# PROJECT ECONOMICS & DECISION ANALYSIS

## DETERMINISTIC AND PROBABILISTIC MODELS

THIRD EDITION

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PB
PENNWELL
BOOKS

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# PREFACE

Welcome to the third edition of Project Economics & Decision Analysis. As mentioned in the previous editions, the international oil and gas industry remains one of the most important, highly capital-intensive and risky industries at the global, regional, and local levels. Global E&P expenditure reached $1,050 billion in 2022 [*Global energy investment in clean energy and in fossil fuels, 2015-2023, International Energy Administration (iea)*]. In comparison, $1,740 billion was invested in clean energy.

Our profit margins are under real pressure due to many factors, including the higher costs of finding and developing new reserves, less oil found per foot drilled, rising inflationary costs of doing business, oversupply of crude, crude oil price volatility, competition for oil company investments, competition for acreage/concessions, competition for funds, and overall business risk and uncertainty.

Therefore, it is crucial to carry out prudent economic evaluations of any capital investments before resources are committed. This, of course, requires a thorough understanding of the techniques available and their application by all those involved in the decision-making process. To assist in achieving this goal, the industry deserves a comprehensive guide to provide all the necessary concepts of capital investment evaluation, capital budgeting, and decision analysis. This book, *Project Economics and Decision Analysis*, in its third edition, will hopefully meet this requirement. I have shared what I have learned and applied over my 40-year career. What is presented in this edition reflects hands-on knowledge and experience, not just the textbook approach. I have also emphasized the mistakes committed by very experienced analysists.

## Objective

One goal in writing this book has been to provide students, practicing engineers, geologists, economists, planners, and managers with a solid foundation in the dynamic and growing field of capital investment evaluation with emphasis on the uncertainty aspect. It describes how investment decisions are currently made under different stages of uncertainty and prescribes techniques for making rational decisions.

This book describes the philosophy, process, and methods of capital investment evaluation and decision analysis. In summary, the main objectives of the book are to:

- Explain the ever-expanding role of economics in prudent capital investment decision-making.
- Assist readers in developing a knowledgeable vocabulary of the terms associated with economic analysis.
- Review the procedures used in preparing capital investment evaluations and decision analysis.
- Relate the new vocabulary and knowledge to some specific problems.
- Understand the limitations of the methods used and ways to alleviate these limitations
- Present ways of interpreting estimates that include uncertainty (i.e. converting probabilistic description into a measure of profitability).
- Provide solid hands-on experience with capital investment evaluation and decision analysis. Many solved problems are given to reinforce each theoretical concept.

The subject of project economics and decisions analysis is not difficult. It does not require you to remember your differential equations, nuclear physics, or atomic theory. However, it does require use of a good deal of logic and common sense and the rest is just number crunching. The analysts doing economic evaluations need to think imaginatively, to identify a problem, to weigh the various factors that will affect these variables, to evolve alternatives, to take a position, and finally to be prepared to defend his/her position.

I urge students and practitioners to have a helicopter view of the entire oil and gas operations and develop an eye for details in order to be able to resolve problems as opposed to completing a series of cookbook computations. This is what Project Economics and Decision Analysis is all about. While I have retained most of the features that have made these books so popular, I have further enhanced the coverage to make it more relevant and more accessible to students of varying backgrounds.

This edition is further improved in order to address the audience who are not sophisticated in the subject. An attempt has been made to present the subject matter clearly and simply so that the reader will be in a position, whether in the classroom or in practice, to move immediately to higher levels of sophistication in understanding and application.

## Changes in the Third Addition

This edition continues the basic philosophy of the first two editions, which is to provide users with coverage of all important areas of Project Economics and Decision Analysis, while providing flexibility in the use of

materials. This objective of flexibility has warranted the addition of some new materials.

Those who will be using these books either as a college text, a learning guide, or as a reference in day-to-day economic decision-making may be interested to know what is different in the third edition. Apart from polishing the material and making the concepts easier to understand, I have made the following changes.

1. The two volumes are combined into one. Since these books are used as textbooks, the two volumes became expensive for students. Feedback from some faculty members using these books suggested to combine the two volumes into one to make it more affordable for students.
2. All materials that have a time aspect have been updated.
3. All the figures and tables have been revised to make them clearer.
4. Throughout the book I have added new, real-world examples to round out the coverage of concepts and to provide appropriate emphasis on areas of central importance.
5. Although most youngsters these days are becoming increasingly proficient in their MS Excel™ (Excel) skills, many still need to be aware of the power and limitations of this valuable software—especially when it comes to economic evaluation of projects.
6. The section on the weighted average cost of capital (WACC) concept has been expanded to make the concept easy to comprehend so that analysts can easily recognize the weakness of this concept in practice.
7. The section on international economics (fiscal systems) has been rewritten and expanded. A section on abandonment cost and ways of accumulating abandonment fund has been included.
8. A new chapter has been added to clarify the commerciality assessment and booking of reserves.
9. A new more advanced technique of depreciation calculation has been introduced.
10. Decline curve analysis spreadsheet models have been provided to help analysts generate production forecasts based on historical production data.
11. Many problems, related to decision trees and Monte Carlo simulations, in the previous editions were solved using the previous versions of the Palisade DecisionTools™ suite. These problems have been updated using the latest version of the DecisionTools suite.
12. After using the books for almost two decades, with significant feedback from participants in my 5-day courses on the subject and some of the professors who use these books in their courses, I found that there was room for improvement in adding clarity to some of the topics. Therefore, I have provided additional examples or reworked the existing examples.

13. For professors who are using these books, a test bank of approximately 300 multiple-choice and true-false questions has been developed. In addition, a comprehensive set of some 700 MS PowerPoint™ slides have been made available.

## Emphasis and Style

The book presents a balanced blend of theoretical concepts and their practical utility. I prefer to focus less on extensive theoretical discussions than what might be found in other books. Theory, I feel, distracts the reader from the most important concepts and their practical application. Moreover, theory can seem sterile and pointless unless its usefulness is made clear.

Therefore, I have focused more on practical applications. The underlying concepts are stressed and made concrete with liberal use of illustrations, many of them taken from actual real-life capital investment evaluations. Algebraic formulations and spreadsheets are used side-by-side to help readers develop conceptual thinking skills. Emphasis is placed on model formulation and interpretation rather than algorithms.

The technical materials have been developed with considerable patience—assuming very little foreknowledge and proceeding in a step-by-step manner to minimize the possibility of the reader getting lost along the way. Moreover, I have resorted to a greater degree of informality in the presentation in the belief that *readability* should be an overriding consideration. Toward the same goal, intuitive and economic explanations are frequently provided to clarify the why of a particular concept/technique.

This book is primarily intended for use by economists, earth scientists, engineers, and students. It is also intended to serve as a refresher and perhaps as a self-study textbook. The problem-solving approach is instructive in nature, but the foundational principles show the practical application of the material. Its chief purpose is two-fold: to render a systematic exposition of certain basic deterministic investment evaluation methods, and to relate these to the decision analysis in such a way that the mutual relevance of the two is clearly brought out.

Therefore, the book is divided into two parts, the first eight chapters deal with deterministic economics and the last five chapters deal with the concepts of decision/risk analysis (i.e., incorporating risk and uncertainty as applied to capital investments). These concepts are seldom covered as broadly or from the same viewpoints in economics and other courses, yet they are fundamental to the proper understanding of all evaluation work.

For optimum benefit, it is recommended that readers explore both parts and benefit from their integrated instruction.

## Examples and Assignment Problems

Being gratified by the success of the first two editions, I have maintained the example-driven approach to the subject matter. I believe that the best way to learn any subject is by working through examples and completing plenty of problems—the problems however have to represent reality, not textbook examples or problems. Although this active learning approach is not new, I believe these books have more fully developed this approach than any other book on the subject. This example-driven approach is further reinforced by imparting valuable modeling skills that students can appreciate and take with them into their careers. *Many rules of thumb from my practical experience are provided to enable the analysts to arrive at consistent results.*

Included in this third edition are additional solved real-life examples (100+) and end-of-chapter assignment material (300+ questions and problems). Examples help reinforce the learning process. Each solved example is straightforward, fully explained, and avoids sudden leaps to conclusions that might confuse the reader. The assignment material is divided into questions and problems. The questions primarily address key concepts and terms in the chapter. The problems either consolidate a number of chapter topics or focus on a comprehensive analysis of a single topic.

The wide variety of assignment material offers practical knowledge since the assignments include various combinations of breadth and depth, theory and procedures, simplicity and complexity. For maximum benefit, the reader should work out as many of these problems as possible, if indeed not all.

## Spreadsheet Applications

During the 5-day courses that I teach on this subject, I noticed that most participants struggle a lot with the use of financial functions provided in Excel. Today, most of us are using spreadsheet programs to build models of the decision problems we face as a regular part of our daily work activities. Spreadsheets also capture users' interest and add new relevance to investment evaluation and decision analysis. Since we extensively use Excel for our economic modeling, it is essential that those who are interested in working in this area be fully conversant with Excel.

In this third edition, I have repeatedly highlighted the mistakes committed by very senior analysts in modeling problems using Excel; such mistakes are unnecessary and avoidable. I stress again and again that the use of software is to organize and expedite our calculations rather than solving the problems for us. We should use software only if we know, given sufficient time, how to solve a given problem by hand.

To fill this gap, I also introduced two-volume books on "Trips and Tricks for Excel-Based Financial Modeling." Excel is a very popular tool, but it is sensitive to how it is used. Entering a comma or bracket in the wrong place will alter the answer. For this reason, I provide hand calculations in these books so that analysts will know how to debug their models/calculations.

A unique feature of this book is the embedded application of computers in solving investment evaluation and decision analysis problems. I have tried to give both aspects of the required calculations—problem solving by hand and using Excel. This is because those who build economic models also need to debug these models. How could one find bugs in any spreadsheet or economic model if he/she does not know how to solve the problems by hand?

Examples are provided to show how computers can be used to help make better evaluations and, hence, better decisions. The Excel spreadsheet software is making it increasingly easy and practical to do sensitivity and scenario analyses. Its use has gained acceptance in the industry and makes it feasible to do a variety of analyses with a multitude of problems. The latest version of DecisionTools™ Suite (an Excel add-in) by Palisade Corp., including the award winning @RISK and PrecisionTree, are used where applicable. Screen captures of the various menus of DecisionTools Suite are used.

## Nomenclature

Throughout the book the following nomenclature is used:

- M for Thousand (M$ is thousand dollars)
- MM for Million (MM$ is million dollars)
- B for Billion
- T for Trillion
- Bbl for barrels
- Oil production in MBOD or BOD
- Gas production in MMScf (MMSCFD) or MScf (MSCFD)

## Reviewers' Comments

Many useful comments were received from PennWell Books technical reviewers. These have been incorporated wherever possible. Some reviewers noted that perhaps I may have overkilled some of the basic concepts, such as the Time Value of Money and using interest tables, etc. That may be true, but this is how I learned these concepts 40 years ago when I took a course from Dr. Franklin J. Stermole at Colorado School of Mines. There was no Excel at that time, we used to perform all calculations by hand. However, that learning put me on solid ground and enabled me to write this book.

It is very ironic that it is these simple concepts where very experienced analysts make mistakes or misinterpret the limitation of the concepts applied. I have specifically brought these mistakes to your attention so that they can be avoided. These basic concepts have been of considerable help to me over the years, enabling me to visualize the investment problems and their time horizons. Therefore, I have decided to leave them as is. Similarly, the use of interest tables (in this modern age of computers) might be considered orthodox. The tables *may* not be used in practice, but they definitely add to understanding the concepts. I feel strongly that readers will benefit, therefore I have included them here.

## Request for Suggestions

It should be noted that one cannot always add new material and never delete some of the existing material. Some examples and materials become dated and are, therefore, natural candidates for deletion. In addition, some material needs to be enhanced by rewriting or restructuring it in order to improve readability and understanding.

A considerable amount of dedication and investment (time and capital) goes into writing and publishing such a book. I have made every effort to introduce this book as a comprehensive desk reference. I sincerely welcome your thoughts as an end user to help us further improve the contents, presentation, and utility of this book so as to make it a standard for the new generation of petroleum industry experts. I will always be very grateful for your comments, suggestions, or corrections sent to me directly (asifmian55@yahoo.com) or through PennWell.

## Acknowledgements

Many people are involved in the successful publication of a book. I wish to thank the following for making significant contributions to this book. Without their assistance, this project could not have been possible.

- I express my gratitude to the educators, students, and businessmen who have provided numerous suggestions for improving the materials in this third edition. I also thank Mr. Matthew Dresher at PennWell for editorial and substantive suggestions for the manuscript.
- I would like to thank all my students, who have attended my short courses on the subject, for making me think and improve my material to assist in their understanding of the subject. Their comments were very valuable.
- I thank my four children for being generous in obtaining excellent education—it is the best investment I have ever made. Special thanks to my son "M. T. Mian" for having been professionally in the Driver's seat;

this has contributed a lot to my enthusiasm. I certainly hope that my grandchildren will dedicate some of their precious time to transferring their knowledge to others.

God bless you all.

***M. A. Mian***

# 1

# INTRODUCTION

This introductory chapter sets the stage for this book by presenting basic concepts and definitions for capital investment evaluation (also referred to as investment appraisal, commerciality assessment or economic evaluation) techniques presented in the following chapters. The chapter is divided into three sections:

1. Profit planning
2. Basic concepts of economics related to capital investments
3. Defining uncertainty and risk

Many terms, such as capital budgeting, inflation, supply and demand, and profit planning, etc., presented in this chapter are referred to in day-to-day decision-making process. These concepts are not only related to the investments in the oil and gas industry, they are also applicable in our personal day-to-day financial activities. However, many of us may not be fully aware of the theory behind them. These terms are often accepted as routine business jargon. The concepts presented in this chapter will assist in clarifying these terms and enabling us to relate them to the evaluation of capital investment projects.

The worldwide oil and gas industry applies advanced techniques of investment analysis. Because of the dynamics of high risk, highly capital-intensive investments, complexity of operations, and profit potential, companies are compelled to seek the most sophisticated investment methods.

The criticality of prudent economic evaluations has significantly increased over the past and this requirement will become more and more critical with time. The increasing importance is due to some of the factors listed below.

1. Less reserves found per footage drilled. There used to be a popular saying that in Saudi Arabia, you drill for water and you find oil. This is not true anymore, now they are drilling for oil and finding water!
2. Increasing cost of development due to marginal discoveries and development of unconventional resources. The easy oil is gone, we are getting more and more into exploiting difficult oil and gas resources.
3. To reduce the cost of field development, there will be increasing emphasis on synergizing development strategies, i.e., green field versus brown field developments.

barrel, respectively. These prices are referred to as the prices in the *money-of-the-day (MOD)*. The CPI-U was 214.537 in 2009, 237.017 in 2015 and 270.97 in 2021. The conversion of the 2009 and 2015 crude oil prices to the *constant 2021 dollars* would be as follows.

2009: (270.970/214.53) × \$61.67 = \$77.89 per barrel

2015: (270.970/237.017) × \$52.39 = \$59.89 per barrel

2021: (270.970/270.970) × \$70.91 = \$70.91 per barrel

The above calculations show that the MOD crude oil price in 2009 was about \$9.24 per barrel lower than the price in 2021. However, real crude oil price in 2009 was actually \$6.98 per barrel higher than the real price in 2021.

As shown in the preceding paragraphs, the average historical inflation (over the years from 2003 to 2023) can be calculated using the following equation.

$$Average\ Inflation = \left(\frac{CPI_{2023}}{CPI_{2003}}\right)^{1/\left(2023-2003\right)} - 1$$

$$= \left(\frac{304.7}{184.0}\right)^{1/20} - 1 = 0.0255\ or\ 2.55\%$$

The inflation adjustment is made using equation $(1+i)^t$, where i = inflation and t = number of years. All projects implemented in United States will be subject to average U.S. annual inflation. Since economics are normally performed over a 25-year period, the average inflation of the past 25 years should be used. In other countries inflation adjustment is performed using weighted average inflation (i.e., local content subject to local inflation and imported content subject to the inflation of the origin).

The target inflation by developed countries is around 2% per year. The Governments have to maintain a monetary policy in such a way that the annual inflation is on target. Appropriate and timely changes in the monetary policy are required to control inflation. One of the common mechanisms of adjusting inflation is by adjusting the prime lending rate of the central banks (such as the U.S. Federal Reserve, European Central Bank (ECB) of the European Union, Bank of Japan, Bank of England, and so on). When inflation is too high, the Central Banks typically raise interest rates to slow down the economy and bring inflation down. The contrary is true when the inflation is too low.

### *Example 1.3*

A project of \$1,000 million is executed in Nigeria where the local annual average inflation is 8% per year. Out of the \$1,000 million, 20% is local content and 80% of the equipment and manpower are imported from United States where the average annual inflation is 2.56%. What will be the appropriate inflation rate used for this project?

The "time value of money calculations" are achieved by using interest tables, mathematical equations, financial calculators, or computer (spreadsheets such as Excel). The Excel has built-in financial functions to facilitate such calculations. Equations and interest tables may not be used in practice because of limited availability. However, understanding the basic concepts presented here helps knowing which equations are in use and why they are used.

Economic models are normally built using Excel. However, to debug the model, the calculations performed by Excel must be randomly checked with an alternative way of manual calculations. To do this, one must know how these calculations are performed manually, to make sure Excel is doing what you want it to do. Excel is a very powerful tool but putting a bracket in the wrong place or comma in the wrong place, Excel will give you incorrect answer or error.

## Present Value of Future Sum

In the preceding section, it was mentioned that present point in time is customarily chosen at which the equivalent value of all the future cash flows is calculated. All the future values are converted to their equivalent of present value. This equivalent value is typically referred to as the *present* value or *present worth* of future cash flows.

Present value of a single sum of money, received at some future point in time, is calculated using the following equation:

$$P_v = F_v\left[\frac{1}{\left(1+i_e\right)^t}\right] \text{ or } P_v = F_v\left(1+i_e\right)^{-t} \tag{2.9}$$

where

$P_v$ = present value (at time zero) of future sum
$F_v$ = future sum received at time $t$
$i_e$ = effective interest rate (discount rate, fraction)

The present value of periodic cash flows is calculated with Equation (2.10).

$$P_v = \left(F_v\right)_1\frac{1}{\left(1+i_e\right)^1} + \left(F_v\right)_2\frac{1}{\left(1+i_e\right)^2} + \left(F_v\right)_3\frac{1}{\left(1+i_e\right)^3} + \text{.....} + \left(F_v\right)_t\frac{1}{\left(1+i_e\right)^t} \tag{2.10}$$

# Problems

2.1 What is meant by the term *time value of money*? Explain the concept of *equivalence*.

2.2 What is meant by the terms *discounting* and *compounding*? Why are these important in investment analysis?

2.3 What is the difference between *simple* and *compound interest*, *nominal* and *effective interest* rates?

2.4 What are the necessary conditions for an ordinary annuity?

2.5 What are the cash flow assumptions with respect to (a) periodic discounting and year-end cash flows, (b) periodic discounting and mid-year cash flows, (c) continuous discounting and periodic cash flows, and (d) continuous discounting and continuous cash flows?

2.6 The time value of money is due to

a) Inflation
b) Interest Rate
c) Opportunity Cost
d) Risk
e) All of the above
f) None of the above
g) b and d
h) a and c

2.7 Your current salary is $60,000/year. What will be your salary after 5 years if you get 5% per year merit increase?

a) 85,245
b) 76,577
c) 66,245
d) 70,650

2.8 If inflation over the next 5 years is 3% per year then the answer in Problem 2.7 is your

a) Money income
b) Real income
c) Both (a) and (b)
d) None of the above

2.9 Your current salary is $60,000/year, your salary is increased every year by 5% per year and the inflation is 3% per year. Your inflation adjusted income after 5 years will be?

a) 76,577
b) 85,245