Introduction
In this course, you should gain an overview of the initial cost differences between flexible and rigid pipe systems and how to analyze the costs that will occur over the lifetime of a project. Become familiar with the 3 different ASTM specifications (C1103, F1675, and A930) and understand the different theories of each along with the terminology used and how they differ in these specifications. Then, delve further into the theories of the concrete pipe industry by starting with a review of the research done by Joseph Perrin on the total costs of a failure. This will give you an understanding of the background on both the Least Cost Analysis Brochure and Design Data 25 which should also be studied. Finally, learn the steps and perform a least cost analysis, (LCA) by following this outline, and working example problems.

Life Cost Factors
So, how do agencies ensure they are getting the best bang for their buck? They must perform a LCA. They can’t just consider the initial cost of the project, but must consider all costs to be incurred throughout the life of the project including initial, maintenance, rehabilitation, direct and indirect replacement costs. There are tangible factors which are fairly easy to calculate. Some of these factors include costs for:

- Planning
- Specifications
- Hydrology
- Hydraulics
- Structures
- Installation

Additional tangible factors that should be considered, but are often forgotten about, include costs associated with:

- Durability
- Maintenance
- Rehabilitation
- Replacement
- Economics

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And lastly, intangible cost factors are many times the most costly, but since they are indirect to the owner, they are often not considered. As representatives of tax payers, agencies should always consider:

- Delay costs to road users
- Economic loss of business dues to road blocks and detours
- Political implications due to media coverage (Ex: The Minnesota Bridge collapse)
- Owner’s Liability

**Least Cost Analysis (LCA)**

The following terms are commonly used when performing a Least Cost Analysis:

- Project Design Life
- Material Service Life
- Initial Cost
- Present Value
- Replacement Cost (Direct and Indirect)
- Interest (Discount) Rate
- Inflation Rate
- Maintenance Cost
- Rehabilitation Cost
- Residual Value

LCA can be calculated by Equation 1 and is further explained throughout this course outline.

\[
\text{LCA} = \text{Initial Cost} + \text{Present Value of Future Costs} (\text{Replacement} + \text{Rehabilitation} + \text{Maintenance} – \text{Residual Value} + \text{User Delay}) \quad (1)
\]

**Initial Costs and Considerations**

**Installation Costs:**

In understanding the differences in costs, you must first realize that rigid and flexible pipe systems are very different. With rigid pipe, up to 85% of the structure is delivered to the job site leaving the remaining 15% of the strength to come from the soil support once the product is installed. A flexible pipe system on the other hand, relies on up to 85% of its structural strength to come from the soil structure that is built in the field around the pipe. So, although a rigid pipe itself might cost more, the final installation costs of these products properly installed are generally similar. For a better understanding of this, review Figure 1 below. The outside diameter and the thickness of the flexible pipes were defined based on ADS, Inc. Drainage Handbook, with a +/- 1 inch accuracy.

Figure 1 Cost Analysis of Pipe Envelope

As a guideline, ranges for the project design lives of the various types of facilities are provided in Figure 2.

![Figure 2 – Project Design Life](image)

<table>
<thead>
<tr>
<th>Facility</th>
<th>Project Design Life</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storm Sewer System</td>
<td>100 years or greater</td>
</tr>
<tr>
<td>Sanitary Sewer System</td>
<td>100 years or greater</td>
</tr>
<tr>
<td>Urban Roadways</td>
<td>100 years or greater</td>
</tr>
<tr>
<td>Interstate Highways</td>
<td>100 years or greater</td>
</tr>
<tr>
<td>Arterial Culverts</td>
<td></td>
</tr>
<tr>
<td>Collector Culverts</td>
<td>50 to 75 years</td>
</tr>
<tr>
<td>Local/Rural Culverts</td>
<td>50 to 75 years</td>
</tr>
</tbody>
</table>

Material Service Life:
Now that we have discussed the factors that contribute to the costs of a project, consider what

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factors contribute to the life of the product. The three main components are:

- Fabrication
- Durability
- Installation

The life of any product can be affected by the fabrication methods and quality control of its manufacturer. The 3-edge-bearing test is one way an owner can ensure that the concrete pipe product they’ve purchased is what they have ordered. Another growing method to ensure production by various producers are equivalent, is to require a standardized quality control program. The ACPA is increasingly seeing the demand from agencies to require QCast, if a producer is going to sell their product to that agency. This certification ensures that agencies are purchasing from a plant that has quality processes in place.

Testing and quality control programs may assist to ensure equal quality among producers of the same product, but it certainly doesn’t present an even playing field for varying materials. Flexible products and rigid products simply do not share the same durability properties. The US Army Corps of Engineers assigns life expectancies of different products as shown in Figure 3 and offers further guidance in Figure 4.

### Figure 3 – US Army Corps of Engineers (Conduits, Culverts, and Pipe)

<table>
<thead>
<tr>
<th>Pipe Material</th>
<th>Material Service Life (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RCP</td>
<td>70-100</td>
</tr>
<tr>
<td>Aluminized CMP</td>
<td>50</td>
</tr>
<tr>
<td>HDPE</td>
<td>50</td>
</tr>
</tbody>
</table>

**Future Costs**

To analyze the cost of a project over its intended life, future costs must be shown in an equivalent dollar values to today. Some costs, like a replacement, are a onetime cost, while others, like maintenance, are annual costs. Finally, one must also consider user delay costs. The following will explain how calculate comparable values all at a given point in time.

**Present Value:**

Present Value is calculated based on the equivalent costs at the current or present time. In other words, this would be the amount of money that would have to set aside today to meet future costs for the life of desired design project.

Present value calculations are made by first inflating estimates of cost expenditures, made in original dollar terms, into the future to the time they will be made. These inflated costs are then discounted to present value terms using an appropriate interest rate in order to compare all products at an equal time.

Three different cases can be examined:

- Case 1: Product Life = Project Design Life
- Case 2: Product Life < Project Design Life
- Case 3: Product Life > Project Design Life

The costs associated with these three cases are as follows:
Case 1: Future Costs = Maintenance Cost
Case 2: Future Costs = Replacement or Rehab Costs + Maintenance Cost + User Delay Cost
Case 3: Future Costs = Maintenance Cost – Residual Value

Figure 4- U.S. Army Corps of Engineers, EM 1110-2-2902, Conduits, Culverts and Pipes

**Excerpt from Paragraph 1-4, Life Cycle Design**

1. **Concrete.** Most studies estimated product service life for concrete pipe to be between 70 and 100 years. Of nine state highway departments, three listed the life as 100 years, five states stated between 70 and 100 years, and one state gave 50 years.

2. **Steel.** Corrugated steel pipe usually fails due to corrosion of the invert or the exterior of the pipe. Properly applied coatings can extend the product life to at least 50 years for most environments.

3. **Aluminum.** Aluminum pipe is usually affected more by soil-side corrosion than by corrosion of the invert. Long-term performance is difficult to predict because of a relatively short history of use, but the designer should not expect a product service life of greater than 50 years.

4. **Plastic.** Many different materials fall under the general category of plastic. Each of these materials may have some unique applications where it is suitable or unsuitable. Performance history of plastic pipe is limited. A designer should not expect a product service life of greater than 50 years.

**Replacement Costs:**
Failures and short life expectancies of pipe systems are just now starting to be recognized as a growing problem. There have been a number of documented cases where pipe has failed, costing agencies hundreds of thousands, to millions of dollars that they didn’t expect to spend. For this reason alone, it is prudent for agencies to perform least cost analysis for all of their projects.

Figure 5 shows how vital it is for specifiers to recognize the importance of choosing a durable and long lasting product. ASCE estimates it would cost $3.6 trillion dollars over 5 years to bring America’s infrastructure up to a satisfactory level. While observing the grades, they are staying relatively constant over time, proving that we are only spending just enough money to keep the US infrastructure just above failing. This proves the need of making sound engineering decisions based on life cycle cost and not based on installation cost alone. An ultimate choice for limiting the maintenance cost for infrastructure is choosing materials with longer life-time expectancies combined with a low life cycle cost. The cost of uninstalling and re-installing pipelines across the country every 25-50 years increases the cost to improve existing projects.
To calculate the present value of a replacement, use the following equation:

\[ PV = (A \times FV \times PVF) = A(F)^n \]

Where:
- \( PV \) = Present Value
- \( A \) = Constant Dollar Value (initial cost)
- \( FV \) = Future Current Dollar Value (Inflation Factor) = \((1+I)^n\)
- \( n \) = Product Life, years
- \( I \) = Inflation Rate
- \( PVF \) = Present Value Factor = \(\left(\frac{1}{1+i}\right)^n\)
- \( i \) = Interest Rate
- \( F \) = Inflation / Interest Factor = \(\frac{1+I}{1+i}\)^n

**Inflation / Interest Rate Factor, F**

Historical relationships between interest rates and inflation rates provide meaningful information. The relationship between the interest rate and the inflation rate is well substantiated in history and economic literature.

The two rates interact and influence each other so that in the long run they tend to move together, resulting in a relatively constant differential between the two. When prices increase, the market forces change in investment behavior so the differential remains positive and relatively constant in
the long-run. If interest rates rise faster than inflation, the real rate of return will rise for lenders inducing a greater supply of funds to financial markets. At the same time, borrowers will face increased real costs for borrowing funds and therefore will tend to reduce their borrowing. The increasing supply of funds and the reduced demand for funds will, over time, force down the price of money, or the interest rate.

If interest rates fall relative to inflation the reverse occurs. The return to lenders falls and the real cost of borrowed money drops. The supply of funds will shrink and the demand for funds will increase introducing upward pressure on interest rates and reestablishing a positive differential of interest rates over inflation.

In the United States, during the 25-year period from 1970 through 2015, similar changes occurred in both interest rates and inflation. Average Interest rates (represented by the prime rate) varied from 3.3 percent for the period 2000 - 2015 to 11.7 percent in the decade ending in 1990, per data shown in Figure 6. Average Inflation rates (represented by the Consumer Price Index or CPI) varied from 1.53 percent for the period from 2010 until 2015 and 7.88 percent for the decade from 1970 until 1980, as per data shown in Figure 7.

Despite these drastic changes, the overall average differential between the two rates remained relatively stable. Throughout the entire period it averaged 3.71 percent in the United States. Therefore, it is not necessary to try to predict what the interest or inflation rates will be over time, but rather to use the Inflation / Interest Rate Factor, F, to calculate the relationship between the two when performing LCA.

**Figure 6 - Prime rates from 1970-2015** [https://en.wikipedia.org/wiki/Wall_Street_Journal_prime_rate](https://en.wikipedia.org/wiki/Wall_Street_Journal_prime_rate)

<table>
<thead>
<tr>
<th>Year</th>
<th>Avg. Prime Rate</th>
<th>Year</th>
<th>Avg. Prime Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>1970</td>
<td>7.7%</td>
<td>1993</td>
<td>6.0%</td>
</tr>
<tr>
<td>1971</td>
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<td>1972</td>
<td>5.3%</td>
<td>1995</td>
<td>8.8%</td>
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<td>1973</td>
<td>8.0%</td>
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<td>8.4%</td>
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<tr>
<td>1978</td>
<td>9.7%</td>
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<td>6.9%</td>
</tr>
<tr>
<td>1979</td>
<td>13.5%</td>
<td>2002</td>
<td>4.5%</td>
</tr>
<tr>
<td>1980</td>
<td>15.7%</td>
<td>2003</td>
<td>4.1%</td>
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<tr>
<td>1981</td>
<td>18.1%</td>
<td>2004</td>
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</tr>
<tr>
<td>1982</td>
<td>14.0%</td>
<td>2005</td>
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<td>8.4%</td>
<td>2014</td>
<td>3.3%</td>
</tr>
<tr>
<td>1992</td>
<td>6.3%</td>
<td>2015</td>
<td>3.5%</td>
</tr>
</tbody>
</table>
Residual value

Residual value is defined as the remaining value of the system or structure at the end of the project design life. If a system or structure has a service life greater than the project design life it would have a residual value. That value should then be discounted back to present value by using the following equation.

\[ S = C(F)^{n_p} \left( \frac{n_s}{n} \right) \]

where:
- \( S \) = Residual Value
- \( C \) = Present Constant Dollar Cost
- \( n_s \) = Number of Years Service Life Exceeds Design Life
- \( n \) = Service Life
- \( n_p \) = Project Design Life, years
- \( F \) = Inflation/Interest factor

Maintenance Costs:

Maintenance is any action taken periodically to help a material reach its service life and ensure the facility functions as originally intended. Typical maintenance activities for pipe installations include removal of debris, flushing, deposition or silt removal, and repair of localized damage. Actions to maintain or improve the pipe's structural integrity are considered remedial actions and are addressed as either rehabilitation or replacement projects.

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Maintenance costs are calculated using the following equation and only need to be calculated if the costs are different for different materials. Common difference in costs would occur with varying durability of two products due to localized damage.

$$M = C_m \left[ \frac{1 - (F)^n}{1 - F} \right]$$

where:
- $M$ = Present Value of Expected Maintenance Costs
- $C_m$ = Annual Maintenance Cost
- $F$ = Inflation/Interest Factor
- $n$ = Service Life

Rehabilitation Costs:
Rehabilitation entails any remedial action taken on a pipe facility to upgrade its structural condition. Rehabilitation actions cannot restore the pipe to its original condition but may extend its service life by a number of years depending on the type and amount of deterioration. The years the material life is extended should be judged on the condition of the pipe and current rate of deterioration. Costs associated with rehabilitation actions not only include the construction and material costs for the work but any other direct or indirect related costs. These may include easements, engineering, safety, detour roadway deterioration and traffic related costs.

To calculate the present value for rehabilitation, the following calculation can be performed:

$$N = C_R F^n$$

where:
- $N$ = Present value of expected rehabilitation cost
- $C_R$ = Total Rehabilitation Cost
- $F$ = Inflation/Interest factor
- $n$ = Service Life

To conclude this course, you will be expected to understand how to use these equations to perform a LCA. It is suggested that you review the example problems given in the Least Cost Analysis Brochure and Design Data 25 along with the rest of the material from those two resources.

User Delay Costs:
User Delay Costs are a major part of replacement costs, but are often forgotten since they do not directly impact the owner paying for the replacement. Instead it affects the tax payers using the area that is under construction during the replacement. Dr. Perrin from the University of Utah has established a viable method to calculate user delays during road closures by using this equation:

$$D = AADT * t * d * (c_v * v_v * v_{off} + c_r * v_f)$$

Where:
- AADT = Annual Average Daily Traffic of the roadway which the culvert is being installed
- $t$ = the average increase in delay to each vehicle per day, in hours
- $d$ = the number of days the project will take

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cv = the average rate of person-delay, in dollars per hour
v_v = the percentage of passenger vehicles traffic
v_of = the vehicle occupancy factor
c_f = the average rate of freight-delay, in dollars per hour
v_f = the percentage of truck traffic

Average Established Delay Costs as 2005, in Dollars:

cv = $18.62 per person-hour of delay
cf = $52.86 per freight-hour of delay
These estimates provide a conservative value due to inflation since 2005.

Typical Traffic Assumptions:
v_v = 97% vehicle passenger traffic
v_f = 3% truck traffic
v_of = 1.2 persons per vehicle

Conclusion
The LCA method includes costs associated with planning, engineering, construction (bid price), maintenance, rehabilitation, replacement, and cost deductions for any residual value at the end of the project life. For each material, system or structure, this LCA method determines the present value or the total initial and future costs deducted back to today’s value in order to give a designer a true picture of the product that is the most economical over the life span of his/her project.