Nonrenewable Resources, Vol. 5, No. 3, 1996

Developing an Exploration Decision Support System (EDSS): A Strategy for Combining Information and Analytics

Michael R. Walls[1,2]

Received April 26, 1996; accepted August 2, 1996

Petroleum exploration companies enter the twenty first century facing an increasingly competitive and risky environment. Under those circumstances, there is a growing need for better systematic decision-making that explicitly embodies the firm's desired goals and resource constraints. Computer-aided decision making, or decision support systems (DSS), provide an aid for those exploration management problems that are large, complex, unstructured, and involve management judgment. Almost every present day DSS falls into one of two general classes. Vehicle DSSs such as linear/nonlinear programming models and other optimization routines, propose and impose specific methodologies to the decision-maker. On the other hand, toolbox DSSs, such as simulation programs, statistical functions, and graphical packages, are generally flexible in enabling their users to employ a variety of approaches and tools for their decision tasks but provide little guidance on both problem representation and investigation. This paper describes the development of a hybrid DSS model that combines the advantages of both the vehicle and toolbox systems components to provide a comprehensive approach to exploration planning from geological development through the capital allocation process. The Exploration Decision Support System (EDSS) preserves the flexibility of the toolbox system while enriching the problem-solving strategies available to the firm. The central objectives for developing an EDSS framework are: (1) better decisions about resource allocations; (2) more systematic understanding of the factors affecting exploration decisions; (3) improved communication about E&P performance objectives and constraints at all levels of decision-making; and (4) an explicit vehicle for continuous improvement of the petroleum exploration firm's decision-making process. The EDSS model can guide geological and exploration managers toward a more formal evaluation of projects, provide insight into the impact of competing choice alternatives, and significantly improve the quality of exploration decisions.

KEY WORDS: Decision making; strategic planning; risk management; petroleum exploration; computers.

INTRODUCTION

Petroleum exploration companies enter the twenty first century in an increasingly competitive and risky business environment. Under those circumstances, managers have a growing need to employ better and more systematic decision-processes that explicitly embody the firm's objectives, desired goals, and resource constraints. Decision support system development has evolved rapidly over the last 15 years with an expanding body of research as well as practical applications. Advances in computer-aided decision making, or decision support systems, provide a mechanism to improve the quality of decision making in the modern petroleum firm. This paper focuses on the application of these important advances to the development of an Exploration Decision Support System

[1] Division of Economics and Business, Colorado School of Mines, Golden, Colorado 80401.

[2] Correspondence should be directed to Michael R. Walls, Division of Economics and Business, Colorado School of Mines, Golden, Colorado 80401.

0961-1444/96/0900-0181$09.50/1

(EDSS) for petroleum companies. The EDSS design described in this work provides an aid for those exploration management problems that are large, complex, unstructured and involve managerial judgment.

The first section of this paper provides a theoretical and practical overview of recent developments in decision support system design. I then provide a discussion of and motivation for an EDSS development strategy and how to integrate the entire exploration organization. The third section discusses the EDSS architecture and how it is linked with the firm's existing geological and economic datasets. The next section describes the EDSS's information and analytics module which includes a discussion of the project inputs, constraints, exploration portfolio construction model, and simulation analysis modules. The last section of the paper provides a description of the EDSS recommendation analysis module; this module provides the decision maker a clearer understanding of the factors affecting portfolio composition, uncovers preferred portfolios and provides guidance in the exploration decision process.

Overview of Decision Support Systems (DSS)

Over the last 15 years, the DSS concept has had rapid growth in both research and practice (Eom and Lee, 1990). DSS tools include expert systems, knowledge-based or intelligent decision systems (DSSs that exploit artificial intelligence techniques), executive information systems (DSSs that address the information needs of top managers), and group and negotiation support systems (DSSs that support teams of cooperative and uncooperative decision-makers).

To provide a general framework for discussion, two broad categories of DSS have been specified in the literature: vehicle DSS and toolbox DSS (Sprague & Carlson, 1982). Vehicle systems are based on the assumption that the task of recognizing a decision-maker's needs can be delegated to an expert. The expert will determine how to represent the decision situation (problem structuring) and how to proceed in order to identify the best solution (problem-solving strategy). The DSS is then implemented as a flexible vehicle for conveying the problem-solving strategy to the decision-maker. Specialized decision models (i.e., linear and nonlinear programming models, Markowitz optimization routines) are representative of this category of DSS. Toolbox DSSs, on the other hand, are not based on any normative model of decision making. They do not impose any specific problem-structuring approach nor do they supply a particular problem-solving technique. The assumption underlying toolbox DSSs is that the objective of providing support can be achieved by simply delivering a set of tools that decision-makers can employ in structuring, representing, and exploring their problems. Toolbox DSSs provide loosely coupled sets of tools, such as modeling languages, statistical functions, graphic packages, and simulation and optimization subroutines.

Almost every present day DSS falls into one of these two general classes. Vehicle DSSs propose and impose specific methodologies to the decision-maker. They deliver strong guidance but at some cost to flexibility. On the other hand, toolbox DSSs are generally flexible in enabling their users to employ a variety of approaches and tools for their decision tasks but provide little guidance on both problem representation and understanding.

The DSS design approach discussed in this paper represents a hybrid model that combines the advantages of both the vehicle and toolbox systems components to provide a comprehensive approach to petroleum exploration planning (see fig. 1). An effective EDSS strategy preserves the flexibility of the toolbox system while enriching the problem-solving strategies available to the firm through the use of an integrative model and data management system.

DSS Development Strategy

The field of DSS development has inherited concepts, techniques, technologies, and methodologies from such disciplines as decision science, economics, operations research, computer science, data-base management, information systems, and to a lesser extent, from psychology, cognitive science, and organizational studies (Bonczek and others, 1981; Keen and Morton, 1978). A common point on which all DSSs converge, independent from framework adopted and technology used to implement them, is the shared objective of providing support to decision-makers (Silver, 1990). This is a basic, but key consideration in that it clearly specifies the general context for DSSs and the types of situations in which these systems can be useful. Figure 2 is a representation of the key elements of the EDSS development process, a process designed to integrate the entire exploration organization. This design approach goes a long way toward developing

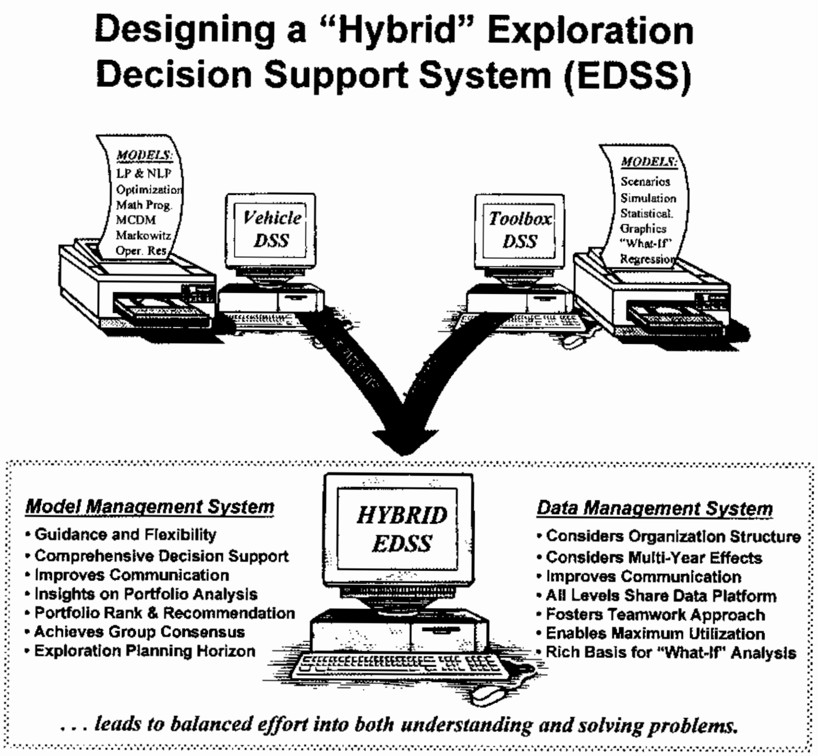

Figure 1. The "hybrid" exploration decision support system (EDSS) combines the flexibility of the toolbox DSS with the problem-solving strategies of a vehicle DSS and includes both model and data management systems.

trust in the system and ensuring company-wide acceptance.

From an architectural point of view, the components of an effective EDSS include several knowledge sources, such as databases, structured collections of analytical techniques, and inference mechanisms which, in combination, provide comprehensive support with regard to exploration decisions. In designing an EDSS that ensures a smooth organizational transition, it is important to make maximum use of the firm's current hardware, databases, and information networks. The more familiar the user interface, the easier it is for the professional staff to take advantage of the increased power of the new exploration decision support system.

Most business organizations are trying to use information technologies to improve their internal and external communication, coordination and cooperation processes. Companies find that cooperation, not just hierarchical coordination, is increasingly necessary. Team-work and cross-functional linkages (e.g., geoscience, finance, and engineering teams) are an important component of the modern petroleum exploration enterprise (Thompson, 1993) and, consequently, demand effective group decision support systems like the EDSS described here.

From an organizational perspective, it is also important to describe the problem framework in terms of the exploration unit's key performance objectives. The EDSS design considers organizational structures,

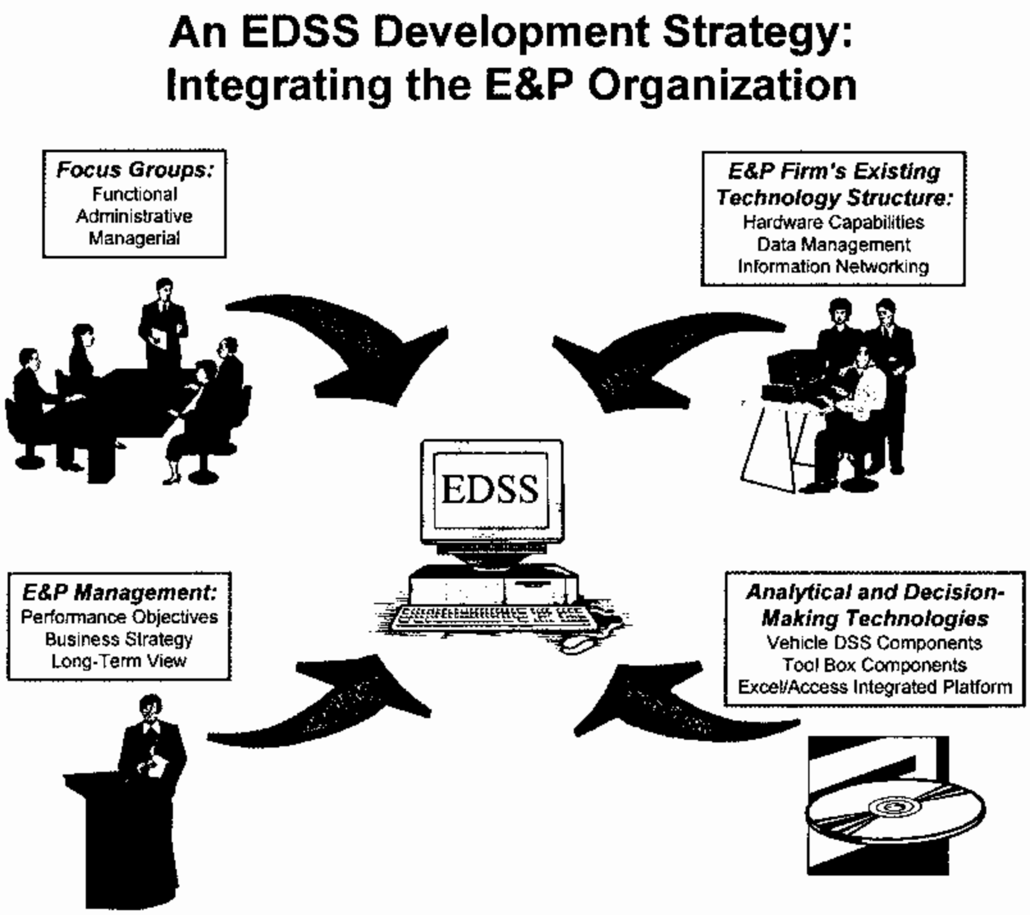

Figure 2. The process of developing an integrated EDSS involves all components of the organization, including functional, administrative, and managerial personnel. It also considers existing technology structure and the firm's E&P objectives.

problems, tasks, and responsibilities associated with ongoing exploration and development activities. The problem situation for EDSS design is described in terms of the common objectives of multiple organizational groups (i.e., the E&P business unit, regions, divisions, individual project teams, etc.) and their joint performance in achieving the firm's exploration objectives. For example, EDSS design would pay special attention to achieving consensus among the geoscience, engineering, and management groups in the organization, all within the context of achieving exploration objectives and performance targets.

To handle information needs, the EDSS incorporates an integrated database management and model management system. The focus here is on how information is sourced, grouped, and processed. The primary concern is to design a database management system, a model management system, and a user interface that allows exploration personnel, at all levels in the firm, to improve the exploration decision process. The user interface, for example, may consist of many task interfaces, each enabling a functional expert or manager to communicate with the EDSS to execute a subtask or coordination task. A primary design goal is to ensure that the system can provide "useful" information and insights at any level of the organization. This phase is best accomplished through a joint effort with the organization's information systems group as well as other functional groups in the company.

Improving the performance of a DSS should be placed in the broader context of improving the performance of the organization. Designing an EDSS should not become a goal in itself. By putting balanced effort into both understanding and solving problems, reference points can be created that help to evaluate the EDSS's effects and to specify the added value of the EDSS to the firm's exploration activities.

Focus Groups

In order to effectively design an EDSS and to ensure its acceptance, it is important to reach out to the various functional and managerial groups in the organization and create as complete a picture as possible of the firm's needs and requirements for exploration planning. Focus groups, facilitated by the EDSS designers, would be comprised of a mix of functional, administrative, and managerial personnel. Input would be solicited from these groups concerning possible design alternatives and solutions for the EDSS. The intent of this process is to get key individuals to think about and prioritize what, in an exploration decision support system, is most important to them.

This process of information gathering is also an essential component of the consensus-building process. When people feel they are part of framing the problem, they are much more willing to take ownership of the solutions to the problem. Input and findings from the focus group process are an important component of the final EDSS design and implementation strategy, as well as a foundation for consensus-building.

EXPLORATION DECISION SUPPORT SYSTEM ARCHITECTURE

User Interface

The Exploration Decision Support System is a PC-based platform built in Microsoft Access, Excel, and Visual Basic for Windows. The interfaces are tailored to the needs of the decision makers and, to every extent possible, shield the user from the underlying application command structure. However, since the powerful engines of Access (relational database program) and Excel (spreadsheet and analytical tools) are available to the end-user, it is also possible to choose the "expert mode." Here the more computer-literate user leaves the "safe" world of guided analysis and can accomplish more idiosyncratic examination not contemplated by the EDSS design.

The primary source of on-going instruction and information about the EDSS is the on-line help system. Here, in a Windows Help environment, one can peruse the contents of the Help system; search for specific terms, concepts or questions; explore the index; or ask for context-sensitive help at any time. Combined with the initial training and the intuitive design of the menu and form system, the EDSS Help should be sufficient to ensure maximum utilization of the planning tool.

Figure 3 provides a broad conceptual outline of the EDSS. Simply put, the EDSS must (1) organize the firm's geological and economic data into flexible and accessible data structures or "receptacles;" (2) design system linkages to current databases and, where necessary, user-friendly data input schemes; (3) construct modeling components that evaluate risk, construct feasible project portfolios, and simulate distributions of outcomes; and (4) devise summary reports that effectively describe investment opportunities, model outputs and rankings of potential resource allocations for any organizational level in the exploration firm.

Linkages with Existing Data Sets

High quality, in-depth data is essential to the validity of EDSS. As figure 3 illustrates, identifying and describing investment opportunities depends upon the firm's ability to accurately define projects or prospects and the constraints under which the firm is potentially able to develop these possibilities. Data structures can include the most basic geologic, engineering, and economic data for each exploration opportunity. The fundamental approach to the EDSS is to rely, as much as practical, upon the normal company data sources to "feed" the data avarice of the analytical models.

The first step is to build a "data receptacle" that can house all of the pertinent information for the EDSS's decision models and allow both easy and powerful access to it for analysis or report writing. The EDSS utilizes a PC-based relational database approach that employs both a standard relational database language, Structured Query Language (SQL) and Query-by-Example (QBE). This DSS architecture can provide a more intuitive method of interacting with the exploration firm's existing exploration database. In addition, the Microsoft Access/Excel platform is well-suited to continuous improvement. Even if the firm makes few modifications to the basic EDSS implementation, performance and reporting enhancements will be the direct result of normal Microsoft software upgrades. An EDSS developed with proprietary code would not normally contain this advantage.

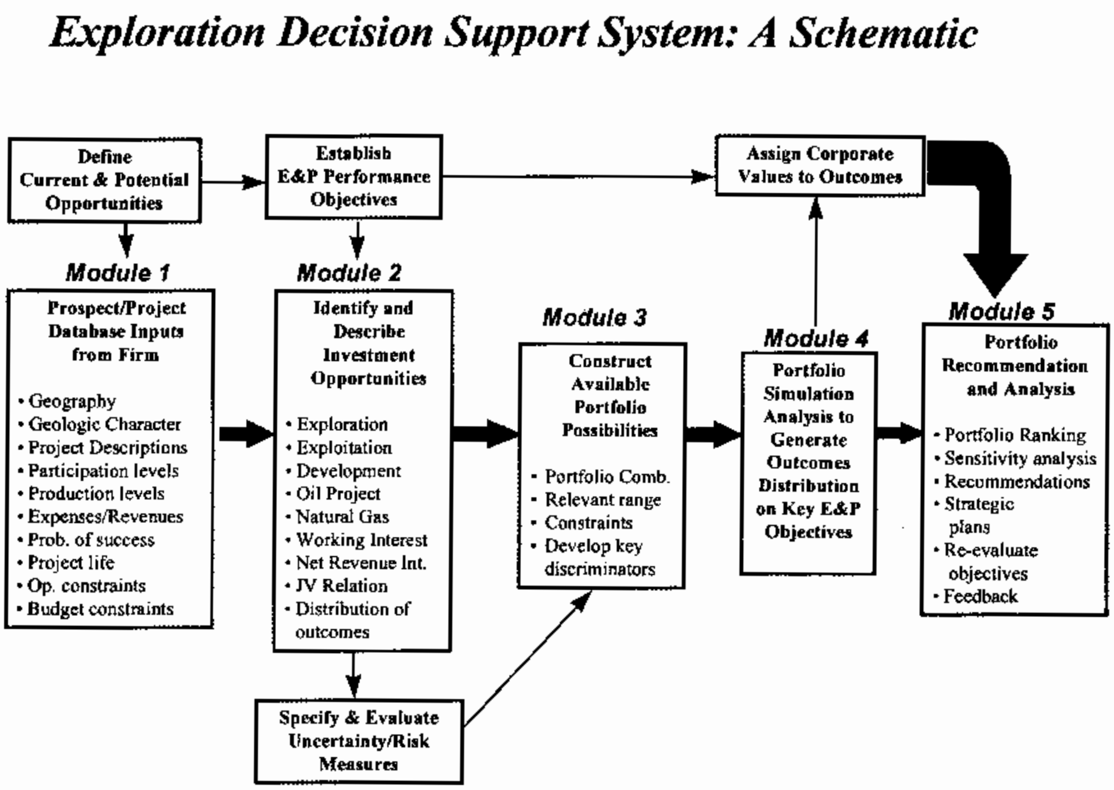

Figure 3. This stylized version of an EDSS schematic shows the important modules, as well as their interrelationships, which are included in the system's development.

Figure 4 is a stylized example illustrating the integrated nature of the database module of an EDSS. Users of the system both input data that everyone utilizes and receive reports and information from the system on portfolio (or resource allocation) possibilities and current or expected future operations. Once the breadth of data is organized in "data receptacles," SQL and QBE can be used to aggregate it to shed light on any aspect of the firm's operation. This includes exploring geographic portfolios of different assets (exploration, exploitation, or development) by geologic region or characteristics, by type of predominant hydrocarbon (gas, oil, condensate), and/or by corporate structure (division vs. region).

So the first crucial step is to design an Access database structure that is both adaptable and comprehensive so that any future question, "Can you help me look at our Asian-Pacific operations?" or "Do we know our expected reserve replacement level in North America over the next three years?" can always be answered affirmatively.

How much new data must be created or to what extent data collection procedures must be newly developed is determined by an initial audit of the firm's current databases. In the "best of worlds," all of the needed data will already be in some form of a database and the design will only need to (1) create a linkage system and (2) reorganize the data into Access tables that take advantage of its relational characteristics. In the "worst of worlds," data will be in distributed spreadsheets with little commonality of structure. In that case, it is necessary to (1) develop a data collection process, (2) program common data input interfaces, (3) link those interfaces to an Access relational database and (4) reorganize the data into Access tables for analysis. Often the real world lies somewhere between the "best" and "worst" of worlds.

EDSS INFORMATION AND ANALYTICS

General Requirements

One of the fundamental objectives in EDSS design is to compile the set of exploration opportunities available to the firm over some designated planning

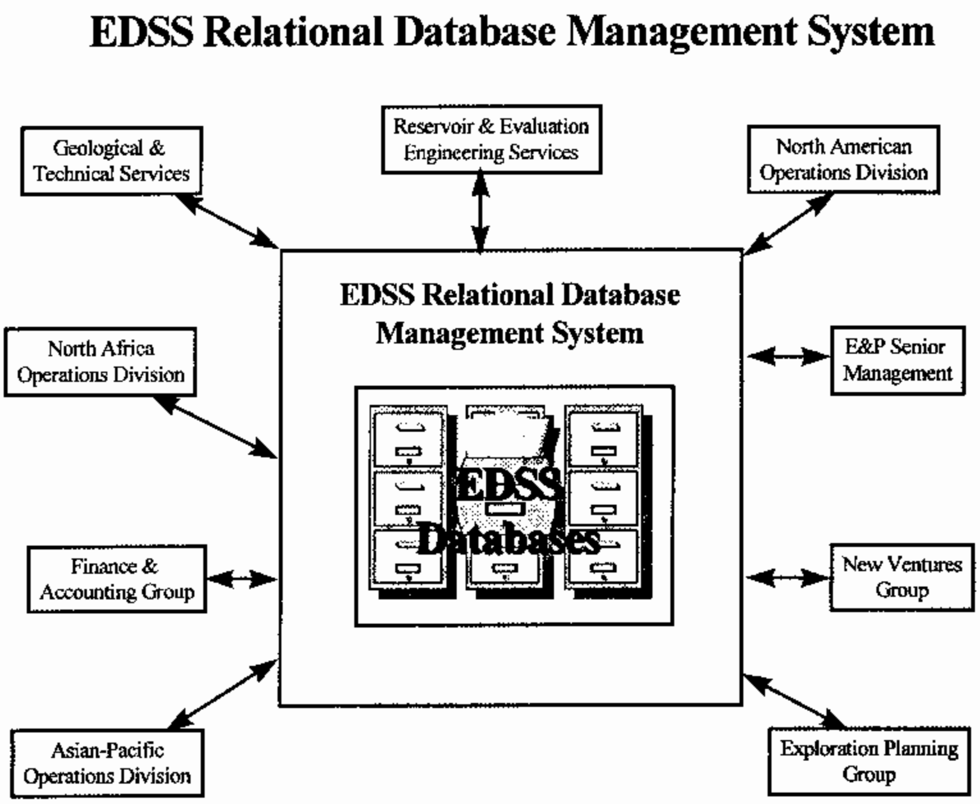

Figure 4. The central EDSS database is accessible at all levels of the organization. This ensures all decision-makers have the best information possible to support their decisions.

cycle to aid in the planning and capital allocation process. The opportunity set is defined by the firm's current exploration and development drilling inventory, as well as its anticipated activities over the planning cycle.

A stylized example of the information, analytics, and feedback loop for the EDSS is shown in figure 5. Exploration projects, initiated in different divisions and regions of the world, provide the fundamental unit of analysis for the EDSS. EDSS modules can be utilized at any level of the organization for portfolio analysis. For example, managers in the Williston basin area may evaluate and optimize portfolios of development projects on one set of key performance objectives (i.e., rate of return or finding cost) while rank exploration portfolios in North Africa may be evaluated on an alternative measure such as reserve contribution. The portfolio construction, simulation, outputs, and recommendation modules could be utilized at any level in the exploration business unit. Similarly, users in corporate exploration planning have the capability to "roll" individually recommended portfolios into a corporate-level analysis. This EDSS approach encourages open review of all projects and provides a rational and justifiable decision process.

Prospect/Project Inputs

The exploration portfolio planning inputs are designed in an Access for MS Windows 95 framework. The data dictionary utilized in the EDSS is designed to manage a comprehensive set of input specifications by the firm. Key project parameters discussed earlier in this paper, such as geological factors, sources of uncertainty, contractual and financial constraints, corporate performance objectives, etc. all become essential inputs to the integrated database and model management system.

In order to adequately characterize the population of available investment portfolios, as well as to measure the key performance objectives over the exploration planning horizon, data inputs are required for each

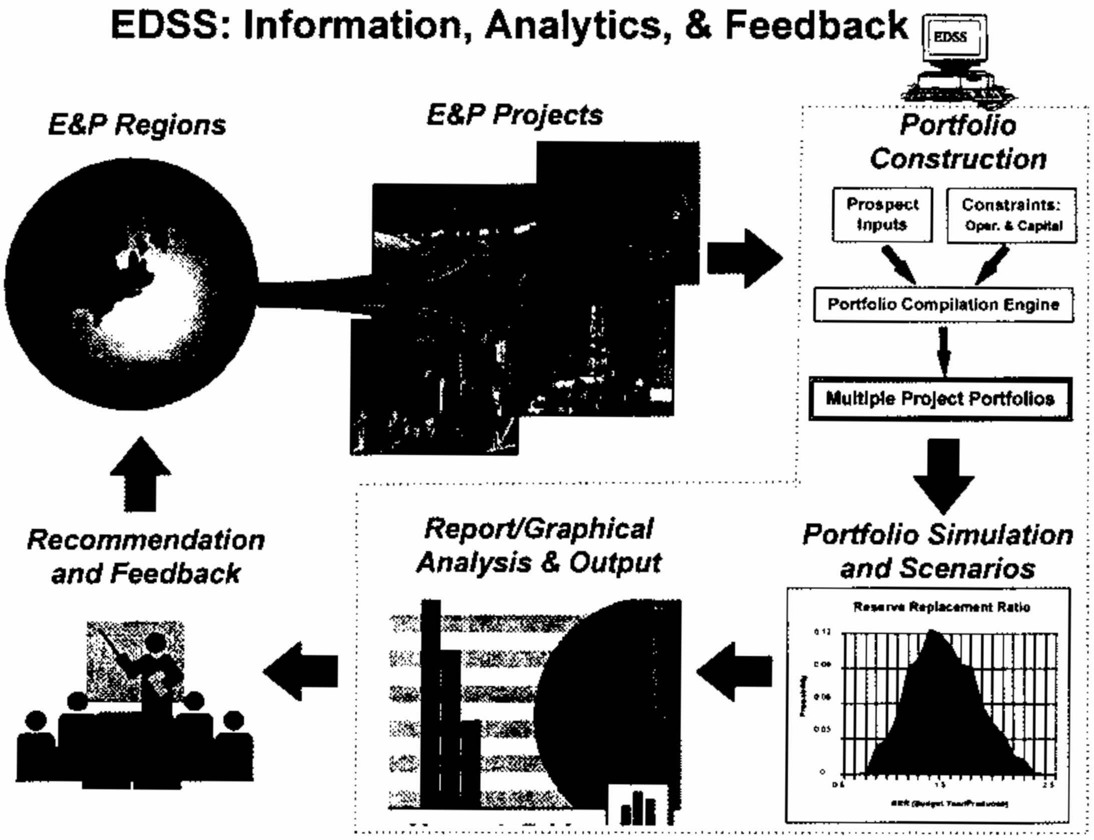

Figure 5. The EDSS is designed to ensure full information is available, precise decision analytical models are utilized, recommendations are acted upon, and that the organization has a process of continuous feedback with regard to important exploration decisions.

specified prospect/project. A non-exhaustive sample of those inputs are listed below:

- ❑ Major asset class (exploration, exploitation, development)
- ❑ Geographical location (domestic, international)
- ❑ Geological characteristics (net pay thickness, porosity, recovery factor)
- ❑ Corporate or geographical region (division)
- ❑ Predominant hydrocarbon (oil, gas, condensate)
- ❑ Capital costs
- ❑ Net present value (exploration and development)
- ❑ BOE production levels
- ❑ Oil revenues
- ❑ Gas revenues
- ❑ Condensate revenues
- ❑ Gross reserve distribution estimate (BOE)
- ❑ Budget year reserve distribution estimate
- ❑ Working interest
- ❑ Net revenue interest
- ❑ Spud or start date
- ❑ Probability of success (P_s) on exploration and development
- ❑ Dry Hole Expense (Including Land, Geophysical, G&A, etc.)
- ❑ Completion Expense
- ❑ Development Expenditures

Constraints

Exploration portfolio construction is subject to the firm's specified operational, capital and contractual constraints. Constraint classifications associated with individual prospects or projects are explicitly considered in the portfolio construction module. Some of the constraints which could be taken into account in terms of portfolio composition on an individual project, divisional, or total program basis are listed below:

- ❑ Minimum participation (working interest) levels
- ❑ Maximum participation (working interest) levels
- ❑ Total exploration budget constraints
- ❑ Limitations on exploration versus development spending, if any
- ❑ Hydrocarbon balance (oil vs. gas projects)
- ❑ Operational and contractual constraints
- ❑ Drilling commitments
- ❑ Deterministic performance targets
- ❑ Target reserve replacement ratio

Additional constraints that may be identified as a result of focus group meetings or specified by management can be incorporated into the database and model management systems. Exploration portfolio optimization routines utilized as part of the model management system are made subject to selected constraints per the user's choice.

Exploration Portfolio Construction

What are the important components of the firm's strategic planning environment and decision problem? What are the exploration unit's objectives and their relative importance in terms of the corporate vision and mission? What do you know and what don't you know and how can you take those factors into account? What elements can the firm influence? What are the key constraints? What investment opportunities does the firm face? How do you systematically integrate all of these concerns into an EDSS that effectively links what you do with "the ultimate picture of what you are and want to achieve?" This is the fundamental set of questions that the EDSS confronts and systematically answers.

The vehicle DSS component of the EDSS can utilize any number of problem-solving strategies. In this example, we describe a multi-criteria portfolio approach (Keeney and Raiffa, 1976; Walls, 1995) to the firm's exploration decision problem. The EDSS identifies the set of portfolio decision opportunities available to the firm over the planning horizon and evaluates those opportunities in the context of the firm's performance objectives, as well as the relative importance of those objectives. In addition, the portfolio approach systematically measures the risks associated with alternative strategies. This integrated portfolio model enables the firm to evaluate the impact of interconnecting decisions, determine the optimal mix of exploration, exploitation, and development projects, identify the optimal geographical and hydrocarbon mix, evaluate its current asset inventory in light of new opportunities, and improve risk communication throughout the organization.

The choice of the mix of exploration projects undertaken by the firm is perhaps the most important element in effecting an overall exploration strategy and crucial in achieving a set of performance objectives. The EDSS is designed to evaluate all reasonable portfolio combinations of exploration and development projects, subject to specified constraints. Exploration portfolio construction and analysis can be undertaken at the division, regional, country, domestic, international, or corporate level (as defined in the system architecture). Portfolio composition and analytics would be available to decision makers at all levels in the firm. At each organizational unit, managers can select and vary key performance objectives or decision criteria to aid them in the process of evaluating project and portfolio opportunities.

In the EDSS, two major distinguishing elements to portfolio composition are project selection and participation level for individual projects. Participation level is subject to the firm's specified constraints in terms of minimum and maximum working interests. Module 3 of the EDSS generates a feasible set of portfolio opportunities available to the business unit or corporate planning manager, subject to capital, operational and participation level constraints. This task is accomplished by varying the mix of projects and level of participation in each project for different portfolios. These potential portfolios can then be compared to the firm or unit's current portfolio and evaluated in the context of key performance objectives.

Simulation Analysis

Simulation analysis is a fundamental and essential element to any comprehensive EDSS and is provided as part of the toolbox of modeling capabilities. The properly-designed EDSS makes it possible to simulate various geological (reserve outcomes, chance of success, etc.), financial (NPV, Finding costs, ROI, etc.) and physical outcomes (production profile), using a large number of pre-specified input variables. Monte carlo simulation analysis is an appealing way to deal with the uncertainty involved in forecasting the outcomes of exploration decisions over the planning horizon. Since the prospect inputs are representative of what one might encounter in the real world, many possible combinations of returns on important performance objectives are generated. Key distribution parameters for each analyzed portfolio, such as expected value, variance, standard deviation, mode and median, are all available to the manager to aid in the decision process.

Exploration, exploitation, and development projects individually have their own components of risk and uncertainty. An important feature of portfolio analysis is uncovering the critical dependencies among exploration projects. Where applicable, users specify key dependencies among variables that more accurately represent the interactions between potential projects in an analyzed portfolio. It is the interaction among the mix of assets in the portfolios that we are interested in capturing through the simulation process. In this way, each portfolio generated in Module 3 (including the firm's current portfolio) will have its own unique measures of risk and uncertainty concerning potential outcomes. Utilizing the portfolio approach, the decision maker can analyze the risk and uncertainty associated with each of its key objectives (i.e., reserve replacement, NPV, finding costs, etc.) at the portfolio level rather than the project level. The simulation techniques in Module 4 facilitate a systematic analysis of the risk/reward tradeoffs among key objectives.

Results of the simulation on each of the key variables are saved and transferred to the Access database system for analysis in Module 5, *Portfolio Recommendation Analysis*, this component of the EDSS provides a formal method of comparing alternative exploration and business strategies and their impact on risks faced by the company. The capability to model interactions and dependencies has far-reaching consequences in terms of constructing the appropriate portfolio consistent with the organization's desired business strategy and performance objectives.

EDSS PORTFOLIO RECOMMENDATION ANALYSIS

Portfolio Ranking

Portfolio ranking is an essential element of the EDSS. Module 5 of the EDSS provides decision-makers the capability to rank portfolios on the basis of any number of key discriminants. Expected performance objectives, such as reserve replacement, NPV, finding cost, etc., each could be selected for ranking analyzed portfolios. Portfolios can also be ranked in terms of key risk dimensions, such as the variance associated with an exploration objective. Rankings can also be made on the basis of portfolio composition. For example, a manager may be interested in the portfolios with emphasis on oil reserves, as opposed to natural gas reserves. He or she may also be interested in portfolios with a particular balance in terms of international vs. domestic emphasis or exploration vs. development projects. In a properly designed EDSS, users are able to access and rank portfolios on any number of key dimensions. This capability leads to a clearer understanding of the factors affecting portfolio composition, uncovers preferred portfolios and provides rich guidance in the decision-making process.

Recommended Portfolio Composition

The comprehensive EDSS is designed to help exploration managers understand what differentiates the "best" portfolios from one another. Decision-makers can observe portfolio composition of similarly ranked portfolios on as many discriminating characteristics as defined in the input module. For example, recommended portfolios could be examined in terms of domestic vs. international composition. They could also be examined in terms of exploration or development emphasis and in terms of hydrocarbon type (oil vs. gas), project scale (% of capital budget), short-lived vs. long-lived, and a host of other factors. Insights about portfolio composition are an essential element in terms of understanding the link between the firm's exploration strategy and decisions about capital allocation. This module of the EDSS provides insights about recommended actions and essentially removes the "black box" syndrome often associated with complex decision support systems.

Scenario and Sensitivity Analysis

The important products of a comprehensive exploration analysis are its insights, which can best be provided by examining several sensitivity analyses on key variables. External factors directly impact the composition of the firm's optimal portfolio selection. The

EDSS is designed to enable managers to readily perform sensitivity analysis on an array of these external factors. Because of the unique Access/Excel interlink, changes in variables associated with the defined EDSS data inputs can quickly be assessed in terms of their impact on optimal portfolio selection. Sensitivity analysis can be performed on any of the geological and financial inputs by simply reevaluating the constructed portfolios based on the new data. This sensitivity analysis capability can provide valuable insights in terms of selecting the most appropriate portfolio in terms of the firm's exploration opportunities and objectives.

The EDSS also can explore the effects, in terms of portfolio selection, of changes in the firm's performance objectives. Planning personnel and decision makers gain valuable insight by observing changes in the optimal portfolio based on changes in corporate objectives. Consider, for example, that finding cost becomes less valuable in the minds of decision makers and maximizing reserve replacement increases in importance. This change could have a fundamental impact on the appropriate portfolio selection. Similarly, an increase in the importance of ROI and an accompanying decrease in the importance of NPV can have a significant impact on the choice of an optimal portfolio. In addition, the EDSS would allow planners and managers to explore the effects of changes in specified constraints. Changes in capital constraints, operational and contractual constraints, hydrocarbon balance, etc. can be explicitly analyzed in terms of their effects on exploration performance targets and portfolio composition.

CONCLUSIONS

The EDSS described in this work aids the exploration firm in developing strategies and action plans for its entire capital budget and asset portfolio. In addition, it can provide geological managers a mechanism for focusing their exploration efforts. The EDSS indicates to managers how to maintain its target reserve replacement ratio, where to target exploration and development capital, where to improve productive capabilities, where to target and implement new exploration efforts, and how to maintain financial flexibility. The EDSS considers multi-year effects on all the company's key objectives, given a comprehensive analysis of alternative exploration strategies.

The recommendations and sensitivity analysis modules "close the loop" in terms of the exploration decision analysis process. Understanding the composition of portfolios, understanding their risk and uncertainty, and developing a formal process for feedback to the firm's major performance objectives represent fundamental elements of a comprehensive EDSS. It enables the exploration firm to systematically evaluate its strategic exploration plan in terms of the available decision opportunities. In other words, the EDSS provides a means to evaluate the firm's exploration position relative to its strategic plan.

All of this requires patient systems development with a maximum of feedback from all of those that will either be required to provide inputs or use the outputs from EDSS. In summary, the EDSS organizes all of the relevant exploration data in a relational database, provides insightful queries of that data to convert it to investment portfolio information; assesses the risk associated with any portfolio; then screens millions of combinations until it can rank them on any dimension that the exploration manager desires. Finally, the EDSS provides that information to decision-makers at any level in the firm in a form that eases the information review process and helps highlight the "best decisions" in the context of the exploration firm's opportunities and constraints.

The EDSS improves the firm's competitive strengths because it results in (1): better decisions about resource allocations; (2) more systematic understanding of the factors affecting exploration decisions; (3) improved communications about exploration performance objectives and constraints at all levels of decision-making; and (4) an explicit vehicle for continuous improvement of the firm's exploration decision-making process.

Before embarking on a very comprehensive and costly effort to develop an EDSS, a few comments on potential roadblocks should be noted. First, no system replaces the technical and business expertise of the firm's professional staff. The purpose of an EDSS is (1) to systematically make available the best information possible and (2) to provide the tools to completely and accurately evaluate that information.

Second, new systems, by themselves, do not affect real change in how organizations conduct business. To be effective, any EDSS must incorporate process (data input, information reporting, real feedback mechanisms, etc.) that make it part of "doing business" at all levels of the organization.

Third, if an EDSS is to become an integral part of the exploration firm's culture, those responsible for inputting the basic data–the EDSS is "data hungry"–

must immediately see a "benefit" to them. Quality and breadth of information is essential to the reliability of the recommended strategies. Thus, an EDSS must be able to produce usable results for all levels of decision makers, not just for corporate personnel. It is the only way to develop trust in the system and to ensure that everyone (1) has a shared interest in providing the best available data, (2) reviews and acts on the EDSS analysis/reports and (3) provides informed feedback to the EDSS, implied recommendations.

Lastly, an EDSS is not a static "solution" to the decision-making challenges of the exploration firm. In fact, these challenges themselves change rapidly. If managers do not build continuous improvement into the process, then the EDSS will be obsolete shortly after its development and irrelevant to the direction of the organization soon thereafter. The EDSS must have continuous improvement as part of its makeup. This is best achieved by an "open architecture" with adaptation to change inherent in its design.

REFERENCES

Bonczek, R. H., Holsapple, C. W. and Whinston, A. B., 1981, Foundations of decision support systems, NY, Academic Press.

Eom, H. B. and Lee, S. M., 1990, A survey of decision support system applications (1971–1988), Interfaces, v. 20, n. 3, p. 65–79.

Keen, P. W. and Scott-Morton, M. S., 1978, Decision support systems: An organizational perspective, Reading, MS, Addison-Wesley.

Keeney, R. L. and Raiffa, H., 1976, Decisions with multiple objectives: Preference and value tradeoffs, NY, John Wiley and Sons.

Silver, M. S., 1990, Decision support systems: Directed and nondirected change, Information Systems Research, v. 1, n. 1, p. 47–70.

Sprague, R. H. and Carlson, E. D., 1982, Building effective decision support systems, Englewood Cliffs, NJ, Prentice-Hall.

Thompson, R. S., 1993, Integrated design by design: Educating for multidisciplinary teamwork, Society of Petroleum Engineers Paper No. 26376, presented at the Sixty-eightieth Annual Technical Conference, Houston, Texas, October 3–6.

Walls, M. R., 1995, Integrating business strategy and capital allocation: an application of multi-objective decision making," Engineering Economist, v. 40, n. 3, p. 247–266.