Design for Cost Effectiveness and Affordability

An Online Continuing Education Course for Engineers

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Design for Cost Effectiveness and Affordability

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This course is meant to provide an overview of the concepts for addressing cost and economic factors in a design. It addresses affordability, which is defined by the United States Defense Acquisition University as the benefit and capability achieved relative to the cost of a good or service. The average consumer may define affordability as the ability to pay for a product. Although definitions of affordability vary between an average consumer and an organization like a federal agency, all suggest that affordability is concerned with the comparison of some monetary measure to known levels of customer income, investment, or budget. That is why it is paramount to describe or measure affordability in terms of cost-effectiveness and economic value.

To achieve maximum value, the methods of value engineering are applied.
Value Engineering is an organized and systematic approach that analyzes the functions of systems, equipment, services, etc., to ensure they achieve their functions at the lowest cost and within the applicable requirements for performance, reliability, quality, and safety. It is about maximizing function relative to cost and not solely about cutting costs. There are examples given later, such as with piping or plumbing engineering, which show that solely cutting costs does not lead to achieving the best value.

Value engineering can be applied to achieve the required functions while minimizing cost by analyzing the design of buildings, equipment, and systems. Or it can be leveraged to maximize the ratio of the benefit and/or function to cost. All this effort balances cost with performance, quality, reliability, and safety.

Value = Benefit / Cost

Value engineering focuses on the life cycle cost, such as the total cost of a product or system from the design phase to its disposal or demolition phase. This course presents value engineering methods, such as life cycle cost analysis and utility curves. Building data is provided, such as the percentage of life cycle costs for the typical building. Examples will be presented with building design and construction as well as military hardware projects.

Value engineering is integral to federal government programs, as it is even mandated within public law such as 41 United States Code 1711. This specific law requires value engineering to be applied for programs, buildings, facilities, and services, and especially for design and construction acquisitions. Further definition of this law is in the Office of Management and Budget (OMB) Circular A131, which provides guidance to federal agencies about the sustained use of value engineering. Each agency will have its own specific guidelines traced to 41 USC 1711 and Circular A131, such as United States Army Corps of Engineering Policy Notice 20-04 (Value Engineering) and Instruction ER-11-1-321 (Value Engineering). Also, as per Federal Acquisition Regulations 48, federal contracts are to include contract requirements for value engineering. Part 48 discusses how to incentivize contractors to promote value engineering within their design and construction effort to realize life cycle costs savings for the agency. 41 USC 1711 states the following about value engineering program requirements:

"Each executive agency shall establish and maintain cost-effective procedures and processes for analyzing the functions of a program, project, system, product, item of equipment, building, facility, service, or supply of the agency. The analysis shall be,

(1) performed by a qualified agency or contractor personnel; and

(2) directed at improving performance, reliability, quality, safety, and life cycle costs."

Cost-effectiveness may require an initial investment or startup cost. The investment leads to greater value and can be measured, such as by return on investment. Another way to measure value is by determining how much the consumer gains based on the cost of the purchase or acquisition. Some examples of measuring or expressing value are shown below.

1) number of fasteners per $100 bulk order
2) increase in corrosion resistance for marine hardware for an extra $500
3) life cycle savings with precast concrete railroad ties versus wood railroad ties

Note that examples 2 (corrosion resistance) and 3 (railroad ties) apply to investment costs in order to realize lower life cycle costs such as maintenance. One valuable resource is the Washington State Department of Transportation's Value Engineering Guidebook. Within this reference is an example of how a precast concrete solution's initial investment (i.e., design, construction, and installation) costs about 20% more than the wood solution; however, the concrete solution's life cycle cost is 17.4% less than that for the wood solution over a 20-year project period.

Life cycle cost

A system is a collection of elements or components that are organized for a common purpose. A building is a system consisting of components that are mechanical, electrical, and structural in nature. The total cost of a system over its intended life is called life cycle cost. Commonly, the total cost is referred to as the system's cradle to grave cost, whereas cradle equates to the design phase, and grave is when the system is deactivated permanently and/or sold for salvage. Understanding life cycle costs are integral to ensuring that the best value (or affordability) is achieved.

Life cycle costs are essentially divided into three major categories:

1) Design and Construction: not only does this include the investment cost for architecture, engineering, and blue-collar trade work, but also the cost of land acquisition and fees for legal consultation and permits

2) Operation and Maintenance (O&M): examples include costs for energy and utilities, as well as for O&M employees

3) Disposal or Demolition: this is generally not a significant cost in most cases, such as placing aircraft in a desert storage area. However, there are unique circumstances, such as the disposal of nuclear power plants which present expensive disposal costs.

One way to quantity life cycle costs is with the equation below.

$NPV = C + R - S + A + M + E$

C = investment costs
R = replacement costs
S = the resale or salvage value at the end of the study period
A = annually recurring operating, maintenance and repair costs (except energy costs)
M = non-annually recurring operating, maintenance, and repair costs (except energy costs)
E = energy costs

NPV is also called present worth and is in the dollar amount for the current year of the design or study effort. The investment cost will also include land acquisition and development, including the permit application process. Replacement cost may apply if making a comparison between two systems that have different service lives. For example, if the life cycle cost comparison is based on the desired 50-year life, and one system has a 25-year life, then the NPV needs to account for one replacement of that system within the 50-year period. The railroad tie example mentioned before accounts for replacement costs at year 10 for the wood ties; in comparison, the concrete ties do not need replacement during the 20-year life of the project. The NPV equation can be tailored as necessary, such as energy costs (E) may be included in annual recurring operating costs (A).

As a primer on life cycle costs, below is a notional case study of a building. It is meant to give a fundamental view of each step or component. Actual life cycle cost case studies are presented later for insulating a building and for flow control of a pumping system. The details for these actual case studies are included in the Appendices.

The construction cost of a commercial building includes land acquisition and excavation and is $150 per square foot. The building size is 50,000 square feet. The interest rate (i) is 4.5%. The project period or term (n) is 30 years; the building will be sold at the end of the term. The average cost for maintenance and operations (O&M) is $5 per square foot per year. The O&M costs include utility costs such as water and electricity. The design cost is 5% of the construction cost. There is a rehabilitation and remodeling cost of 20 years, and it is projected to be 25% of the present worth of the building. The O&M and rehabilitation and remodeling are meant to at least maintain the suitability of the building. As a conservative estimate, the salvage value at year 30 is 50% of the present worth. The owner of the commercial building intends to retire at year 30 and sell the building during the same year.

The present worth of the construction cost is calculated below and assumed to be paid upfront without having to take a loan.

$P_{construction}$ = $150 per square foot x 50,000 square feet = $7,500,000

The present worth of annual costs is based on a conversion from annual costs (A). The part of the equation below that is within the parenthesis is called the discount factor.

$$P_{O\&M} = A\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right)$$

$$P_{O\&M} = \frac{\$5}{\text{ft}^2 - \text{yr}} \times 50{,}000\ \text{ft}^2 \times \left(\frac{(1+0.045)^{30} - 1}{0.045(1+0.045)^{30}}\right)$$

$$P_{O\&M} = \frac{\$250{,}000}{\text{yr}} \times \left(\frac{2.75}{0.17}\right) = \$4{,}044{,}118$$

The present worth of the design (P_{design}) is 5% of $7,500,000, or $375,000.

The present worth of the rehab (P_{rehab}) is 25% of $7,500,000, or $1,875,000.

The present worth of salvage ($P_{salvage}$) is 50% of $7,500,00, or $3,750,000.

The total life cycle cost of the commercial building at present worth is $10,044,118.

$P_{total} = P_{construction} + P_{O\&M} + P_{design} + P_{rehab} - P_{salvage}$

P_{total} = $7,500,000 + $4,044,118 + $375,000 ...),044,118

How much a ... would be required to recover the ... mplex analysis, use P_{total} to calcul... xes. Convert P_{total} to A_{total}. The d...

If a 3% annual i...

i_{adj} = i + f + (i x f...

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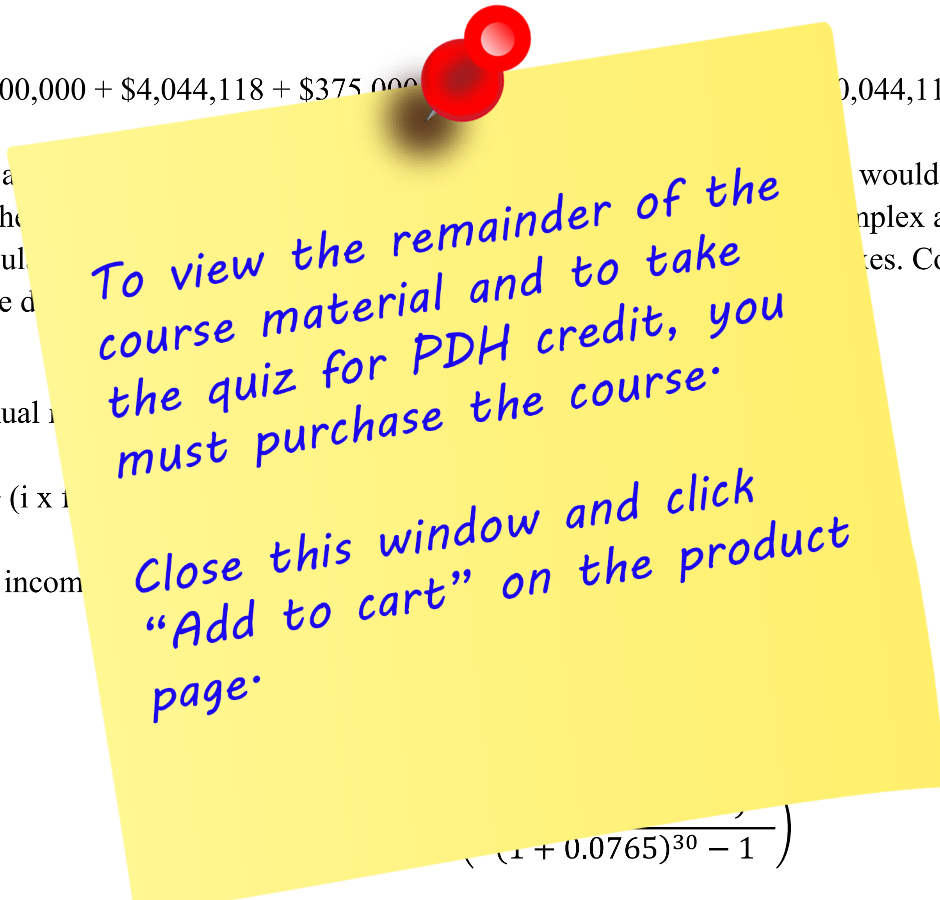

$$(1 + 0.0765)^{30} - 1$$

$$A_{total} = \$10{,}044{,}118\left(\frac{0.70}{8.13}\right) = \$864{,}807$$

The building would need to generate $864,807 of annual income to break even.

Interest rate (i) is based on the context of the life cycle cost analysis; it is sometimes called the discount rate. For business examples, the interest rate may represent the rate that reflects an investor's opportunity cost of money over time, meaning that an investor wants to achieve a return at least as high as that of the next best investment. Hence, the interest rate represents the