Feature Report

Lifecycle Costs for Capital Equipment In the CPI

Longterm equipment costs need to be fully considered in capital-cost assessments

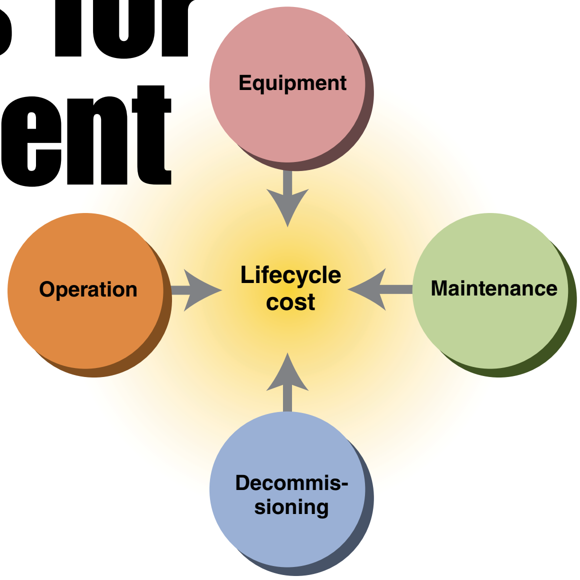

FIGURE 1. Initial capital costs alone are too often the primary criteria for selecting process equipment

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When considering project proposals for new processes in the chemical process industries (CPI), capital equipment costs often become the primary focus. The purpose of this article is to provide a detailed examination of the cost of process equipment and the implications that the initial equipment cost has for longterm costs over the life of the process.

When the lifetime of a process is considered, equipment costs may account for as little as 5–10% of the total cost (Figure 1). Other critical costs to consider include installation, operation, utility, maintenance and decommissioning. Since a process generates revenue only when it is operating, downtime must be added to the total costs.

There are a number of questions that should be considered before moving ahead with projects. Defining the product output, quality, unit operations, support equipment and profitability? Who is responsible for operating and maintaining the process? Do the demands for process performance conflict with operating and maintenance realities? What is the likelihood the equipment will operate trouble-free? Are replacement parts available for both routine and non-routine maintenance?

Minimizing total cost

The emphasis on total operating costs over the life of a process does not imply that the initial equipment costs are unimportant. On the contrary, it is precisely the investment in the correct equipment in the first place that is to be examined. The purpose of the procurement of process equipment is to perform a particular unit operation. The goal is not the purchase of a particular piece of equipment. If we add the dimension of time, then our definition for process equipment becomes a piece of equipment that performs a specific function under various condistions over a prescribed period of time. Therefore, we should not focus on equipment with the lowest initial cost, but rather on the realistic longterm cost of that purchase.

In the early 1980s, Edward Deming — the father of quality management — stated that organizations should "end the practice of awarding business on the basis of price tag alone and, instead, minimize the total cost." This sentiment is consistent with evaluating lifecycle cost.

Lifecycle cost

The purpose of lifecycle-cost (LCC) analysis is to make informed decisions based on available alternatives in order to achieve the most economical process from inception to decommissioning. LCC takes into account the design, equipment selection, operation, maintenance and final disposition costs of a project over its lifespan (Figure 2). LCC is useful for engineers to justify equipment and process design based on total costs rather than the initial purchase price of equipment alone.

Procurement strategies focused on lowest initial costs are more likely to lead to higher longterm costs. We are often directed to reduce costs and work within budgets. In the short run, this approach can make us and our department appear efficient. However, the lower capital costs may come with maintenance or other problems that eventually will be realized by the company shareholders in the coming years and decades. LCC can help avoid unnecessary downtime and help make a process more competitive and profitable. At the very least, an LCC analysis may prompt engineers to consider a wider range of possibilities.

The remainder of this article pres-

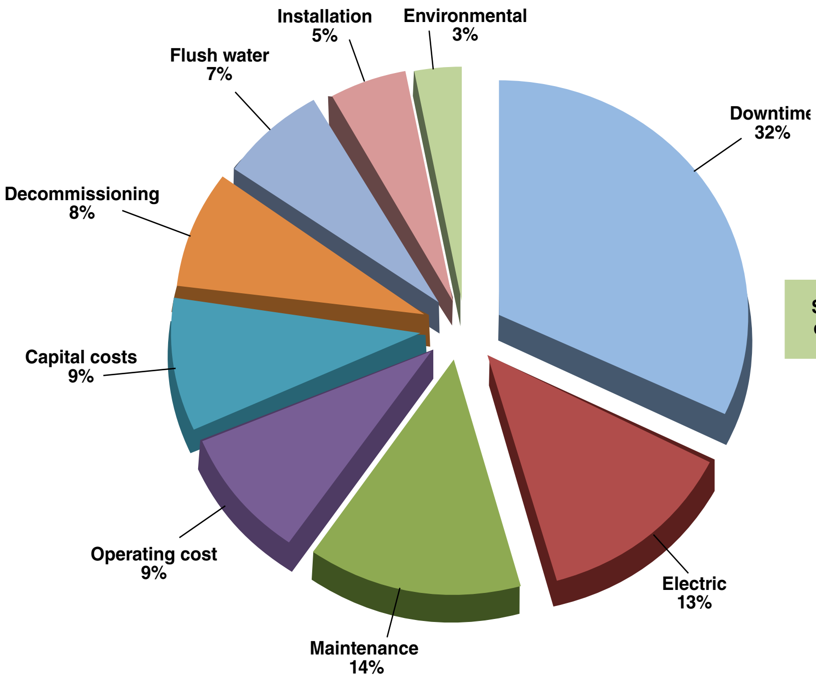

FIGURE 2. Initial capital costs represent a small fraction of the total lifecycle costs for process equipment. Operating costs, maintenance and cost of downtime can contribute more heavily to the total

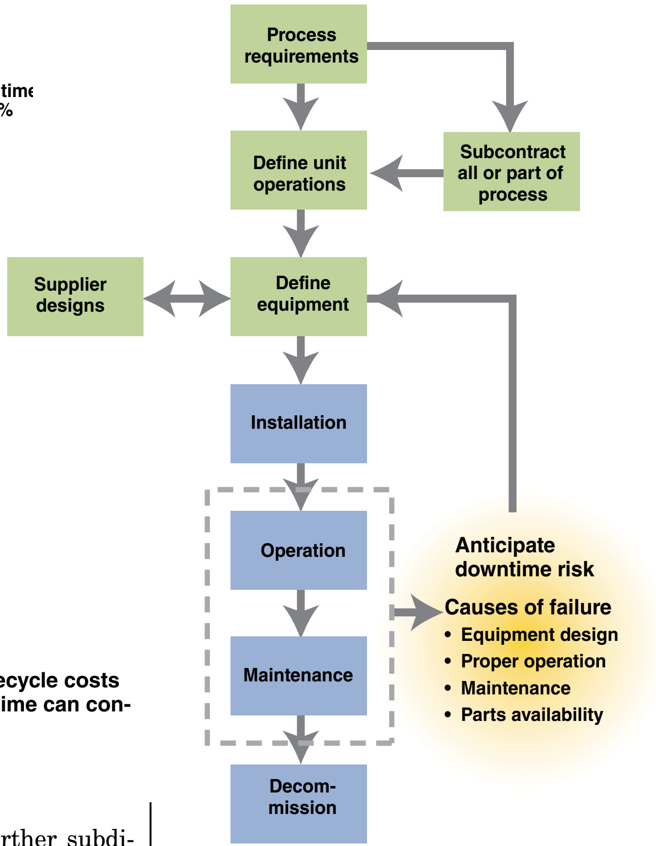

FIGURE 3. The LCC analysis process shown here is designed to minimize total cost, even if initial capital costs are higher

ents a more-or-less qualitative view of the LCC analysis process and the elements that go into LCC. The "Further reading" list at the end of the article refers readers to more analytic versions of LCC, including Weibull analysis, risk-based cost analysis, Monte Carlo modeling, and other "what-if" analyses.

The main goals of LCC are: 1) To identify risks to process operation and efficiency; 2) Quantify these risks in terms of downtime; and 3) Determine how to avoid these risks and subsequent losses early in the design of the system.

LCC for the CPI

Of all the industries and all the types of manufacturing plants in the world, it is safe to say that the process industries are some of the most variable and complex. With more than 36 million identifiable chemicals and a near-infinite number of combinations, and given the number of unit operations possible, there are many opportunities to examine process costs. The four primary components involved in the LCC are:

- Capital equipment costs
- Operating costs
- Maintenance costs
- Decommissioning costs

These components are further subdivided, as shown in Figure 3.

STEPS IN LCC ANALYSIS

LCC considers everything in the life of a process, starting with a definition of the process, its unit operations, and the equipment required to fulfill those unit operations, as well as operating costs, maintenance costs and finally decommissioning costs. The following are the major steps involved in determining LCC.

Assess process requirements.

Tasks to consider when undertaking a new process include the following:

- Determine present and future capacity for the product
- Anticipate the lifetime of the process. Some processes may have a lifespan of anywhere from a year or two to decades. Anticipating process lifetime will either concentrate or extend cost impacts and affect the long-term maintenance and reliability of the process
- Define product quality based on customer requirements
- Determine process flexibility. How easily can the equipment and system be modified to accommodate increased output, changes in formulation or the addition of a step in the process?
- Quantify waste. What percent waste is acceptable? What is the cost of waste disposal? How can waste be minimized by a change in the process? Can off-specification product be reprocessed or sold "off-spec" to a different market?

Define unit operations

This step involves identifying the unit operations and types of equipment required by the process.

Subcontract. Subcontracting one or more operations in a process is something often overlooked, but can increase cost efficiencies and flexibility. Few manufacturers of process equipment manufacture everything — motors, gear drives and bearings are not manufactured in-house. Likewise, chemical companies do not manufacture all of their raw materials, nor do they necessarily perform all tasks in-house. Subcontracting is, for most businesses, a matter of degree rather than a yes-or-no decision. Some steps in a process may not be cost-effective to execute in-house. For example, high-pressure reactors, spray-drying or packaging may best be outsourced, at least until the operation grows and the investment can be better justified.

Continuous, batch or a combination. The decision for a continuous or batch process (or a combination of the two) is sometimes dictated by the process, and sometimes optional. Within this decision, a set of factors should be considered:

- Continuous process operations can often have much higher output and may require less equipment, but they may have more variability in quality and reworking off-spec product in a continuous process may be difficult
- Batch operations may require more storage and intermediate buffer tanks and larger equipment, but they have the advantage of consistency and often have a better chance to re-work off-spec product

Storage strategy. A storage strategy should be creatd. Can the finished product be stored and, if so, can the downstream process or packaging accommodate a surge in capacity?

Process bottlenecks. Which aspects of the process have the most variation? Liquid mixing is fairly consistent, whereas solids drying can vary considerably with particle size. Does a dryer need excess capacity? Evaporator capacity can fall off quickly due to tube fouling either on the product or heat-transfer-fluid side. In the example on page 39 (Figure 5), the performance of the evaporator falling below 800 gal/min can be the result of scale build-up or fouling. Investing in a water demineralization system may be worthwhile if the bottleneck affects productivity and profitability. Likewise, too large an evaporator with low velocity may be more prone to fouling. Bigger is not always better.

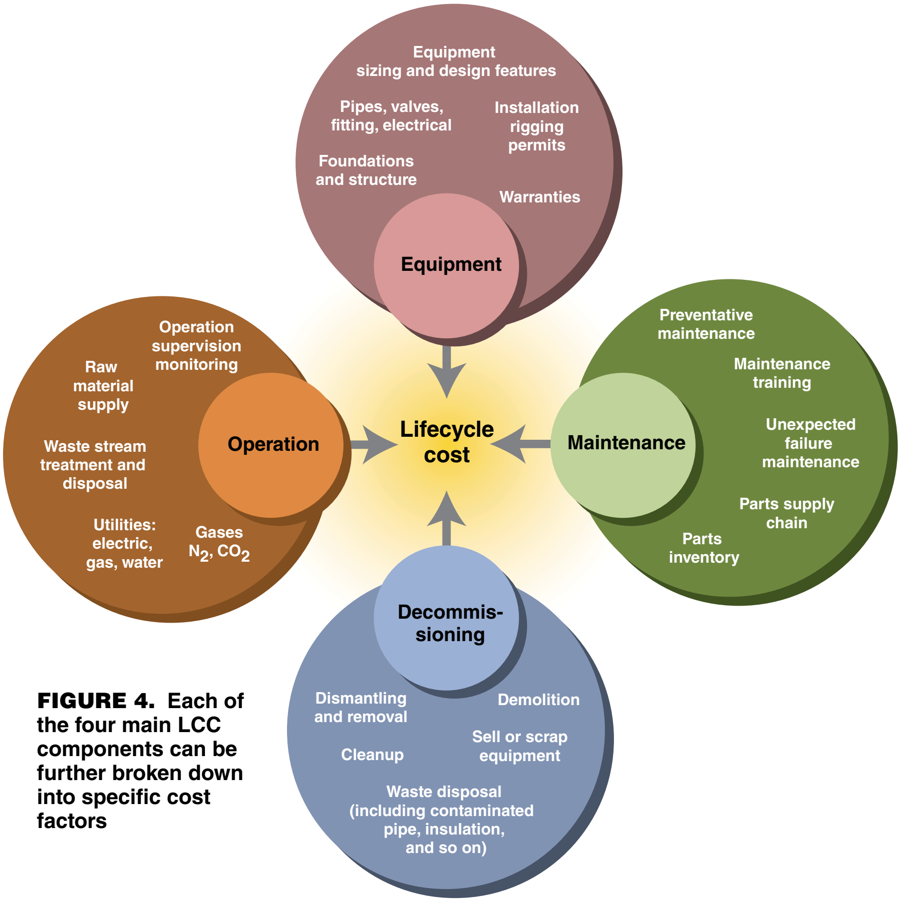

FIGURE 4. Each of the four main LCC components can be further broken down into specific cost factors

Define required equipment

Process equipment has many variations in basic design and design options. Discuss your requirements with equipment manufacturers and gather information on: performance; design; options; installation; foundation and support requirements; utility requirements; mean-time between failures; and recommended spare parts for the first few years of operation. This is also the time to start gathering information on refurbished and used equipment (discussed later). The steps are as follows:

1) Identify suppliers and dealers for new versus used versus reconditioned equipment. Identify alternate designs (for example, shell-and-tube versus plate-and-frame heat exchanger, or fluid-bed versus vacuum dryer).

2) Identify design features that may improve product quality, increase uptime and reduce maintenance. These might include automatic lubrication, and monitoring devices for vibration, over-temperature and low-level protection. Evaluate whether a clean-in-place (CIP) system would be cost-effective, or whether the equipment would be better cleaned manually. Also, it is important to understand what level of operator exposure to product and cleaning chemicals is acceptable. Other options might include maintenance-reducing features, such as additional access hatches, sight glasses and lights, split seals and bearings and replaceable wear liners.

Equipment installation

Installation costs may equal or exceed equipment costs, depending on the size and complexity of the equipment. An important consideration during the layout and installation of equipment is the accessibility to allow preventive maintenance and future repair. Sufficient space must be provided for the extraction of shafts, rotors and motors, as well as to provide access to seals and bearings. Overhead structure should allow for portable hoisting chains or permanently installed hoists.

Although not routine, anticipating the removal of large pieces of equipment should not be made impossible by physical constraints. Without clear access, preventative maintenance may suffer and repair time may be ex-

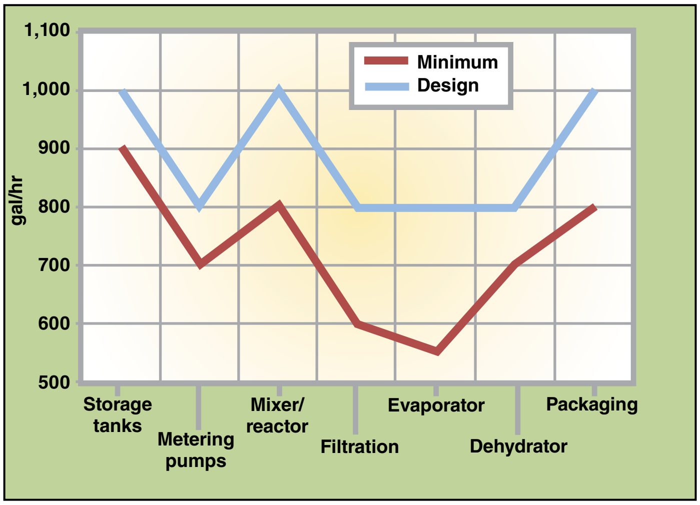

FIGURE 5. Certain aspects of a process have higher potential to present process bottlenecks than others

tended. Factors involved in the installation cost may include the following:
- Machine foundations
- Accessibility for maintenance and repair
- Support structures and mezzanines
- Piping, valves and fittings
- Instrumentation
- Electrical controls
- Monitoring equipment
- Electrical switchgear

Operation

Operation and maintenance are two areas that are critical to avoiding downtime and both are affected by equipment selection, design and operating procedures.

If the equipment was sized properly, there should be no reason to operate it beyond safe design capacities. Many types of equipment are tested at, or designed for 150 to 200% of the rated capacity, but operating at these capacities may risk shortening the life of the equipment. Other aspects of operation costs include the training of operations personnel, utilities (electricity, gas, water, steam and cooling tower capacity) and the time that the equipment is offline for preventative maintenance.

The costs of raw materials, water treatment (demineralizing, pH adjustment), purge gas (N_2, CO_2) and waste disposal are also key operations costs. Most CPI processes, even in the food industry, have to dispose of waste product or waste streams from washing, off-specification product or simply contaminated water coming from a wash step.

Maintenance

Generally, maintenance can be classified into two types: preventative and repair. Some failures occur randomly and cannot be predicted, but other failures occur as a result of lack of preventative maintenance (PM).

PM is an area that has evolved into a service that can be subcontracted and may be economical when considering the total longterm value provided. PM companies often have superior knowledge of pumps, drives, lubrication and routine maintenance issues, including good record keeping. The PM record keeping can also help support any warranty claims and avoid disputes with original equipment manufacturers (OEMs). The cost of subcontracting PM must be considered against the benefits of avoiding downtime. Parts availability is important in avoiding downtime both for PM and unexpected failures. Questions to consider in having parts available when required are the following:
- Do you know your parts' supply chain?
- Do you know your OEM parts and service contacts?
- Are you considering non-OEM or counterfeit parts?
- Do you have a recommend parts list for each machine for the first few years of operation?
- What are the availability of standard parts?
- What is the availability of special non-standard parts?
- What is the cost to purchase and stock the recommended parts?
- Will your OEM put consigned stock in your facility? What is involved in administering consigned stock? Are you prepared to safely store and protect the parts?
- What is the cost to stock parts for catastrophic failures? Some large parts, such as motors, gear drives or centrifuge scrolls and bowls, can take weeks or months to obtain. The low probability of failure may be offset by the very long lead times and may require investment in costly parts that may sit on the shelf for years.
- Is maintenance staff knowledgeable and prepared to identify symptoms of failure early, and diagnose and repair issues quickly and correctly the first time? Check with the OEM for guidance and training. Do you have the installation and operating manuals on file? Have they been thoroughly reviewed?
- What are the anticipated preventative maintenance intervals?
- What is the expected time between failures for seals, bearings, belt adjustment, filter replacement and so on?
- Should all or some PM be outsourced?
- Does the OEM offer PM services?
- What is the repair turnaround time for a specific failure?

Decommissioning

The concept of decommissioning is not something most engineers tend to consider as they are designing a plant, but some plants will have finite lives of just a few years due to licensing agreements, patents, changes in markets or plans to shift to overseas production in the future.

Planning for decommissioning a process plant can vary from planning to simple tear-down and selling of equipment to preparing for a sophisticated decontamination procedure. Chemical process equipment has special considerations that can increase the cost of decommissioning. Not only will waste material have to be disposed of, but piping, insulation and flooring may have to

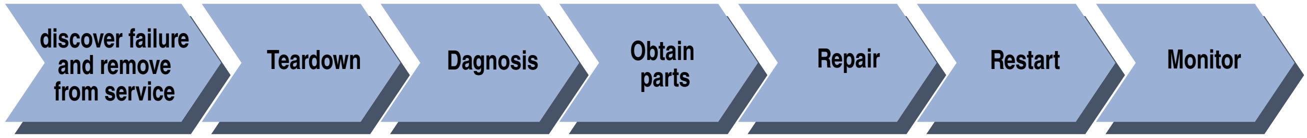

FIGURE 6. Downtime represents one of the most significant and costly issues for many processes

be decontaminated or treated as hazardous waste.

Other costs of decommissioning include dismantling of equipment, waste disposal of chemicals (unused chemicals, water-treatment and cleaning chemicals, as well as those in above- and below-ground tanks, evaporation ponds and contaminated pipes) and disposing of used valves, insulation and flooring.

Costs of downtime

Process downtime is one of the most significant and costly issues for many processes. To properly take into account the costs of downtime over the life of the process, engineers must estimate how much cost is accrued if the process fails, either in whole or in part. Further, once it fails, the question becomes how long will it take to restore operation?

In terms of equipment selection and design, which equipment and design features will be less likely to cause downtime? Which will be most easily maintained? How quickly can an expected failure be repaired so the equipment can be put back in service?

The risks and costs of process downtime can be considered in a semi-quantitative form by examining the likelihood of an event occurring in a given time period and the cost per unit time of that failure.

$$\textit{Downtime Cost} = \textit{frequency of failure / year} \times \textit{downtime / days} \times \textit{\$ losses / day}$$

Downtime starts with the failure of the equipment and stops when it is put back in service. Better maintenance training can reduce the diagnosis and repair time significantly. The basic sequence is discovery of a failure, teardown, diagnosis, obtaining parts, repair and restart and monitoring (Figure 6).

Events per year	$100	$1,000	$10,000	$100,000	$1,000,000
5	$500	$5,000	$50,000	$500,000	$5,000,000
4	$400	$4,000	$40,000	$400,000	$4,000,000
3	$300	$3,000	$30,000	$300,000	$3,000,000
2	$200	$2,000	$20,000	$200,000	$2,000,000
1	$100	$1,000	$10,000	$100,000	$1,000,000

Cost of event

FIGURE 7. A matrix can help quantify the costs of downtime in a process

A factor with the greatest impact on reducing downtime is availability of parts. The parts may be common, such as O-rings or gaskets, seals or bearings, or they may be less common parts, such as pump housings or drive shafts.

If a complete shutdown costs $100,000 per day, the expected frequency of a catastrophic shutdown three times per year is $300,000. For a non-critical failure that reduces productivity, but does not shut down the process entirely, the event cost would be $50,000, with a frequency of five times per year at a cost of $10,000 (Figure 7).

The following examples (Figure 8 and Table 1) emphasize maintenance training and parts availability in the prevention of downtime. Suppose the additional cost of training and parts is $80,000. With downtime cost at $20,000 per day, the investment of $80,000 saved $86,000 compared to without the training and parts after just one outage event.

In a second example, a $70,000 design feature that downtime by making a routine and expected part replacement faster, from three days to one day. Over the 10-year life of the process, the saving is $890,000.

That represents the costs of just one critical unit operation and one design feature. When considering similar analyses across an entire plant, the cost savings can be substantial.

NEW, USED, REFURBISHED?

There is a saying that all process plants run on used equipment, and that is true. The LCC analysis is not prejudiced with regard to used or refurbished equipment — LCC considers the balance of downtime prevention and investment in equipment and preventative maintenance. If you know your process requirements and have the resources to keep used equipment functioning as reliably as necessary, then used or refurbished equipment is the right choice. There are several LCC issues to consider when deciding between new, refurbished and used equipment.

Not all buyers are in a position to purchase new equipment because of cost considerations or time. Used equipment may also be the appropriate alternative when time is a consideration, either in terms of de-

Sequential step	Event	Dwell time, days: Scenario 1	Dwell time, days: Scenario 2	Preventative action	Annual cost
1	*Discover failure*	1	0.1	Maintenance training	$ 30,000
2	*Teardown*	1	0.5	Maintenance training	
3	*Diagnosis*	1	0.5	Maintenance training	
4	*Accquire parts*	5	0.1	Parts in stock	$ 50,000
5	*Repair*	1	0.5	Maintenance training	
6	*Re-start*	1	0.5	Maintenance training	
7	*Monitor*	1	0.5	Maintenance training	
	Total days of downtime	11	2.7		$ 80,000
	Investment in training and parts	$0	$80,000		
	Downtime cost $20,000/day	$220,000	$54,000		
	Total	$220,000	$134,000		
	Additional cost of lack of preparation	$86,000			

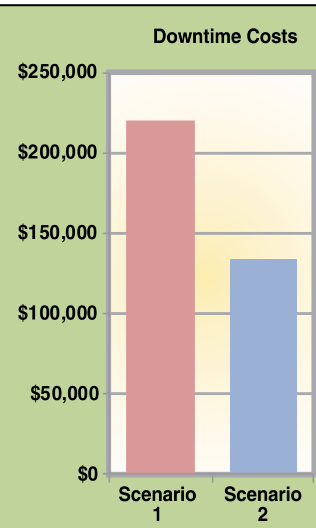

FIGURE 8. Different downtime scenarios for availability of parts and other factors can yield variable costs

TABLE 1. THE IMPACT OF VARYING DOWNTIME COSTS

Scenario 1 High-pressure reactor mixer	Year 1	2	3	4	5	6	7	8	9	10	**Total**
Initial capital costs	$380,000										$380,000
Installation and commissioning	$230,000										$230,000
Utilities - electric ($0.12/kwh)	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$600,000
- flush water ($0.04/gal.)	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$300,000
Operating costs (normal supervision)	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$400,000
Maintenance costs	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$600,000
Downtime costs ($48,000/d x 3 d)	$144,000	$144,000	$144,000	$144,000	$144,000	$144,000	$144,000	$144,000	$144,000	$144,000	$1,440,000
Environmental costs	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$130,000
Decommissioning										$350,000	$360,000
Total	$347,000	$347,000	$347,000	$347,000	$347,000	$347,000	$347,000	$347,000	$347,000	$697,000	$4,430,000

Scenario 2 High-pressure reactor mixer	Year 1	2	3	4	5	6	7	8	9	10	**Total**
Initial capital costs	$380,000										$450,000
Split seal and bearing option	$70,000										
Installation and commissioning	$230,000										$230,000
Utilities - electric ($0.12/kWh)	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$600,000
- flush water ($0.04/gal)	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$30,000	$300,000
Operating costs (normal supervision)	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$40,000	$400,000
Maintenance costs	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$60,000	$600,000
Downtime costs ($48,000/d x 1 d)	$48,000	$48,000	$48,000	$48,000	$148,000	$48,000	$48,000	$48,000	$48,000	$48,000	$480,000
Environmental costs	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$13,000	$130,000
Decommissioning										$350,000	$350,000
Total	$931,000	$251,000	$251,000	$251,000	$251,000	$251,000	$251,000	$251,000	$251,000	$601,000	$3,540,000

livery or usage. Used equipment is frequently available for immediate delivery, compared to the relatively long lead times that are typical of new capital equipment. In these cases, used equipment may provide the optimal alternative (Table 2).

The following scenarios favor the purchasing of used or refurbished equipment:

- Price is of prime importance because of investment limitations
- The equipment is needed immediately for an emerging market
- The equipment will be used for a limited time, such as a feasibility study or short-production run for a special product or market
- The equipment can be economically modified to fit the purpose. This will have a lot to do with your ability to refurbish and maintain the equipment
- The process is routine, low output or low risk. Infrequently run equipment will have more opportunity for PM and will be more "forgiving"

TABLE 2. COMPARISON OF NEW, USED AND REFURBISHED EQUIPMENT

	New	Refurbished	Used
Application assistance	Application definition and machine design	Limited	Limited to none
Design features	Unlimited	Some variations or modifications possible as part of the rebuild process	None (whatever is in stock)
Delivery	4–8 months	1–2 months	Immediate
Price	100%	40–50% of new	20–40% of new
Mechanical warranty	12 months from installation or 18 months from shipment	90 days to a few months	None ("as is")
Right to return	None	None	10–30 days
Parts availability	In-stock or readily available	The fact that the unit is being refurbished indicates that parts are available from the OEM. Variable parts availability	Call OEM and find out how available parts are before purchasing. Parts availability diminishes with time
Aftermarket technical support	Complete technical support	Limited	None

Aftermarket support

Most companies that manufacture process equipment would rather sell new, but most are quite pleased to support their older equipment.

Not every company has the same business model. The same company mentioned above has a European competitor who tends to obsolete equipment after 10 years and charge higher prices for the spare parts. It is important to know your equipment and the parts supply chain.

The following are some areas of comparison that must be considered between new, refurbished or used equipment:

Aftermarket parts. This is a very-important consideration for maintenance and repair turnaround time. No matter if you are considering new or used equipment, you should contact the OEM to find out the availability of parts. It is especially important to be sure you can obtain parts when needed, especially if the OEM is located in another country. Trying to get parts for an overseas machine made 30 years ago, for example, may be a challenge. Is the company still in business? Where are their foreign offices? Some resourceful companies have recognized a gap in the supply chain and decided to manufacture parts for older domestic or foreign equipment. Once you find them, you may be in good shape.

Aftermarket technical support. With new equipment, the availability of good aftersale support is almost assured. But when purchasing used equipment, the OEM may or may not provide adequate technical support. Find out if drawings, manuals and parts lists are available. They may charge $500 to $1,000 for these documents, but it is a good investment to ensure you have the right information on hand.

Application assistance. There is no doubt that a new equipment manufacturer has a vested interest in guiding you toward the correct equipment for your application. Due to the nature of chemical processing, subtle changes in product characteristics can have significant effects on the process and the equipment, which is why process guarantees are very rare. It is in the best interest of the OEM to help you acquire equipment that will accommodate your process.

Mechanical warranty. These are a certainty with new equipment, but their real purpose should not be overestimated. Warranties are not substitutes for proper operation or preventative maintenance and should not be construed as process guarantees. Mechanical warranties provide benefits especially during the initial startup period. If faults arise, they will likely occur during the initial warranty period.

Avoid surprises and disappointment by verifying the specifics of the warranties before purchasing.

Delivery timing. The delivery time for used equipment is typically just days, while new equipment will likely be months.

Design features. Within limits, new equipment can be outfitted with virtually every manner of control, CIP systems, quick access to internal parts, and other features to improve productivity and uptime. Used equipment is sold "as-is," so you will either need to find a good match or compromise on the features you would like to have. Refurbished equipment may present some opportunities for upgrades and modifications.

Price. New equipment is not expensive if you buy into Edward Deming's idea that you are purchasing *total* value. If you only consider price, then new equipment may appear to be more costly. LCC is blind to new versus used equipment, so let the risk data fall where they may.

Right to return. With new equipment, once you have placed the order, you are essentially committed to the equipment. Backing out after the initial deposit has been made will have some definite costs. If you buy refurbished equipment, you are also committed once a deposit is made and work is undertaken.

Most used equipment dealers will allow equipment returns within 10 to 30 days if it does not work as anticipated. All dealers differ, so it is important to ask specifically before making the purchase.

Concluding remarks

Understanding the lifecycle costs of one piece of equipment or an entire process requires examining not just the cost of the capital equipment, but also the operating, maintenance and decommissioning costs. The other major longterm cost is the cost of downtime compared to investments in training, preventative maintenance and spare parts. Lifecycle cost analysis can be done in a rudimentary fashion or it can employ complex what-if algorithms, but in either case, the benefits of taking a broader view of the factors that may impact the longterm cost of a process will benefit you and your company. ■

Edited by Scott Jenkins

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