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COST ESTIMATING FOR ENGINEERING AND MANAGEMENT

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COST ESTIMATING FOR ENGINEERING AND MANAGEMENT

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To Doris, Mark, Phil, Lynne

preface

Cost estimating is introduced in this text. As the first unified treatment, the book covers the philosophy, concepts, and practices of a field that is feeling a resurgence of interest and enthusiasm. This specialization is concerned with evaluation of engineering designs in economic terms. While designs certainly differ, the principles and practices used for their appraisement are remarkably similar. We state, without proof, that all designs undergo an economic appraisal. This book, then, covers those subjects that contribute positively to the successful economic attainment of the engineer's design.

Design is given a broad and liberal interpretation. Every design (1) is a new combination (2) of pre-existing knowledge (3) which satisfies an economic want. This three-part definition includes virtually every product, such as bridges, cars, chemical plants, highways, machine tools, production lines, radios, rockets, ships, systems of machines and people, and tooling. Plans, technical reports, and models that are a part of the engineering job are allowed in this definition because they undergo the reckoning. Design is a unifying term for the practice of engineering. With this as the focal point, cost estimating is the body of theory and practice which provides an economic value for the design.

The experienced cost estimator, who, after a few times "looking down the barrel" defending his estimate (management calls it probing for softness; the estimator calls it picking on his professionalism), misunderstands management's interest in this topic. The exposure of cost overruns for weapon systems and public work projects testifies to the serious embarrassment that cost estimating has faced and the importance of this specialization for management. Indeed, the well-being of firms and our country rests, in part, on cost estimating. Business firms have realized that computer management information systems, notwithstanding their unmatched ability to handle data, are helpless to overcome a lack of trust in the truth of estimated data in their cost-forecasting systems. International trade and foreign competition with our past and future trading partners present a challenge, and cost and cost estimating will be important. Productivity needs an index, and cost estimating plays a prominent role in its measurement. The engineer's design impact on changing times, em-

ployment, growth and development, pricing efficiency, income, gold and foreign trade, and the blessings of our kind of democratic society are topics of today.

Cost estimating discloses the strengths of a company, or country, or trading group for executive management—it should never hide weakness from management. Decisions, both great and small, rest in part on estimates. "Looking down the barrel" need not be an embarrassment for the cost estimator if newer techniques, professional staffing, and a greater awareness are provided for the cost-estimating function.

Cost is a nebulous term which has no standardized definition. Used in some contexts, it implies a meaning that is clearly not cost. To appreciate these distinctions, one must be prepared to understand the particular setting in which the word is used. Surprisingly, the word cost could mean profit, rate of return, or effectiveness, and dollars are one dimension for these measures. For management and many engineers, dollars are more important than amperes, foot-pounds, or mass flow. Whether the engineer is principally involved with cost-finding, profit, cost reduction, and value analysis, subtle variations of the word cost are understood.

A great number of engineers are concerned with cost engineering and estimating. Although their professional title may be something other than cost estimator, their work uses many of these concepts. These professional engineers have found that their career paths lead to economic evaluation of design. For instance, in municipal, state, and federal design sections, these matters may be handled by the designers themselves. In industry, special groups are groomed to do this exacting work. R & D design calls for a special understanding. Whatever the organization, the engineer performing estimating has a more than average amount of engineering experience. This is necessary because designs are complicated. Practicing engineers will find in this book the kinds of thinking that will help them do the cost evaluation.

Many men rise to cost estimating from the practical ranks of industry, construction, business, and government. Often they find self-study necessary to supplement their intimate grasp of practice with an appreciation of academic topics. To them this book will give a taste of the principles of a special kind of topic.

Throughout this text the terms *cost estimator* and *cost engineer* are used interchangeably. In addition, business students, practicing accountants and economists are closely identified with these activities. Their contributions are necessary in conducting a successful cost-estimating enterprise.

This text is an outgrowth of notes from a one-semester cost-estimating course and various industrial clinics and seminars. This book would be suitable for courses such as Cost Engineering, Industrial Analysis, Estimating, Manufacturing Analysis and Planning, and Economic Systems Engineering, to name a few. These courses cover practical and theoretical techniques of cost estimating/engineering for various kinds of engineering designs. It is suitable for engineering students whenever they reach their first level of specialization. For most it would be their junior or senior year, because specific programs restrict early opportunity for experimentation and broadening, and design evaluation is deferred. Schools of technology, technical institutes, and junior colleges with various programs in technology will find their students prepared to understand the material of this text. Although a great diversity of occupational and vocational problems has been included, the instructor may want to supplement the problems and design studies using his own experience. A liberal listing of chapter references helps in forming new problems and case studies.

The arrangement of the chapters and topics allows for a variety of teaching and self study approaches. Basically, the text is broken down into four areas: engineering design and the economic environment, cost-estimating methods, design

estimating, and management. As design customarily precedes its calculation, this is discussed with emphasis on the art and technique of design. No reference is made to any specific specialty of designing, as that is left to other books. But on the design base, practices of cost engineering and estimating are built. The design-estimating portion, which is the largest of the four, considers the kinds of information and estimates for four categories of design. Operation, product, project, and system design contexts are constructed. Then various techniques that are pertinent to each are associated with that kind of design. After various designs are cost-estimated, the process of optimization or fine tuning is considered. The cost engineer is well suited for this task, as he has many of the economic facts at his fingertips and understands the design. Finally, a single chapter on management gives attention to the special problems of self-administration for cost engineering. It is not intended to be exhaustive.

The teacher can select those portions of the book that best meet the objectives of the class. Mathematical rigor is mostly algebra, and while some calculus is found, with suitable section selections this need not be an obstacle.

I am grateful to Lawrence E. Doyle of the University of Illinois for his encouragement and guidance. The Charles K. Kettering Foundation who funded a grant called The BUILD Program, a cooperative venture between the University of Colorado and the University of Illinois, supported tangibly many of the thoughts and underpinning ideas in this text. In a great measure the relevance of this book has been enhanced by my association with many estimators in industry, government, clinics, and seminars for over fifteen years. I hope that this text does justice to their practice.

Industrial friends, Smokey P. Call of Dana Corporation, Al Christianson of the American Paper Bottle Company, Eugene W. Groff of the New Holland Division of Sperry Rand Corporation, Ray Kincheloe of Collins Radio, Donald H. McBee of Monroe Auto Equipment, Gianni Peri of the Olivetti Corporation of America, James J. Thompson of American Lava Corporation, Donald F. Vehrs of Machine Specialties, William H. Wakerley of Ex-Cell-0, and Glen R. Wyness of the Proctor and Gamble Company provided a sense of proportion that gives balance to this text. My colleagues in the teaching of engineering design and economic evaluation have been helpful in many ways. I am indebted to the Literary Executor of the late Sir Ronald A. Fisher, F.R.S.; to Dr. Frank Yates, F.R.S.; and to Oliver & Boyd, Ltd., Edinburgh, for permission to reprint Table III from their book *Statistical Tables for Biological, Agricultural and Medical Research.* The skills of Cheryl Welsh, Lorraine Ruka, Marie Hornbostel, and Virginia Birkey persevered over some bad drafts.

Finally, I wish to thank my wife Doris for her help and encouragement, without which this book would have never been completed.

Boulder, Colorado — Phillip F. Ostwald

contents

chapter 1

When shallow critics denounce the profit motive inherent in our system of free enterprise, they ignore the fact that it is an economic support of every human right we possess and without it all rights would soon disappear.

DWIGHT D. EISENHOWER, 1890–1969

IMPORTANCE OF COST ESTIMATING

1.1 PROFIT IS NECESSARY FOR BUSINESS SURVIVAL

The Winston Dictionary defines *profit* as the amount by which income exceeds expense in a given time. This notion about profit leads to unfortunate conclusions. First, profit is necessary for taxes, dividends, and capital re-investment in the firm. Taxes, whether they are national, state, or local, are the inescapable reward for successful operation—a vital contribution to continue a democratic society. If dividends, the rent on invested capital and money, were not paid, it would negate the faith of investors and jeopardize a source of money for growth. Once taxes and dividends are removed from profit, a portion referred to as plowback is necessary for equipment or other modernization needs. Successful managements do not ignore debt repayment, research funding, plant maintenance cost, salaries, or other expenses, but it is surprising that profit is sometimes overlooked. Is profit less vital than anticipated costs? Consequently, it is important that profit become a planned expense.

A new approach can be suggested: Everything is going to be spent. Thus it becomes a question of partitioning income and expense. To use a simple illustration, assume that sales revenue is going to be $1000. You expect to realize a net profit of $50. Based on your calculation the "net profit dollars after taxes" is $50 and all other costs, including income taxes, must be found within the $950. It is common at this point to hear the excuse "You can't tell until afterwards." What about prediction of sales income? Can it be safely approximated? Sales forecasts are surprisingly accurate and provide a foundation for profit estimating. The planning recognizes that what counts are current costs, not those of the previous quarter. How successfully can expenses be held to 95%? In controlling performance versus target a significant body of experience indicates that management can react to unplanned contingency costs as well as ordinary types of cost. For a long-term survival plan, the creation and assurance of profit remains a primary goal.

1.2 STEWARDSHIP NECESSARY FOR ECONOMIC SURVIVAL

Business, whether large or small, is not alone in its quest for survival. The pursuit of this objective includes government and the governed. A democratic government with its authority to impose economic laws on its citizens is not a wealth producer and has no inexhaustible source of wealth. Governmental activities such as public works, welfare, the military establishments, and a host of legislative-directed projects use the resources of its nation. Despite the nobility of cause and honest-meaning goals, governments suffer from financial bankruptcy. Curtailment of welfare programs, de-evaluation, and heavy tax loads are symptoms and manifestations of failure. Politics does not provide a shield against national ruin as the accounting ledger between nations is a reminder for long-term fiscal sobriety.

Even churches, foundations, charitable organizations, and not-for-profit trusts must have positive balances between short- and long-term debt and income. Individuals need no economic reminders. Despite credit, loans, or notes, bankruptcy or poverty is not uncommon. Unfortunately, there is no inviolate equation that will prevent financial failure. The notion that receipts and expenses must maintain a positive cash flow is an oversimplification. Benefit-cost ratios, whereby social goals are evaluated in monetary terms, provide a narrow solution. Legally imposed restrictions on credit and spending are imperfect. Knowing the profound nature of this problem, a general objective for any steward is to simply husband resources.

1.3 COMPETITION AND FAILURE

It has been generally assumed that competition of all kinds is increasing. This statement can be examined on pragmatic grounds. A monopolist's product must be indispensible and have no substitutes, no potential competition, and possibility of control by the government. These conditions are practically impossible to find, although they are sometimes approximated. Pure competition, on the other hand, is present when many firms provide a standard product to numerous purchasers. No single supplier or purchaser is strong enough to affect the price significantly by his actions. Pure competition does not prevail either. Rather a form of imperfect competition is the usual marketplace.

Evidence of financial failure as a consequence of increasing competition may be found by examining companies, products, governments and their programs, and individuals. The profit squeeze on companies may result in public disclosure of bankruptcy or a receivership action. Mergers or sales of assets of the company, changes in the title of a company, and interdivisional failures within a larger corporation disguise the more subtle company failures. There is a good deal of empirical evidence that products fail as well. The high rate of new products which enter the market but are withdrawn within a short time is a case in point. Curtailment or complete abandonment of various governmental programs, although politically inspired, is asserted to be a result of increasing social competition. If poverty may be accepted as a norm for the individual, evidence of that is well known.

Although evidence of all types of failure is clear, the factors causing it are not. With production exceeding public demand, particularly true in the Western world, a temperamental society cannot guarantee long-term stability in the marketplace. Shifting consumer preferences, pliable and elusive, illustrate short- and long-term effects of increasing competition. The interaction of control by governmental legislation is an obvious business factor; increasing costs of production, inflation or recession, rising nonproduction or policy costs, new inventions, and improving technology are candidates for the causes of business failure.

Inasmuch as we are concerned with cost estimating, our attention is naturally directed to the matters of invention and the pace of general technology. For our purpose invention and technology are classified into four distinct areas: operations, products, projects, and systems. The understanding and manipulation of these areas is a result of the employment of the engineering sciences, economics, and mathematics. Thus we choose to deal with the onrushing inventions and technology as factors of increasing competition within the firm and government. The reader may want to suggest other determining factors that show the importance of cost estimating within a competitive society.

1.4 ESTIMATING: AN EVERYDAY PROBLEM

One may wonder what describes the act of estimating. Stories involving teacup fortunes, foretelling, palmistry, mystics, or wandering gypsies are known by school children. The mystic and showman—fraudulent or not—have created a legend that is difficult for the legitimate act of estimating to dispel. Throw out the unknown quantities of E.S.P. and miracle workers, and consider seriously weather forecasting, control of national economics, and gambling. On the surface it appears that these three are unrelated. Examined more closely it must be admitted that weather forecasting is an inexact science, particularly at the

local level; national politics has been, ineptly at times, trying to achieve economic control of the nation; and mathematics has not always won the pot in the art of gambling. All three involve estimating. For the engineering situation, the act of estimating uses concepts of engineering sciences, economics, and mathematics. Within the engineering environment there is generally an exterior problem insisting on an interior solution. Social, economic, and technical overtones exist within and without. There is always disclosed as well as undisclosed information.

Estimating is practiced by the housewife, farmer, manager, military planner, engineer, and you, the reader. Let us forever dispel the myth that estimating cannot be done. It remains, of course, to show that estimating is able to provide reliable estimates.

1.5 CERTAINTY, RISK, AND UNCERTAINTY IN ESTIMATING

With the recognition that estimating is a common art, the task beckoning the analyst becomes clearer. Few engineers enjoy the admission that their problems are subject to unknown forces. However, this is the case: The accuracy of the estimate is inversely proportional to the span of time between the estimate and the event. Thus the estimating activity is not for the short sighted. Three broad categories characterize future environmental conditions of the estimate: (1) estimates assuming certainty, (2) estimates recognizing risk, and (3) estimates admitting uncertainty.

The simplest of the states of nature is that of certainty. This simplicity seldom exists in nature or in a competitive society, but we achieve it by ignoring complications. For example, if an estimate is required, it would be easier if it were made on the basis that demand, design, product, production rate, and vendor's cost were stipulated and known with certainty. In performing the analysis, experience and wisdom lead us to believe that a set of assumptions have a high expectation of occurring. This expectation is fully warranted in many cases—labor costs, production rates, and cost indexes are sometimes stable especially in the short term. In a primitive estimate we make these assumptions to expedite a workable means of analysis. The event of certainty assumes that each action undertaken results in the same outcome and has a probability of 1.

Situations involving risk are appropriate whenever the analyst can obtain good estimates of the probability of future conditions. Research and study may be required. Risk is defined where each of several outcomes is assigned a probability and their sum equals 1. Uncontrollable factors of the future, by their very nature, can at best be anticipated. The probabilities of failure of several designs, for instance, can be estimated by experts. Sometimes these probabilities are subjective as actual measurement is either impossible or undesirable.

Engineering and physical laws, which depend to an extent on well-ordered cause and effect relationships, are unlike economic laws which depend on the action of people. The estimator does not have the good fortune of commanding the circumstances that follow his estimate. Accordingly, the state of uncertainty may be more applicable than certainty. Now we suppose that this uncertainty applies to the probabilities or relative values which describe a specific set of states of nature. For these states of nature, or competitive reactions, we have little bits and pieces of information so poorly understood that we are unable to assign any probability ranking. This is the qualification for the condition of uncertainty. It is presumed that the outcomes are identified in some context. This is a normal situation facing an estimator.

It must be admitted that in practice estimates which clearly define certainty, risk, or uncertainty are generally not found, but it remains a philosophy for dealing with future forces. Because of their importance, these theories are extended throughout this book.