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**TITLE:** COMPUTER PROGRAMS FOR CAPITAL COST ESTIMATION, LIFETIME ECONOMIC PERFORMANCE SIMULATION, AND COMPUTATION OF COST INDEXES FOR LASER FUSION AND OTHER ADVANCED TECHNOLOGY FACILITIES

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**COMPUTER PROGRAMS FOR CAPITAL COST ESTIMATION, LIFETIME ECONOMIC PERFORMANCE SIMULATION, AND COMPUTATION OF COST INDEXES FOR LASER FUSION AND OTHER ADVANCED TECHNOLOGY FACILITIES**

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Three FORTRAN programs, CAPITAL, VENTURE, and INDEXER, have been developed to automate computations used in assessing the economic viability of proposed or conceptual laser fusion and other advanced-technology facilities, as well as conventional projects. The types of calculations performed by these programs are, respectively, capital cost estimation, lifetime economic performance simulation, and computation of cost indexes. The codes permit these three topics to be addressed with considerable sophistication commensurate with user requirements and available data.

## INTRODUCTION

Among the most important tasks of the systems analysis group in LASL's Laser Division is the assessment of the economic merit of various concepts for the production and application of inertial-confinement fusion energy, e.g., for electric power production, as a thermal energy source for synthetic fuel production, and for process heat in general. Occasionally, we also perform [illegible] assessments for more conventional projects. [illegible] assessments are required by program planners to provide rational guidance in the selection of projects deserving of continued support from a [illegible] pool of research and development funds.

To automate, to the extent possible, computations performed in estimating, e.g., capital, operating, and maintenance costs for proposed or conceptual, conventional, and advanced-technology commercial and experimental facilities, subsystems, and components, and in simulating lifetime economic performance of commercial ventures, [illegible] the goal of estimating levelized product costs, we have written three FORTRAN computer programs: CAPITAL, VENTURE, and INDEXER. They have been written in independent stand-alone form and will be discussed separately. However, these programs can be merged if a comprehensive package is desired; such merger, however, may or may not prove useful. We hope for two primary benefits from the automation of such computations:

- fewer computational errors, and
- less personnel time required, coupled with more sophisticated and accurate estimation techniques.

In developing these computational tools we have attempted to provide considerable generality in treatment, while simultaneously allowing for treatment of various topics in great detail and [illegible] options for many of the computations. At the same time the programs allow less sophisticated and less detailed treatments when such treatments suffice or when dictated by lack of detailed data. We have attempted to provide the data input and output of computed results in the form required by, and [illegible] is acceptable to, the end user [illegible] as indicated by [illegible] to architect and [illegible] possible. The programs [illegible] and additions.

Because of the potentially very wide range of application of the first two programs, no attempt

*Work performed under the auspices of the [illegible] has been made to provide data bases for them. The user must supply all data, either as input or through merger or linkup with other computer programs.

No detailed users' manuals have yet been written for these programs. However, program listings can be provided on request, and the provision of tapes or card decks can be discussed. Clearly, the inclusion of program listings, detailed instructions for use of these programs, and detailed descriptions of the computational methods are not possible in the allotted space. Therefore, the following discussion of the programs can only address their general characteristics and capabilities.

<u>PROGRAM CAPITAL</u>

CAPITAL was developed to automate the computation of capital cost, including interest on borrowed capital incurred during construction, for complex, proposed or conceptual, conventional or advanced-technology, experimental, demonstration, or commercial facilities from basic cost data for the components that make up the facility. The features and capabilities included in CAPITAL were inspired by a number of less sophisticated programs, including CONCEPT, which was developed for capital cost estimation of conventional pressurized-water and boiling-water fission nuclear and oil-, gas-, and coal-fired power plants. CAPITAL can, although it need not, compute more detailed estimates of capital costs and interest expense during construction in several optional ways. However, unlike CONCEPT, whose application is more specialized, CAPITAL has not been provided with a cost data base. For each generic class of installations for which capital cost estimates are desired, an appropriate cost data base must be assembled and provided to CAPITAL. We are assembling such a data base for estimating capital costs of, e.g., laser fusion-driven electric power generation, process-heat generation, and synthetic fuel manufacturing plants. The data are to be supplied by commercial architect-engineering firms, where feasible, and by recent experience of the national laboratories and their suppliers and subcontractors, where necessary.

<u>Account Structure Treated By CAPITAL</u>

The subsystems, components, and subcontracts that make up the facility whose capital cost is being estimated can be grouped in a semi-arbitrary manner by the user of CAPITAL and assigned to accounts that constitute the entities with which CAPITAL associates costs. Each account can be identified by an account number, associated with an arbitrary description of the items included in the account, e.g., equipment, materials, or craft labor tasks. The account numbering system has the following features:

- Each account number consists of six two-digit numbers, separated by decimal points, with each two-digit number corresponding to an account level and with the highest (lowest) account level corresponding to the first (last) two-digit number.
- If two account numbers have the same first n two-digit numbers, but the (n+1)st and subsequent two-digit numbers are zero for one of the two accounts, then that account is included in the other as a subaccount.

This account numbering system is very flexible and should accomodate almost any breakdown of almost any construction project. An example of the account numbering system is presented in Table I.

**TABLE I**

EXAMPLE OF ACCOUNT STRUCTURE TREATED BY CAPITAL

| Account Number | Description of Items Included in Account |
|---|---|
| 24 | Electric plant equipment |
| 24.01 | Switchgear |
| 24.01.01 | Generator Circuits |
| 24.01.02 | Station Service |
| 24.02 | Station Service Equipment |
| 24.02.01 | Station Service and Startup Transformers |
| 24.02.02 | Low Voltage Unit Substation and Lighting Transformers |
| 24.02.03 | Battery System |
| 24.02.04 | Diesel Engine Generators |
| 24.02.05 | Gas Turbine Generators |
| 24.02.06 | Motor Generator Sets |
| 24.03 | Switchboards (Including Heat Tracing) |
| etc. | etc. |

The user designates a semi-arbitrary subset of the entire set of accounts as base-level accounts for which basic cost data are to be supplied and basic cost estimates are to be computed. No account designated as base-level can be contained in another base-level account. However, not all accounts designated as base-level accounts need be on the same level. This involves the tacit assumption that costs for all the items contained in higher-level accounts are to be lumped. The available cost data may, of course, be in unlumped form or it may be convenient to lump costs if acceptable loss in accuracy is involved.

The user can also designate several arbitrary subsets of the entire set of accounts as summary account subsets. For each summary account the costs associated with all base-level accounts contained in the summary account are summed and printed. Base-level accounts can be designated as summary accounts.

Features and Capabilities of CAPITAL

Eleven cost categories are associated with each base-level account:

- factory equipment,
- spares,
- site materials,
- engineering and design,
- inspection and testing,
- craft labor, which can be further divided into individual craft labor types,
- equipment and transportation,
- package deal or subcontract,
- use taxes,
- overhead, and
- profit.

Factory equipment costs for each base-level account for each construction period during which expenditures for that type of equipment are made for that account are computed as the product of a base cost for that equipment, the scaling law for that account, the amount of equipment purchased for that account during that construction period, a site factor for that account, an escalation factor for that equipment during that period, and a contingency factor for that account. Spares, engineering and design, inspection and testing, equipment and transportation, and package deals or subcontracts are estimated in a similar manner. Craft labor costs for a base-level account covering a particular construction period during which that account is active for each craft labor type is computed as the product of a labor productivity factor for that craft labor type, an efficiency factor for that craft labor type, an expression that takes into account overtime for that craft labor type, a supervision factor for that craft labor type, a basic hourly wage for that craft labor type, the number of hours of craft labor of that type required for that account during that construction period, a site factor for that account, and an escalation factor for that craft labor type during that construction period.

Use taxes are assessed against the total of the computed costs for the various cost categories for each base-level account for each construction period by multiplying by a use-tax factor for that construction period. Overhead and profit are obtained by multiplying the sum of the computed costs and the use taxes for each base-level account and construction period by an overhead factor for that account and then multiplying the resultant sum of the costs, use taxes, and overhead by a profit factor for that account. Values for most of the parameters listed in this and the preceding paragraph must be supplied by the user, but a selection of default values for some of the parameters is provided. Also, common parameter values can be distributed over all construction periods, base-level accounts, or craft labor types, where such dependences exist, to reduce the required amount of input where such simplifications are necessitated by lack of data or the resultant loss of accuracy is acceptable.

The total cost associated with each base-level account can be modified by use of a scaling law of the form:

$$a + bS^c$$

,

where a, b, and c are scaling-law parameters for that account and S is the scale, i.e., size, capacity, or number of the items covered by that account relative to some reference scale.

An arbitrary construction schedule is defined by specifying an arbitrary number of construction periods of arbitrary durations.

Several optional methods for computation of interest expense on borrowed capital incurred during construction are available to the user of CAPITAL. They are listed in Table II. The calculations are straightforward and will not be discussed in further detail here. The interest expense incurred and the cash flow during each construction period and the cumulative interest expense incurred and the cumulative cash flow through each construction period can be computed, printed, and print-plotted. Note that if all construction periods are to be of exactly one year in duration, then the associated interest rates are annual interest rates and, if compounded, are the familiar annually compounded annual rates. If all construction periods are to be of equal duration, but not equal to one year, and if the interest rate associated with each construction period is the same, then relating these interest rates to annually compounded annual rates is relatively straight forward. For other cases, the relationship of interest rates to annually compounded annual rates can still be deduced, but with some difficulty.

TABLE II

OPTIONAL [illegible] EXPENSE [illegible] PERIOD [illegible] CAPITAL

| Option Number | Interest Compounded Every Construction Period | Timing of Borrowing | Current or Historical Interest Rate Applicable |
|---|---|---|---|
| 1 | No | A | 1 |
| 2 | No | B | 1 |
| 3 | Yes | A | 1 |
| 4 | Yes | 3 | 1 |
| 5 | No | A | 2 |
| 6 | No | B | 2 |
| 7 | Yes | A | 2 |
| 8 | Yes | B | 2 |

A - Borrow[illegible] period at beginning [illegible].
B - Uniform [illegible] construction period.
1 - Interest [illegible] applied [illegible] plus [illegible].
2 - Interest [illegible] period [illegible] principal [illegible] through [illegible] construction period.

Costs for generic facility equipment, such as wiring or piping, can be summed across account boundaries using CAPITAL. This is a relatively standard architect-engineering firm cost estimating practice. However, this practice apparently does not meet with fusion community wishes with regard to cost estimation. There is apparently a strong desire to conduct, e.g., comparative cost studies, trade-off studies, parametric cost studies, and to report the results by breaking down fusion facilities into distinct subsystems and associating with each the costs of the necessary wiring, or piping, which are logically regarded as constituting integral parts of those subsystems.

PROGRAM VENTURE

VENTURE was developed for simulation of the economic performance of proposed or conceptual publicly or privately owned, single- and multiunit electric power stations, energy parks, or entire utility organizations using a discounted cash-flow method, the venture-worth method. A thorough discussion of the venture-worth method is presented by Happel and Jordan.[12] Although the terminology of VENTURE is that of the electric power industry, VENTURE can be readily adapted for evaluation of the economic performance of virtually any commercial enterprise.

A discounted cash-flow method was adopted because there appears to be widespread agreement that this approach to profitability assessment is the most accurate and useful for complex enterprises. According to the Chemical Engineers' Handbook,[13] all economic factors are properly treated. The widely used, simpler fixed-charge-rate method cannot treat multiple investments made at arbitrary times. Many thermonuclear power plant concepts involve periodic replacements of major pieces of equipment, which will have to be capitalized rather than treated as ordinary expenses for income tax purposes. There are also limitations on the scale of investments that can be treated by using the fixed-charge-rate method, and changes in tax and insurance rates cannot be treated accurately. In addition, one is apt to lose sight of the various factors that make up a fixed charge rate, and blind application of the method can lead to serious error under rapidly changing economic conditions. VENTURE permits parameter studies involving variations in all the basic economic variables. Arbitrary time dependences of the values of the basic economic parameters can also be treated, permitting the consequences of various scenarios of economic conditions to be explored. However, where appropriate, i.e., in the case of a single investment under constant economic conditions, VENTURE also computes an equivalent fixed charge rate.

One parameter of particular interest in assessing the relative merits of competing thermonuclear reactor power plant conceptual designs is levelized unit product cost. VENTURE can also be used to compute a levelized unit cost of power production.

## Definitions

Definitions of a few basic terms may provide better understanding of the foregoing introduction to VENTURE and the following discussion of its features. A discounted annual profit or loss for a venture is defined as the algebraic summation of discounted annual cash flows for the venture in a particular venture year. The venture worth for that venture year is defined as the algebraic sum of the discounted annual profits and losses for the venture for all the years during which the venture was conducted. It represents the profit (or loss) for the venture relative to the cost of doing business for the venture including return on invested capital, discounted to take into account the time value of money and monetary inflation, if present. Venture worth represents an economic figure of merit for a commercial enterprise. Selecting projects for investments of corporate funds with highest present worths will maximize future worths of companies.

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The levelized unit cost of electric power for an electric utility venture is defined as the constant unit sales price for electric power for which the venture worth of the venture is zero. It represents the cost of doing business on a unit electrical energy output basis. Transmission and distribution costs can be included in the estimation of levelized power cost, in which case a delivered cost is computed. If transmission and distribution costs are not included, then a levelized production cost is obtained.

Under the proper circumstances, i.e., if:

- all capital investment is made at the start of the life of the venture,
- the utility organization represents a limitless reservoir of funds from which funds can be withdrawn or into which funds can flow without appreciably affecting other utility activities,
- the utility organization is sufficiently profitable that immediate advantage can be taken of all tax credits,
- the cost of money, capital recovery payments, tax rates, etc., remain constant over the lifetime of the venture,

the fixed-charge-rate method can provide a simple, single figure of merit for assessing the merits of alternative investment opportunities. The goal is calculation of an equivalent levelized annual cost of owning and operating the venture associated with each investment option. The total cost of owning and operating a venture is conveniently divided into fixed and variable charges. Fixed charges result from the investment involved in owning the venture and the variable charges cover operation, maintenance, fuel, etc. The fixed charges include the cost of money acquired to finance the capital investment, income taxes on equity profit if the utility is investor-owned, capital recovery, property taxes, and property damage insurance minus investment tax credits and depreciation.

A rule of thumb regarding the maximum size of investments that can be treated accurately by the fixed-charge-rate method is that care must be exercised if the investment whose economic worth is being assessed exceeds 10% of the total worth of the organization making the investment. For many utility organizations this means that the fixed charge rate probably should not be used in assessing the economic viability of entire generating plants. A more detailed description of the fixed charge rate and or the fixed-charged-rate method as applied to electric utility ventures has been published by James.(4)

Structure of Electric Utility Ventures Treated by VENTURE

An arbitrary number of depreciable capital investments of the same or different arbitrary values made at the beginning of the same or different arbitrary venture years and salvaged during the same or different arbitrary estimated and actual (greater than estimated) venture years with the same or different arbitrary estimated (for income tax purposes) and actual salvage values can be treated by VENTURE. An arbitrary number of nondepreciable capital investments of the same or different arbitrary values made at the beginning of the same or different arbitrary venture years and disposed of during the same or different arbitrary venture years for the same or different arbitrary sales prices can be accomodated. Nondepreciable capital investments include, e.g., land and permanent improvements. The same or different arbitrary working capital requirements for each venture year can be treated.

An arbitrary number of operating units with the same or different arbitrary operating characteristics for each unit and venture year, i.e., nominal power ratings, plant factors, and thermal efficiencies, and the same or different arbitrary operating histories, i.e., venture years in which normal operations commence and venture years in which the units are decommissioned, and decommissioning costs, and which consume the same or different numbers, kinds, and amounts of fuels per unit of generated power can be accomodated.

Both investor-owned and publicly owned utility companies can be treated, with the principal differences in treatment of the economic performances of the two types of utilities being that:

- investor-owned utilities are assessed income taxes, whereas publicly owned utilities are not,
- investor-owned utilities finance power plant ventures by a combination of debt and equity, whereas publicly owned power plant ventures are wholly debt-financed,
- the size and profitability of investor-owned utility organizations are assumed to be sufficiently great that immediate advantage can be taken of all income tax credits, e.g., arising from investment tax credits, net negative taxable incomes, etc., so that carry-forward and carry-back provisions of the income tax laws need not be invoked, whereas such considerations do not apply to publicly owned utility organizations.

Features and Capabilities of VENTURE

The annual cash flows treated by VENTURE, incomes and outlays during a venture year, include:

- revenues from sales of electric power,
- operating costs,
- maintenance costs,
- capital recovery sinking-fund deposits,
- decommissioning sinking-fund deposits,
- decommissioning costs,
- returns on capital investments, including working capital,
- income (or losses) resulting from actual salvage values for depreciable investments, which differ from salvage values estimated for income-tax depreciation purposes,
- capital gains (or losses) arising from sales of nondepreciable capital investments,
- federal, state, and local income tax payments,
- federal, state, and local investment tax credits,
- state and local property tax payments,
- state and local sales or gross receipts taxes collected,
- state and local franchise tax payments,
- insurance premiums, including premiums for public liability, business interruption, comprehensive crime, venture property damage, employee benefits, workman's compensation, and special hazards insurance, and

- expenditures for fuel.

The latter two categories can be treated as part of operating costs, if desired. The principal reason for separating insurance premiums from operating expenses is that property damage insurance premiums contribute to the fixed-charge rate.

The annual revenue from sales of electric power is computed as the product of the total electric power generated by generating units that are operational during the year and the unit sales price during that year. The total electric power generated during a venture year is computed as the summation of the products of the nominal power ratings and availability factors for all units operational during that year. The nominal thermal power of each operating unit is calculated by dividing its nominal power rating by a unit thermal conversion efficiency.

Annual operating and maintenance costs and the decommissioning cost for each generating unit are specified directly. The decommissioning cost for each unit is associated with the venture year in which that unit is decommissioned. The annual cost of money to the venture is calculated as the summation of the products of the fractions of financing by bond sales, common stock sales, and preferred stock sales, and the interest rate paid to bond purchasers and rates of return received by common and preferred stockholders respectively. Annual capital recovery sinking-fund deposits for each depreciable investment and decommissioning sinking-fund deposits for each operating unit are calculated by using the computed annual cost of money to the venture in the standard manner. The depreciable capital to be recovered is basically the difference between the original and estimated salvage values of the depreciable investment, but can be increased by an amount sufficient to ensure that the purchasing power of the original investment value is recovered. Nondepreciable investments are recovered by sale of the investments, and working capital is recovered intact as a matter of course.

Income (or losses) resulting from differences in the actual salvage values and the salvage values estimated for computation of depreciation allowances for income tax purposes for depreciable investments are computed as the difference between the actual and estimated values and can be negative. The income (or loss) associated with each depreciable investment is assigned to the venture year during which that investment is actually salvaged. Taxable capital gains (or losses) arising from sales of nondepreciable investments are computed as the product of the difference between the original cost of the investments and their sales prices and a fraction of the capital gain or loss, which is specified as taxable according to the current tax laws. The capital gain (or loss) associated with each nondepreciable investment is assigned to the venture year in which that investment is disposed of.

Annual state and local property taxes can be assessed against the total of either the depreciated or undepreciated depreciable capital investment in force during the venture year, the total nondepreciable capital investment in force during the year, and the working capital for that year. The tax assessments are computed as the products of the corresponding tax rates, assessed valuation factors, which can be greater than one to permit taxation at appreciated values, and the values of the capital investments. State and local franchise tax payments are computed as the products of franchise tax rates and directly specified franchise tax bases.

Annual public liability, business interruption, comprehensive crime, and special hazards insurance premiums are specified directly. Annual workman's compensation and employee benefits insurance premiums are calculated as the products of the corresponding insurance rates and the total annual payroll. Annual property damage insurance premiums are calculated as the summation of the products of corresponding insurance rates and the total of the nondepreciable and the total of either the depreciated or the undepreciated depreciable capital investments in force during the venture year.

The number and types of fuels for each operating unit can be specified. The amounts of each fuel required by each operating unit per unit of thermal energy supplied to that unit and the unit cost of that fuel can be specified. The annual fuel cost for each operating unit is computed as the total thermal energy liberated in that unit during the venture year multiplied by the summation of the products of the amounts of each fuel required by that unit per unit of thermal energy and the cost per unit of that fuel. The total annual expenditure for fuel is the summation of the annual expenditures for fuel for each generating unit that is operational during the venture year.

The basic taxable income for a venture year is computed as the algebraic sum of the following annual quantities for that year:

- total revenue from sales of electric power (positive),
- depreciation allowance (negative),
- difference between estimated and actual salvage values for depreciable investments salvaged during year (positive if actual salvage value greater than estimated, negative otherwise),
- portion of return of invested capital which is interest (negative),
- operating costs (negative),
- maintenance costs (negative),
- state and local property taxes paid during year (negative),
- state and local franchise taxes paid during year (negative),
- state and local sales taxes paid during year (negative),
- decommissioning costs incurred during year (negative),
- portion of capital gains (or losses) from sale of nondepreciable assets during year which is taxable (positive if gain, negative if loss),
- insurance premiums (negative),
- expenditures for fuel (negative).

State and local income taxes paid during year are subtracted from federal taxable income. At the option of the user, federal income taxes can be subtracted from state and/or local taxable incomes, and/or state income taxes can be subtracted from local taxable income and/or vice versa.

Annual federal, state, and local income tax liabilities are calculated as the products of the corresponding tax rates and the federal, state, and local taxable incomes for that venture year minus federal, state, and local investment tax credits applicable during that venture year. Federal, state, and local investment tax credits granted during a venture year are computed as the products of the corresponding tax credit rates and specified fractions of depreciable capital investments made during that venture year and are subtracted directly from income tax liabilities.

Arbitrary distinct values can be specified for all the economic parameters for each investment, venture year, operating unit, fuel type, etc., where applicable when desired. When less detailed treatments are acceptable, values common to all investments, and/or venture years and/or operating units and/or fuel types can be input for an arbitrary subsets of the economic parameters. The required data input can be reduced significantly in this manner.

Two methods can be invoked by the user of VENTURE for computation of depreciation allowances for income tax purposes, the straight-line method and the sum-of-years'-digits method. The first method is simple and easier to understand and the second method provides more realistic accelerated depreciation during the early portion of the service life of a depreciable investment. The use of these two methods is widespread and the simple formulas for the depreciation allowance factors will not be derived here. The depreciation allowance for each depreciable investment for each venture year is computed as the product of the depreciation factor for that year for that investment and the difference between the original value of that investment and its estimated salvage value.

Seven methods for discounting cash flows are available to the user of VENTURE. They are identified by the type of cash flow to which they are intended to apply:

- single, annual, discrete, end-of-year,
- single, annual, discrete, beginning-of-year,
- equal, semiannual, discrete, end-of-year, but

not beginning-of-year,

- equal, semiannual, discrete, beginning-of-year, but not end-of-year,
- equal, quarterly, discrete, end-of-year, but not beginning-of-year,
- equal, quarterly, discrete, beginning-of-year, but not end-of-year,
- uniformly distributed throughout the year.

Treatment of equal, discrete, monthly cash flows was not included in VENTURE because the differences between discounted uniformly distributed cash flows and discounted equal, discrete, monthly cash flows is generally not significant. Because there is an infinity of nonuniform continuous cash flow distributions, no attempt was made to address discounting of such cash flows. The modular nature of VENTURE should, however, make it easy to introduce alternative discounting schemes. The discounting formulas are easily derived and will not be reproduced here. The cost of money to the venture is used in the usual fashion to compute the discount factors.

A simple iterative root-finding technique, the regula falsi method, which requires two starting values for which the function venture worth must have opposite signs, is used to find levelized power cost. The calculations involved are essentially the same as for venture worth calculations when a constant sales price for electric power is specified. The function venture worth has only a single root.

The output provided by VENTURE includes the following options:

- an immediate echo check on raw input data,
- venture worth and annual and cumulative discounted venture profits or losses,
- levelized unit electric power cost, and
- equivalent fixed-charge rate where applicable,
- detailed tables of input data and intermediate computed results, including all cash flows and discounted cash flows.

PROGRAM INDEXER

INDEXER was developed to automate the process of computation of values of cost indexes used to convert estimates or known values of capital, operating, maintenance, production, etc., costs for conceptual or proposed, conventional or advanced-technology facilities, subsystems, or components valid for one time interval or point in time to values valid for another time interval or point in time. The use of such indexes allows cost information, which may have been laboriously developed for one time frame, to be transformed easily to provide useful cost estimates for another, usually later, time frame, without having to repeat the entire cost estimation process for the new time frame. We feel that INDEXER and its associated data base provide ready access to an enormous amount of cost index data, and a convenient means of using this data.

Basic Definitions

In discussing the capabilities of INDEXER, we begin with a few basic definitions. A cost index is a representation of the cost of an item, i.e., a facility or one of its subsystems or components, a unit of a raw material, a manufactured product, a unit of labor, a plant maintenance or operation activity, etc., relative to its cost for some reference time or during some reference time interval. The value of a cost index for a specified time frame is usually expressed as the ratio of its cost during that time frame to its cost for the reference time frame or as this ratio multiplied by 100. We have adopted the latter method of expressing the value of a cost index. Under this convention, a value greater than 100 for a cost index corresponds to an increase in cost for the item represented by the cost index relative to its cost during the reference time frame. A value less than 100 corresponds to a decrease in cost.

We refer to a cost index included in the data base for INDEXER or supplied by a user as a component cost index, although such indexes may themselves have been computed from many more basic cost indexes. A weighted, normalized sum, whose values represent the time dependence of the cost of some composite item relative to its cost for some reference time frame, of component indexes, whose values represent the time dependences of the component items which make up the composite item in the proportions indicated by the weighting factors, all relative to the same reference time frame, we call a composite cost index.

A divisor of a cost-index value, which modifies that value to account for the effect of changes in productivity and is usually applied to craft labor hourly wage indexes, engineering and design cost indexes, operation and maintenance cost indexes, etc., we refer to as a productivity factor. Productivity factor values greater than one, corresponding to increases in productivity, may arise as a result, e.g., of the introduction of superior techniques, new machinery and equipment, or experience acquired in the design, engineering, and construction of similar items or projects in the past, or to the introduction of new work rules. Productivity factors less than one, corresponding to decreases in productivity, may result, e.g., from the introduction of more restrictive work rules through the collective bargaining process by agreement with craft, operating and/or maintenance unions, or from the introduction of more restrictive work rules and/or design restrictions mandated by regulatory bodies for reasons of construction, operating, and/or maintenance personnel health and safety, public health and safety, and environmental protection.

Features and Capabilities of INDEXER

The user of INDEXER defines a composite cost index by designating an arbitrary set of component cost indexes for which values are contained in the data base for INDEXER or for which values have been supplied by the user and a corresponding set of arbitrary weighting factors to be associated with an arbitrary time frame. Monthly, quarterly, and yearly index values can be easily added to the data base provided for INDEXER or provided as input to INDEXER. Monthly, quarterly, and yearly index values, any or all at user option, can be computed for arbitrary sequences of months, quarters, or years within the time period covered by the component cost index values included in the data base for INDEXER or provided to INDEXER by the user as input. Quarterly and yearly composite cost index values are computed as averages of the corresponding composite cost index monthly values. Monthly composite cost index values can be computed using any mix of monthly, quarterly, and yearly component cost index values because quarterly and yearly component cost index values in the data base or provided as input are automatically assigned to the corresponding months.

The user-specified weighting factors can be maintained constant throughout the period for which index values are to be computed or can be automatically updated for each time interval, i.e., month, quarter, or year, during the period. The automatic updating of weighting factors is based on relative changes in the costs of the component items that make up a composite item as indicated by the time dependences of the values of the component cost indexes themselves.

The reference time frames for any or all component cost indexes for which values are contained in the data base or are supplied by the user and/or for computed composite indexes can be arbitrarily altered by the user by providing new reference index values for the component cost indexes whose reference time frames are to be altered and/or the composite cost index. Each new reference value is then divided into all the index values for the appropriate index. Default values of 100.0 are provided for all reference index values in INDEXER.

Arbitrary productivity factor values can be specified for any or all of the component indexes used to compute a composite index, and for the composite index as well, for each month in the period for which composite index values are to be computed. Default values of 1.0 are supplied by INDEXER.

We illustrate the computation of composite cost index values by giving the formula for a monthly composite cost index value with automatic updating of weighting factors for the kth month in the sequence of months for which values are to be computed:

$$I_{C,M,k} = \frac{1}{I_{C,R}P_{C,k}} ,$$

$$\sum_{n=1}^{N} \frac{W_{n,k^*} \left(I_{M,n,k}/p_{n,k}\right)/\left(I_{M,n,k^*}/p_{n,k}\right) I_{M,n,k}}{\sum_{n=1}^{N} W_{n,k^*} \left(I_{M,n,k}/p_{n,k}\right)/I_{M,n,k^*}/p_{n,k^*}) I_{R,n} p_{n,k}}$$

**where:**

- $I_{C,M,k}$ = **monthly composite index value for kth month,**
- $I_{C,R}$ = reference index value for composite index (different from 100.0 only if the reference time frame is to be altered),
- $p_{C,k}$ = composite index productivity factor value for kth month,
- $W_{n,k^*}$ = nth component cost index weighting factor value for k*th month,
- $I_{M,n,k}$ = nth monthly component index value for kth month,
- $I_{M,n,k^*}$ = nth monthly component index value for k*th month,
- $I_{R,n}$ = reference value for nth component index (different from 100.0 only if reference time frames are to be altered),
- $p_{n,k}$ = nth component index productivity factor value for kth month,
- $p_{n,k^*}$ = nth component index productivity factor value for k*th month, and
- $N$ = number of component cost indexes used in definining composite cost index.

Simpler formulas apply if computation using constant weighting factors is specified.

The types of output provided by INDEXER in addition to computed composite index values include:

- an automatic echo check on raw input data,
- any part of the data base for INDEXER, whether or not used in computing composite index values, at user option, and
- only that part of the data base for INDEXER or component index values provided as input which was used in computing composite cost index values, at user option.

Data Base for INDEXER

The number of component cost indexes for which values have been included in INDEXER's data base is now 400 and new ones are being continually added. Sources of the component cost index values or cost data from which they have been derived include the following:

- Bureau of Labor Statistics, Wholesale Price Indexes,
- Bureau of Labor Statistics, Monthly Labor Review,
- Bureau of Labor Statistics, Employment and Earnings,
- McGraw-Hill, Chemical Engineering,
- McGraw-Hill, Oil and Gas Journal,
- McGraw-Hill, Engineering News-Record.

The reference time frame for all the component indexes covered by the data base for which the raw data were available in that form, or for which the information necessary for conversion of the raw data to give index values corresponding to that time frame was available or could be accurately estimated, is the average for 1967. This includes a majority of the cost indexes covered by the data base. All other indexes for which values are included in the data base have as reference time frames the reference time frames associated with the raw data. We have not hesitated to fill in small gaps in the data base by interpolation or estimation. The period covered by the data base for the majority of the component indexes is January 1970, to May 1977. For some, more-recently-introduced, component indexes, the period covered extends past May 1977. In other cases, reporting of component index values was not instituted until after January 1970, and, hence, values from January 1970 are not available. We plan to update and add values for new component indexes to the data base as time and resources permit. The data base is presently slanted toward, e.g., construction, operating, and maintenance costs conversions for process industry and energy-related facilities, subsystems, and components, but could be enlarged to cover, e.g., general manufacturing and the service industries. We feel that the data base for INDEXER represents a unique compilation of cost index data not readily available elsewhere to the public.

## REFERENCES

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