A Risk-Analytic Approach to Learning Engineering Economy

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Abstract. The traditional approach to learning Engineering Economy in the undergraduate program focuses on solving problems in a deterministic manner. Students generally have little exposure to the uncertain and stochastic nature of, as examples, project cash flows and interest rates. Unfortunately, this traditional approach does not provide students with the skills to deal with real world situations, which inherently involve uncertainty and thereby, risk. Typically, most Engineering Economy texts for undergraduate students deal with uncertainty and risk only in brief chapters, usually at the end of the book. The uncertain environment is introduced as a special case, rather than as the norm. In this paper, we propose an approach to learning Engineering Economy that is characterized by treatment of uncertainty and is motivated by risk; in fact, it considers the deterministic case as a special case. The availability of computers today facilitates introducing this risk-analytic approach. Computer spreadsheets and software can provide students with the ability to analyze entire probability distributions. Such a junior or senior level Engineering Economy course would build on an earlier course in probability and statistics, as well as courses in design and computing. A new Engineering Economy text is also proposed and outlined herein.

1. Introduction

The purpose of Engineering Economy is to enable engineers and managers to accurately evaluate the economic consequences of capital investments in products, processes, and services. The time value of money, taxes and inflation are a few factors which can significantly impact the attractiveness of an investment. Undergraduate students -- usually in their junior or senior year -- learn about such factors and related analysis methods in a course on Engineering Economy.

However, evaluating capital investments is also about identifying, analyzing and managing risk. It is our view that Engineering Economy, as traditionally taught, does not provide students with sufficient tools for considering risk. Risk is an inherent part of any investment decision. By risk, we mean the possibility of economic or other loss resulting from the investment decision. Equipment costs, labor requirements, interest rates, and cash flows are all estimated quantities; the actual values may well differ from these estimates. Of course, the largest risk to a company is insolvency or bankruptcy due to a negative cash balance; this could occur from poor timings of uncertain cash flows, even though the overall net present value may remain quite attractive.

The traditional approach to learning Engineering Economy assumes that all quantities are deterministic, fixed, or "crisp." While leading texts on Engineering Economy e.g., Blank and Tarquin[2]; DeGarmo et al.[5]; Eschenbach[6]; Park[10]; Thuesen and Fabrycky[13]; and Young[17] note the practical importance of uncertainty, methods for evaluating uncertainty and risk are typically relegated to one or two chapters at the end of their books. Why has this been the case? We postulate three key reasons. First, as Lavelle[8] notes, this approach conditions students to accept input data as given so that solution methodologies -- rather than data modeling techniques -- can be emphasized. While such an approach is certainly expedient, it does not reflect reality. Second, engineering curricula have only recently included the tools for modeling and analyzing uncertainty (i.e., probability and statistics) in their core courses; thus, an Engineering Economy course could not until recently assume that its students have knowledge of probability and statistics. Third, analysis of uncertain y requires much computation which, if done by hand or even with the use of a calculator, would be a significant amount of work and would detract from the focus on Engineering Economy methodologies.

The time has come to revise and advance Engineering Economy -- to provide engineering students with practical tools for assessing uncertainty and risk as an integral part of capital investment decisions. Engineering curricula increasingly emphasize critical thinking and modeling skills in addition to solution methodologies. Courses in probability and statistics are now a common part of the core curriculum in engineering. By the time students study Engineering Economy in their junior or senior year, they already should have a firm grasp of probability and statistics. Additionally, sufficient computer hardware and software are available to allow engineering students to handle the increased computational requirements. Computer spreadsheets, such as Microsoft Excel, are well established in Engineering Economy courses. With available software, Monte Carlo simulations can be easily undertaken as shown by Alloway[1]. Where analytical results are desired, applications software such as Mathematical can be employed to simplify the necessary calculus and algebra, as in Wolfram[16].

Actually, there are several ways of characterizing uncertainty in an engineering economic analysis. Shiu and Park[12] identify three: i) "crisp" deterministic data; ii) "risky" probability distributions; and iii) "fuzzy" numbers. In the second method, input variables are assumed to take on a range of possible values with estimated probability distributions. The distributions for the resultant performance variables such as present worth or internal rate of return are derived using probability theory or through simulation. However, when variables are difficult to express quantitatively, subjective statements -- e.g., "around 30 years" or somewhere between $10,000 and $15,000"-- can still be made. Such statements constitute the basis for fuzzy numbers, first developed by Zadeh[18]. Fuzzy numbers have been applied to engineering economic analysis by Shiu and Park[12], Wang and Liang[15], and Buckley[4], among others. A fourth category, interval analysis, as in Moore[9], can also be included in the above list. In interval analysis, the analyst simply states reasonable limits of uncertainty for each variable without assuming a distribution or fuzzy membership function. These limits are then translated to limits of uncertainty for the resultant performance variables. This simple and intuitive method has been applied in engineering economy studies by Shaalan et al. [11].

This paper proposes a risk-analytic approach to learning Engineering Economy. In this approach, decision making in an uncertain environment is introduced both early on and as the norm, rather than the exception. In fact, the concept of risk should serve as the motivation for learning Engineering Economy. Tools for assessing risk are developed along with time-money relationships and other concepts. Creativity and realism in evaluating alternatives and in defining potential outcomes are underscored. This approach builds on the trend to include courses in probability and statistics within the core engineering curriculum. Integrating uncertainty and risk with Engineering Economy at the outset is not new. Indeed, risk-analytic methods have existed for decades e.g., Hertz' and Uhl and Lowthian[14] and have been taught in graduate level courses on Engineering Economy e.g., Buck[3]. What we propose is to integrate simplifications of these critical topics at the undergraduate level, so as to provide engineering students with practical tools for assessing all aspects of a capital investment decision.

We detail our approach by proposing and outlining a new Engineering Economy text in Section 2. Section 3 provides an illustrative example; it serves to highlight the importanceof considering uncertainty and risk at even the early stages of an Engineering Economy course. Finally, some concluding remarks are contained in Section 4.

2. A New Text for Engineering Economy

As stated earlier, the current Engineering Economy texts for undergraduates emphasize the deterministic approach to analyzing alternatives. The approach is to reduce the range of possible values of each variable to a single expected value and then analyzing the problem as if each of these expected values were certain to occur. Using this approach, no measure of risk is available; additionally, expected value as a measure of merit is by itself invalid, as we illustrate through an example in Section 3. The current texts do not help students to appreciate the important concept of uncertainty that is inherent in project variables. To learn Engineering Economy in a risk-analytic way, a new text is needed that would emphasize the concept of uncertainty. We need to characterize and model valid, well-defined, and comprehensive data in order to analyze risky alternatives. The focus of the proposed new text is on employing probability distributions for such characterizations and modeling; fuzzy numbers and interval analysis can be introduced as pertinent topics later in the text. Moreover, in our opinion, it would be better to restrict the text to discrete probabilistic distributions, so as not to overwhelm the undergraduate student with probability theory. Our emphasis is to teach students "the nondeterministic-way-of-thinking" in their analysis of real-world Engineering Economy problems. Furthermore, the text should be of value to the students not only during the course but also as a reference after graduation. The current texts fall short of helping students to analyze real-world problems.

An outline of this proposed new text is shown in Figure 1, where it is compared to a typical outline of a current text. The proposed text goes beyond the simplified deterministic approach to provide additional and more realistic tools for decision making in Engineering Economy. The sections of the new text are briefly discussed below.

1. Introduction: The concept of risk should be conveyed to the students in the introductory chapter itself. It should emphasize that Engineering Economy involves analyzing future projects that inherently involve uncertainty and risk. Risk should be a principal motivation for learning Engineering Economy.

2. Basic Probability and Statistics Concepts: Basic concepts of probability and statistics should be introduced at the beginning. It is assumed that the student would have taken an introductory course in probability and statistics; consequently, this section should serve to refresh the student's understanding of the subject matter.

3. Engineering Project Variables: Most analysis in the current texts is done using fixed values of initial cost, annual cash flow, salvage value, life cycle cost, and interest rate. The identification of different costs is not emphasized. The concepts of life-cycle costing, interest rate and other project variables should be introduced at the outset so that the student can understand the complexity inherent in Engineering Economy problems. In a real-world setting, identification of project variables should be the first step and a good analysis should identify most of the hidden project costs and other variables. An important aspect in real-world projects is the consideration of non-economic factors in decision making. Examples should be provided to illustrate the importance of such factors.

Figure 1

A Comparison of Engineering Economy Texts

Typical Outline of A Current Text

1. **Introduction:** Definition of engineering economy; steps in an engineering economic analysis.
2. **Cost concepts:** Types of costs -- fixed or variable, direct or indirect; life cycle costs, including initial cost, and operating and maintenance costs; basics of cost accounting.
3. Time **value of money:** Simple and compound interest; development of interest formulas for standard discrete deterministic cash flows, such as gradients, annuities, and single payments.
4. Economic worth measures: Formulation of present worth, annual worth, internal rate of return, and payback period methods for deterministic case; making decisions using deterministic measures of merit.
5. Comparing alternatives: Deterministic analysis of mutually exclusive and independent alternatives.
6. Replacement analysis: Economic life of a new asset; economic life of an old asset.
7. **Depreciation: Purposes** of depreciation, Depreciation methods: straight-line, declining balance, sum-of-years' digits, ACRS, MACRS.
8. Taxes: Federal and state income taxes; after-tax analysis of projects using deterministic values.
9. Inflation: General and differential inflation; real interest rate; constant versus current dollars; analysis of deterministic inflationary cash flows.
10. Estimating cash flows: Estimation techniques for life cycle costs such as learning curve and capacity function.
11. Uncertainty analysis: Break-even analysis; sensitivity y analysis; simple probabilistic analysis.
12. Public projects: Issues in public projects; analysis of public projects for deterministic case.

Proposed Outline of New Text

1. Introduction: Definition of engineering economy; definition of risk; risk in engineering economy; sources of risk; influence of risk in decision making; overview of risk-anal ytic approach.
2. Basic probability and statistics concepts: Random variable; discrete probability distributions; derived distributions; point estimation; variance and risk.
3. Engineering project variables: Cash flows; cost concepts; life cycle costing; timing of cash flows, interest rate (opportunity cost), and inflation.
4. Uncertainty **in** project variables: Sources of uncertain y; risks posed by uncertain y; quantifying uncertainty in terms of probability distributions.
5. Estimation of project variables: Uncertainty in variable estimates; techniques for quantifying range and uncertainty of estimates; discrete probability distributions of variable estimates.
6. **Nondeterministic** economic worth: Formulation of present worth, annual worth, internal rate of return and payback period methods for general nondeterministic case, assuming discrete probability y distributions.
7. Risk analysis of **alternatives:** Risk perception; risk assessment assuming discrete probability distributions; making risky decisions; risk/return tradeoffs.
8. Replacement of risky projects: Reliability; risks of reliability y with age; failure costs; technological changes.
9. Inflation risk: Inflation-sensitive cash flows; general and differential inflation; inflation risk, constant versus current dollars.
10. Depreciation: Purposes of depreciation; depreciation methods: straight-line, declining balance, sum-of-years' digits, ACRS, MACRS.
11. Taxes: Federal and state income taxes; after-tax analysis of projects using deterministic values.
12. Public projects: Issues in public projects; analysis of public projects for deterministic case.

4. Uncertainty in Project Variables: This- section should discuss the sources of uncertainty and the risks posed in an uncertain environment. The use of probability distributions in quantifying uncertainty should be illustrated. The current texts discuss uncertainty much later in the text. Furthermore, the concept of risk due to uncertainty does iiot come through in most of the current texts.

5. Estimation of Project Variables: Most current texts only discuss estimation of costs in a chapter on estimating cash flows. These texts do not include estimation and forecasting of many important variables such as the economic environment, the market size, the market growth rate, and the useful life. Furthermore, none of the current texts describe techniques for estimating the uncertainty in project variables. The new text should emphasize estimation of the uncertainty in all the identified project variables. The student should realize that the data to be analyzed are inherently uncertain. For instance, the interest rate or the cost of capital is assumed to be constant in current texts. However, the cost of capital is uncertain and changes as the opportunities for capital investment change with time. The idea of uncertainty should be introduced before introducing any techniques for project analysis. The techniques for quantifying uncertainty should include methods that are both subjective (e.g., subjective probabilities derived from individual opinions) and objective (e.g., probabilities derived from historical data). With the advancement of informational technology in recent years, the availability of data has become less of a problem; consequently, any real-world analysis should make use of this availability. Introducing advanced statistical estimation techniques such as regression analysis and time series analysis may not be suitable for undergraduate students. However, for future reference, a brief introduction to such techniques may be provided in an appendix to the section.

6. Nondeterministic Economic Worth: Analytic approaches should be introduced as a general formulation based on uncertainty in the variables. In the current texts, there is undue emphasis on developing interest formulas for various standard cash flows. Emphasis should be more on nondeterministic Engineering Economy problems rather than deterministic problems. Indeed, the deterministic problem should be considered a special case of the general non-deterministic problem. It should be emphasized that present worth is not a number but a distribution since the data itself is nondeterministic. Analytic approaches should be restricted to discrete cash flows and discrete probability distributions so as not to overwhelm the student. However, introduction to simple continuous probability distributions such as uniform, triangular and normal distributions may be provided in the appendix of the section.

7. Risk Analysis of Alternatives: Risk is the consequence of undesirable project performance whereas uncertainty is simply a lack of knowledge of the values of project variables. A measure of risk can be provided after we have quantified the uncertainties of a project and their financial ramifications. This section should focus on decision making for risky alternatives. Current text books use point estimates of the measure of merit of a project. For instance, if the point estimate of present worth is greater than zero, then the project is claimed to be economically justifiable. However, for a risky alternative, the decision making process is not that simple. First, the decision would be influenced by risk-taking characteristics of the decision-maker or by how risk is perceived. For instance, a risk averse decision-maker may exchange a risky alternative with a high expected rate of return for another alternative with a lower, yet more certain rate of return. Second, the information on the probability distribution of the measure of merit should be used to assess the risk of the alternative. Furthermore, it should be noted that using expected values of parameters for decision making may not provide the expected measure of merit and may result in wrong conclusions. To analyze the alternatives accurately, one must account for the probability distributions of the project variables. Furthermore, introducing a probability-based approach forces the analyst to quantify the uncertainty in the project variables, leading to a more informed and valid analysis. A technique that is emphasized in current texts for considering risk is sensitivity analysis. This technique involves revising uncertain estimates of variables and investigating the sensitivity of the measure of merit to such revised estimates. Sensitivity analysis provides only limited information about the risk involved.

For instance, it does not allow for the analysis of possible combinations of errors in the estimates, even though this is a case for concern. In short, sensitivity analysis is useful but its conclusions tend to suffer from a lack of accuracy and comprehensiveness. The appendix of this section can include more advanced techniques such as Mont. Carlo simulation of continuous probability distributions. Monte Carlo simulation allows the combination of uncertainties of estimates from all sources in a finite series of computer runs; each estimate's uncertainty is characterized by a probability distribution. The model criteria are calculated using randomly generated variable values and this results in a distribution of possible model criteria.

8. Replacement of Risky Projects: One of the important risks in studying replacement involves reliability of old assets. As assets age, the risk of failure increases, which in turn might have other economic and non-economic consequences. Replacement analysis, as covered in current texts, does not focus on such important issues.

9. Inflation Risk: Sources of inflation should be identified. The effects of inflation on different cash flows should be described. More importantly, inflation should be analyzed as a risk factor. The uncertainty of inflation should be assessed. The focus should be on the impact of inflation on cash flows and the measure of merit. The current texts only focus on analyzing cash flows with deterministic inflationary factors.

10. Depreciation: Additional topics, like depreciation and taxes, may be introduced using a deterministic approach since the analysis might otherwise get too complicated. We understand that in presenting these ideas to the student, the student should not be burdened with unnecessary computation. We would recommend keeping these topics in the text and presenting them in the traditional manner. However, this section should emphasize that the case being considered is only a special case.

11. Taxes: See above comments for the depreciation section.

12. Public Projects: Public projects usually tend to be more uncertain and difficult to quantify. Again, it maybe easier to present this material in a deterministic manner, with the recognition that this is a special case.

3. **Illustrative Example**

As an example of employing the risk-analytic approach to Engineering Economy, consider that $9,000 can be invested in three mutually exclusive alternatives: A, B and C. We assume that there are three mutually independent variables (namely, the constant annual cash flow over the project life, the length of project life, and the effective interest rate) associated with each of the three alternatives. We further assume a discrete probability distribution for each of these variables. The probability distributions of these variables are identified in Table 1. Table 2 shows that the present worth of each of these three projects is not a single value but a probability distribution.

Table 3 considers risk from a present worth (PW) perspective. If one were to employ a deterministic approach, then the PW of each alternative can be estimated from the expected value of each project variable. This deterministic PW amount for each alternative is different from the expected PW of the alternative, as is shown in Table 3. Thus, the deterministic procedure used in current texts would conclude that Alternative C has the maximum PW and hence this alternative should be preferred over the other two alternatives. However, a risk-analytic approach in which the expected PW should be considered would suggest that Alternative A should be preferred. Additionally, if risk is analyzed further, a decision-maker may well choose Alternative B, since this alternative poses minimum risk (i.e., has the least standard deviation and a greater probability of having PW > O).

Table 1
Example: Quantifving Uncertainty in Project Variables

	Alternative A estimate (probability)	Alternative B estimate (probability)	Alternative C estimate (probability)
Constant annual cash flow ($)	1500 (0.3);	1500 (0.2);	1600 (0.3);
	2000 (0.4);	2100 (0.6);	2000 (0.4);
	3000 (0.3).	2500 (0.2).	3000 (0.3).
Expected value	$2150	$2060	$2180
Project life (years)	9 (0.2);	9 (0.3);	6 (0.3);
	10 (0.6);	10 (0.4);	10 (0.4);
	11 (0.2).	11 (0.3).	14 (0.3).
Expected value	10 years	10 years	10 years
Effective interest rate (% per year)	10 (0.3);	13 (0.3);	14 (0.3);
	15 (0.4);	15 (0.6);	15 (0.4);
	20 (0.3).	16 (0.1).	16 (0.3).
Exnected value	15%	14.5%	15%

Table 2
Example: Determining Present Worth Distributions

Present Worth of Project A				Present Worth of Project B				Present Worth of Project C		
Value	Probability	Cumulative probability		Value	Probability	Cumulative probability		Value	Probability	Cumulative probability
(2,954)	0.018	0.018		(2,090)	0.006	0.006		(3,104)	0.027	0.027
(2,711)	0.054	0.072		(1,843)	0.036	0.042		(2,945)	0.036	0.063
(2,509)	0.018	0.09		(1,750)	0.008	0.05		(2,778)	0.027	0.09
(1,843)	0.024	0.114		(1,472)	0.048	0.098		(1,631)	0.036	0.126
(1,472)	0.072	0.186		(1,457)	0.006	0.104		(1,431)	0.048	0.174
(1,149)	0.024	0.21		(1,303)	0.018	0.122		(1,267)	0.036	0.21
(938)	0.024	0.234		(1,149)	0.036	0.158		(1,223)	0.036	0.246
(615)	0.072	0.306		(861)	0.024	0.182		(970)	0.048	0.294
(361)	0.018	0.324		(470)	0.018	0.2		(654)	0.036	0.33
(346)	0.024	0.348		674	0.018	0.218		(252)	0.027	0.357
217	0.054	0.402		1,020	0.108	0.326		159	0.036	0.393
543	0.032	0.434		1,150	0.024	0.35		603	0.027	0.42
743	0.018	0.452		1,539	0.144	0.494		666	0.048	0.468
1,038	0.096	0.548		1,560	0.018	0.512		1,038	0.064	0.532
1,467	0.032	0.58		1,776	0.054	0.566		1,432	0.048	0.58
2,518	0.024	0.604		1,991	0.108	0.674		1,935	0.036	0.616
3,093	0.018	0.622		2,395	0.072	0.746		2,054	0.027	0.643
3,289	0.072	0.694		2,516	0.006	0.752		2,353	0.036	0.679
3,577	0.054	0.748		2,929	0.036	0.788		2,449	0.048	0.727
3,981	0.018	0.766		2,943	0.054	0.842		2,666	0.027	0.754
3,990	0.024	0.79		3,083	0.008	0.85		3,004	0.036	0.79
5,315	0.024	0.814		3,547	0.048	0.898		5,500	0.036	0.826
6,056	0.072	0.886		3,572	0.006	0.904		6,056	0.048	0.874
6,701	0.024	0.91		3,829	0.018	0.922		6,648	0.036	0.91
8,277	0.018	0.928		4,084	0.036	0.958		7,403	0.027	0.937
9,434	0.054	0.982		4,566	0.024	0.982		8,173	0.036	0.973
10,485	0.018	1		5,217	0.018	1		9,006	0.027	1

Table 3
Example: Risk Assessment of Alternatives

	Determining Present Worth using expected values of estimates	Expected Present Worth	Standard deviation of Present Worth	Probability of Present Worth >0
Alternative A	$1,790	$1,969	$3,490	0.652
Alternative B	$1,539	$1,532	$1,791	0.800
Alternative C	$1,941	$1,603	$3,268	0.643
Project Ranking	C, A, B	A, C, B	B, A, C	B, A, C

This simple example has demonstrated that using expected estimates of project variables can lead to erroneous conclusions. The example also impresses upon us the fact that choosing among risky alternatives is not an easy one and could be influenced by the decision-maker's attitude towards risk. The expected measure of merit represents only one point out of several possible outcomes. Additionally, in some cases, it may not even be a feasible outcome; for instance, the expected outcome of a tasted die is 3.5, but the die will never show this outcome. Therefore, the information on both the expected measure of merit and its variability/risk should be considered in analyzing investments.

4. Concluding Remarks

We have presented a risk-analytic approach to learning Engineering Economy. This approach emphasizes quantifying and analyzing uncertainty and risk at the outset since they are inherent in real-world problems. An outline has been provided for a proposed new text which integrates the issues relating to uncertainty throughout the text, while retaining the topics covered in a standard Engineering Economy text for undergraduates. It de-emphasizes the deterministic approach to evaluating alternatives; in fact, it considers the deterministic approach as a special case of the non-deterministic approach.

It should be noted that redesigning the undergraduate course on Engineering Economy can only be successful if it fits well into the overall engineering curriculum. The course should preferably be offered in the junior or senior year, after the students have taken basic courses in engineering design, computing, and probability and statistics. The course should also serve to reinforce what the students have learned in these earlier courses. Thus, in many respects it can be considered to be a capstone-type course.

Finally, it is a fact that the Fundamentals of Engineering exam (which is a part of the engineering licensing process) requires only a deterministic understanding of Engineering Economy. This fact will serve to retard the introduction of a risk-analytic understanding of the subject matter. However, it should not stop academia from progressing and moving forward with a more relevant and up-to-date course on Engineering Economy, a course that would more appropriately serve our graduates as they practice in their respective engineering profession.

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