Methodologies for Benefit Estimation of Research Programs

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There is a growing need to effectively measure the outcomes and value of research programs. These estimates are not only good business practice, but for federally-funded programs, they are mandated by statutes such as the Government Performance and Results Act of 1993 (GPRA). This paper describes methodologies and tools developed to estimate the benefits to be derived from the U.S. Department of Energy's (DOE's) National Petroleum Technology Program (NPTP). The NPTP is a petroleum research program cooperatively conducted with industry and universities. Development of this benefit estimation forecast has been aided by the application of a consistent methodology, peer review of results, project validations, and creation of a PC-based software application to facilitate users in developing estimates. Our methods have been very successful in communicating the value of the NPTP, setting priorities among projects and programs, and developing a baseline for project validation. The methods and tools used for this program should have wide applicability for those interested in undertaking the difficult task of forecasting future benefits of current activities.

Introduction

The NPTP is focused on developing new technologies to enhance the efficiency and reduce the environmental impact of domestic oil exploration, recovery, and processing. Program funding stands at approximately $50 million per year, with the research itself being conducted by partners from industry, universities, the DOE's National Laboratories, and state agencies. Currently, there are over 200 active projects in progress across the U.S., comprising six major product lines.

The majority of NPTP projects are selected competitively during a procurement process. Most of the projects are cost-shared with industry or other partners. The program development process requires that the selected research projects demonstrate technical competence and a clear federal role. If the research successfully solves the problem(s) put forward, then demonstrable application(s) of the technology or technologies is required. More recently, in view of increased competition and regulation and a need to decrease costs, there has been a push to estimate the likely outcomes and value of such research.

The GPRA legislation requires that program administrators define specific program goals and track their progress in meeting these goals. This includes programmatic as well as technical achievements. In order to meet GPRA requirements, the DOE developed a strategic plan that listed specific goals (for example, "reduce the decline of domestic oil production").

Program administrators are now required to develop annual performance plans, describing intermediate goals and specific accomplishments. All these factors have led the National Petroleum Technology Office (NPTO) staff to consider how and what type of forecasting tool could be developed that would be applicable to NPTP research results. The audience for this forecast is highly varied. It ranges from those research scientists involved with a particular technology, to legislative staffs that request summary benefit information. Thus, estimates have had to be developed that meet the criteria in Table 1.

Table 1. Criteria and Design Requirements for Benefits Estimation

Criteria	Design Requirements
Clear and Intuitive	Standard formats for input and reporting. Supports review of multiple levels of detail. All components of estimates are accessible.
Solid Technical Basis	Keep industry statistics and other references with estimates.
Defendable Basis	Identify and record subjective judgement. Store chain of logic explanations.
Benefit Traceable Program	Make estimates at project level and aggregate as necessary.
Quantitative Benefit Forecast	Benefit measurement should be quantitative (for example, oil reserves, dollars saved, or natural gas production).

At a more detailed level, the development should lead to estimates being:

- *Clear and Understandable.* The development of estimates should be unambiguous. Each estimate needs to follow the same process. Aggregation of results should follow set patterns and produce results in specific manners. Standardization across all project types is necessary.
- *Intuitive.* Each step in the estimating process should be defined and should be expected. There should be a flow to the process that includes all necessary components of the estimates.
- *Solid References.* Estimates should be clearly referenced. There should be a clear distinction between known input factors and assumed factors.
- *Defendable Basis.* The basis of estimates should be defendable, that is, from published, publicly available information. Reviewers' comments should also be accessible.
- *Traceable Logic.* Each step should be defendable. There should not be gaps in the logic that would cause confusion on the part of those unfamiliar with the specific technology or project.

Approach

Forecasting of any future event is a highly speculative venture — estimates of research benefits are made more difficult by several factors. First, the *benefits* of research are not direct. The primary impact of a research program is the development and introduction of a new technology, product, or process. This new advance must then be commercialized and introduced to the marketplace if a secondary impact or end result is to be realized. Second, research is risky. The NPTP sponsors many types of research — some areas cover demonstration only, some forms are more applied than basic, and so forth. The focus is to discover, understand, and develop what does not exist in current scientific knowledge.

Third, there are strong influences other than technology affecting the future of U.S. energy concerns. While technology plays a significant role in the energy future of the U.S., factors such as world oil prices, industry trends, technology utilization, and environmental requirements can and will have equal or greater impacts. For example, a world oil price collapse in 1998 and early 1999 dramatically affected the U.S. domestic production rate and potential for exploration and development.

With these challenges in mind, we have developed our metrics in a systematic, easily understandable way. The acronym, Oil Program Research Assessment (OPRA), has been coined for both our methods and our PC-based software application. Under this assessment process, Technology Managers estimate several parameters for either single projects or groups of projects, that will result in a technological advance. For example, one technology area pertains to the development of improved three-dimensional seismic imaging techniques. The successful application of this technology requires several supporting projects (that is, better field acquisition tools, seismic data analysis algorithms and processes, and so forth). Benefit estimates, however, are made for these projects as a single unit. In many ways, we are trying to capture the domain knowledge of the Program Manager in order to combine it with project information and industry trends, and thus make the best forecast possible.

The sidebar (pages 87–88) discusses some of the aspects of the traditional decision-making process as practiced by TRW and changes that are currently being considered and implemented.

Process

The NPTO has established an annual process for developing benefit estimates. The process generally occurs over several months and involves several steps. TRW has and continues to coordinate this process, collects and provides data support and analyses, and develops and maintains the OPRA software. The process is timed to coincide with significant program planning and budgeting activities, as summarized in Figure 1.

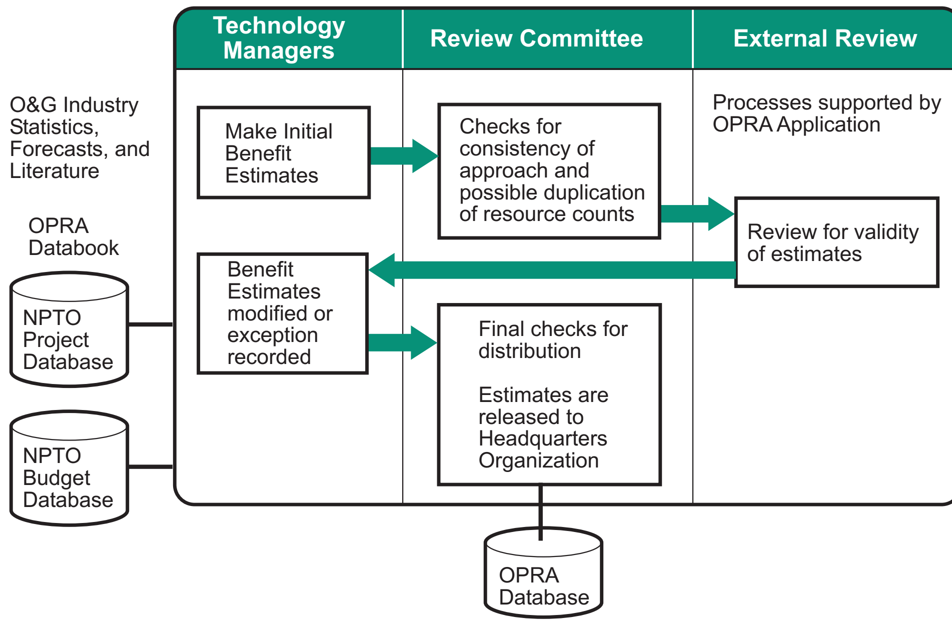

Figure 1. Process Diagram for Benefits Estimation

In order to facilitate the development of estimates, the NPTO determined that the primary author and owner of each estimate would be the DOE Technology Manager responsible for each respective project or group of projects, with such Managers responsible for 15 to 30 research projects apiece. In turn, they are provided with a variety of informative reference data about the oil and gas industry; for example, prices, production, number of producing wells, proved reserves, undiscovered resource, consumption, and so forth. These materials are collected in the OPRA Databook and support the overall effort. For both internal and external traceability of an estimate's analysis logic, accuracy, relevance, and completeness, the Databook pages have unique identifiers that are listed in the OPRA explanation section that is pertinent to the benefit estimate for each project or group of projects.

In addition to Technology Managers, there is a Review Committee consisting of DOE senior management and TRW staff. This committee provides an internal review of estimates and checks estimates for completeness and reasonableness. In building estimates of benefits from the bottom up, as we are doing here, there is a danger of double-counting benefits. For example, two different technologies may lead to a cost benefit by reducing drilling costs. One technology might improve the life of drill bits, and another might reduce the environmental costs associated with the disposal of drilling fluids. These independent estimates of future reduced drilling costs need to be considered together for overall reasonableness.

After internal review, estimates are presented to an external panel of industry experts for review and comment. Participants in the external review are recognized as leaders in their fields and are often former/retired oil and gas company technologists. Their comments are returned to the Technology Managers, and after discussion, the Technology Managers implement adjustments or changes. These comments and subsequent actions are then

Decision-Making and Technology from a Historical/TRW Perspective

— *TRW's Science and Technology department and TRW Systems and Information Technology Group*

The process of decision-making has evolved throughout history. From metrics recorded by ancient Egyptians relative to production quotas, labor rates, and union demands, to today's complex algorithms running on powerful computers, the art and science of business decisions has a profound affect on the way business is pursued. With the advent of the Industrial Revolution, *technological* innovation became the dominant means by which products and services were refined, improved, developed, or targeted for specific markets. Resultant decreases in the costs of production, increased standardization, and the glories of mass-production led to staggering growth and the need for more sophisticated ways to decide what business to be in, where and how much to invest, who was likely to benefit or use the business's product or output, and what future benefits/returns on investment were likely to be realized. By the turn of the 20th century, the management of business decisions in many fields, had become a full-time function. Indeed, ever since Thomas A. Edison established the prototypical corporate R&D laboratory, managers have been trying to understand the R&D investment process, and the myriad different valuation tools and procedures, in order to optimize the amount of profit annually retained to underwrite their industrial R&D efforts.

Modern, defense-oriented industries have been no exception. At the beginning of the industrial boom after World War II, the general focus was on the promise of technology as industry, and R&D laboratories, built up during war time, began to move from supporting the war effort, to making products for the marketplace. Broad R&D investment was increasingly viewed as investing in a company's future. In tandem, the need for understanding technology management became more pressing as industry, and the nation, focused more on the specific value created by technology investments.

The *cost* of doing business, always an object of concern, came under heavier scrutiny as successive generations of technology were created and their associated marginal profits followed a declining trend. For TRW, the impact of cost as a decision-making factor, has varied according to the environment, customer demands, and other overriding reasons for pursuing a line of business. In the case of its ballistic missile programs, national security and Cold War threats (societal factors) made cost a secondary consideration. Alternative uses of company resources were considered, and the decision was made to pursue a course that has led to TRW's domination of this business area for over 40 years. Over time, however, technical performance and scheduling parameters have come to be based more often on the dollar value of an investment (whether actual or anticipated).

Risk also influences the decision-making process. The statistics for R&D success are similar to those for new-venture start-ups. Often successes or failures are quantified from the time an idea is first promulgated, leading to extremely high statistical failure rates. Even if the actual expenditure of funds or allocation of resources is taken as a starting metric, the failure rate of new ventures is still very high. In the technology arena, perhaps one of 20 programs initiated ever result in significant commercial success, and on average, the time between initial concept and positive cash flow ranges from seven to 10 years. While costs often increase exponentially between start-up and full-up production, some risks may decrease, while others fluctuate. Even in cases where costs are not at unacceptable levels, the type and fluidity of risk factors may cause a project to be abandoned. In the current climate, it is often a failure to properly manage risks or correctly identify the proposed market/product line that poses the greatest threat to a venture.

From an academic standpoint, technology *management* became a topic of academic research in the 1960s. By the 1970s, many of the themes of modern R&D management research had been identified; during the 1980s and 1990s metrics were refined and took on their current forms. It has become clear that the long-term success of technology-based enterprises requires an extremely close linkage of the technology and a company's business strategies — the degree of this strategic alignment is one measure of the value of innovation. Two other popular measures are *financial return* (that is, new sales ratio, cost savings ratio, R&D yield) and the *projected value* of the R&D venture.

TRW's business decision methodology uses a tiered structure designed to optimize decisions/investments at both the corporate level and by specialized business areas. Several questions form a starting point for considering whether to pursue a line of business or not:

- Is the business a good fit with our company?
- Who are our competitors and what are they doing relative to this line of business?
- What are the industry trends, and can we afford to pursue this business?
- What is the likelihood of obsolescence, and when might it occur?
- What is the likely return on current investment?
- What is the future value relative to future investments?

Strategic business areas have been established to support specific TRW business lines/objectives. Each area develops a Strategic Business Plan, which is reviewed and adjusted on a regular basis. The plan must be cost-, performance-, and customer-sensitive and consistent with any supporting Product Plans. Appropriate metrics are collected, developed, codified, and analyzed in support of projected Product Plan(s). Financial investment and investment return profiles must also be included and be consistent with the Plans. Next, the Product Plans are laid out to create, refine, adapt, or otherwise produce a specific product or product line. Finally, Technical Plans are developed to support the creation of products. These plans draw upon available and potential technologies. Because of the dynamic nature of the R&D process, if a technology necessary to the creation of a product cannot be developed, adapted, or obtained, all levels of the business plans must be modified as necessary and goals reassessed. Often starting metrics tend to be somewhat independent of technology aims; therefore, management must decide if the technology is truly available and/or worth pursuing. Furthermore, it must decide how much technical investment to make in a product line, and when and where to market the product. In addition to internal engineering risks, external factors/forces outside of our control (including the actions of competitors), may constitute considerable business risk factors.

reviewed by the review committee, quantified, and published. These final estimates then form the basis for project validation.

Components of Estimate

In order to forecast future benefits, information about four domains is collected — Technology, Resource, Time, and Probability. The type of information and specific data elements collected in the OPRA system are shown in Figure 2.

Domain	Technology Domain	Resource Domain	Time Domain	Probability Domain
Questions Addressed	How much will the new technology improve or change?	What Resource or Activity will be impacted?	When will the technology be available, commercialized, and to what extent will it be commercialized?	How risky is the forecast as defined?
Data Elements	• Percent of Change • Explanation	• Resource Name • One-time or Recurring • Measured as • Explanation	• Years to fund development • Years to commercialize • Percent ultimate penetration • Explanation	• Probability of success • Explanation

Figure 2. Domain Parameters for Benefits Estimation

Critical parameters for estimation are developed by the Technical Managers and their staffs and include:

- The expected change, normally recorded as *percent change*, that a new technology will produce;
- The actual resource that will be impacted by the new technology;
- The number of years and funding required to complete research into the technology;
- The number of years needed to effectively commercialize the technology;
- Determination of the benefit as being either one-time or recurring — one-time benefits are those acting on a finite resource base; recurring benefits accumulate as often as the product is used;
- Ultimate market penetration, normally recorded as the percentage of the resource the technology will be applicable to;
- Estimation of the probability of success. This probability factor should take technical and programmatic risks into account. It is really an estimate of the level of the Technology Manager's confidence that a forecasted event will occur.

Wherever possible, reference materials are identified that support Technology Managers' estimates of such factors as applicable resource, the time to commercialize, ultimate market penetration, and the probability of success. A panel of industry experts reviews the managers' estimates. Recommended changes to these estimates are input directly into the OPRA system, a multi-user Windows application running on a local area network. The application, written in Visual Basic, contains many validation and reporting functions, as well as interfaces to various projects' data. An interactive online screen provides "front-end" access to the system as shown in Figure 3. Note that two estimates are actually input, one titled "Industry Only" and the other titled "Industry + DOE." This is done so that advancements anticipated from industry-sponsored research are forecast as well as those from the DOE. This enables an easy comparison of OPRA forecasts to national forecasts made by external industry organizations.

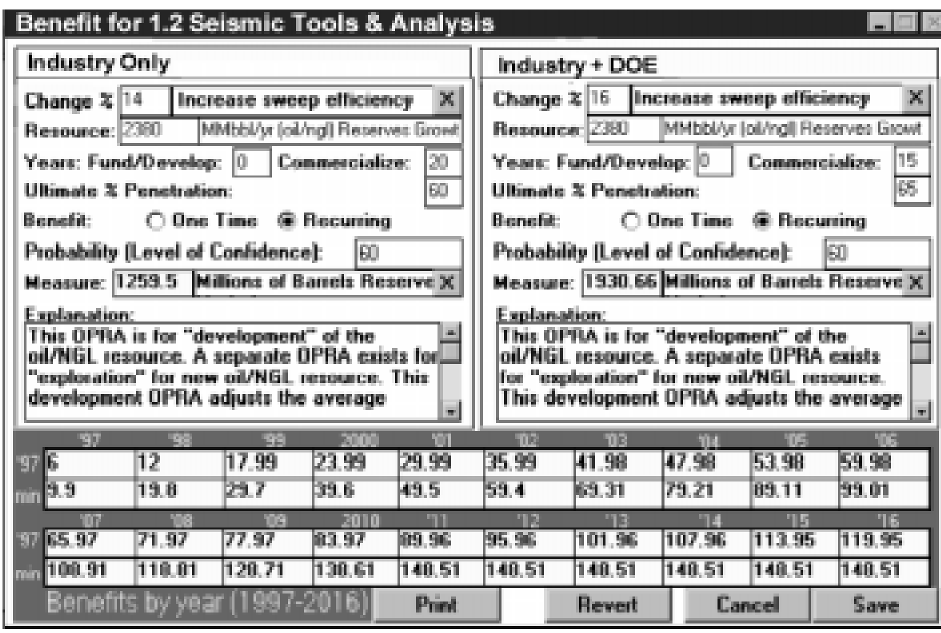

Figure 3. Estimation Entry Screen of the OPRA System

In our methodology, benefits are projected for 20 years by two simplistic formulas — one for recurring benefits and another for one-time benefits. One-time benefits are assigned to projects that act on a finite resource. For example, a technology that will allow the recovery of more oil from a geologic region would have a one-time benefit. Once this technology is applied and the oil is recovered, there is no additional benefit. Recurring benefits are those that occur any time the technology is applied. For example, a petroleum refining technology that reduces CO_2 emissions will result in a benefit every time it is applied. In both cases there is assumed to be no benefit while the project is being funded, prior to beginning of commercialization. A schematic of these patterns is shown in Figure 4.

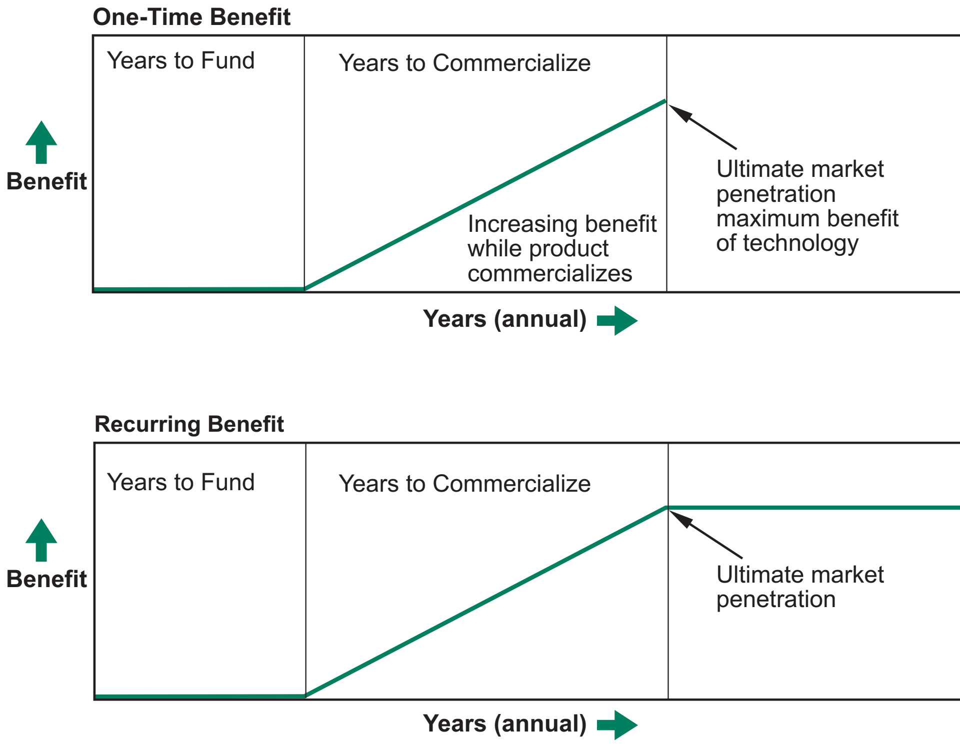

Figure 4. Benefit Patterns for One-Time and Recurring Benefits

The formulas used for the calculations in Figure 4 are provided below:

(1) If the benefit is a one-time benefit the annual benefit is calculated by:

for $Y_x \le Y_f$; benefit at $Y_x = 0$

for $Y_x > Y_f$ and $\le (Y_f + Y_c)$; benefit at $Y_x = [R*C*U*P*(Y_x\text{-}Y_f)]/Y_c*(Y_c+1)/2)$

for $Y_x > (Y_f + Y_c)$; benefit at $Y_x = 0$

Where:
Y_x = Benefit at Year X
Y_f = Years to Fund/Develop
Y_c = Years to Commercialize
R = Resource in Measurement Units
C = Percent Change
U = Ultimate Market Penetration
P = Probability of Success

(2) If the benefit is recurring the annual benefit is calculated by:

for $Y_x \le Y_f$; benefit at $Y_x = 0$

for $Y_x > Y_f$ and $\le (Y_f + Y_c)$; benefit at $Y_x = R*C*P*(U/Y_c)*(Y_x\text{-}Y_f)$

for $Y_x > (Y_f + Y_c)$; benefit at $Y_x = R*C*P*U$

Results

Once validated, OPRA estimates provide annual estimates of benefits for a 20-year period. These can be aggregated at any technology or programmatic level and are measured in several ways. Some of the more important benefits of the NPTP forecast through the year 2020 are:

(1) Increased U.S. domestic production of over eight billion barrels of oil and 20 trillion cubic feet (TCF) of natural gas;

(2) Cost savings to the industry of more than $18 billion;

(3) More than $20 billion in Federal tax revenues;

(4) Increased production on Federal lands by two billion barrels of oil and eight TCF of natural gas;

(5) Increased Federal royalty payments to the U.S. Treasury by over $9 billion.

A sample output forecast is shown in Figure 5, illustrating the annual benefit of Federal lands' oil and natural gas liquids (NGL) production broken out by product lines.

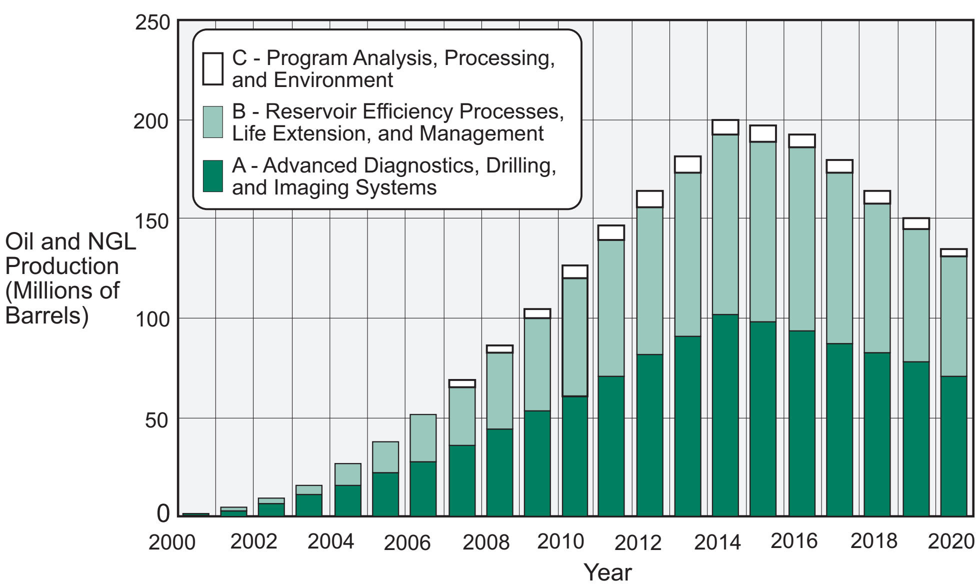

Figure 5. Forecast Production Benefit of NPOPRA

OPRA estimates are one part of the NPTP metrics effort. Other activities include:

- *Institutional Metrics* — program efficiency measures.
- *Program Story Line* — a high-level program logic defining the DOE's critical role in oil research and the national importance of oil research.
- *Project Validation* — traditionally described in terms of detailed success stories for completed research projects, where the realized benefit has been documented.

The application of OPRA methods and tools has increased the acceptance and utility of our metrics for the NPTP. Forecasts have been used in high-level reviews of the program by DOE staff and the President's Committee of Advisors on Science and Technology.

Application to Other Areas

The OPRA approach can be applied wherever there is a need to make projections of future outcomes. The main prerequisites for making intelligent projections of future outcomes are access to the domain knowledge of experts and the availability of a sufficient amount of historical trend data. Historical data is used to establish the resource baseline and estimate the impact of changes. Expert judgement is key to estimating the amount of change, the impact of schedule implementations, ultimate market penetration, and the probability of scenario occurrence. Our OPRA approach and software provide an excellent way to capture both historical data and the judgement of experts, for many potential applications.

While the OPRA approach/software have been developed and tailored for the needs of the NPTP, they are based on a flexible framework that can be modified for other problems. For example, the benefit profile as a function of time is currently restricted to two simple options, one-time or recurring. But there is no reason that more complicated distributions could not be analyzed. Also, there may be a need to address multiple scenarios possessing different component parameters. This can be accomplished by using "probability weighted" scenarios or by modifying the software to accommodate multiple scenarios.

Sales Projections. An OPRA-type approach could be used for making sales projections, since a large amount of known, often geographically-specific marketing data is usually available for making these projections. The benefit formulas within OPRA could be modified or converted to apply more conventional α-factor forecasting or S-shaped penetration curves, or to link software output to budget schedule inputs. The advantage of modifying the OPRA approach over a more traditional time-series forecast is that external impacts and changes based on experts' subjective judgements can be considered and quantified. [Editor's Note: An α-factor forecast is a weighted moving average forecast method that uses exponentially smoothed averages. The term "exponential smoothing" gets its name because it results in a series of weights assigned to past data that decay exponentially as the data gets older. The α-factor is a smoothing constant with a decimal value between 0 and 1. The value of α is chosen such that its use produces forecasts that fit past forecasts better than any other value of α. It is used to "smooth" variations in sales (or production management) demand forecasts that are caused when demand trend and/or seasonal demand variations occur [1].]

Revenue and Tax Projections. Revenue is derived whenever anything is sold, and when taxes are subsequently paid to various government entities. An OPRA-type software package can be used to project the expected revenues, taxes paid, or tax receipts in year *x* or between years *x* and *y*, either in nominal dollars or in discounted-value dollars. *Discounted value* is an adjusted valuation based in most cases on the devaluation of the value of money over time due to inflation. Certain functions, such as applying expected price tracks for revenue projections, prorating revenues to taxes paid, and calculating net present values, could be applied and presented in the report output.

Social Service Projections. An OPRA-type software package can be used for answering such questions as: How many more (or fewer) recipients of Program X will be served (or not) on an annualized basis for a given time period if certain changes are instituted in a program? How many additional contribution dollars (or new members) can a charitable non-profit organization expect given an *x*-dollar promotional campaign? How many more (or fewer) incidents of a given type (for example, terrorist, criminal, accidental, explosive, and so forth) are expected to occur over a given time period if certain social changes occur or if certain social programs are implemented? It is important to remember when considering these potential applications, that OPRA forecasts are very effective at communicating the basis of a forecast at many levels of detail.

Environmental Projections. OPRA was used to project future impacts of environmental research conducted under the DOE's NPTP. Environmental impacts were expressed as reductions in emissions (for example, millions of tons reduction of CO_2), number of sites remediated, reductions in compliance costs, increases in cost savings, and so forth. OPRA addressed many of the DOE's environmental impacts through the use of multiple scenarios. This approach can also be applied when analyzing/researching many non-oil or gas environmental policies or technical issues.

The above examples are just several of the possible applications of an OPRA-type software package. To date, OPRA has only been used to project the short- and long-term impacts of research conducted under the DOE's NPTP. However, the only real limit to possible applications is the level of imagination of potential users, as well as design and programming resources available to tailor the software. Software design modifications for new areas of application would most likely be implemented via graphical user input interfaces, connections with external systems, user interface output formulas, and report algorithms and formats.

Summary

The OPRA approach and software are valuable tools for estimating the benefit of the National Petroleum Technology Program. By collecting technology-specific information to estimate percent change, when and how the technology will be utilized, and the probability of occurrence, logical and reasonable forecasts of 20-year technology benefits can be made. The resulting collection of applications, databases, and references provide an easily understandable and logical presentation of the objectives of the research program.

Our approach can be applied to any forecasting need that is dependent upon many external factors, that is likely to have considerable variance in probable outcomes, and has substantial trend or statistical data available.

Reference

[1] James B. Dilworth, *Production and Operations Management: Manufacturing and Nonmanufacturing*, 3rd Edition, Random House-Business Division, New York, New York, 1986, pp. 101–102.

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