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In selecting process equipment, most engineers acknowledge the importance of trying to look beyond the actual purchase and consider future costs. But, few engineers know how to identify these, and the same is true for the vendors. So the initial purchase price, being more certain, often becomes the dominant or even sole input for the selection decision.

This is unfortunate because in many instances the initial cost proves to be a relatively insignificant component of the total cost incurred by a piece of equipment over its lifetime. The service life, energy consumption, product yield (when relevant), number of required spare parts, and cost and frequency of maintenance can all have an impact. The sum of the present values of the future costs attributable to these factors, plus the initial cost of the equipment, is often referred to as the Total Cost of Ownership (TCO).

Even though estimating the future costs may involve a considerable degree of educated guesswork, it is better to take them into account. Here we present a systematic method for doing so.

Laying the groundwork

The starting point for calculating TCO is the equation

$$TCO = IC + FC \times PVF \qquad (1)$$

where IC is initial cost, FC is future cost and PVF the present value factor.

The PVF determines the present value of a future cost. For a single future cost,

$$PVF(1) = 1/(1+i)^N \qquad (2)$$

where $PVF(1)$ is the present value factor for a single future cost, i is the applicable annual interest rate (reflecting either the cost of capital for the business or the expected internal rate of return) and N is the number of years into the future at which the cost occurs.

If the future cost instead reoccurs on a regular basis (for example, annual maintenance costs, or biennial replacement costs),

$$PVF(r) = [(1+z)^n - 1]/z(1+z)^n \qquad (3)$$

where $PVF(r)$ is the present value factor for repeating future costs, n is the number of times the future cost repeats over the service life of the equipment, and z is the applicable interest rate for the period between future costs. The last-named term can be found as follows:

$$z = (1+i)^p - 1 \qquad (4)$$

where p is the period of time, in years, that elapses between each repeating future cost.

For simplicity, the equations in this article do not distinguish between operating expenses and depreciable capital investments. The tax effects, and thus the net cost, of investments and expenses will vary depending on the depreciation and tax structures applicable to each company. The equations can easily be modified to take into account these and other specific circumstances, as well as any constraints specific to any given plant.

The initial cost may be just the tip of the iceberg

Initial cost

The initial cost (IC) of a piece of equipment has four components. These are selection, actual purchase outlay, installation and startup.

Selection costs: These must cover the resources needed to determine the process requirements, write the specifications, issue and evaluate the bids and alternative proposals, produce and study any drawings or other required equipment documents, and choose and, in some cases, test the equipment.

These costs may be significant. In many cases, however, the equipment vendor now absorbs some of them as a consequence of a supplier-partnership relationship with the customer.

The selection cost is of course larger for major projects than for day-to-day upkeep and repair operations. However, as a percentage of total cost, the selection costs for the latter are often much higher than for project work.

Actual purchase outlay: As already indicated, this is the most visible and easily measured component of TCO.

Installation and startup costs: It is difficult to generalize about these. They differ greatly, according to not only the type of equipment that is involved but also the different designs available for a given kind of equipment.

This latter point is especially true for instrumentation. For example, some microprocessor-based instruments may require only a single pair of wires to establish two-way communication between the field and the control room, whereas other options may entail far more complexity. Similarly, some instruments may be easier to modify and debug, which streamlines the startup. (It also reduces the future maintenance and operating costs, discussed below.)

In summary, one may expand the IC term in Equation 1 above as follows:

$$IC = E + Se + In \qquad (5)$$

where E is the actual purchase outlay (i.e., the equipment purchase price), Se represents the selection costs, and the In term stands for the installation and startup costs.

Future costs*

As pointed out earlier, this is the more-speculative, but at the same time the more-important, element of TCO. It

*The potential future cost of accidents and outage is not considered in this article. Such cost may stem from lost production, equipment damage, cleanup, regulatory penalties, and lawsuits. The likelihood of such an occurrence being caused by a given piece of equipment is small; conversely, the cost of the occurrence would in many cases be so large as to overshadow any other elements of the TCO. If an equipment alternative under consideration seems more likely to cause such an event than do the other options, it is wise to eliminate that alternative from consideration.

EQUIPMENT CO$TS:

An equipment purchase takes in a wide range of factores

VALVE	A	B	C
Equipment life, yr	20	20	20
Time between maintenance (*p*), yr	2	3	4
Applicable interest rate (*i*)	0.12	0.12	0.12
Initial purchase price (*E*), $	1,900	2,000	2,500
Selection cost (*Se*), $	250	250	250
Installation cost (*In*), $	150	150	150
Maintenance labor rate (*H*), $/h	50	50	50
Maintenance hours required (*T*)	11	9	9
Additional spare parts cost (*S*), $	500	500	500
Cost of purchasing spare parts (*C*), $	80	80	80
Spare parts stocking cost (*B*), $	90	90	90
Additional number of spare parts (*Q*)	15	3	0
Annual operating cost difference (*K*), $	43	60	43
Total cost of ownership (*TCO*), $	17,134	7,591	4,831
Initial cost (*IC*), $	2,300	2,400	2,900
Present value: maintenance costs (*PVM*), $	3,981	2,279	1,610
Present value: carrying spare parts (*PVS*), $	10,532	2,464	0
Present value: operating costs (*PVO*), $	321	448	321

TABLE 1. Example comparing three control-valve options brings out the importance of taking future costs into account. They can dramatically affect the total cost of ownership

consists of maintenance, spare parts inventory, and operation costs.

Maintenance costs: These depend on the frequency of maintenance, the labor hours required to perform it, and the labor rate per hour. The frequency should be estimated from records of past experience with the vendor's equipment or with the same type of equipment in the particular service.

Many modern equipment designs promise to reduce the maintenance frequency. For example, numerous process pumps offer features that extend the mean time between required maintenance by a factor of two or more. And various valve-packing systems designed to meet the U.S. Environmental Protection Agency's fugitive-emission standards require no service or adjustments before the rest of the valve needs maintenance. In weighing such features, however, the engineer must make sure that they are applicable in his or her particular situation.

Labor-hour estimates must take into account not only the actual repair but also the time needed to de-pressurize and clean the equipment, remove it from the system, transport it to the shop (if necessary), re-install it, and restart the system. Time required for maintenance personnel to arrive at the operating unit, organize their tools and special repair equipment, study the manuals, and take breaks and clean up, should also be considered.

The process plant's own operation and maintenance staff is ordinarily the best source for labor-hour estimates. While equipment vendors may offer such information, their figures are usually low because the vendors overestimate the customer's familiarity with the equipment. Also, the vendor is not aware of the customer's plant layout, working practices, and repair equipment. Vendors may, however, be helpful in supplying input for comparing maintenance procedures between different design alternates.

The maintenance-labor wage rates should come from the plant accountant. Be sure that the figures he or she gives you include overhead.

The present value of future maintenance costs is, thus,

$$PVM = PVF(r) \times (H \times T + S + C) \quad (6)$$

where PVM is present value of future maintenance costs, H is hourly maintenance labor cost, T is time required to perform maintenance, S is the purchase price of parts required to perform the maintenance, C is the indirect cost of re-ordering the parts consumed (i.e., the resources required to issue a purchase order, receive the material, and issue a check for payment). The value for $PVF(r)$ is found from Equation 3 above, where in this case p stands for the predicted maintenance interval, in years, and n equals the service life of the operating unit divided by the maintenance interval.*

Spare-parts-inventory costs: Unfortunately, engineers often ignore differences in carrying cost for spare parts when comparing alternate equipment. Such costs arise annually throughout the life of the operating unit. They consist of two elements: interest on the investment in owning the parts, and the overhead associated with operating the parts-storage facility.

The annual interest cost is the product of the inventory cost and the applicable interest rate. Annual overhead costs take into account the personnel required to operate and manage the storage facility, as well as the cost of providing and maintaining the facility and the storage racks.

These overhead costs are usually allocated in either of two ways: an equal amount for each item stocked, or a prorating scheme that assigns the more-expensive and more-frequently-purchased parts a greater share of the total. Many experts consider the first approach the more realistic, because the handling and storage costs are related more to the mere existence of a part than to its cost or size.

Based on this "equal amount per item stocked" option, the present value of spare parts carrying costs is

$$PVS = PVF(r) \times Q\,[(S \times i/Q) + B] \quad (7)$$

where PVS is the present value of spare parts carrying costs, Q the increase in the number of spare parts required due to buying the equipment, S the increased cost of spare parts inventory, i the annual interest rate and B the annual overhead cost per parts item

*Alternatively, one can obtain a simple approximation of maintenance costs by dividing the total annual maintenance- department budget, (excluding direct material costs), by the number of direct hours of maintenance work performed. This approach has an added virtue — it takes into account not only the labor costs, but also the costs of supervision, maintenance tools and equipment, and upkeep of the maintenance shop itself. For most plants today, these costs are in the vicinity of $50/h.

Sensitivity analyses enable "what if" explorations regarding TCO

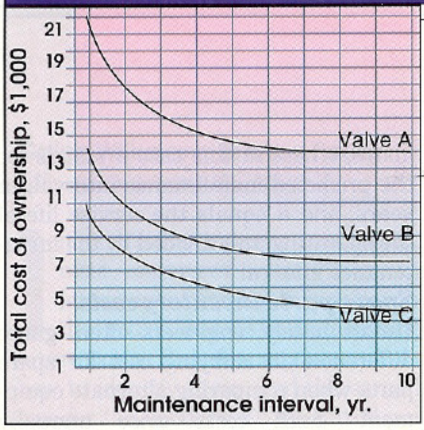

FIGURE 1. The numerical findings presented in Table 1 would be affected if the maintenance intervals for the three cases took on different values

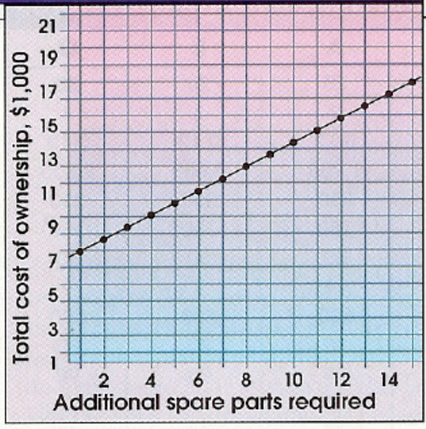

FIGURE 2. The total cost of ownership (illustrated in this graph for valve A from Table 1) may rise notably with the number of spare parts the equipment requires

stocked. In this case, $PVF(r)$ is based on the annual applicable interest, i, and the service life of the process unit. The value of p is 1, so z equals i (Equation 4).

In Equation 7, we use the expression $Q\,[S \times i/Q + B]$ rather than the simpler $[S \times i + B \times Q]$. Our construction makes it clearer that the expression equals zero if the equipment purchase does not entail buying additional spare parts. Such a situation can arise if the new equipment duplicates equipment already used on the site. As shown later, this can strikingly lower TCO.

Operating costs. Operating costs associated with a piece of equipment generally include its energy consumption, and any loss in product yield that may be attributable to its use. Typically, operating cost is calculated by difference: the predicted performance of one of the equipment alternatives being considered is taken as the standard, and the predicted performance of each of the other alternatives is related to it.

With this approach, the present value of the annual operating cost is

$$PVO = PVF(r) \times K \qquad (8)$$

where PVO is the present value of the annual operating cost and K the estimated difference in annual operating cost. Here, $PVF(r)$ is based on the applicable annual interest rate and the service life of the process unit. As with Equation 7, p equals 1 so z equals i.

Putting it together

Substituting Equations 5, 6, 7 and 8 into Equation 1 yields

$$TCO = IC + PVM + PVS + PVO$$

To illustrate the insights offered by this approach, we present in Table 1 hypothetical but realistic cost estimates for three control valves. For each, the table shows the calculated TCO as well as the four elements that make up that total. The calculations demonstrate that the initial cost can be a small part of the TCO, as can the operating cost. They also show that the carrying costs for spare parts can exceed all other components of TCO.

Sensitivity analysis

Prudent readers may well be skeptical about the assertion that initial cost can be of limited importance. For example, one may wonder how much an overestimate of the future costs of maintenance and spare parts might skew the example just presented.

Sensitivity analyses can shed light on this question. Analogous to taking partial derivatives, such analyses indicate (in this particular case) how the total cost of ownership is affected by changes in the variables and factors that make it up.

Table 1 suggests that two factors of particular significance are the maintenance interval and the spare-parts inventory. Sensitivity analysis of the maintenance interval for each valve appears in Figure 1.

This figure shows that while sizable changes in maintenance interval might admittedly affect the tradeoff between valves B and C, the unattractive relative ranking of valve A is for all practical purposes unaffected. It also reveals that for the set of conditions in Table 1, the added economic benefit of extending maintenance intervals beyond about 5 years is limited.

Figure 2 shows for a given valve (in this case, valve A) how TCO is affected by the number of different spare parts that must be inventoried. It confirms that the TCO for valve A can be reduced substantially by a drop in the number of additional spare parts required.

Wrapup

The best way to minimize cost of ownership is to calculate TCO for each equipment-purchase alternative. Unfortunately, this strategy often isn't practical, due to lack of sufficient data.

Even so, using the TCO equations forces the decisionmaker to consider costs besides purchase price. And, the equations can help find the critical cost elements in equipment alternatives.

For example, we see that spare-parts inventory cannot be ignored. One effect of this may be to enhance the attractiveness of spare parts kits (if these are offered by any of the vendors under consideration), which can reduce inventory carrying costs compared to storing individual parts. It also strengthens the rationale for selecting equipment similar or identical to equipment that is already used in the plant.

The services that a vendor offers may reduce the indirect costs required to select, purchase, install and start-up the equipment. These savings may more than offset a higher price for that equipment. Finally, equipment that promises a relatively long interval between maintenance, or will require fewer resources for diagnosing and remedying problems, may have a low total cost of ownership. ■

Edited by Nicholas P. Chopey

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