ASSESSING INFRASTRUCTURE’S TRUE COSTS

Life cycle cost analysis is a critical, data-driven tool that engineers can use to make decisions about materials, maintenance, and operating costs that make the most of infrastructure investments over the long term. Here’s what engineers need to know to begin considering the use of life cycle cost techniques. •••• **By Robert L. Reid**

ACCORDING TO ASCE’s *2017 Infrastructure Report Card,* “[we] can no longer afford to defer investment in our nation’s infrastructure.” Instead, to close the existing investment gap, meet future needs, and restore America’s global competitive advantage, infrastructure owners and managers must charge—and the American people must be willing to pay—“rates and fees that reflect the true cost of using, maintaining, and improving all infrastructure, including our water, waste, transportation, and energy services,” the report explains.

But what exactly is the “true cost” of our infrastructure systems, especially when future maintenance and improvements are considered? Civil engineers are “pretty good at estimating what it costs to construct a project, but how good are we at estimating the maintenance costs over its life?” asks Gregory DiLoreto, P.E., P.L.S., D.WRE, Pres.13.ASCE, now retired after serving as the chief executive officer of the Tualatin Valley Water District in Portland, Oregon. “How good are we at estimating the replacement cost that will come at some point? That’s the piece we’ve got to get better at so that when we make a presentation to our elected officials or to a board of directors of a private company to approve a project, we can actually tell them that over the life of this project, ‘Here’s what it’s going to cost.’”

To answer such critical questions, engineers can utilize an approach called life cycle cost analysis, which was defined as “a data-driven tool that provides a detailed account of the total costs of a project over its expected life” in a 2014 report entitled *Maximizing the Value of Investments Using Life Cycle Cost Analysis.* Although that report, prepared by ASCE and the Eno Center for Transportation, based in Washington, D.C., focused on life cycle cost analysis in the transportation sector, many of its findings would probably sound familiar to engineers charged with the design, operation, or maintenance of other infrastructure systems. For example, the report noted: “When the cost of a project is estimated only for design and construction, the long-term costs associated with maintenance, operation, and the retiring of a project are often overlooked.” Likewise, the report contained the following warning: “Without careful examination of the full life cycle costs, investment decisions today could cost an agency even more in years ahead.”

Unfortunately, the report also stated, a series of surveys of public-sector entities involved in transportation infrastructure across the nation carried out during the spring of 2014 found that while nearly every respondent “agreed that [life cycle cost analysis] should be a part of the decision-making process . . . only 59 percent said they currently employ some form of it.” Barriers to the implementation of life cycle cost analysis included a lack of coordination “from the design through the operation stage” among the various parties within the respondents’ organizations, the report said. Likewise, 48 percent of respondents reported that predicting future costs within their organization was “extremely” difficult.

A subsequent survey of civil engineers conducted by ASCE mainly of engineers working on transportation infrastructure in the private sector found results “very similar to the results from the public sector,” the report said. A positive sign, however, was that 65 percent of the private-sector respondents expressed interest in expanding their knowledge of life cycle cost analysis, although they also “indicated that they needed public-sector leadership to move forward in this area.”

Such leadership will obviously be necessary if one of the key goals outlined in the *2017 Infrastructure Report Card* is to be achieved. This goal would require that “all projects greater than $5 million that receive federal funding use life cycle cost analysis and develop a plan for funding the project, including its maintenance and operation, until the end of its service life.” Civil engineers themselves can also play a “unique leadership role in addressing our infrastructure challenges,” the report card stresses, through ASCE’s Grand Challenge, which involves “a commitment to rethinking what’s possible through life cycle cost assessments, innovation, performance-based standards, and enhanced resiliency, with the goal of reducing the life cycle costs of infrastructure by 50 percent by 2025.” (See the chart on page 58.)

Unfortunately, many elected officials are more interested in “cutting ribbons” on new infrastructure projects than in making long-term investments, and that often means they “want to minimize the up-front costs so they can build more projects,” notes Norma Jean Mattei, Ph.D., P.E., F.SEI, F.ASCE, the Society’s current president and a professor in the civil and environmental engineering department at the

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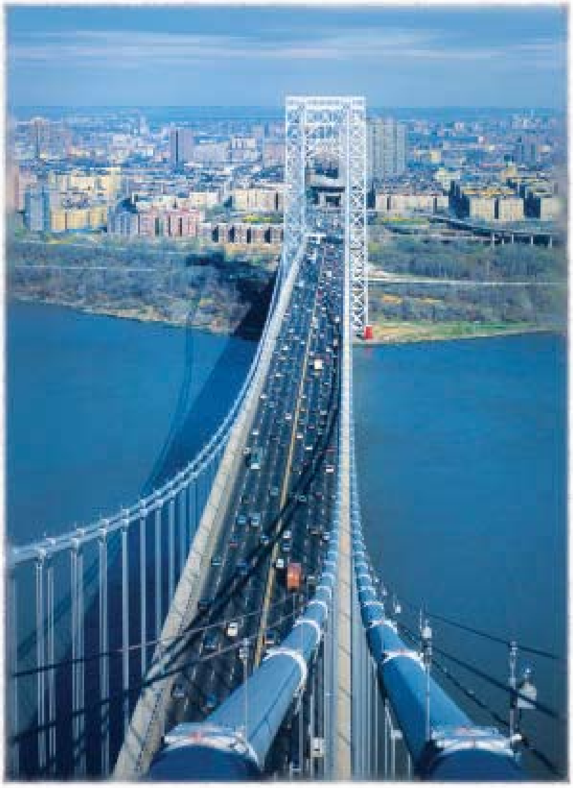
University of New Orleans. So engineers need to work hard to convince not only their elected decision makers but also the public that elects these decision makers that it makes more sense to design and construct infrastructure projects "in a wise and clever way up front so that you're minimizing your operating and maintenance costs over the lifetime of the project." And, of course, the money saved over the long term is money that can be invested up front in future projects.

The ideal time to consider life cycle costs is clearly during the design phase of a project, when multiple factors, for example, the materials chosen, can have a pronounced effect on how a structure performs over its service life, notes Dan Frangopol, Sc.D., P.E., Dist.M.ASCE, who holds the Fazlur R. Khan Endowed Chair of Structural Engineering and Architecture at Lehigh University and is a member of ASCE's Industry Leaders Council. Nearly 20 years ago, when Frangopol was teaching at the Boulder campus of the University of Colorado, he coauthored a pioneering paper on life cycle cost analysis and design, "Life-Cycle Cost Design of Deteriorating Structures," which was published in the October 1997 issue of ASCE's *Journal of Structural Engineering.* Frangopol was also the founding president of the International Association for Life-Cycle Civil Engineering, formed in 2006 to "promote international cooperation in the field of life-cycle civil engineering for the purpose of enhancing the welfare of society," according to the organization's website.



The use of life cycle cost analysis is helping the Port Authority of New York and New Jersey save an estimated $100 million over 20 years on repairs to the George Washington Bridge.

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At Lehigh, Frangopol recently conducted a research project comparing different materials suitable for constructing a representative steel bridge in Pennsylvania. Using computer models, the project compared the life cycle costs that would be incurred if the bridge were constructed using conventional carbon steel with those that would be incurred if it were constructed using a corrosion-resistant steel manufactured by the international steel producer ArcelorMittal in conformity with the ASTM International A1010 (*Standard Specification for Higher-Strength Martensitic Stainless Steel Plate, Sheet, and Strip*). The study was described in the spring 2016 newsletter of the Pennsylvania Infrastructure Technology Alliance, which is funded by the Pennsylvania Department of Community and Economic Development and administered by Lehigh and Carnegie Mellon University.

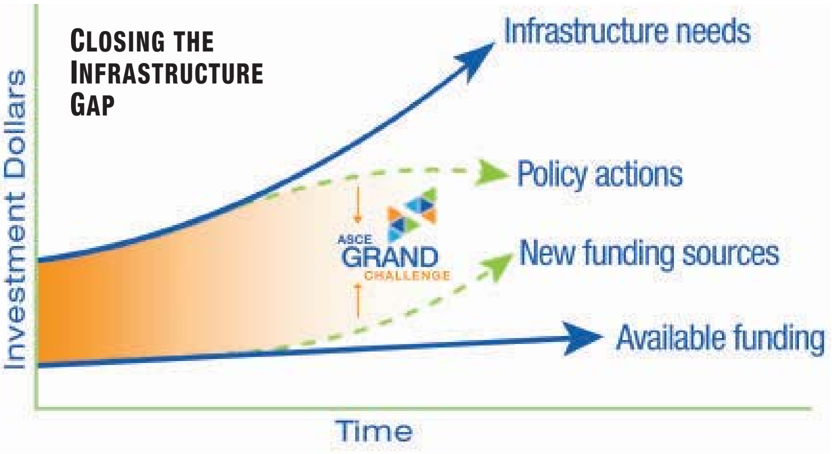
The A1010 steel is designed to never need painting or other maintenance, Frangopol explains, whereas the conventional steel must be painted and repainted. Over an estimated 100 years of service life, the use of traditional carbon steel would cost up to twice as much as the use of the new steel, which although more expensive initially is designed to be maintenance free, the Pennsylvania Infrastructure Technology Alliance's newsletter reported. The savings from a maintenance-free steel become even greater when the total costs of performing bridge maintenance are considered. These costs include disruption of traffic, and if the bridge crosses water, marine traffic also is disrupted and work must be carried out to prevent debris from the painting operation from falling into the water, Frangopol concludes. Thus far, eight bridges in the United States and Canada have been constructed or are being constructed with A1010 steel, Frangopol adds.

Several examples of the long-term savings obtained though life cycle cost analysis are highlighted in the ASCE and Eno Center for Transportation report, *Maximizing the Value of Investments Using Life Cycle Cost Analysis:*

- The Pennsylvania Department of Transportation has saved more than $30 million since the 1980s through its efforts to reduce the lifetime costs of pavements, including a new policy that requires life cycle cost analysis on interstate highway projects with estimated costs of more than $1 million and all projects with estimated costs of more than $10 million.
- The Port Authority of New York and New Jersey estimates that it will save $140 million over 40 years on a runway replacement project at John F. Kennedy International Airport, as well as an estimated $100 million over 20 years on repairs to the George Washington Bridge, through life cycle cost analysis. In view of this potential, the agency developed a pilot program that eventually led to the creation of a 12-page guide on using the life cycle cost analysis process.
- The winning bidder on a 36 mi long commuter rail project in Denver for the Regional Transportation District used life cycle cost analysis to cut $300 million from the up-front costs, operating costs, and certain other expenses on a 34-year contract carried out through a public-private partnership.

The report also praised the U.S. Army Corps of Engineers for developing methods to conduct economic analyses of the life cycle costs and benefits of projects involving the nation's waterways, practices that have been in use since the 1930s and that have "helped to create transparency and to facilitate investment in advantageous projects," the report noted. Surveying the Corps's roughly 80-year history of economic analysis, which has seen both successful efforts and dramatic reforms, the report concluded that the Corps's processes "have the potential to serve as a model for other agencies or private-sector practices" but pointed out that these tools "need to be updated to meet challenges as they arise."

As noted, the best time to consider life cycle costs is at the start of a new project. But as several of the examples from the ASCE and Eno Center for Transportation report indicate, engineers will often be asked to improve the life cycle performance of existing structures, from runways and highways to bridges and buildings. They will even be asked to improve the performance of such buried facets of infrastructure as water and wastewater pipelines (see the sidebar, "Predicting Pipeline Performance").


CLOSING THE INFRASTRUCTURE GAP

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There are many challenges associated with predicting or improving the life cycle performance of existing structures, and these can vary widely depending on the type of infrastructure. A bridge, for instance, might be easier to examine for deterioration than a building because its structure is out in the open. But since there are a variety of factors at work on a bridge, among them exposure to water and salt and fatigue from vehicular or rail traffic, it can be difficult to predict a bridge's condition over time, notes Mark Sarkisian, P.E., S.E., LEED AP, M.ASCE, a partner of the international firm Skidmore, Owings & Merrill LLP. And while a building may face fewer structural variables, its life cycle performance also can be complicated by various nonstructural issues, including the interior finishes and the building services, and these can adversely affect the costs of maintaining or operating the building in the event of, say, a seismic event, Sarkisian explains.

Fortunately, engineers are able to introduce technologies to existing structures to help improve their performance. These include such long-standing approaches as seismic isolation and such new technologies as braced frames with sliding joints for dissipating energy during seismic events, Sarkisian explains.

To help predict when maintenance needs to occur, engineers responsible for operating and maintaining underground infrastructure, for example, pipes, can avail themselves of new leak detection systems as well as innovative asset management approaches that examine an entire network of pipelines via a computerized model, notes DiLoreto. "That's what engineers do," he adds. "We keep trying to come up with new and better methods."

At the Virginia Department of Transportation, Adam Matteo, P.E., M.ASCE, an assistant state structure and bridge engineer for bridge maintenance, uses life cycle cost principles in helping the department make decisions about bridge maintenance, repair, and replacement. Utilizing a performance and condition tracking method called the Virginia health index, which is calculated with the aid of bridge software tools that form part of AASHTOWare—developed by the American Association of State Highway and Transportation Officials (AASHTO), of Washington, D.C.—Matteo can compare scenarios involving various levels of deterioration and possible interventions over periods of time to determine the value of a particular bridge or of the commonwealth's entire network of bridges. The health index is indexed to the current bridge valuation, and it grades each bridge on a scale of 0 to 1, 1 denoting a brand-new structure and 0 a bridge that no longer has any value.

Matteo explains how the health index can be used to select among various intervention options for a notional bridge with a replacement cost of $100 million and a health index of 0.42. Here there are two competing repair and rehabilitation scenarios: the first would raise the health index from 0.42 to 0.80 at a cost of $20 million, and the other would raise the health index to 0.62 at a cost of $16 million. The first option is preferred, Matteo explains, because it would increase the value of the bridge by $38 million for a $20-million investment, whereas the second would increase it by $20 million, which in view of the expenditure of $16 million would provide a lower return on investment. "It's all about comparing the cost to the resulting improvement in value," Matteo explains.

The evaluation involves a simple and immediate decision based on return on investment and is not a genuine life cycle cost analysis, Matteo says. By taking additional steps, for example, measuring the expected deterioration over time, "we can measure how fast we will be losing value every year," he adds, "and that is where we can do some powerful things."

In order to conduct a life cycle cost analysis, of course, engineers must be familiar with the principles and techniques. So are engineering schools helping prepare future engineers to use such methods? The answer seems to be mixed. In 1983 Frangopol introduced an undergraduate course for civil engineers at the University of Colorado at Boulder on probability, statistics, and decision making, but at that time he did not know of any schools that offered an undergraduate course specifically on life cycle cost analysis and design in civil engineering. At Lehigh, Frangopol teaches four graduate-level courses on life cycle issues, and he founded a computational laboratory for life cycle structural engineering.

At the University of Maryland, Bilal M. Ayyub, Ph.D., P.E., F.ASCE, a professor in the civil and environmental

PREDICTING PIPELINE PERFORMANCE

PAUL F. BOULOS, PH.D., Dist. M.ASCE, a member of ASCE's Industry Leaders Council and the chief executive officer of the infrastructure software firm Innovyze, of Broomfield, Colorado, advocates a risk-based, analytical strategic asset management method that demonstrates how life cycle costs can be analyzed. His system relies on a geographic information system to help managers of water and wastewater networks accurately estimate the economic lifetime performance of individual pipes in their systems, including their expected failures, repairs, and eventual replacement, and provides information on the associated costs of optimizing the management of these high-risk assets. This approach could be applied to other infrastructure systems as well.

Boulos's approach focuses on four central components: a geographic information system, network models, asset integrity models, and finance models. Combining these components would enable utility managers to proactively rehabilitate or replace their pipes only when warranted by a cost-benefit analysis. They would thus be able to balance the cost of replacement—the capital cost—against the expected cost or consequences of failure and the accelerating cost to maintain and operate the asset. The analysis would also take the declining level of service of that asset into consideration.

The geographic information system acts as the central storehouse for all of the water and wastewater network's asset data, which include pipe lengths, pipe diameters, material types, locations, ages, closed-circuit television data, work order and maintenance histories, and other factors. This spatial database could be used to generate models that would help the utility develop a condition assessment and rating system for all of its pipes. The data could also be used to predict the future rate of deterioration and the occurrence of pipe failures. The information could be displayed on a network map, creating a powerful tool for recognizing spatial trends and so-called hot spots.

The network models provide the most effective method for predicting network behavior under a wide range of loading and operating conditions, Boulos explains. Tracking the system's actual hydraulic and water quality performance over time, the models help characterize the importance of each asset and its relationship to, for example, storage capacity, disinfectant concentration, system losses, inflow and infiltration, extent of flooding and overflows, and operating pressures. The models, which also consider regulations, permit conditions, water quality standards, and discharge limits, can be used to conduct vulnerability assessments to determine the consequences of the failure of any given pipe or segment of pipe.

Asset integrity models are used to estimate the likelihood (probability) of failure for all network pipes and whether such failures can be expected to continue in the future. Critical pipes with the highest risks of failure, that is, the consequence multiplied by the likelihood, are listed and ranked, Boulos states. The pipes having the highest risk and with the greatest potential negative effect are normally assigned the highest scores and given the most attention. For example, a sewer overflow in a densely populated area that would pose grave public health risks would probably rank higher on the priority list than an overflow with minimal consequences in a sparsely populated area, even if the latter event produced a larger overflow, Boulos explains.

Finance models are used to balance capital expenditures for the replacement of infrastructure against the marginal costs required to minimize the overall cost of asset ownership. These marginal costs include the expected costs or other consequences of a pipe failure, the accelerating costs of operating and maintaining the pipe, and the pipe's declining level of service. The models specifically consider such costs as internal resources and overhead; the costs associated with leakage, additional pumping, and disruption; and the costs related to sustainability, resiliency, the emission of greenhouse gases, and health and safety concerns. By understanding the full economic costs and revenue generated by water distribution and wastewater collection systems, the utility manager can make a financial forecast and develop a long-term funding strategy that allocates utility resources in the most efficient way, notes Boulos.

Used together, these highly complementary models constitute a powerful and comprehensive decision support tool for strategic asset management by utility managers, Boulos says. With the knowledge gained from these models, utility managers would be able to ensure that their networks operated well into the future in a way that maximizes reliability and provides cost savings. Furthermore, by seeking the lowest life cycle cost and reinvesting the savings in their infrastructure, they would be able to help close their infrastructure funding gap and place their assets on the path to efficiency and sustainability.

engineering department and the director of the Center for Technology and Systems Management, acknowledges that life cycle cost issues are mostly taught at the graduate level. In part, this is because time and credit hours are unavailable for a comprehensive life cycle program at the undergraduate level. But Ayyub also believes that many of the fundamental concepts at the core of life cycle cost analysis, among them probability, statistics, engineering economics, and risk analysis, are available to undergraduates through various courses, at least at the larger universities. Engineering students might have to look for classes outside the engineering department—statistics, for example, might be offered through a mathematics department—but the basic concepts are often there, even for undergraduates, Ayyub says.

Mattei agrees that "the little pieces and parts [of life cycle cost analysis] may be in the undergraduate curriculum, but they're not all tied together so that the students are aware of what they're learning." So as these students enter the workforce, life cycle cost analysis "is something they might have read about," she adds, so that they understand that they need to consider more than just the initial costs of a project. "But I don't think that many of them truly know it thoroughly," she says. "I'm not sure that many of them put a lot of emphasis into actually minimizing that lifetime cost."

Moreover, as engineers move into practice and their profession, many tend to specialize, becoming, say, structural or geotechnical engineers, and such specialization can distance them from the concepts they learned

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Assessing Infrastructure's True Cost

(Continued from Page 59) in courses dealing with probability, statistics, and engineering economics. As a result, "when they see the literature and what's out there needed to perform life cycle analysis, some might see it as overwhelming," Ayyub says.

Fortunately, says Jack Dempsey, P.E., a director of business strategies within the building and infrastructure group for North America for the international engineering firm Jacobs, "as engineers progress along the profession, they become more aware of and understanding of the cost implications of the decisions they make." So even if new engineers straight out of college aren't prepared to utilize "higher-level life cycle analysis, risk-based trade-offs," or similar concepts, "the context of understanding or really appreciating how you go about [those techniques] tends to happen after a number of years in the practice," says Dempsey, who works in Jacobs's Washington, D.C., office.

In a perfect world, Mattei muses, life cycle cost analysis would be added to the ABET accreditation program for engineering schools so that every new engineer would gain at least an understanding of the concepts and a broad overview. Then those who needed more advanced knowledge could go back to school later or learn some of the higher-level techniques through continuing education programs, Mattei suggests.

Because the whole purpose of life cycle cost analysis is to consider the costs of infrastructure systems as they are used now and in the future, such analysis must account for future maintenance and repair costs or the potential for shortened operating life if design conditions are exceeded, notes Dan Walker, Ph.D., A.M.ASCE, the associate director for multidisciplinary studies at the University of Maryland's Center for Technology and Systems Management. Thus, Walker and other engineers are urging the profession to consider changes in future weather and climate extremes resulting from climate change, including rises in sea level, as an integral part of these cost projections. For example, ice loadings on structures could change dramatically as the amount of ice each winter increased or decreased over time, Walker notes. Likewise, engineers might want to build additional capacity into the foundations of a new sea wall so that the wall could if necessary be raised to accommodate observed changes in sea level, Walker says. This strategy, called the low-regrets approach, is consistent with the observational method used in geotechnical engineering, Walker adds.


Reid

Many current design standards "are pretty much built on assumptions of stationary [climate] conditions that use 30 to 50 years of historical data to understand conditions for the next 50 to 75 years," Walker explains. But engineers need "a better understanding of the uncertainty associated with future climate conditions," he warns.

Sarkisian adds that engineers need to better account for the amount of carbon associated with infrastructure "from the moment the materials come out of the ground," through the manufacturing of the materials, the construction of the infrastructure elements, and the operation of the asset. "There's an argument that [life cycle cost analysis] is not just commercial—it's an environmental goal that we should be much more sensitive to," Sarkisian concludes.

For engineers who wish to learn more about the topics discussed here, various organizations can provide assistance: ASCE's Industry Leaders Council (www.asce.org/industry_leaders_council/); the International Association for Life-Cycle Civil Engineering (www.ialcce.org/); the Asset Leadership Network (http://assetleadership.net/); the U.S. Resiliency Council (www.usrc.org/); and the Institute for Sustainable Infrastructure (https://sustainableinfrastructure.org/), of which ASCE is a founding member. **CE**

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