New Trends in Exploration Risk Analysis

Glenn E. McMaster

Manager Exploration Risk System
Worldwide Exploration Business Group
Amoco Corporation, Houston, Texas

ABSTRACT

The use of Risk Analysis in the evaluation of exploration wildcat wells has gained acceptance in the petroleum industry in the last eight to ten years. At Amoco, we believe the future lies in ***Portfolio Management****: the utilization of risk assessment information and data to impact and guide our business decisions.*

Risk Analysis *requires a systematic and consistent approach to prospect evaluation that uses individual and team skills and judgment, together with technical information to evaluate the risk and reward of each and every opportunity. A petroleum system approach that addresses charge, trap, seal and reservoir performance parameters is essential to success.*

Risk Management *uses this information to compare alternatives. To achieve a consistent outcome from the process and standardization across the corporation requires a centralized approach. Amoco's Prospect Quality Team provides a worldwide perspective on the technical aspects of plays and prospects by reviewing each and every exploration opportunity that is considered for funding. Through the use of a pre-drill consensus evaluation and rigorous postwell appraisal it is possible to calibrate the system*

Portfolio Analysis *builds on risk analysis and risk management by determining the interrelationships of individual assets or opportunities and developing options for the decision-makers. In addition to the risk and value, portfolio analysis has to consider other characteristics such as environmental concerns, geographic factors, political issues, etc. Amoco has utilized Expert Choice to combine the qualitative information with the quantitative data to provide decision-makers with a rating and ranking system.*

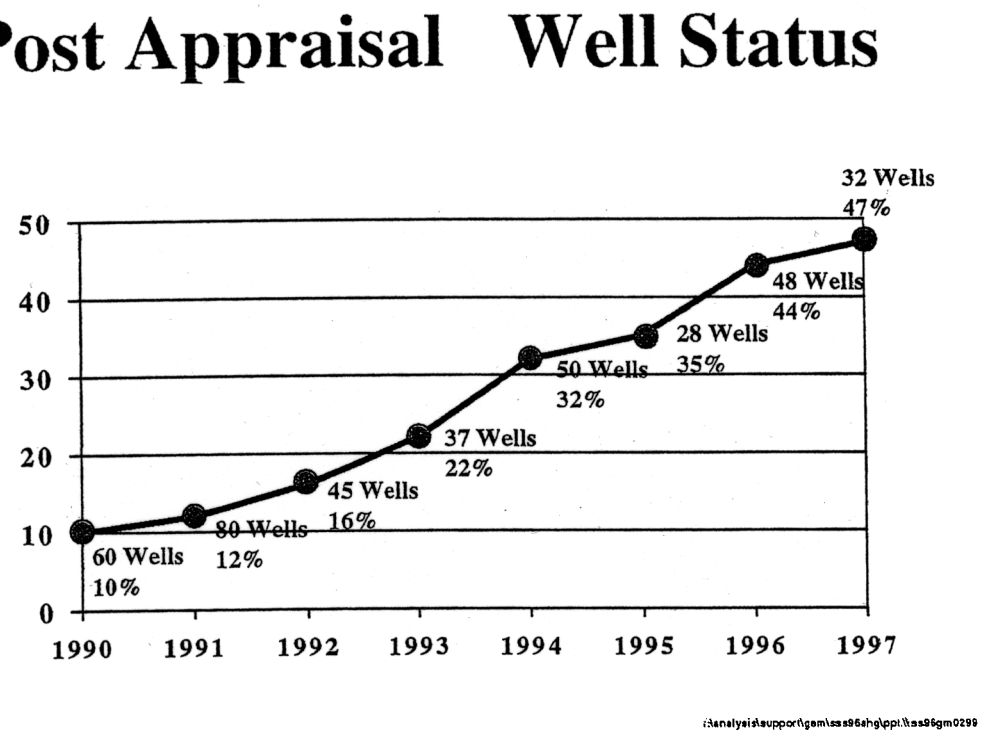
Portfolio Management *is the last but most important step in the business decision process. Within the framework of the exploration strategy it is crucial that the portfolio chosen exposes you to a successful outcome. The use of optimization and other asset allocation criteria provides a background and a basis on which to strategically manage your company. The model reveals future strategic gaps and issues which impact the success of the strategy.*

*The implementation of **Risk Analysis, Risk Management, Portfolio Analysis and Portfolio Management** will lead to a paradigm shift **from:** drilling lots of wells is the key to finding oil and gas, **to:** discoveries are found through thorough technical evaluation and risk assessment, followed by selective drilling of a portfolio of wells that achieve the business goals of the organization. Companies who make use of decision and valuation methods that are based on rigorous financial and decision science principles improve the chances for both short and long term success of their exploration departments.*

INTRODUCTION

The results of implementing rigorous risk assessment and portfolio management at Amoco have been dramatic. The Exploration Department has more than quadrupled the economic wildcat success rate from 10% in 1990 to 47% in 1997 (Figure 1). Amoco has also improved the pre-drill estimate of the commercial resources it will find on a portfolio basis from 20% in 1990 to 90% in 1997. By focusing on quality prospects, avoiding high-risk wells, and utilizing decision and valuation methods, Amoco's Worldwide Exploration Business Group (WEBG) has created value for our shareholders, partners and countries where we operate.

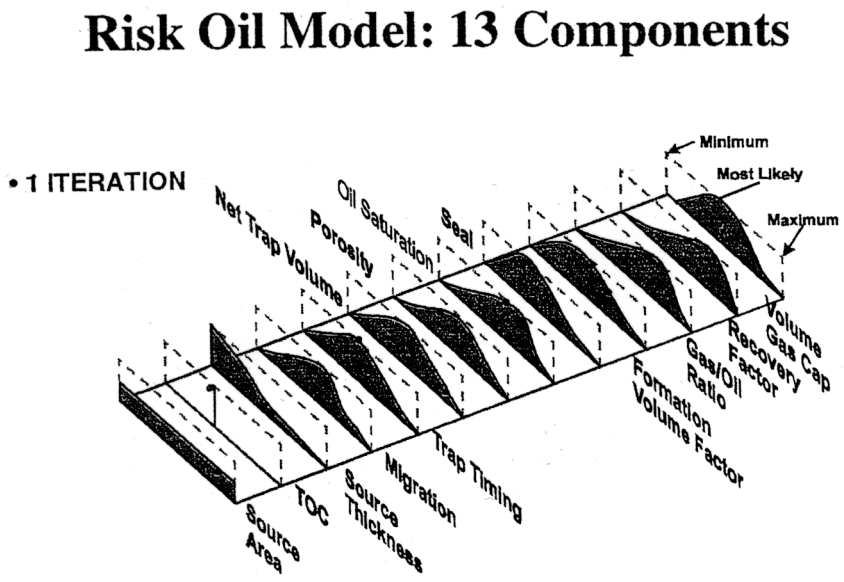
Figure 1



RISK ANALYSIS

Successful implementation requires a common understanding of risk principles, input and output definitions and the processes used to achieve these results. Amoco has trained over 1500 geologists, geophysicists, engineers, economists and managers in the principles of risk assessment and the use of Amoco's proprietary software, as it applies to prospect analysis. Amoco's RISK Program requires explorers to use skill and judgment together with technical information to analyze drilling opportunities. For each of the modeled components of the petroleum system the user is asked to determine the minimum, most likely and maximum values from direct measurement, through studies of analogous fields or regional control. These include charge components (source rock data and volumes), migration efficiencies, capacity information (reservoir volume and quality), reservoir engineering parameters and seal information. These data utilize Amoco's proprietary distribution builder to create distributions for all the individual parameters (Figure 2).

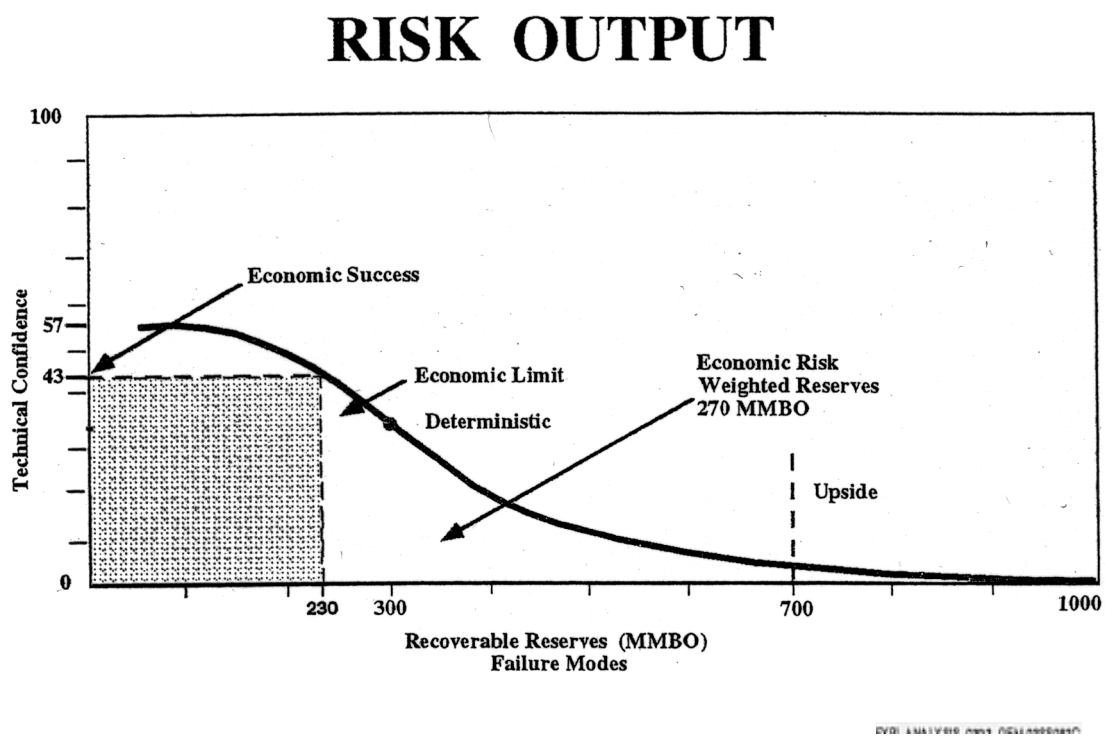
Figure 2



In Amoco's RISK Process, risk is the technical probability that a hydrocarbon accumulation of some minimum size exists. Resource variability expresses the range of possible outcomes in the volume of an undiscovered hydrocarbon pool.

These data are combined together through Monte Carlo Simulation to provide a cumulative frequency curve (Figure 3). The resulting RISK curve is generated for every prospect and represents a point-in-time view of risk-resource variability.

Figure 3



Typically for single level exploration prospects the curve that represents the distribution of resource values intercepts the Y-axis below 100%. This is because RISK has calculated a total (technical) chance of success, which is defined as the chance that this prospect will generate at least the minimum amount of resources defined from the input variables associated with the prospect. Many parameters in RISK have associated "chance-of-failure" values. The chance-of-failure is defined as the chance that the actual value for the variable will be less that the minimum value input by the user or that it doesn't exist. The user is cautioned not to double-dip or penalize the chance of success multiple times for the same failure by putting similar failure levels in related parameters. The RISK

program assumes the chances-of-failure are independent, and then multiplies them as shown below, to arrive at the "technical or total chance of success".

TCS = (1-COF parameter 1) * (1-COF parameter 2)... * (1-COF parameter N)

COF is the chance-of-failure.

For example: Seal Failure = 25%, Fetch Area Failure = 20%, Migration Failure = 5%

TCS = (1-0.25) * (1-0.2) * (1-0.05)
= 57%.

Thus on Figure 3 the distribution curve intersects the Y-axis at 57%.

As one of the last inputs into the RISK model the user is asked to provide the economic limit or threshold for the prospect. This represents the level of resources that need to be met, based on the development costs and reservoir performance, shape, size etc., to make the project economically viable. The economics department provides this economic limit as a close approximation based on their current knowledge of the fiscal regime, taxes etc. All resource values to the left of the economic limit are failure cases, to the right all of the potentially profitable reservoir outcomes. The probability of achieving the economic limit is read off the RISK curve at the intersection of the economic limit and the distribution curve. In Figure 3 the Probability of Economic Success **PES** is 43%.

The Economic Risk Weighted Resource (ERWR) level can be calculated by combining the full commercial resource range over the corresponding failure range to provide a risk-weighted value for comparing prospects. This is the yellow shaded area under the curve in Figure 3, and has a value of 270 MMBO. This is not what the well will find, but represents what this prospect, fully risk weighted contributes to the portfolio. This number is used for portfolio resource prediction and for comparing and ranking prospects.

RISK MANAGEMENT

Risk Management uses this information to compare alternatives. A centralized approach is required to achieve a consistent outcome to the process and standardization across the corporation.

Amoco's RISK Process involves three stages: (1) **Pre-drill Assessment** of all exploration prospects with emphasis on the prospect size and the technical strengths and weaknesses of the opportunity. (2) **Post Appraisal** of all wells drilled by Amoco or our partners, focusing on identifying the reasons for success or failure, calibrating our system and capturing key learning's from the data. This is fed back to the staff to improve our success in the future. (3) **Archiving** the pre-drill and post-drill assessments to look at the entire program. Review(s) of a prospect can happen several times during the life of a project. These technical reviews can involve different people; technical experts, consultants, etc., or be focused on specific components of the play; source, reservoir, seal, etc.

Amoco created the Prospect Quality Team (PQT) to achieve a consistent outcome to the process and normalization across the corporation (see McMaster and Carragher, 1996).

The PQT mission is to contribute to the Worldwide Exploration Business Group's ability to create value by improving Amoco's ability to accurately assess risk and resource potential through technical risk assessment. The PQT provides a worldwide perspective on technical aspects of the plays and prospects by reviewing every opportunity that Amoco participates in. This may include license rounds, farm-ins, acquisitions, or drilling decisions. These reviews provide a forum for open discussion of the technical strengths and weaknesses of each prospect. Amoco utilizes a consensus approach to determining the final level of risk associated with a prospect. We believe the consensus process has been an important factor in bringing exploration results into calibration over the last five years. Each PQT member's opinion is recorded, along with the exploration team's opinion on the risk for each geological factor. The differences of opinion are discussed. This usually leads to a new common insight on the risk level of failure, and to consensus on the point-in-time chance of technical success for the prospect. Documentation provides a basis for post investment calibration. Not only do we post appraise the consensus decision, we also have the opportunity to reflect on the personal assessments each individual PQT member has made. Most times, we see the superior assessment that comes from the consensus approach.

The last step in the process, but probably the most important, is post appraisal. This is the critical feedback loop in our process. The PQT, in conjunction with the presenting team, review the results of all wells Amoco drills, as well as those that are drilled that Amoco chose not to participate in. The objectives of post appraisal are as follows:

1. Better understanding of exploratory risks

2. Focus the application of our best technology

3. Drive exploration research technology strategy

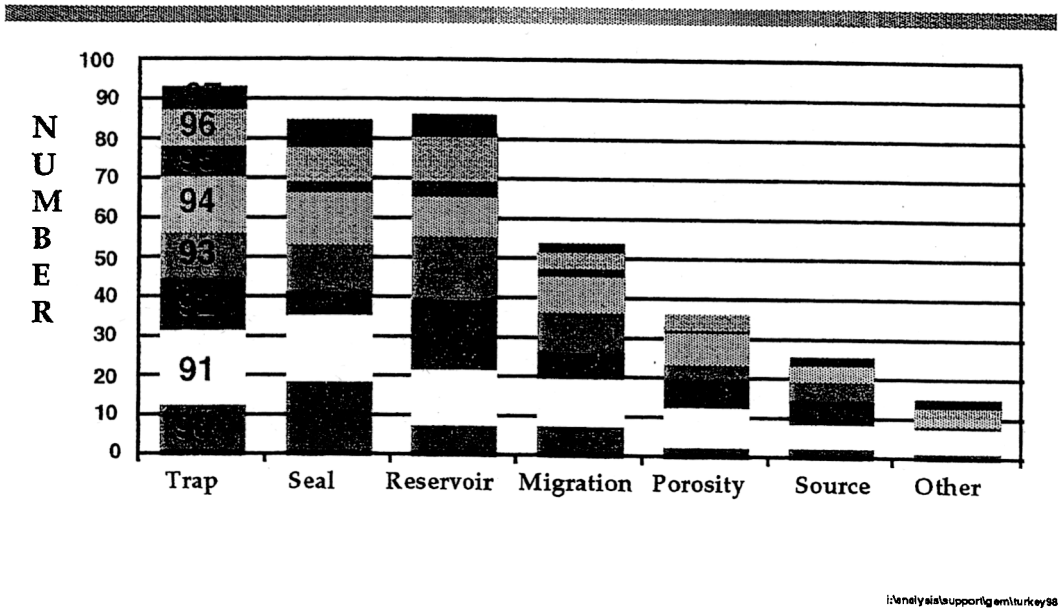
4. Share the lessons learned across the organization and apply these lessons to future prospects

5. Calibrate our RISK System

Amoco has collected very detailed data on all the wells we have drilled from 1990 to 1997 and classified the reasons for failure. The data in Figure 4 show that the most important issues were trap definition, seal and reservoir presence. Lesser concerns were migration, porosity and source. Because this data is in a database, Amoco is able to evaluate the distributions used, the difference between oil and gas well failure modes, play type risks, etc. These findings have allowed Amoco to focus our portfolio, focus our Geoscience Technology Programs, and choose our best opportunities in line with our business needs.

Figure 4

Failure Modes Through Time (1990 - 1997)

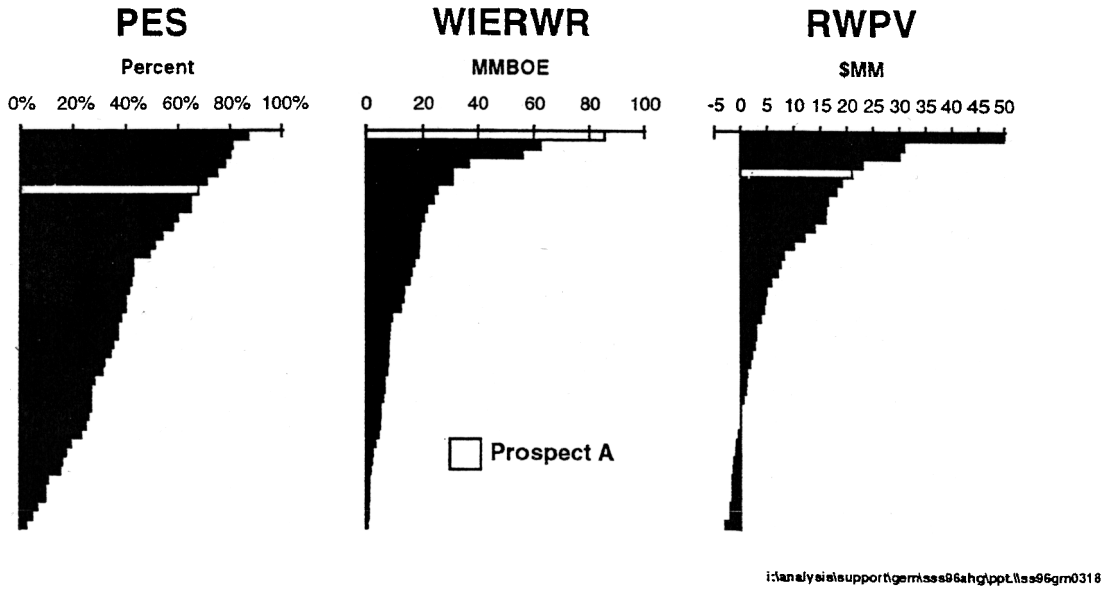


PORTFOLIO ANALYSIS

Portfolio Analysis builds on risk analysis and risk management by determining the interrelationships of individual opportunities or assets and combining these together to generate options for the decision-makers. The WEBG utilizes several different ranking schemes to compare prospects (Figure 5). These are based on both physical measures (Probability of Economic Success, Working Interest Economic Risk Weighted Resource, Uncertainty Index etc.) and financial measures (Risk Weighted Value, Drilling Dollar Finding Rate, Cost/Barrel etc.) to contrast our Prospects.

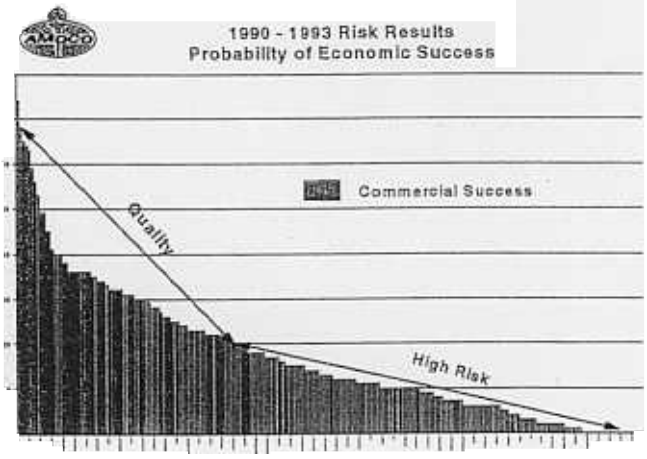
Figure 5

Ranking Schemes

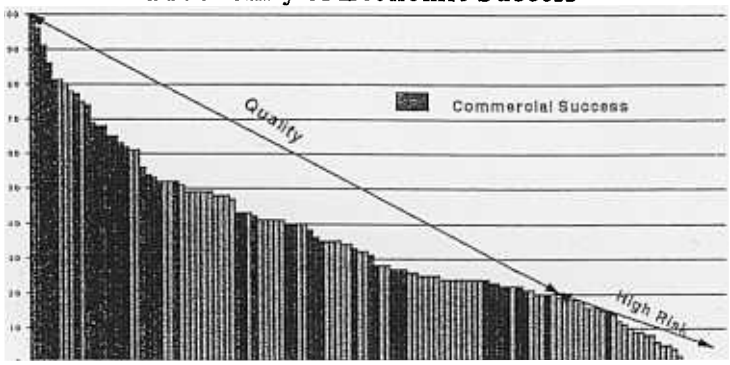


The Probability of Economic Success (PES), as determined from the RISK cumulative frequency curve has shown to be an important ranking tool for Amoco exploration. Figure 6 shows the results of the drilling portfolio from 1990-1993, sorted by decreasing PES. During that period Amoco drilled 222 exploration wildcat wells, 31 commercial successes and 191 failures. Several of the wells on the extreme right of the graph had less than a 1% PES. As can be seen from the plot almost all of the wells with a PES<20% failed, while almost all of the discoveries occurred above the 20% threshold. Both discoveries below 20% were small. These two populations have become known as Quality Opportunities and High Risk Opportunities. Quality is defined as having a PES greater or equal to 20% (see Carragher 1992). Since we began utilizing quality as a criteria, Amoco has drilled an additional 158 exploration wildcats. Figure 7 shows the PES results for 1994-1996. All but one success has a PES greater than 20%.

Figures 6 and 7

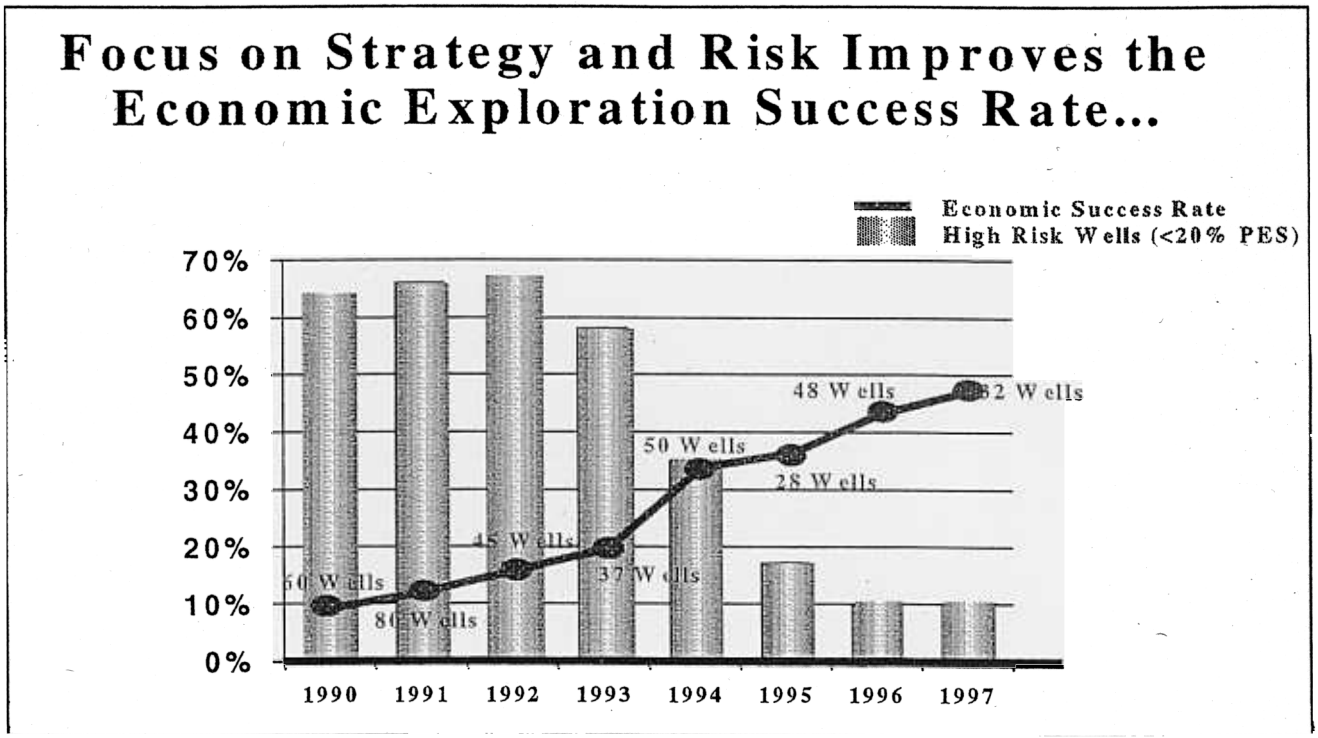


1994 - 1996 Risk Results
Probability of Economic Success



Additional analysis of this data shows that 58%-65% of the wells drilled by Amoco each year, from 1990 to 1993, were high risk (Figure 8). As the number of high-risk wells decreased from 1990-1997 the wildcat commercial success rate continually climbed, from 10% in 1990 to 47% in 1997. This focus on avoiding many high-risk wells has help improve the overall quality of Amoco's drilling portfolio. The intent is not to totally remove all the high-risk prospects but to drill only a few high-with many follow-up prospects or a giant field. The objective is to create a balanced portfolio that uses the quality wells to achieve business targets and goals and the high-risk wells as potential upside. From 1990-1993 the few quality wells drilled could not deliver the necessary resources for a successful portfolio and the lack of success from the high-risk part of the portfolio led to the poor performance of the WEBG.

Figure 8



The Working Interest Economic Risk Weighted Resource (WIERWR) is a ranking value that reflects the risked resources greater than the commercial threshold as illustrated in Figure 3. This value is also used to make forecasts and predictions on the portfolio.

Risk –Weighted economics account for the risk inherent in a program by incorporating a quantitative assessment of exploration risk and the associated costs of failure. By multiplying the estimated commercial value of a prospect at success by the probability of economic success (PES) and subtracting the probability weighted costs of failure, an estimated monetary value for the prospect is derived.

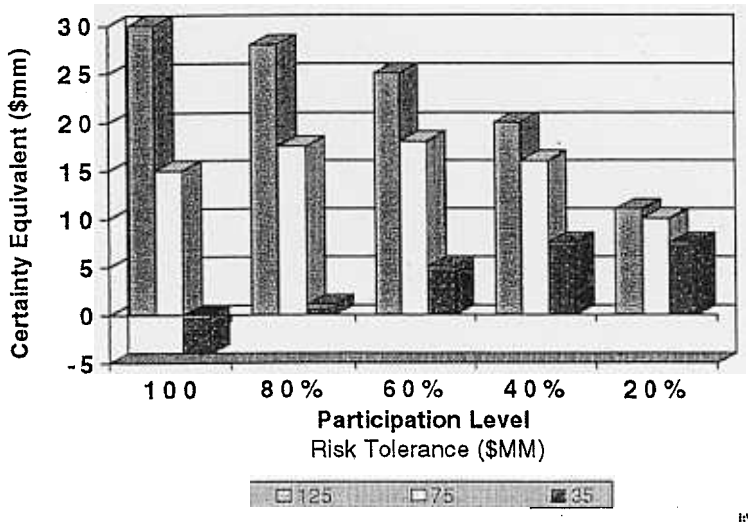
Expected monetary value (EMV) = PES * (value of success) – (1-PES) * (cost of failure)

These ranking schemes ignore the WEBG's ability or willingness to assume the business risk of the project during the capital allocation process. The level of risk tolerance that a firm is willing to take impacts the level of participation in any project. Preference or expected utility theory provides a mechanism to alleviate some of the shortcomings of expected value analysis (see Walls, 1995). The certainty equivalent valuation (CEQ) approach also provides guidance to the WEBG in terms of the level of participation in a project consistent with its risk propensity. This valuation model provides a formal means to quantify the advantages of selling down or "spreading the risk."

For example consider the prospect shown in Figure 9. The analysis provides a CEQ valuation across a range of risk tolerances (RT) for multiple participation levels. Note that the choice of participation level is significantly different for each level of risk tolerance. At the $75MM risk tolerance, you should choose the 60% working interest, while a RT value of $35MM indicates an optimal participation level between 20% and 40%.

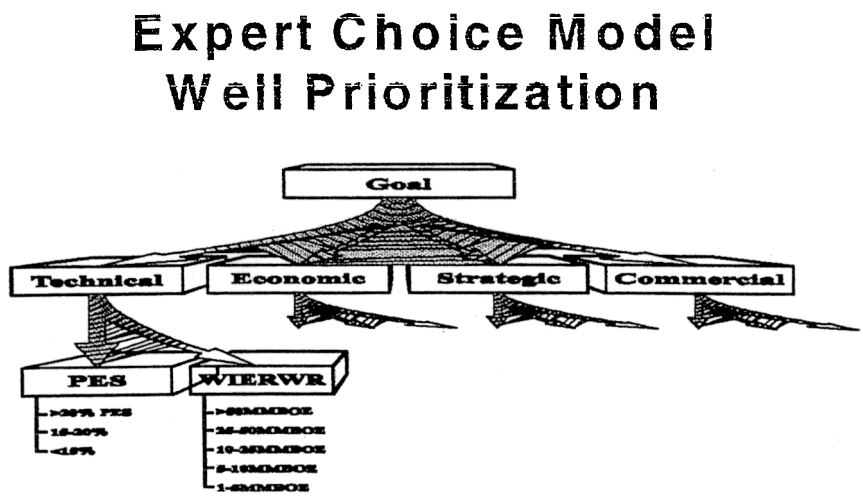
Figure 9

Optimal Share Analysis



In addition to the level of risk and value of each opportunity in the inventory, portfolio management should also consider many other characteristics. These include environmental concerns, geographic factors, political issues, etc. Amoco utilizes Expert Choice Software to combine the qualitative information with the quantitative data to provide decision-makers with a logical hierarchical structure that can be used for rating and ranking. Figure 10 illustrates the WEBG's Well Prioritization model that includes technical, economic, strategic and commercial data and opinions. Expert Choice was developed and patented by Dr. T. Saaty of the Wharton Business School and is marketed as decision support software (see Saaty, 1994). It has widespread use in both business and political organizations. Each component of the model can be weighted to reflect the varying levels of importance of the components of the model. The model does not make the choice, but helps management to make an informed judgment based on their knowledge, experience and preferences that have been input into the model.

Figure 10



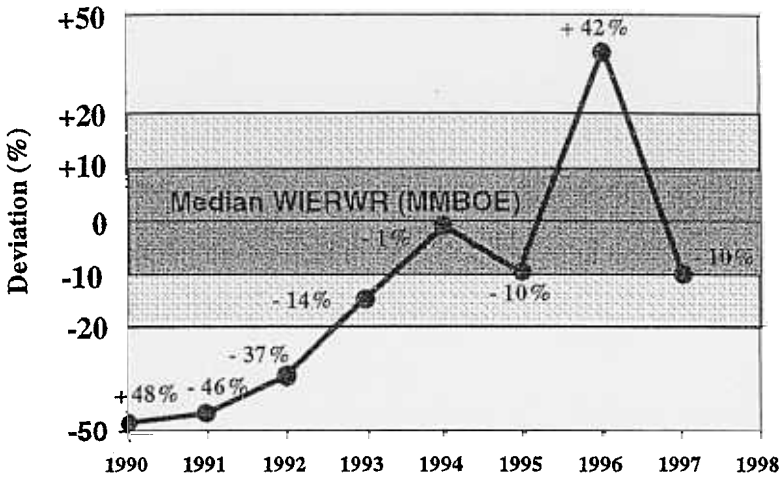
With these data at hand, decision-makers can evaluate their options more systematically than was previously possible. It is now possible to evaluate, decide upon and execute large strategies with a reasonable prediction of the likely outcomes. The management team has the information to consider alternatives to the current strategy, and is always in a position to react to competitive, political or economic shifts. The model reveals future strategic gaps and issues which need to be addressed today.

PORTFOLIO MANAGEMENT

Portfolio Management is the last but most important step in the business decision process. It utilizes the financial tools and techniques developed in portfolio analysis to develop a series of options for the decision-maker. Critical to its success is having calibrated information on which to build the predictions. In 1990 Amoco began forecasting the number of successes and the level of resources it would find with its drilling portfolio utilizing the WIERWR from the RISK program. As illustrated in the performance chart in Figure 11, when we first began the median prediction deviated from the result by 48%. After three years of pre- and post-drill assessments Amoco was able to bring its results within 10% of the pre-drill prediction. During 1994-1996 this measure was one component of Amoco's variable incentive pay criteria. Exploration staff received financial bonuses if they achieved a +/- 20% range around the median prediction. This had a significant impact by requiring RISK to be run on all our prospects and driving more realism into our prospect assessments. It also increased the importance of the consensus process during PQT reviews. The result was mutual ownership of our results and organizational accountability.

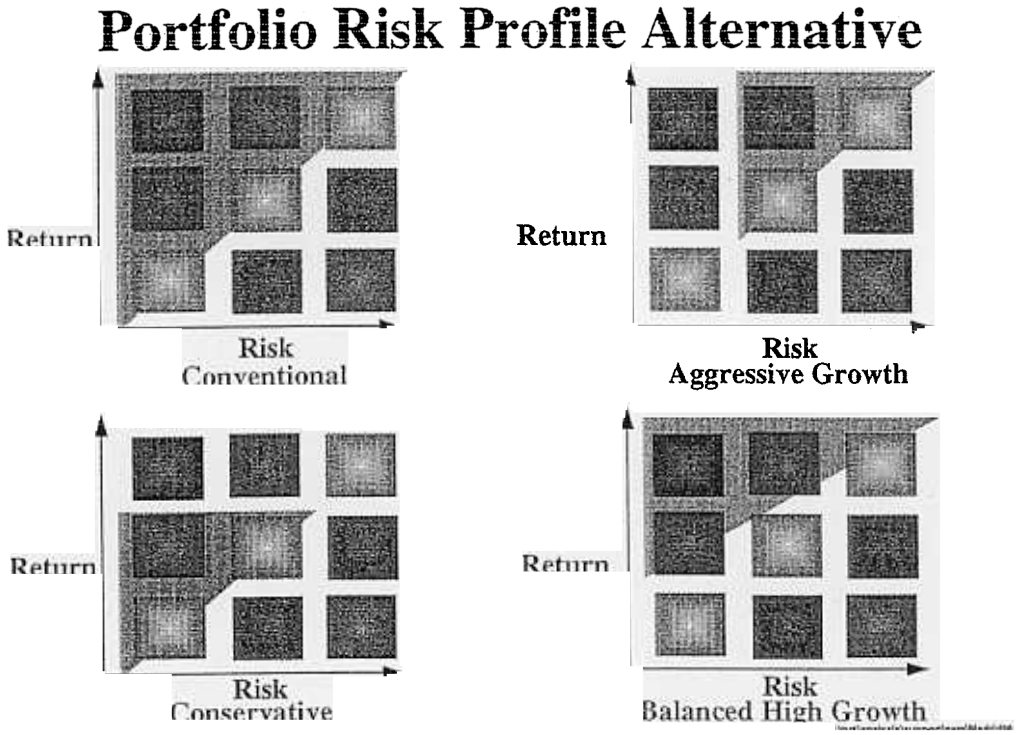
Figure 11

Resource Prediction Accuracy



Within the framework of the exploration strategy it is crucial that the portfolio chosen exposes you to a successful outcome and to the level of risk you desire. Asset allocation criteria, commonly used in building stock portfolios are directly applicable to exploration (see Kepes, 1998). The investor is required to determine their level of risk; conservative, conventional, balanced high growth or aggressive growth. This is combined with the level of return desired to develop a series of risk-reward profiles (Figure 12). As with any portfolio or mutual fund you must balance your core areas of operations or blue chip stocks against the growth-new venture areas and new frontiers.

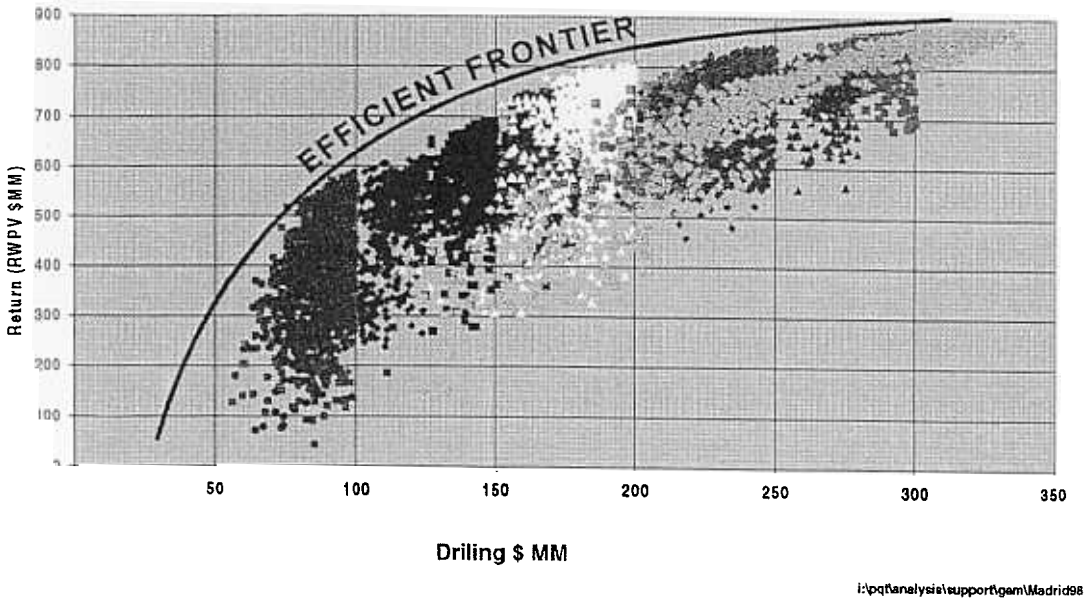
Figure 12



Because the decision-maker is required to satisfy several objectives or goals and is generally limited in the funds they have to spend, one of the most difficult tasks is the selection of an optimum portfolio of investments from a set of possible opportunities. For example a better portfolio may be obtained using several less expensive, but lower individually valued projects, than one expensive high value opportunity. To handle this complex combination of input criteria and output desires, Amoco has utilized a genetic algorithm. Genetic algorithms are a method of solving complex problems by emulation of the principles of biological evolution. They have been show to be especially powerful as a means for finding global and/or multi-model solutions during the optimization of functions (Goldberg 1989). The objective is to find the maximum function or combination of prospects that yields the desired results. In Figure 13 the objective is to choose the portfolio that maximizes net risk-weighted present value for varying levels of drilling (major cash $). This can be further constrained by setting a minimum commercial finding rate, reserve replacement levels, finding costs and other financial and physical measures. The efficient frontier is the best return for each dollar spent. By determining which wells occur in the best portfolios and those which are usually rejected by the optimization procedure, it helps reduce the number of choices the decision-maker is confronted with.

Figure 13

Efficient Frontier (Optimized on PV)



The use of portfolio prediction, optimization and other asset allocation criteria provides a background and a basis on which to strategically manage the company. Models reveal future strategic gaps and issues which impact the success of the strategy.

SUMMARY

The implementation of **Risk Analysis, Risk Management, Portfolio Analysis and Portfolio Management** will lead to a paradigm shift. ***From:*** drilling lots of wells is the key to finding oil and gas, ***to:*** oil and gas discoveries are found through thorough technical evaluation and risk assessment, followed by selective drilling of a portfolio of wells that achieve the business goals of the organization. Companies who make use of decision and valuation methods that are based on rigorous financial and decision science principles improve the chances for both short and long term success of their exploration departments.

The goal of implementing risk processes in business is to create value to our shareholders, partners and the countries where we operate. Extra value is created as the quality of management's decisions is improved over time. The information and results from **Risk Analysis, Risk Management, Portfolio Analysis and Portfolio Management** within the broader exploration strategy have been key to exploration success at Amoco.

ACKNOWLEDGMENT

The author wishes to thank Sue Saad and Maryann McGinnis for assembling the text and graphics. Special thanks to Glenn Koller who created and wrote the Amoco RISK Program, and to the Prospect Quality Team who reviewed the prospects and analyzed the data. Of critical importance to the successful implementation and acceptance of these ideas and techniques is Peter Carragher, who has carried the risk and portfolio management concepts to the sector and corporate levels of Amoco, without his guidance and desire, none of this would have been possible.

REFERENCES

Carragher, P. D. (1995) "Exploration Decisions and the Learning Organization" Society of Exploration Geophysicists August 1995, Rio de Janeiro

Goldberg, D. E. (1989) "Genetic Algorithms in Search, Optimization and Machine Learning" (Addison-Wesley, Reading MA.)

Kepes, G. (1998) "Portfolio Balance and the Difference Between Asset Management and Portfolio Management" Petroleum Finance Company March 1998

McMaster, G. E. and Carragher, P.D (1996). "Risk Assessment and Portfolio Analysis: The Key to Exploration Success" 13th Petroleum Conference, Cairo Egypt 1996

Saaty, T. L. and Vargas, L.G. (1994) "Decision Making with the Analytic Hierarchy Process" University of Pittsburgh Press 1994

Walls, M. R. (1995) "Integrating Business Strategy and Capital Allocation: An Application of Multi-Objective Decision Making" The Engineering Economist volume 40 No. 3