Life-Cycle Cost Analysis Guidance for CTDOT Bridge Projects

Introduction

This document is an effort to standardize the parameters used for Life-Cycle Cost Analysis (LCCA) on CTDOT bridge projects. Much of this material has been adapted from the sources listed in the References section. It is anticipated that the guidelines will evolve as the Department gains more experience with the process, and as deterioration models become more refined.

It is important to note that the purpose of the LCCA prepared in accordance with these guidelines is to serve as a future planning tool for the Department in addition to evaluating current alternatives. The actual expected construction costs, inflated to the anticipated year of construction, will be entered into the Department's bridge management program as planned future work. Therefore, some of the analysis approaches used below may differ somewhat from a strictly academic exercise.

This method will be a useful instrument to compare the relative merit of bridge alternatives for the CTDOT Division of Bridges Rehabilitation Study Report (RSR) and Structure Type Study Report process during the design of bridge projects. It also provides a unified and consistent methodology that will be used for future bridge projects by all designers.

LCCA Defined

The life-cycle of a bridge involves the following phases in the life of the structure:

- Design
- Initial Construction
- In-Service: Operation, Maintenance, and periodic Repair/Rehabilitation
- Removal from service/Demolition

LCCA is an engineering economic analysis tool that allows the Department to quantify the differential costs of alternative treatment strategies for a given project. LCCA allows different project alternatives to be compared not only when the initial costs differ, but when costs following the initial expenditure are expected to occur at different times and in varying amounts.

For existing bridges, LCCA seeks to determine the cost-effectiveness of various rehabilitation options. For new bridges, LCCA of alternative designs seeks to quantify the difference in costs associated with varying design features to allow optimization of costs over the life of the structure. It considers not only the initial construction cost, but also all of the costs that are expected to occur over the entire service life of the bridge, such as maintenance, repair, major rehabilitation, component or element replacement (including associated demolition and disposal costs).

Ideally, the alternative with the lowest total life-cycle cost would be the preferred alternative. However, current budget limitations and competing needs, site constraints, user impacts, or other factors may dictate that an alternative other than the one with the lowest life-cycle cost be selected. In that case, LCCA helps to quantify the anticipated additional cost associated with the selected alternative.

LCCA differs from Benefit/Cost Analysis (BCA) in that it only considers agency costs, not intangible benefits, or any costs not borne by the structure's owner. LCCA can only be used to evaluate alternatives which provide equivalent levels of service. If the alternatives provide different levels of service, BCA should be used.

Agency Costs

Agency costs include all the costs borne by the owner and maintainer of the bridge, such as design, initial construction, inspection, maintenance, repair, rehabilitation, and replacement.

User Costs

User costs are borne by the users of the bridge, typically the travelling public. They are primarily associated with functional limitations of the existing structure and reduced traffic capacity in work zones. They involve costs to the users because of delays, detours, vehicle operating costs, wear-and-tear, accidents, safety, environmental impact, level of service, and other quality of life issues. Estimating these costs are difficult and involve considerable subjectivity. Therefore, there is currently no universally accepted method to calculate user costs; the use of different approaches can result in wildly different "optimum" solutions. Under certain circumstances, some alternatives may warrant methods to consider user costs, such as those used for accelerated bridge construction techniques. These tools incorporate some quantified user costs as part of an LCCA evaluation.

Steps in LCCA

The LCCA process begins with the development of alternatives to accomplish the structural and performance objectives, or "purpose and need statement", for a project. In addition to the initial costs, the design alternatives selected will commit the agency to future expenditures for maintenance and rehabilitation actions over the life-cycle of the bridge. Furthermore, the selected alternative will accrue costs to facility users through project activities that directly impact the traveling public.

Economic methods are used to convert anticipated future costs to present dollar values so that lifetime total costs of various alternatives can be directly compared.

The five basic steps in the LCCA process are described in the following sections (adapted from FHWA 2002b).

Step 1. Establish Design Alternatives

The first step involves establishing the elements of initial design and identifying the associated activities that will be required throughout the structure's service life for maintenance, rehabilitation, or element replacement for each alternative proposed.

At least two alternatives which meet the project's stated purpose and need are necessary for a valid comparison. Ideally, at least one alternative will include full replacement of the bridge. If the project goals can only be met by a full bridge replacement, the design alternatives should include at least two different structure types (for example, a steel structure, and a concrete structure). No alternative should provide for a service life of less than 20 years before another major rehabilitation project will be needed. Whenever possible, all design alternatives should aim to correct all of the structure's know deficiencies. An evaluation should also be made as to the level of effort that would be required so that when the project is completed, all bridge components have a rating of 7 (Good) or above.

Step 2. Determine Activity Timing

Each alternative will have initial costs and future follow-on treatments which will be necessary. The follow-on actions will vary depending upon the initial treatment chosen. For example, a deck replacement will require a future replacement of the waterproofing membrane and overlay. Likewise, choosing a deck repair as the initial treatment will necessitate a future deck replacement at some point.

The timing of future maintenance and rehabilitation activities throughout the period of comparison must be determined as part of the process. Estimating when and how often maintenance and rehabilitation activities must be performed is essential in making realistic comparisons.

Step 3. Estimate Costs

This step involves estimating the initial construction cost associated with each design alternative and the costs associated with the various future maintenance, rehabilitation, and replacement activities which are anticipated for each alternative. For planning purposes, the costs of each activity should be estimated in the anticipated year of construction. The anticipated activities for all bridges will be compiled to form the foundation of Department's future bridge work program.

Currently, the estimated cost only includes agency costs, but it is anticipated that user costs will be considered in the future.

Step 4. Compute Life-Cycle Costs

This step involves computing the present value of all costs identified for each given alternative.

Step 5. Compile and Analyze Results

The final step involves comparing the initial and life-cycle costs associated with the various alternatives and identifying the alternative which meets the project's purpose and needs at the lowest total cost over the analysis period. Alternatives must provide equivalent levels of service to be compared using LCCA.

Activity timing, Service Life, and Life-Cycle

Deterioration Models

Deterioration models describe how the bridge component or element decays over time and can be used to estimate remaining service life. The models assume that no rehabilitation is performed but *does* assume that routine maintenance actions are performed. "Rehabilitation" consists of major repair or replacement of components, done with the intent of raising component or element ratings. "Maintenance" actions may slow the deterioration process, but do not increase any ratings. Typically, maintenance actions are not well-documented, making it difficult to quantify their impact on deterioration rates.

Service Life and Design Life

Service Life: The service life is the time duration during which the bridge element, component, system, or subsystem provides the desired level of performance or functionality, with the specified level of repair or maintenance as established at the time of initial design or plan for rehabilitation. When a component reaches an NBI rating of 4, or an element reaches condition state 3, the need for rehabilitation is triggered and the service life is considered to be over.

Design alternatives should be evaluated over equivalent analysis periods in order to yield fair comparisons of life-cycle costs. However, in many cases, one or more alternatives will have service lives that exceed the analysis period. Any service life exceeding the analysis period is known as remaining service life (RSL). Failure to account for differing RSLs can result in an economic bias toward one or another alternative when using life-cycle cost analysis. The different RSLs of various alternatives should be accounted for as part of the salvage/residual value. All proposed alternatives should provide for a service life of at least 20 years before a major rehabilitation will again be required. It is understood that maintenance and minor rehabilitation (like joint replacement) will be necessary between major rehabilitations.

Design Life: The period of time which a new bridge is expected to be in service, assuming that the specified level of repair or maintenance as established at the time of design is performed. This will be 75 years for most bridges and culverts; 100 years for Major Bridges.

Analysis Period:

Because bridges decay slowly, the time horizon selected for the analysis will have a dramatic impact on LCCA results. A short time horizon will fail to capture major rehabilitation costs and will also not capture the cumulative cost of multiple future rehab projects which might have been avoided if a more extensive project were undertaken initially or will not capture the future benefits of a more aggressive initial project.

For the short term, a minor rehab project may remove a bridge from the poor category temporarily, only to have it fall back into the poor category within a few inspection cycles. This will necessitate another rehabilitation project. Even though the costs of the individual rehab projects are low, taken together, they may exceed the cost of a more aggressive initial rehabilitation. In fact, given a long enough time horizon and unlimited funding, the lowest life-cycle cost approach to handling a bridge in poor condition would almost always be to replace it, then maintain it properly. However, in the real world, we never have unlimited funds, so alternatives with less initial cost have to be considered, and the difference in overall life-cycle cost may be small enough to justify the less aggressive initial approach. Saving money on one bridge project allows the limited funding to be used on another bridge project where it may be of greater benefit to the overall network health.

To ensure accurate representation of future costs, it is necessary to select an analysis period which spans a major portion of the bridge’s design life, and ideally, includes the possibility of at least one full bridge replacement. Unless directed otherwise, the analysis period should be the anticipated design life for a new structure:

Typical Bridge: 75 years

Major Bridge: 100 years

Economic Assumptions:

Inflation Rate: **6.0% through 2024, 3.5% for 2025 and beyond.** Because it is driven primarily by increases in wages and material costs, construction inflation tracks more closely with the Producer Price Index (PPI), or roughly twice the rate of the general Consumer Price Index (CPI). Until recently, the CPI had been averaging just under 2% for many years, and the Federal Reserve has announced a goal of holding the CPI to under 2%, so CTDOT forecasts for the TAMP have used an inflation rate of 3.5%. Historically, annual construction inflation rates have ranged from over 9%, to zero or less during the Great Recession. Currently, the CPI is running at an annual rate of over 6% and the PPI at over 7%; economists expect that the underlying drivers of inflation will remain in place at least through the end of 2023, so it is necessary to increase the assumed inflation rate for the next several years. Because of uncertainty in forecasting more than a few years out, it is assumed that inflation returns to historical averages for the more distant future. These assumptions should be reviewed annually.

Discount Rate: **0%.** People tend to psychologically value money that they have to spend now more highly than money that they'll have to spend in the future: current dollars are real, future dollars are less real. The discount rate is a way of adjusting for that bias. Another definition of the discount rate is the opportunity cost of choosing one investment over an alternative investment with differing rates of return. There are several ways of establishing a discount rate, but the simplest and most common way is to define the discount rate as the inflation-adjusted cost of borrowing.

This is an explanation of discount rate that is used by the federal government: *"In order to be able to add and compare cash flows that are incurred at different times during the life-cycle of a project, they have to be made time-equivalent. To make cash flows time-equivalent, the LCC method converts them to present values by discounting them to a common point in time, usually the base date. The interest rate used for discounting is a rate that reflects an investor's opportunity cost of money over time, meaning that an investor wants to achieve a return at least as high as that of her next best investment. Hence, the discount rate represents the investor's minimum acceptable rate of return."*

Conversion of future values (FV) to common present values (PV) to allow for comparison of expenditures falling in different years is done according to the following formula:

$$PV = FV / (1 + DR)^n$$

Where: $DR = (i_{int} - i_{inf}) / (1 + i_{inf})$= real discount rate, which for low rates can be simplified as $(i_{int} - i_{inf})$

i_{int} = Interest Rate

i_{inf} = Inflation Rate

n = number of years in the future when the cost will be incurred

In the public sector, this approach has several shortcomings. Firstly, we have no non-transportation alternative investments to compare to. Secondly, Connecticut's inflation-adjusted borrowing costs for transportation projects are either zero, or very low. The majority of CTDOT funding (federal funding) has an interest rate of 0% for the asset owner. State funding comes from a variety of sources: some of it is current revenue (0% interest), but most of it is borrowed at very low interest rates. In the above formula, if the interest rate is zero, or less than inflation, then the discount rate will be negative.

For example, in 2019, the State refinanced general obligation bonds at a 1.67% interest rate. For 2019, the Consumer Price Index increased 2.3%. Therefore, the real discount rate for 2019 for borrowed funds would be 1.67 – 2.3 = - 0.63%; for non-borrowed funds, it would be – 2.3% (a NEGATIVE discount rate). Because the construction inflation rate generally runs higher than the CPI (roughly twice the CPI, or closer to the Producer Price Index), the actual discount rate, if computed, would be even lower (more negative).

Historically, Connecticut's borrowing costs have been at or below the rate of inflation. Therefore, CTDOT has been using a 0% discount rate in Deighton dTIMS forecasts and the TAMP because: 1) we have no alternative use for the funding other than building transportation project, and 2) if we did use a conventional discount rate, it would have to be negative, which would lead to odd results. This can be hard for public-sector engineers to accept, because they were taught private-sector engineering economics, where funds always have alternate uses, and are almost always borrowed at rates higher than inflation. Therefore, since any calculated discount rate would be either close to zero or even negative, we can simply the equation to PV=FV.

For public works projects, an argument can be made for using something other than the conventional discount rate, to factor in user costs, or anticipated future funding streams, but there is no general agreement on how to do that. A variety of alternative approaches to establishing a discount rate for public sector projects have been proposed, such as weighing future funding streams, but none have been accepted as an industry standard. This paper from the 2006 TRB compares 11 different ways to calculate the discount rate for public works transportation projects: https://rits.rutgers.edu/files/discountrate_lifecycle.pdf

Salvage/Residual value:

In traditional LCCA, the "salvage value" is the value of the asset if sold on the market as a used product or for scrap. Fully deteriorated bridges have no resale value – in fact, we pay to have them demolished – so the primary purpose of calculating a salvage or residual value is to allow comparisons of alternatives which have different remaining service lives at the end of the analysis period. This should be calculated based on service life remaining as a percentage of full replacement cost. For example, if a typical bridge is 25 years old at the end of the analysis period, it would have 2/3 (50/75) of its life remaining, so the residual value would be 2/3 of its replacement cost. For example, if the bridge cost $3,000,000 to replace, its residual value would be (50/75) x $3,000,000 = $2,000,000. A bridge at the end of its service life (75 years for a typical bridge, 100 years for a major bridge) would be worth $0. Any actual demolition costs, or material salvage value (for scrap steel, for example) is assumed to be part of the calculated replacement cost of the new structure.

When estimating remaining life, it is important to note that components with prior repairs tend to decay faster than un-repaired components with the same ratings. Concrete with prior repairs due to rebar corrosion is especially suspect: the processes which caused localized failures (typically chloride and water penetration) are progressing at various rates all over the structure. Visible failures occur where the progression is most advanced, but other areas may not be far behind in the decay process. Concrete patches themselves are also known to accelerate rebar corrosion in surrounding areas. Even though repaired concrete may technically meet the requirements for a condition rating of 6 (Satisfactory), consideration should be given to regarding the component as being rated 5 (Fair) for purposes of estimating remaining life.

Periodic Repair/Rehabilitation Actions

Here are some examples of typical repair or rehabilitation actions over a bridge's life:

- Every 5 -10 years (depending upon joint type): replace joints.
- 15 years: Mill wearing surface and resurface overlay, replace joints, replace bearings.
- 30 Years: Replace waterproof membrane & overlay, patch deck, replace joints, replace bearings, partially re-paint steel.
- 45 years: Replace deck, replace bearings, rehab superstructure, repair substructure, full repaint of steel.
- 60 years: Mill wearing surface and resurface overlay, replace joints, replace bearings, repair substructure, minor repairs to superstructure, spot painting
- 75 years: Replace typical bridge (extensive rehab project on a major bridge).
- 100 Years: Replace major bridge.
- Moveable bridges will require an electrical & mechanical rehab project approximately every 15 -20 years, in addition to the above.

The actual repair cycle will vary depending upon the structure type, material, and local conditions. Some typical lifespans, based on historical CTDOT inspection data, are provided in the section below for guidance. Different lifespan assumptions may be needed for atypical materials or designs. For example, using stainless steel rebar and low-permeability concrete would eliminate the deck replacement at 45 years and deck repair at 30 years, and possibly any need for an overlay, and might justify an increase in residual value based on an anticipated service life longer than 75 years.

Service Life (New Structures)

For new construction, the following tables show the number of years of service life expected under typical conditions before a component is in poor condition (rated 4 or less). The components are grouped by structure type and material. Substructures do not have the same level of information as to type and material in the bridge records, so substructures are grouped according to the associated superstructure type. These tables can be used as a guide to estimate the number of years before major rehabilitation is needed. Given modern materials and methods, it is likely that a new structure will exceed the life shown in the tables.

Paint: 30 years (3-coat system), 60 years (paint over galvanizing or metalizing)
Wearing Surface: 19 years

Culverts:

FAMILY	Design Main (Structure Type)	Material Main	Years to Poor
CULVERT01	19 (Culvert)	1 Concrete, and 2 Concrete Continuous	67
CULVERT02	19 (Culvert)	3 Steel	52
CULVERT03	19 (Culvert)	Others	69

Decks:

FAMILY	Deck Structure Type (107)	Wearing Surface Type (108)	Years to Poor
DECK01	Concrete-Cast-in-Place (1)	Concrete (0,1,2)	41
DECK02	Concrete-Cast-in-Place (1)	Latex Modified Concrete (3)	48
DECK03	Concrete-Cast-in-Place (1)	Bituminous (6)	42
DECK04	Concrete-Cast-in-Place (1)	Other (8,9)	42
DECK05	Concrete Precast Panel (2)	All	30
DECK06	Grating/Plate (3,4,5,6)	Bituminous (6)	31
DECK07	Grating/Plate (3,4,5,6)	Other (all except 6)	25
DECK08	Wood (8)	Bituminous (6)	32
DECK80	Wood (8)	Other (all except 6)	38
DECK90	9 (Other)	All	44

Substructures (grouped by associated superstructure type):

FAMILY	Design Main (Structure Type)	Material Main	Years to Poor
SUB01	1 (Slab)	1 (Concrete), 8 (Masonry)	57
SUB02	1 (Slab)	2 (Concrete Continuous)	58
SUB04	1 (Slab)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	51
SUB05	1 (Slab)	7 (Wood or Timber)	34
SUB08	2, 3 (Stringer, Girder/Floorbeam)	3 (Steel)	68
SUB09	2, 3 (Stringer, Girder/Floorbeam)	4 (Steel Continuous)	54
SUB10	2, 3 (Stringer, Girder/Floorbeam)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	60
SUB11	2, 3 (Stringer, Girder/Floorbeam)	7 (Wood or Timber)	49
SUB12	4 (Tee Beam)	1 (Concrete)	49
SUB13	4 (Tee Beam)	2 (Concrete Continuous)	61
SUB14	4 (Tee Beam)	5 (Prestressed Concrete)	44
SUB15	5, 6 (Box Beam Multiple/Single)	3 (Steel)	34
SUB16	5, 6 (Box Beam Multiple/Single)	4 (Steel Continuous)	30
SUB17	5, 6 (Box Beam Multiple/Single)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	40
SUB18	7 (Frame)	1 (Concrete)	59

FAMILY	Design Main (Structure Type)	Material Main	Years to Poor
SUB19	7 (Frame)	2 (Concrete Continuous)	74
SUB20	7 (Frame)	3 (Steel)	68
SUB21	7 (Frame)	4 (Steel Continuous)	60
SUB22	7 (Frame)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	45
SUB24	9, 10 (Truss – Deck & Thru)	3 (Steel)	39
SUB25	9, 10 (Truss – Deck & Thru)	4 (Steel Continuous)	55
SUB27	11, 12 (Arch – Deck & Thru)	1 (Concrete)	63
SUB28	11, 12 (Arch – Deck & Thru)	2 (Concrete Continuous)	45
SUB29	11, 12 (Arch – Deck & Thru)	3 (Steel), 9 (Aluminum, Iron)	46
SUB30	11, 12 (Arch – Deck & Thru)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	43
SUB31	11, 12 (Arch – Deck & Thru)	8 (Masonry)	83
SUB32	15, 16, 17 (Movable)	All	50
SUB33	Other (20,21,22)	All	36

Superstructures:

FAMILY	Design Main (Structure Type)	Material Main	Years to Poor
SUP01	1 (Slab)	1 (Concrete)	75
SUP02	1 (Slab)	2 (Concrete Continuous)	54
SUP04	1 (Slab)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	52
SUP05	1 (Slab)	7 (Wood or Timber)	45
SUP08	2, 3 (Stringer, Girder/Floorbeam)	3 (Steel)	64
SUP09	2, 3 (Stringer, Girder/Floorbeam)	4 (Steel Continuous)	54
SUP10	2, 3 (Stringer, Girder/Floorbeam)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	53
SUP11	2, 3 (Stringer, Girder/Floorbeam)	7 (Wood or Timber)	49
SUP12	4 (Tee Beam)	1 (Concrete)	43
SUP13	4 (Tee Beam)	2 (Concrete Continuous)	32
SUP14	4 (Tee Beam)	5 (Prestressed Concrete)	40
SUP15	5, 6 (Box Beam Multiple/Single)	3 (Steel)	36
SUP16	5, 6 (Box Beam Multiple/Single)	4 (Steel Continuous)	32
SUP17	5, 6 (Box Beam Multiple/Single)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	39
SUP18	7 (Frame)	1 (Concrete)	46
SUP19	7 (Frame)	2 (Concrete Continuous)	61
SUP20	7 (Frame)	3 (Steel)	47
SUP21	7 (Frame)	4 (Steel Continuous)	61
SUP22	7 (Frame)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	37
SUP24	9, 10 (Truss – Deck & Thru)	3 (Steel)	48
SUP25	9, 10 (Truss – Deck & Thru)	4 (Steel Continuous)	50
SUP27	11, 12 (Arch – Deck & Thru)	1 (Concrete)	62

FAMILY	Design Main (Structure Type)	Material Main	Years to Poor
SUP28	11, 12 (Arch – Deck & Thru)	2 (Concrete Continuous)	50
SUP29	11, 12 (Arch – Deck & Thru)	3 (Steel), 9 (Aluminum, Iron)	57
SUP30	11, 12 (Arch – Deck & Thru)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	41
SUP31	11, 12 (Arch – Deck & Thru)	8 (Masonry)	77
SUP32	15, 16, 17 (Movable)	All	40
SUP33	Other (20,21,22)	All	25

Remaining Service Life (Existing Structures)

For existing bridges, the following tables show the number of years of service life which can be expected on average before a component is in poor condition (rated 4 or less), given its initial NBI rating. The tables can be used as an aid to determine the advisability of a proposed action. For example, it would be unwise to put a new concrete deck with an estimated life in excess of 41 years (from the above Deck table) on a steel stringer superstructure (SUP08) currently rated a 5, which from the table below only has an expected time to poor of 15 years.

Culverts:

FAMILY	Design	Material	Initial NBI	Years to POOR
CULVERT01	19 (Culvert)	1 Concrete, and 2 Concrete Continuous	5	12
CULVERT01	19 (Culvert)	1 Concrete, and 2 Concrete Continuous	6	24
CULVERT01	19 (Culvert)	1 Concrete, and 2 Concrete Continuous	7	35
CULVERT02	19 (Culvert)	3 Steel	5	9
CULVERT02	19 (Culvert)	3 Steel	6	17
CULVERT02	19 (Culvert)	3 Steel	7	25
CULVERT03	19 (Culvert)	Others	5	18
CULVERT03	19 (Culvert)	Others	6	35
CULVERT03	19 (Culvert)	Others	7	51

Decks:

FAMILY	Design	Material	Initial NBI	Years to POOR
DECK01	Concrete-Cast-in-Place (1)	Concrete (0,1,2)	5	11
DECK01	Concrete-Cast-in-Place (1)	Concrete (0,1,2)	6	19
DECK01	Concrete-Cast-in-Place (1)	Concrete (0,1,2)	7	30
DECK02	Concrete-Cast-in-Place (1)	Latex Modified Concrete (3)	5	11

FAMILY	Design	Material	Initial NBI	Years to POOR
DECK02	Concrete-Cast-in-Place (1)	Latex Modified Concrete (3)	6	23
DECK02	Concrete-Cast-in-Place (1)	Latex Modified Concrete (3)	7	34
DECK03	Concrete-Cast-in-Place (1)	Bituminous (6)	5	9
DECK03	Concrete-Cast-in-Place (1)	Bituminous (6)	6	22
DECK03	Concrete-Cast-in-Place (1)	Bituminous (6)	7	34
DECK04	Concrete-Cast-in-Place (1)	Other (8,9)	5	10
DECK04	Concrete-Cast-in-Place (1)	Other (8,9)	6	19
DECK04	Concrete-Cast-in-Place (1)	Other (8,9)	7	31
DECK05	Concrete Precast Panel (2)	All	5	7
DECK05	Concrete Precast Panel (2)	All	6	15
DECK05	Concrete Precast Panel (2)	All	7	23
DECK06	Grating/Plate (3,4,5,6)	Bituminous (6)	5	6
DECK06	Grating/Plate (3,4,5,6)	Bituminous (6)	6	13
DECK06	Grating/Plate (3,4,5,6)	Bituminous (6)	7	24
DECK07	Grating/Plate (3,4,5,6)	Other (all except 6)	5	7
DECK07	Grating/Plate (3,4,5,6)	Other (all except 6)	6	12
DECK07	Grating/Plate (3,4,5,6)	Other (all except 6)	7	18
DECK08	Wood (8)	Bituminous (6)	5	7
DECK08	Wood (8)	Bituminous (6)	6	13
DECK08	Wood (8)	Bituminous (6)	7	24
DECK80	Wood (8)	Other (all except 6)	5	6
DECK80	Wood (8)	Other (all except 6)	6	13
DECK80	Wood (8)	Other (all except 6)	7	21
DECK90	9 (Other)	All	5	11
DECK90	9 (Other)	All	6	23
DECK90	9 (Other)	All	7	35

Paint & Wearing Surface:

FAMILY	Design	Material	Initial NBI	Years to POOR
PAINT		All	5	10
PAINT		All	6	20
PAINT		All	7	34
Wearing Surface		All	5	5
Wearing Surface		All	6	10
Wearing Surface		All	7	14

Substructures (grouped by associated superstructure type):

FAMILY	Design	Material	Initial NBI	Years to POOR
SUB01	1 (Slab)	1 (Concrete), 8 (Masonry)	5	15
SUB01	1 (Slab)	1 (Concrete), 8 (Masonry)	6	25
SUB01	1 (Slab)	1 (Concrete), 8 (Masonry)	7	49
SUB02	1 (Slab)	2 (Concrete Continuous)	5	12
SUB02	1 (Slab)	2 (Concrete Continuous)	6	24
SUB02	1 (Slab)	2 (Concrete Continuous)	7	36
SUB04	1 (Slab)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	5	12
SUB04	1 (Slab)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	6	23
SUB04	1 (Slab)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	7	36
SUB05	1 (Slab)	7 (Wood or Timber)	5	9
SUB05	1 (Slab)	7 (Wood or Timber)	6	16
SUB05	1 (Slab)	7 (Wood or Timber)	7	23
SUB08	2, 3 (Stringer, Girder/Floorbeam)	3 (Steel)	5	16
SUB08	2, 3 (Stringer, Girder/Floorbeam)	3 (Steel)	6	32
SUB08	2, 3 (Stringer, Girder/Floorbeam)	3 (Steel)	7	47
SUB09	2, 3 (Stringer, Girder/Floorbeam)	4 (Steel Continuous)	5	14
SUB09	2, 3 (Stringer, Girder/Floorbeam)	4 (Steel Continuous)	6	26
SUB09	2, 3 (Stringer, Girder/Floorbeam)	4 (Steel Continuous)	7	38
SUB10	2, 3 (Stringer, Girder/Floorbeam)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	5	14
SUB10	2, 3 (Stringer, Girder/Floorbeam)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	6	27
SUB10	2, 3 (Stringer, Girder/Floorbeam)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	7	40
SUB11	2, 3 (Stringer, Girder/Floorbeam)	7 (Wood or Timber)	5	11
SUB11	2, 3 (Stringer, Girder/Floorbeam)	7 (Wood or Timber)	6	21
SUB11	2, 3 (Stringer, Girder/Floorbeam)	7 (Wood or Timber)	7	31
SUB12	4 (Tee Beam)	1 (Concrete)	5	13
SUB12	4 (Tee Beam)	1 (Concrete)	6	23
SUB12	4 (Tee Beam)	1 (Concrete)	7	35
SUB13	4 (Tee Beam)	2 (Concrete Continuous)	5	15
SUB13	4 (Tee Beam)	2 (Concrete Continuous)	6	29
SUB13	4 (Tee Beam)	2 (Concrete Continuous)	7	42
SUB14	4 (Tee Beam)	5 (Prestressed Concrete)	5	12
SUB14	4 (Tee Beam)	5 (Prestressed Concrete)	6	21
SUB14	4 (Tee Beam)	5 (Prestressed Concrete)	7	30
SUB15	5, 6 (Box Beam Multiple/Single)	3 (Steel)	5	9
SUB15	5, 6 (Box Beam Multiple/Single)	3 (Steel)	6	17
SUB15	5, 6 (Box Beam Multiple/Single)	3 (Steel)	7	24
SUB16	5, 6 (Box Beam Multiple/Single)	4 (Steel Continuous)	5	9
SUB16	5, 6 (Box Beam Multiple/Single)	4 (Steel Continuous)	6	17

FAMILY	Design	Material	Initial NBI	Years to POOR
SUB16	5, 6 (Box Beam Multiple/Single)	4 (Steel Continuous)	7	24
SUB17	5, 6 (Box Beam Multiple/Single)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	5	10
SUB17	5, 6 (Box Beam Multiple/Single)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	6	19
SUB17	5, 6 (Box Beam Multiple/Single)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	7	28
SUB18	7 (Frame)	1 (Concrete)	5	17
SUB18	7 (Frame)	1 (Concrete)	6	33
SUB18	7 (Frame)	1 (Concrete)	7	49
SUB19	7 (Frame)	2 (Concrete Continuous)	5	17
SUB19	7 (Frame)	2 (Concrete Continuous)	6	37
SUB19	7 (Frame)	2 (Concrete Continuous)	7	55
SUB20	7 (Frame)	3 (Steel)	5	19
SUB20	7 (Frame)	3 (Steel)	6	46
SUB20	7 (Frame)	3 (Steel)	7	65
SUB21	7 (Frame)	4 (Steel Continuous)	5	19
SUB21	7 (Frame)	4 (Steel Continuous)	6	39
SUB21	7 (Frame)	4 (Steel Continuous)	7	57
SUB22	7 (Frame)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	5	12
SUB22	7 (Frame)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	6	24
SUB22	7 (Frame)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	7	36
SUB24	9, 10 (Truss – Deck & Thru)	3 (Steel)	5	12
SUB24	9, 10 (Truss – Deck & Thru)	3 (Steel)	6	23
SUB24	9, 10 (Truss – Deck & Thru)	3 (Steel)	7	34
SUB25	9, 10 (Truss – Deck & Thru)	4 (Steel Continuous)	5	20
SUB25	9, 10 (Truss – Deck & Thru)	4 (Steel Continuous)	6	35
SUB25	9, 10 (Truss – Deck & Thru)	4 (Steel Continuous)	7	51
SUB27	11, 12 (Arch – Deck & Thru)	1 (Concrete)	5	18
SUB27	11, 12 (Arch – Deck & Thru)	1 (Concrete)	6	37
SUB27	11, 12 (Arch – Deck & Thru)	1 (Concrete)	7	54
SUB28	11, 12 (Arch – Deck & Thru)	2 (Concrete Continuous)	5	13
SUB28	11, 12 (Arch – Deck & Thru)	2 (Concrete Continuous)	6	25
SUB28	11, 12 (Arch – Deck & Thru)	2 (Concrete Continuous)	7	37
SUB29	11, 12 (Arch – Deck & Thru)	3 (Steel), 9 (Aluminum, Iron)	5	12
SUB29	11, 12 (Arch – Deck & Thru)	3 (Steel), 9 (Aluminum, Iron)	6	23
SUB29	11, 12 (Arch – Deck & Thru)	3 (Steel), 9 (Aluminum, Iron)	7	34
SUB30	11, 12 (Arch – Deck & Thru)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	5	12
SUB30	11, 12 (Arch – Deck & Thru)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	6	23
SUB30	11, 12 (Arch – Deck & Thru)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	7	33
SUB31	11, 12 (Arch – Deck & Thru)	8 (Masonry)	5	26
SUB31	11, 12 (Arch – Deck & Thru)	8 (Masonry)	6	51

FAMILY	Design	Material	Initial NBI	Years to POOR
SUB31	11, 12 (Arch – Deck & Thru)	8 (Masonry)	7	76
SUB32	15, 16, 17 (Movable)	All	5	12
SUB32	15, 16, 17 (Movable)	All	6	25
SUB32	15, 16, 17 (Movable)	All	7	36
SUB33	Other (20,21,22)	All	5	10
SUB33	Other (20,21,22)	All	6	20
SUB33	Other (20,21,22)	All	7	29

Superstructures:

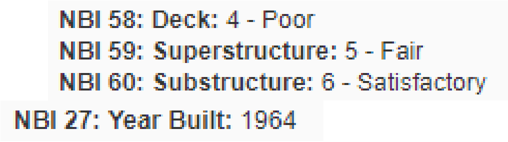
FAMILY	Design	Material	Initial NBI	Years to POOR
SUP01	1 (Slab)	1 (Concrete)	5	20
SUP01	1 (Slab)	1 (Concrete)	6	47
SUP01	1 (Slab)	1 (Concrete)	7	70
SUP02	1 (Slab)	2 (Concrete Continuous)	5	14
SUP02	1 (Slab)	2 (Concrete Continuous)	6	26
SUP02	1 (Slab)	2 (Concrete Continuous)	7	39
SUP04	1 (Slab)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	5	13
SUP04	1 (Slab)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	6	25
SUP04	1 (Slab)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	7	37
SUP05	1 (Slab)	7 (Wood or Timber)	5	11
SUP05	1 (Slab)	7 (Wood or Timber)	6	20
SUP05	1 (Slab)	7 (Wood or Timber)	7	30
SUP08	2, 3 (Stringer, Girder/Floorbeam)	3 (Steel)	5	15
SUP08	2, 3 (Stringer, Girder/Floorbeam)	3 (Steel)	6	31
SUP08	2, 3 (Stringer, Girder/Floorbeam)	3 (Steel)	7	45
SUP09	2, 3 (Stringer, Girder/Floorbeam)	4 (Steel Continuous)	5	13
SUP09	2, 3 (Stringer, Girder/Floorbeam)	4 (Steel Continuous)	6	25
SUP09	2, 3 (Stringer, Girder/Floorbeam)	4 (Steel Continuous)	7	37
SUP10	2, 3 (Stringer, Girder/Floorbeam)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	5	12
SUP10	2, 3 (Stringer, Girder/Floorbeam)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	6	25
SUP10	2, 3 (Stringer, Girder/Floorbeam)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	7	36
SUP11	2, 3 (Stringer, Girder/Floorbeam)	7 (Wood or Timber)	5	12
SUP11	2, 3 (Stringer, Girder/Floorbeam)	7 (Wood or Timber)	6	23
SUP11	2, 3 (Stringer, Girder/Floorbeam)	7 (Wood or Timber)	7	34
SUP12	4 (Tee Beam)	1 (Concrete)	5	11

FAMILY	Design	Material	Initial NBI	Years to POOR
SUP12	4 (Tee Beam)	1 (Concrete)	6	21
SUP12	4 (Tee Beam)	1 (Concrete)	7	30
SUP13	4 (Tee Beam)	2 (Concrete Continuous)	5	9
SUP13	4 (Tee Beam)	2 (Concrete Continuous)	6	17
SUP13	4 (Tee Beam)	2 (Concrete Continuous)	7	26
SUP14	4 (Tee Beam)	5 (Prestressed Concrete)	5	11
SUP14	4 (Tee Beam)	5 (Prestressed Concrete)	6	20
SUP14	4 (Tee Beam)	5 (Prestressed Concrete)	7	29
SUP15	5, 6 (Box Beam Multiple/Single)	3 (Steel)	5	9
SUP15	5, 6 (Box Beam Multiple/Single)	3 (Steel)	6	17
SUP15	5, 6 (Box Beam Multiple/Single)	3 (Steel)	7	25
SUP16	5, 6 (Box Beam Multiple/Single)	4 (Steel Continuous)	5	7
SUP16	5, 6 (Box Beam Multiple/Single)	4 (Steel Continuous)	6	15
SUP16	5, 6 (Box Beam Multiple/Single)	4 (Steel Continuous)	7	21
SUP17	5, 6 (Box Beam Multiple/Single)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	5	10
SUP17	5, 6 (Box Beam Multiple/Single)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	6	18
SUP17	5, 6 (Box Beam Multiple/Single)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	7	28
SUP18	7 (Frame)	1 (Concrete)	5	14
SUP18	7 (Frame)	1 (Concrete)	6	27
SUP18	7 (Frame)	1 (Concrete)	7	41
SUP19	7 (Frame)	2 (Concrete Continuous)	5	14
SUP19	7 (Frame)	2 (Concrete Continuous)	6	31
SUP19	7 (Frame)	2 (Concrete Continuous)	7	46
SUP20	7 (Frame)	3 (Steel)	5	15
SUP20	7 (Frame)	3 (Steel)	6	29
SUP20	7 (Frame)	3 (Steel)	7	43
SUP21	7 (Frame)	4 (Steel Continuous)	5	21
SUP21	7 (Frame)	4 (Steel Continuous)	6	40
SUP21	7 (Frame)	4 (Steel Continuous)	7	58
SUP22	7 (Frame)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	5	12
SUP22	7 (Frame)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	6	22
SUP22	7 (Frame)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	7	33
SUP24	9, 10 (Truss – Deck & Thru)	3 (Steel)	5	7
SUP24	9, 10 (Truss – Deck & Thru)	3 (Steel)	6	14
SUP24	9, 10 (Truss – Deck & Thru)	3 (Steel)	7	19
SUP25	9, 10 (Truss – Deck & Thru)	4 (Steel Continuous)	5	21
SUP25	9, 10 (Truss – Deck & Thru)	4 (Steel Continuous)	6	41
SUP25	9, 10 (Truss – Deck & Thru)	4 (Steel Continuous)	7	45
SUP27	11, 12 (Arch – Deck & Thru)	1 (Concrete)	5	16

FAMILY	Design	Material	Initial NBI	Years to POOR
SUP27	11, 12 (Arch – Deck & Thru)	1 (Concrete)	6	34
SUP27	11, 12 (Arch – Deck & Thru)	1 (Concrete)	7	50
SUP28	11, 12 (Arch – Deck & Thru)	2 (Concrete Continuous)	5	16
SUP28	11, 12 (Arch – Deck & Thru)	2 (Concrete Continuous)	6	31
SUP28	11, 12 (Arch – Deck & Thru)	2 (Concrete Continuous)	7	37
SUP29	11, 12 (Arch – Deck & Thru)	3 (Steel), 9 (Aluminum, Iron)	5	15
SUP29	11, 12 (Arch – Deck & Thru)	3 (Steel), 9 (Aluminum, Iron)	6	29
SUP29	11, 12 (Arch – Deck & Thru)	3 (Steel), 9 (Aluminum, Iron)	7	43
SUP30	11, 12 (Arch – Deck & Thru)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	5	11
SUP30	11, 12 (Arch – Deck & Thru)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	6	21
SUP30	11, 12 (Arch – Deck & Thru)	5 (Prestressed Concrete), 6 (P/S Conc Continuous)	7	31
SUP31	11, 12 (Arch – Deck & Thru)	8 (Masonry)	5	25
SUP31	11, 12 (Arch – Deck & Thru)	8 (Masonry)	6	49
SUP31	11, 12 (Arch – Deck & Thru)	8 (Masonry)	7	73
SUP32	15, 16, 17 (Movable)	All	5	10
SUP32	15, 16, 17 (Movable)	All	6	19
SUP32	15, 16, 17 (Movable)	All	7	27
SUP33	Other (20,21,22)	All	5	7
SUP33	Other (20,21,22)	All	6	13
SUP33	Other (20,21,22)	All	7	19

EXAMPLE

Bridge Life-Cycle Cost Analysis


NBI 58: Deck: 4 - Poor
NBI 59: Superstructure: 5 - Fair
NBI 60: Substructure: 6 - Satisfactory
NBI 27: Year Built: 1964

Calculating future cost of a project with the same work present values

Future Cost is inflated to value at n years from now
Interest Rate = 6.0% for first 3 years, then 3.50% after that

Bridge Costs- 75 Year Life (Construction Costs Only)

Alternative A - Deck Patching and Other Repairs

Item	Present Value (PV)	Inflation Rate*	Future Year	Future Cost (FV)**
Deck Patching & Other Repairs	$4,000,000	6.00%	0	$4,000,000
Full Replacement (Year 10)	$30,000,000	3.50%	10	$45,459,149
Milling and Paving (Year 25)	$340,220	3.50%	25	$863,704
Deck Replacement (Year 35)	$4,000,641	3.50%	35	$14,326,443
Milling and Paving (Year 45)	$340,220	3.50%	45	$1,718,589
Superstructure Replacement (Year 60)	$22,300,000	3.50%	60	$188,721,942
Partial Overlay (Year 70)	$226,813	3.50%	70	$2,707,632
Less Salvage Value	-$4,000,000	3.50%	75	-$56,713,020
Total Cost over next 75 years	$57,207,894			$253,797,459

Alternative B - Deck Replacement and Other Repairs

Item	Present Value (PV)	Inflation Rate*	Future Year	Future Cost (FV)**
Deck Replacement, Other Minor Repairs	$7,600,000	6.00%	0	$7,600,000
Milling and Paving (Year 15)	$340,220	3.50%	15	$612,296
Full Replacement (Year 25)	$30,000,000	3.50%	25	$76,159,932
Milling and Paving (Year 40)	$340,220	3.50%	40	$1,447,006
Deck Replacement (Year 60)	$4,000,641	3.50%	60	$33,856,894
Milling and Paving (Year 70)	$340,220	3.50%	70	$4,061,448
Less Salvage Value	-$10,000,000	3.50%	75	-$141,782,549
Total Cost over next 75 years	$32,621,301			$113,737,567

* Future costs are calculated using 6% inflation for the first 3 years, then 3.5% inflation for remaining years.
** Future Costs are the actual amounts expected to be budgeted for construction in the designated future year.

(continued on next page)

Alternative C - Superstructure Replacement and Substructure Repairs

Item	Present Value (PV)	Inflation Rate*	Future Year	Future Cost (FV)**
Superstructure Replacement	$22,300,000	6.00%	0	$22,300,000
Milling and Paving (Year 15)	$340,220	3.50%	15	$612,296
Deck Repair; Other Repairs (Year 25)	$4,000,000	3.50%	25	$10,156,285
Milling and Paving (Year 40)	$340,220	3.50%	40	$1,447,006
Full Replacement (Year 50)	$30,000,000	3.50%	50	$179,984,577
Partial Overlay (Year 60)	$226,813	3.50%	60	$1,919,491
Milling and Paving (Year 70)	$340,220	3.50%	70	$4,061,448
Less Salvage Value	-$20,000,000	3.50%	75	-$283,565,099
Total Cost over next 75 years	$37,548,114			$200,481,103

Alternative D - Full Replacement

Item	Present Value (PV)	Inflation Rate*	Future Year	Future Cost (FV)**
Full Replacement	$30,000,000	6.00%	0	$30,000,000
Milling and Paving (Year 15)	$340,220	3.50%	15	$612,296
Deck Repair; Other Repairs (Year 25)	$4,000,000	3.50%	25	$10,154,658
Milling and Paving (Year 40)	$340,220	3.50%	40	$1,447,006
Superstructure Replacement (Year 50)	$22,300,000	3.50%	50	$133,788,535
Partial Overlay (Year 60)	$226,813	3.50%	60	$1,919,491
Milling and Paving (Year 70)	$340,220	3.50%	70	$4,061,448
Salvage Value	-$0	3.50%	75	-$0
Total Cost over next 75 years	$57,547,473			$181,983,434

* Future costs are calculated using 6% inflation for the first 3 years, then 3.5% inflation for remaining years.

** Future Costs are the actual amounts expected to be budgeted for construction in the designated future year.

Project LCCA Example

Essentially, the total shown in the "Present Value" column is the total cost of all the work related to the selected alternate in today's dollars. The "Future Cost" is the actual amount that the Department will need to spend on the bridge if the given alternate is selected; the amounts shown in the Future Costs columns are the anticipated dollar amounts that the Department will need to include in its budget for the given year if the proposed alternate is selected.

Depending on the purpose of the comparison, either the total Present Value or the total Future Costs can be used for comparison of alternates. Using present value simplifies comparisons, but the future costs show the future budget implications of each alternate. There may be a case where saving some money today results in a "budget buster" in the future, especially if there are a large number of bridges with expensive needs falling into the same future year.

It is anticipated that once a project's RSR is completed, the future action plan necessitated by the selected alternative will be entered into the Department's bridge management system.

REFERENCES

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