The first meeting was brief, but the December meeting was a two-day process of hands-on model demonstration involving a variety of cases and sensitivities that the MMS analysts proposed as the meeting progressed. Several model calibration issues developed, but the model seemed to be producing meaningful results at this point.

3. Model Structure and Overview

As noted earlier, MMS's specifications suggested that a fast-running expected value simulation was appropriate. We programmed it in the C# language with database and spreadsheet interfaces. Primary outputs are wells drilled of various types, fields discovered, production of oil and gas, infrastructure additions and removals, but the IIC EDP Model makes available a myriad of secondary parameters that the user can extract from the status variables generated by the model. The detailed output required by some applications of the model suggested that an aggregate perspective (e.g., GoM wide or play-level) would either be inadequate, or require excessive aggregation of widely disparate variables. Therefore, we elected to include a substantial amount of field-level modeling, while retaining the capability to aggregate where appropriate.

Flexibility is permitted by not tying the model to a precise geographic or geologic structural depiction of the GoM. Rather, the analyst may define multiple model areas for which discovered and undiscovered field counts are input by field size (according to the latest USGS category classification method) along with other state variable inputs such as exploration search coefficients, exploratory well generation equation parameters, producing field counts by age of field, etc.

The lack of a pre-programmed model structure permits the analyst to define the problem area arbitrarily as the entire GoM, a particular subset of GoM geography (e.g., the Eastern GoM), water depth category, some cross-cutting category subset of these, or even in geologic terms (e.g., by play or province). While developing inputs for a very esoteric problem definition might require a substantial amount of exogenous analysis, the model structure does not preclude it, and is made easier by the fact that the logic is designed to employ relationships defined from readily available MMS data.

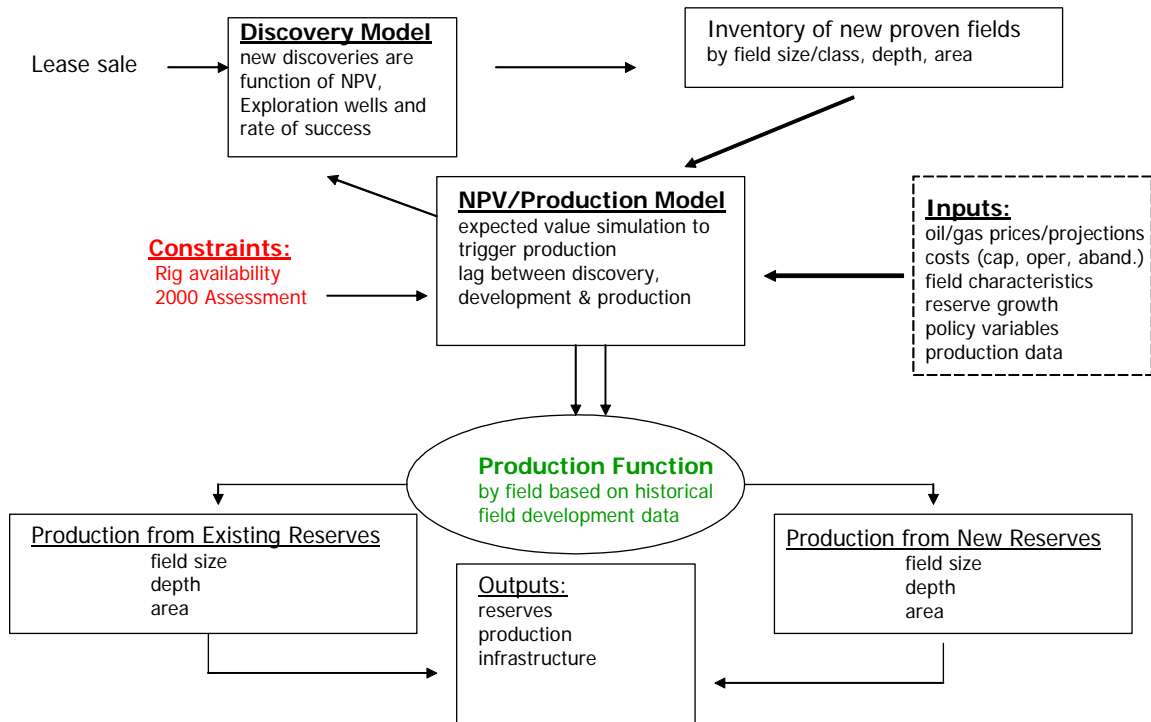
A central feature of the IIC EDP Model is its economic submodel that computes revenue from production and estimates costs. Each model year, a net present value (NPV) for each area

and size of field is computed. User inputs include a commodity price path, cost escalators that apply to internal capital and operating costs, and royalty rules and incentive structures. The NPVs are used as primary components of the model's simulation of a producer/explorer's decision process. Rising (falling) NPVs stimulate (reduce) exploratory drilling and make smaller fields more (less) attractive to develop and produce.

The principal components of the NPV determination are expected revenues, exploration and drilling costs, development costs, operating costs, depreciation and user-defined inputs such as the tax rate, royalty rate, possible suspension volume, and discount rate. The NPV calculation begins with the determination of a typical unconstrained field production profile, and then computes the annual costs of exploration, development, and production of the field. Revenues are based on the production profile, the current model year price, and the decision-maker's estimation of where the price will head in the future via a price escalator (which can be positive, zero or negative). In addition, revenues are adjusted for taxes and royalties. Once the cost and net revenue streams are determined, the discounted cash flow over a forty-year cycle is summed to arrive at the NPV for a particular area and size of field. These values are stored in an array, where they are retrieved as needed to determine the economic viability of a field.

Figure I.1 presents a stylized overview of the IIC EDP model. The model itself is composed of several components or submodels including one which models the process of discovering new fields, another which generates economic parameters by which exploration/producers are simulated to make decisions affecting both the discovery process and the development/production process, and finally a component that estimates field production and reserves appreciation. As noted above, the model generates a series of output tables indicating number and type of wells drilled, fields discovered, production of oil and gas, infrastructure additions and remaining resources.

Figure I.1. Schematic of IIC EDP Model



The simulation is easiest to describe in terms of the normal flow of the exploration and development process as follows:

- Profitability, both due to recent and prospective discoveries, stimulates exploratory “wildcat” well drilling. Factors that influence profitability include oil and gas prices, costs of development and production, taxes, royalties, size of field, potential fields left to be discovered, and many other factors, both input and internally generated.
- Exploratory wells find new fields. The number of fields found in an area in a particular year depends on the total field estimate input for that area and what has been found in previous years.
- If newly discovered fields are economic to produce, i.e., the economic submodule generated a positive net present value (NPV), they enter a queue and move toward production in a subsequent year if resources (principally in-field well drilling) are available for development.
- After discovery, a field’s reserves appreciate according to a user input schedule (simulating the continual in-field exploration and delineation process). Production is a function of reserve levels for fields as they mature.

- At some point, a field's reserves are essentially exhausted, so its infrastructure assets are retired, and it ceases production.
- Output variables such as reserves added, production, revenue flows, wells drilled, platforms installed and removed, and pipeline miles installed, are tabulated and made available to the analyst.

Table I.1. List of Model Outputs

Discovered fields
Exploratory wells drilled
Reserves discovered
Oil production
Gas production
Production wells drilled
Non-production wells drilled
Platforms added
Platforms removed
Pipeline miles added
Royalty revenue
Total drill depth of exploratory wells
Total drill depth of production wells
Total drill depth of non-production wells

4. Overview of the Study Documentation

In accordance with the Work Statement, Volume I describes the work performed, the model development process and an overview of the model structure and attributes. Volume II is the User's Guide, which provides more detail on model flow and how to use the model. Volume III devotes multiple chapters to describing in detail the model logic, mathematics, and data sources, as well as observations resulting from the model data analysis.



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.