40

Investment optimization: a methodology for life-cycle cost analysis

This chapter presents a methodology for life-cycle cost analysis that has been developed and subjected to marketplace experiences in both the private sector and state institutional sector.

Life-cycle costing (LCC) is a concept to which most practitioners in the building design profession readily relate. Much work has been recently done to promote the state of the art in this concept, the majority being funded and effected by various departments of the federal government. Dissemination of the data obtained, complex economic concepts employed, and experiences gained have been aggressively pursued both by the sponsoring agencies and the contractual manufacturers who have participated in some of the demonstration programs.

The fact remains, however, that the commercial and nongovernmental institutional sectors of the building industry—although anxious to take advantage of any available sound investment opportunities—have been slow to accept LCC techniques. As energy costs become an evermore significant component of the owning costs of thermal systems, and in keeping with tried and proven business practices, the need for a sound methodology for applying those concepts increases.

Establish life expectancy

Most previous attempts at purchasing on the basis of LCC have not been successful because they were based upon a false premise. That premise was that one must identify the "life expectancy of the subject" to establish the LCC. To support this recognition, the fact is that life expectancy of such things as major machinery components, piping systems, building structures, and the like, is not a specific time span. It is, rather, one variable in a complex formula, dependent upon numerous other variables. The major independent variables, both interrelated with economics, are maintenance and obsolescence. As an example, a properly maintained refrigeration compressor will last indefinitely (barring destruction from "system" malfunctions), if the maintenance program established assures replacement of the wearing components prior to their total failure. If it is a nonmaintainable or nonserviceable compressor, then the compressor as a whole becomes a replaceable component of a larger subsystem (such as a chiller). Thus, in determining owning costs, if adequate monies are allocated for maintenance

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and service (M/S), the machine will never "wear out." Machinery and buildings are not organic objects such as animal and plant life—thus, man has total control over their "life expectancy."

Consider obsolescence

The second independent variable is the only one which truly limits the life of the building and the building system: obsolescence. The subject becomes obsolete when a more desirable subject is available to perform the same function.

Thus, to establish a true LCC study on a building (and its energy systems) the only realistic "life" that can be established must be based upon the estimate of the time preceding obsolescence.

The proposition, then, is that decisions made in the expending of funds to construct a building are not actualy made on the basis of the life expectancy of the structure erected. They are made on the basis of return on the investment in the case of commercial ventures, resolution or repayment of construction or corporate bonds in large businesses and institutions, and optimum cost/benefit ratios in state and local government institutions. Other bases sometimes exist, but most relate in some way to the free enterprise concept of return on investment (ROI). *The time preceding anticipated obsolescence, in this regard becomes the upper limit.*

To expand this proposition, then, perhaps the term life-cycle costing—when applied to monetary investments—should be changed to something such as investment optimization, or otherwise redefined to remove the stigma of direct life expectancy of the subject. Every astute businessman or investor is concerned with the solidarity of his investment for its life span, but his first and foremost concern is the economic wisdom of the investment! Thus, to interest such investors, the methodology employed will succeed only if it results in a more favorable investment.

Back to basics

In the development of the methodology, some basic economic concepts must be addressed. First, no component of a building or building project "earns" money. To the contrary, virtually every component costs money to purchase and install, and thereafter continues to cost money to operate and maintain. For example, when a building investor purchases an air handling unit, after paying for it, he continues to pay to operate, maintain, and service it for as long as *he* owns it. What earns money is the space which is usable for a purpose. In an office building, the income is generated by the usable area, in a hospital it is the patient beds, laboratory products, etc. In both investment and operating costs, the component is simply one of the costs in providing the usable or revenue-generating area, beds, or whatever. The same is true in industrial production: The product earns the revenue; the economic complexities of the production machinery simply represent costs. Every investor recognizes this since the difference between sale price and costs either represents profit or improved service.

Thus, the familiar pro forma, or revenue-to-costs projection format is not the form to employ in developing an investment optimization analysis. The analysis assumes that either wisdom of the investment has already been confirmed on the basis of approximated or anticipated goals, or that the analysis is being employed to validate the pro forma.

No absolute best decision

Second, there is no "absolute" best decision in the purchasing of a component of a revenue-generating entity if the component has both investment cost burdens and operating cost burdens. Rather, there is only a comparative "best." For example, the decision to build a commercial office building, school, hospital, etc., is made on the basis of statistical economics, one parameter of which is "need." Once this parameter is tempered with other parameters such as the cost of investment monies, the degree of the need which reflects in possible rental revenue, tax parameters, and rough estimates of operating costs (energy, maintenance, insurance, taxes, etc.), the preliminary decision to proceed with the project is made. It is after this that the specifics of addressing the individual design decisions regarding systems and components are manifest. At this point, all decisions are comparative—System A versus System B, Unit C versus Unit D, etc. By resolution of these decisions, the value of the overall investment is optimized.

Third, the most beneficial or optimum investment is not the same for all investors or for all projects. Failure to recognize this is the paramount reason that the statement has been made "... *life cycle costing, as applied to the building industries, is relatively unaccepted*."[1] Most techniques of LCC previously presented endeavored to key the formula into the life expectancy of the building or the component being analyzed. When, in fact, to the specific investor for a specific venture, this has little to do with his concerns.

Investment optimization method

A life-cycle costing methodology based upon the foregoing observations, entitled investment optimization (IO) is suggested. The first step at developing an IO analysis is to establish the requirements for the ROI on the basis of straight payback. The investor must, after taking all of the relevant parameters into consideration, reduce his expression of the invested dollar to a straight payback constant. This constant (n) is dimensionally "years." The formula is

$$I_d/R_d = n$$

where

I_d = differential investment (dollars),
R_d = differential return (dollars/year),
n = payback period (years).

The ratio n, is a function of many complex economic parameters. These include interest rates or value of investment monies, present value of future monies, tax parameters relating to capital investment versus operating costs, availability of investment monies, etc. Experience in the commercial and institutional building markets has shown that virtually *every* investor on *every* project can relate all these complex economic variables to the straight payback formula. (This is not to suggest that more sophisticated approaches such as "Rate of Return Method," "Discounted Cash Flow," etc. are not valid, just that once the decision is made, it be reexpressed in terms of straight payback.

Once the payback period "n" has been established, all investment associated terms of the owning cost have been removed from the formula. This feature facilitates the accomplishment of the investment optimization with a degree of simplicity which enables it to be used for all systems decisions and the component purchasing decision—to the extent that competitive bids can be submitted on the basis of investment optimization by applying a relatively simple bidding procedure. The steps in the methodology (including the first step above) are:

- Establish the straight payback period (n) that satisfies the economic parameters of the investor and specific project.
- Determine *all* operating costs associated with the system or components being considered for each year of the n year period starting with the first year. (*Note*: Interest, debt service, and depreciation are not a component of operating costs, they are taken into account in the step above). Operating costs include energy, maintenance/service, insurance, taxes (if relevant), and any other direct cost outlay related to the component or subsystem being analyzed.
- Add the initial purchase cost and the sum of the annual operating costs for the period of n years, for each of the systems or components being considered.
- The lowest total of the compared systems or components will provide the optimum investment.

As an example, consider the comparison between two competitive products, A and B, with first costs of $100 and $80, respectively, and annual operating cost burdens of $20 and $25, respectively.

Example 1. Investor has a requirement of a straight payback ratio, "n," of 3 years on invested monies:

	Product A	Product B
Investment Cost	100	80
Operating Cost		
1st Year	20	25
2nd Year	20	25
3rd Year	20	25
Total	160	155

The most favorable purchase would be product B. To substantiate the wisdom of the decision, if the incremental difference in investment were compared to the incremental return:

$I = (100 - 80) = \$20,$
$R = (25 - 20) = \$5/\text{year}$, and
$n = 20/5 = 4$ years.

Thus, the 4-year straight payback is greater than the 3-year requirement, illustrating that the method used to select product B was valid.

Example 2. If the same products were compared for an investor who required a straight payback of 5 years:

	Product A	Product B
Investment Cost	100	80
Operating Cost		
1st Year	20	25
2nd Year	20	25
3rd Year	20	25
4th Year	20	25
5th Year	20	25
	200	205

In this case, the most favorable investment would be product A. As shown above, the straight payback rate of return would be 4 years, which is less than the 5 years which was established.

The costs

Investment Cost: Includes all actual costs (purchase and installation of component or system). Not included are interest costs and investment tax credits. If the component being considered is a water chiller, cost consideration would include chiller, freight, sales tax, contract cost to move into place and connect piping and electrical services, and insulation of components. Thus, *any* cash outlay associated with purchasing and installing the unit that could possibly be different than any cash outlay associated with purchasing and installing a competitive unit. It is mandatory that the bid form analysis not use comparative costs but rather actual total costs.

Operating Costs: Include all conceivable cash flow burdens related to the specific component or system being analyzed, i.e., energy, power (demand), maintenance/service, insurance, and taxes. Any other item that relates should be included. Each item should be calculated separately. For more accurate analysis, anticipated escalation or inflationary increases should be taken into account. Also, economic analyses reveal that different escalation rates should be applied to various cost items as the case warrants, i.e., energy cost inflation may be anticipated to follow a curve different than M/S cost inflation. For each item of cost, then, an escalation rate unique to that item can be applied. The escalation rate formula is simply:

$$C = c_1\left(\frac{(1+x)^n - 1}{x}\right)$$

where

C = total cost of the operating component over n years;
c_1 = annual operating cost component for first year;
n = straight payback ratio;
x = annual (compounded) escalation rate (10 percent = 0.10).

Energy and Power: These costs are probably the easiest major operating cost component to quantify with a reasonable degree of accuracy. Systems analysis techniques that relate to energy and power burdens for systems and most system components have been formulated in computer programs that are commercially available to design professionals. These programs can assist the designer in determining maximum machinery loads per month (demand), energy input per month, operating hours per month, and part load profiles. These data can then be used to determine power and energy burdens for any specific machinery component or integrated system. For bidding purposes, the data can be integrated with the applicable energy rate or fuel costs and reduced to a series of constants to be used as multipliers for various energy burden characteristics of the machinery being compared. For example, for a centrifugal water chiller, constants would be generated for power costs by multiplying full load power input for the specific unit, by a constant to produce the "*n*" year costs. The part load analysis is integrated with a linear approximation of part load power curves to be multiplied by the power input at some relevant fraction of part load to produce the "*n*" year primary energy cost. The evaporator flow rate incorporated with either the total hours of operation (constant flow), or part load analysis (throttled flow control) is integrated with energy cost parameters to develop constant to be multiplied by the head loss through the respective evaporator to produce the "*n*" year chiller pumping energy burden. The operating hours analysis integrated with energy rate parameters is used to develop a constant to be multiplied by the product of the required flow rate and head loss through the condenser to produce the condenser pumping energy burden.

Maintenance/Service: Costs associated with a particular item of machinery or system are the most difficult to quantify accurately. Most published data are statistical-historical in nature have not been correlated with specific machinery. ASHRAE Technical Committee 1.7 (Durability, Reliability, Maintainability) is currently working on the development of a methodology to enable the industry to address this problem.[2] Until some progress is made in this effort, the only reasonable method of incorporating M/S in the IO formula is either for the design professional to perform a thorough investigation on typical classes of components when doing the analysis on comparative system; or, when applying IO to bidding, to require bidders to include a total maintenance/service contract proposal for some years, including as a minimum, the "*n*th" year.

Insurance: As a general rule, the energy and M/S cost burdens are the major differential financial burdens of operating machinery. However, in some cases, machinery insurance rates will reflect the statistical differences in probability of loss or liability for alternative selections of machinery. Thus, prior to conducting an IO analysis or preparing IO bid documents, the investor's insurance underwriter should be consulted to determine if any potential differences, in fact, do relate. For example, some premiums on electric refrigeration machinery are based on *motor* horsepower; thus if a smaller prime mover can be used for the specified tonnage, some savings could result. If such a situation exists, appropriate consideration should be given in the analysis.

Taxes (Real Estate): They are generally the least significant contributor to the differential operating cost. However, if any differences are identified, they should be considered. Most taxing agencies base the appraised valuation, not on actual cost, but on the revenue-generating capability of the venture or some statistical appraisal. If, however, actual costs are considered, an appropriate constant should be applied to the purchase price to reflect any such tax burdens.

The investor in Example 1 may be representative of the speculative investor for whom investment monies are costly, and the investment is short term. If the straight payback ratio is not skillfully applied, the investor could do himself a costly disservice. Consider that if the investor of Example 1 retains the property for, say, 20 years, with no escalation of operating costs, his differential operating costs at the end of the period will have been five times the savings in first cost. Thus, it is extremely important that the consultant advising an investor on investment optimization make him totally aware of the significance of the straight payback ratio established. Failure on the part of many nonsophisticated investors to recognize the importance of a realistic straight payback ratio has resulted in the economic failure of building projects through foreclosures, and the subsequent ownership of properties by investment banking houses who found it difficult to salvage the invested capital. On the other hand, all sophisticated investors fully understand the wisdom of increasing the "*n*" ratio to the greatest number possible when they anticipate so-called permanent ownership. Another germane consideration is that the anticipated time preceding obsolescence must be, as a minimum, equal to $2n$ years.

Case history examples

Case history examples of the IO methodology for LCC reveal a significant improvement in the decision-making process of purchasing major machinery under competitive bidding procedures.

- *Case 1*: Being considered were two water chillers for a commercial building development. Constants for the energy and power components were developed, following systems analysis, to determine the part load profiles and monthly hours of operation, and integrating this data with the local utility rates. For this bid, the straight payback ratio (n) was set by the owner as 5 years, and no escalation in energy was included because of a unique local condition relating to electric-generating capacity and fuel source. The "bid form" in a capsulated format is shown in Fig. 40-1.

A rather well-detailed specification on performance tests, and the maintenance/service cost was, needless to say, required. The results of the bids are presented graphically in Fig. 40-2. The lower curve is the sum of lines A and B, or the total first cost, and the upper curve is the total IO bid cost. Note that the incremental first cost difference between the lowest IO bid cost units and the second lowest is \$8750. The difference in annual operating costs is \$1907. The straight payback ratio, in years, is then

$$8750/1907 = 4.59.$$

Thus the investor's ROI ratio has been satisfied. It might be mentioned, that if only the energy component of operating costs is considered, and present dollars are applied for a 20-year ownership "life cycle" or investment duration, the lowest IO bid compared to the second lowest will reduce the 20-year energy cost by \$49,615. The same comparison made between the lowest IO bid unit (highest first cost) and the lowest first cost unit yields a 20-year energy cost saving of \$87,472—not to mention the reduction in resource depletion.

- *Case 2*: Being considered is a single water chiller to be connected into a campus chilled water-loop system. The same procedure for establishing the analysis constants was employed as in Case 1, and again, the owner established a straight payback ratio, "n," of 5 years. However, there were four significant differences mandated by the specific or unique circumstances of the project and bidding procedures: (*1*) *The chiller was a component of a large integrated system. Thus, any capacity in excess of the specified minimum amount (385 tons) could be utilized in the system. A cost per ton correction was employed in the IO bidding procedure;* (*2*) *The IO procedure for bidding the chillers was structured as a set of alternates to the base bid.*

A. Sale Price—on delivery	$ ________
B. Start-Up and Performance Test	$ ________
C. *Compressor Energy* kW of two machines operating in series at 720 tons total load ________ × 266	= $ ________
D. Compressor Power kW of two machines operating in series at 1200 tons total load ________ × 79.6	= $ ________
E. *Chilled Water Energy* ft chilled water head loss through one machine ________ × 682.86	= $ ________
F. Condenser Water Energy ft head loss one machine ________ × GPM one machine ________ × 0.150	= $ ________
G. Five-year charge for total maintenance and service contract	= $ ________
IO Bid Cost (Total A through G)	$ ________

Fig. 40-1.

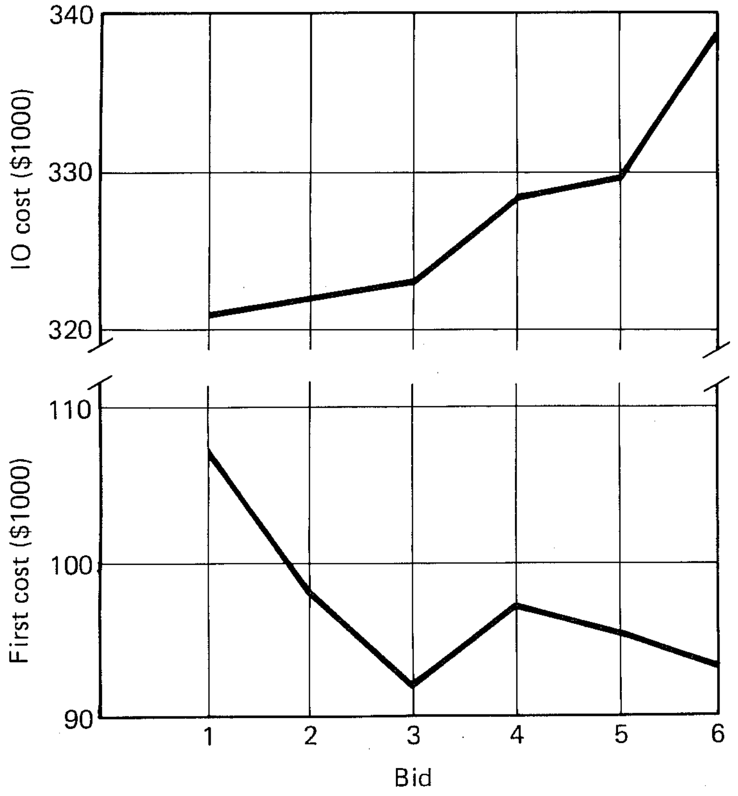

Fig. 40-2. Comparison of IO cost versus first cost for Case 1 example

Thus, the first costs were actually installed costs reflecting any machinery-related differences in contractor installation costs; (3) The owner was a state institution and could not legally receive bids for a five-year maintenance operations contract. Thus, the IO bids did not reflect differences in maintenance costs between alternative selections; (4) The energy and power constants were developed on the basis of 10 percent per year compounded cost escalation.

The "bid form" for this project, in a capsulated form appears in Fig. 40-3.

The results of the bids are presented graphic-

Alternate No. X, IO Evaluation of Alternate X = $ ______

A. *Weighted Sale Price Value*
Quoted Price ______ × 385/Capacity ______ = $ ______

B. *Compressor Energy*
Machine kW at 290 tons load ______ kW × 451.4 = $ ______

C. *Compressor Power*
Machine kW at 385 tons load ______ kW × 102.5 = $ ______

D. *Chilled Water Energy*
ft of heat pressure drop thru chiller at
1400 GPM ______ ft × 246.5 = $ ______

E. *Condenser Water Energy*
ft head ______ × GPM ______ × .176 = $ ______
IO Bid Cost (Total A thru E) $ ______

Fig. 40-3.

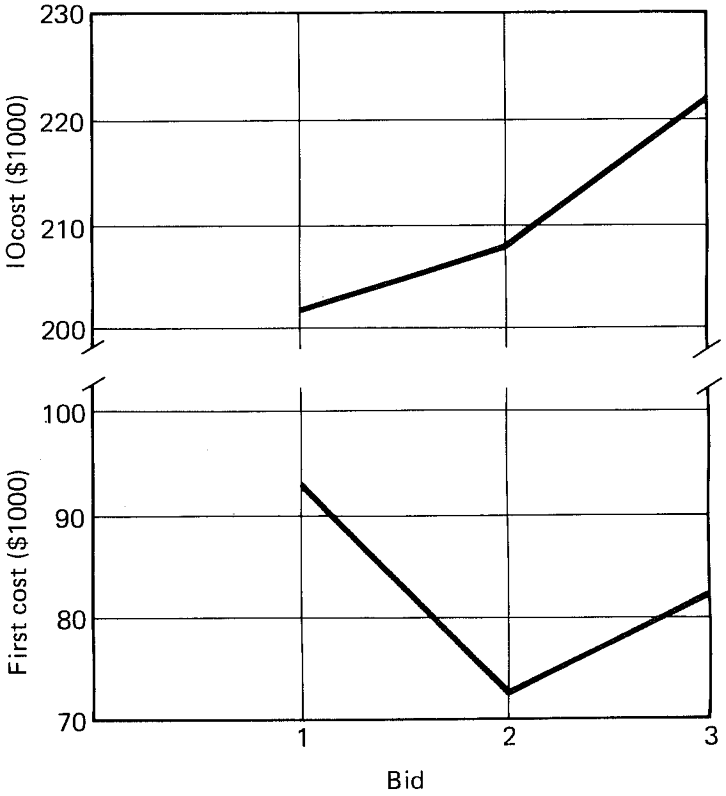

Fig. 40.4. Comparison of IO cost versus first cost for Case 2 example

ally in Fig. 40-4. Again, the lower curve is the alternate bid price or first cost, and the upper curve is the stated IO bid costs. Comparing the lowest IO bid cost to the second alternative, it is found that the quotient of the difference in investment cost between the lowest IO cost unit and the lowest first cost unit (second lowest IO cost) is:

$$\frac{\text{differential investment}}{\text{differential annual operating cost}} = \text{“}n\text{”}$$

$$20{,}820/7277 = 2.86 \text{ years.}$$

The additional investment, returned in 2.86 years (straight payback) will reduce the owner's energy costs compared to the lowest first cost alternative over a 20-year ownership life by $114,428.

In both cases cited, the owners elected to purchase the more costly machinery to obtain the desirable return on investment and the added benefit of considerable reduction in the so-called "life-cycle cost."

Conclusion

The IO methodology for life-cycle purchasing is a technique that enables commercial and institutional investors in buildings to obtain a realistic balance between the economic advantages of return on investment and the benefits of LCC. Although not necessarily achieving the lowest LCC as defined or addressed by earlier demonstrations, it does enable the earlier concepts to be applied to the real world of monetary economics of investment and return. Furthermore, it has the flexibility in structure to be applicable to virtually any economic and technical situation.

The use and validity of the IO technique has been proved in numerous systems analysis decisions in the design process. Its simplicity has made it readily adaptable to competitive bidding procedures. The only requirements are the ability of the owner or investor to express his ROI requirements in straight payback terms, and the ability of the analyst or designer to quantify the primary and relevant cost variables of operation.

References

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2. ASHRAE Handbook, 1973 "Systems," Chapter 44 "Owning & Operating Costs."