Estimating Life-cycle Cost of West Virginia Fiber Reinforced Polymer (FRP) Bridge Decks

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WV Bridge Deck Alternatives

Concrete Deck

FRP Deck

FRP for Bridge Deck : Why not?

The application of fiber-reinforced polymer (FRP) composites to replace concrete bridge decks has been successfully demonstrated on a technological basis.

The issue that must be determined is :

Are FRP bridge decks competitive on a cost basis with SRC decks?

Economic Feasibility

There are two approaches one could use for cost analysis:

- Initial Cost Analysis and
- Life-cycle cost Analysis

- **Life-cycle cost** *(Business Dictionary.com)*

  Sum of all recurring and one-time (non-recurring) costs over the full life span or a specified period of a good, service, structure, or system. It includes purchase price, installation cost, operating costs, maintenance and upgrade costs, and salvage value at the end of ownership or its useful life.

Importance of Life -cycle cost Analysis

- Comparison of infrastructural projects that have high investment costs and a long life expectancy requires using a Life-cycle costing (LCC) methodology. There are costs beyond the initial construction costs that should be considered.
- The Federal Highway Administration (FHWA) encourages states to use LCC when determining which roadway projects to fund.
- This technique can be used for many reasons, but its primary uses are:
  * Comparison of competing alternatives
  * Long range planning and budgeting
  * Selection among competing contractors
  * Decisions about replacement of ageing equipment
  * Control over ongoing programs

Life Cycle Cost Estimations for WV FRP Bridge Decks:

- Include 3 important features not covered in existing studies/ LCC models:

(1) Estimation of FRP deck cost (based on Learning curve method)

(2) Consideration of cost savings from reduced substructure costs when FRP is used

(3) Estimation of FRP bridge deck service life using the factor method.

FRP Deck Cost Estimation

Bridge #	Year	Cost/ft sq	Ft Sq	Cum ft sq	Total cost	Cum tot cost	Average unit cost	log cum ft sq	log avg unit (C)
(1)	(2)	(3)	(4)	(5)	(6)=(3)x(4)	(7)	(8)=(7)/(5)	(9)=log(5)	(10)=log(8)
1	1997	$147.00	320	320	$47,040	$47,040	$147.00	2.51	2.17
2	1997	$140.00	651	971	$91,140	$138,180	$142.31	2.99	2.15
3	2000	$69.90	1245	2,216	$87,026	$225,206	$101.63	3.35	2.01
4	2002	$55.70	1100	3,316	$61,270	$286,476	$86.39	3.52	1.94
5	2002	$57.47	780	4,096	$44,827	$331,302	$80.88	3.61	1.91
6	2003	$54.00	1000	5,096	$54,000	$385,302	$75.61	3.71	1.88

$C = a * N^b$

$\log (C) = \log(a) + b*\log (N)$

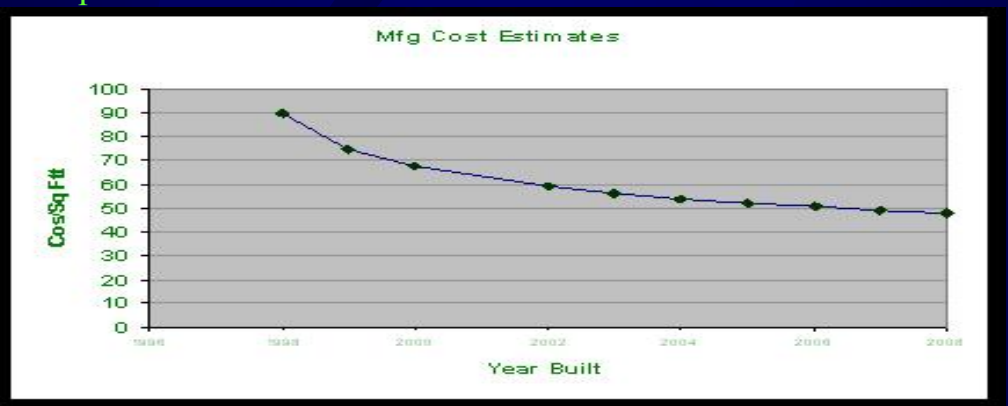
Where
a =cost for 1st unit
b = exponent of learning curve
C = average cumulative cost of X ($/ft2)
N = cumulative square feet produced. 53

$Ct = N* (a * N^b) = a * N^{b+1}$

Where
Ct = total cumulative cost to produce N units
The equation for unit cost basis, Cu, was:
$Cu (\$/ft2) = dCt/dN = d(a * N^{b+1})/dN = (b+1)*a* N^b$

$Cu (\$/ft2) = a*(b+1)* N^b.$

Using the West Virginia data found:
$Cu(\$/ft2) = 540.95*N^{-0.26}$



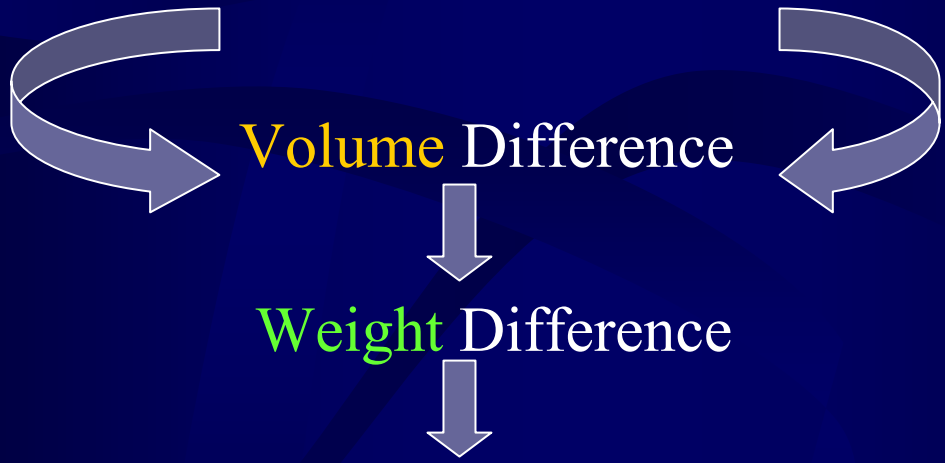
Cost Saving Calculation

FRP Deck →

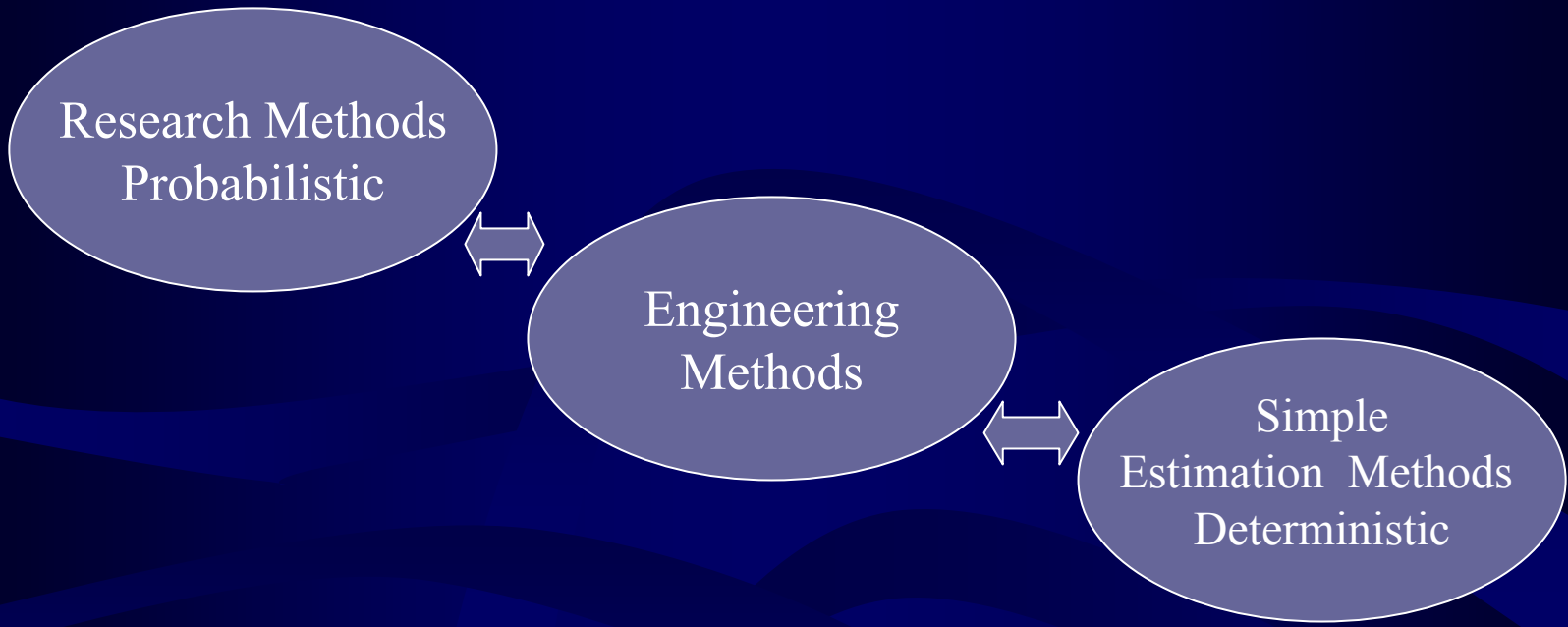
Required Stringer Sections
(Deflection, Stresses, Shear)

Concrete Deck →

Required Stringer Section



Service Life Prediction Methods

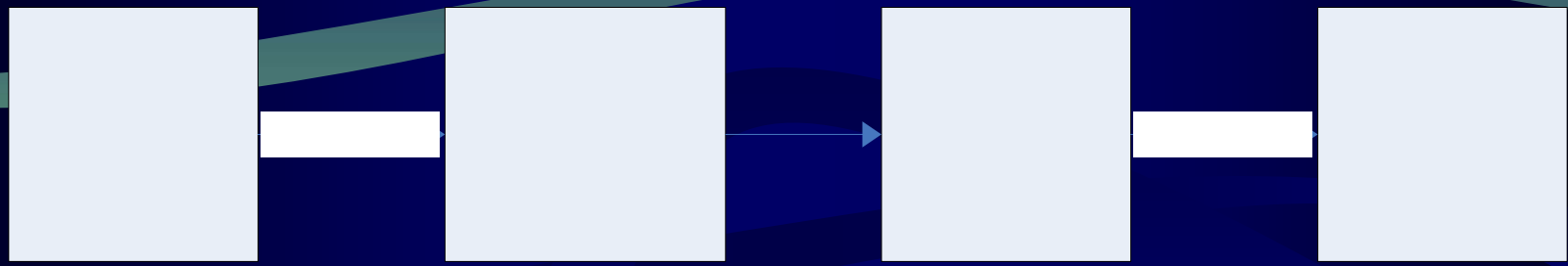


The factor method was developed as a tool to support service life prediction when there is a lack of adequate or reliable data.

This method is based on a reference service life and modifying factors that relate to the specific condition of the element.

Estimate Service Life = RSLC * A * B * C * ….(factors)

Life Cycle Cost

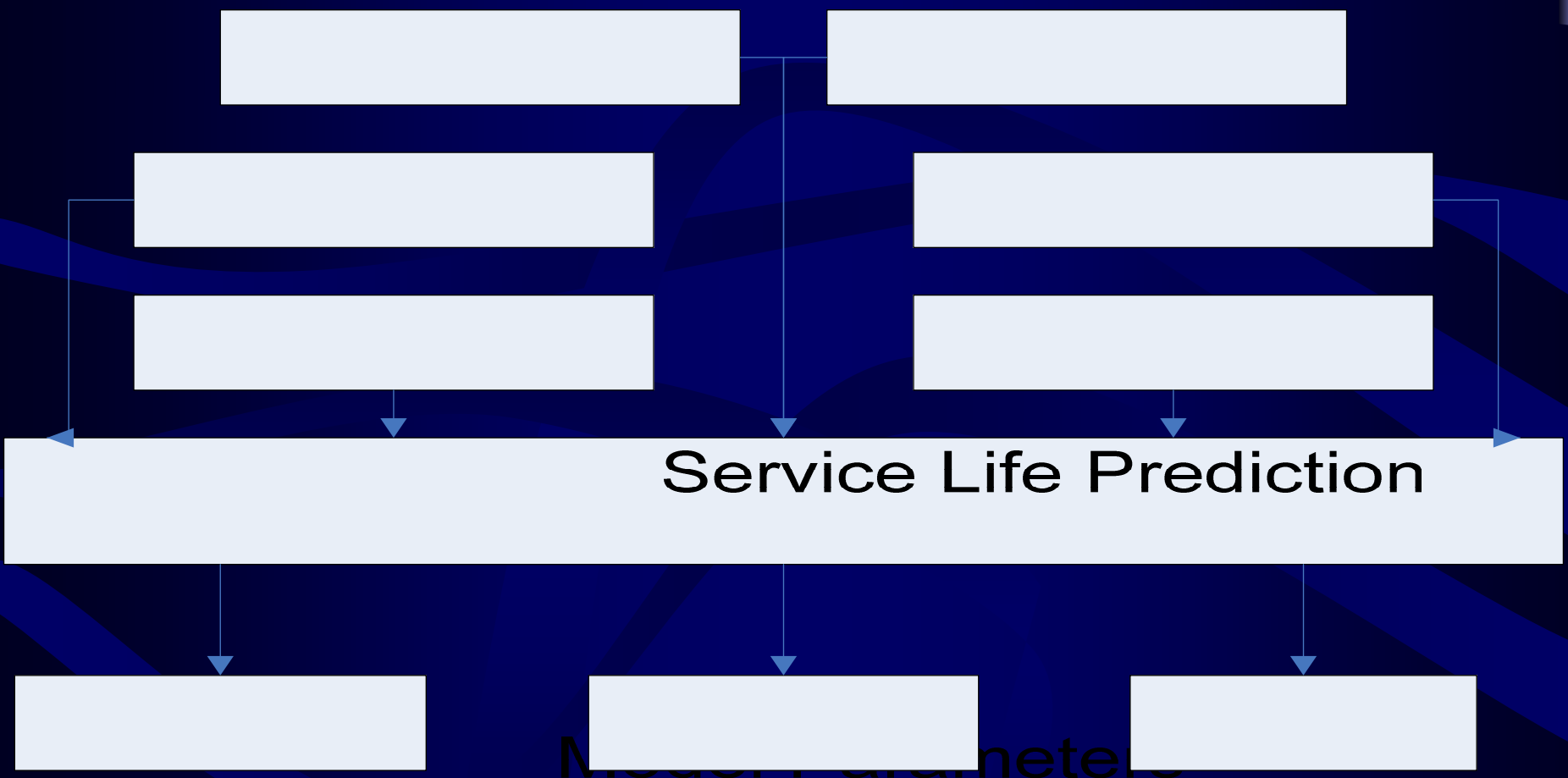


Life Cycle Cost for FRP bridge deck include

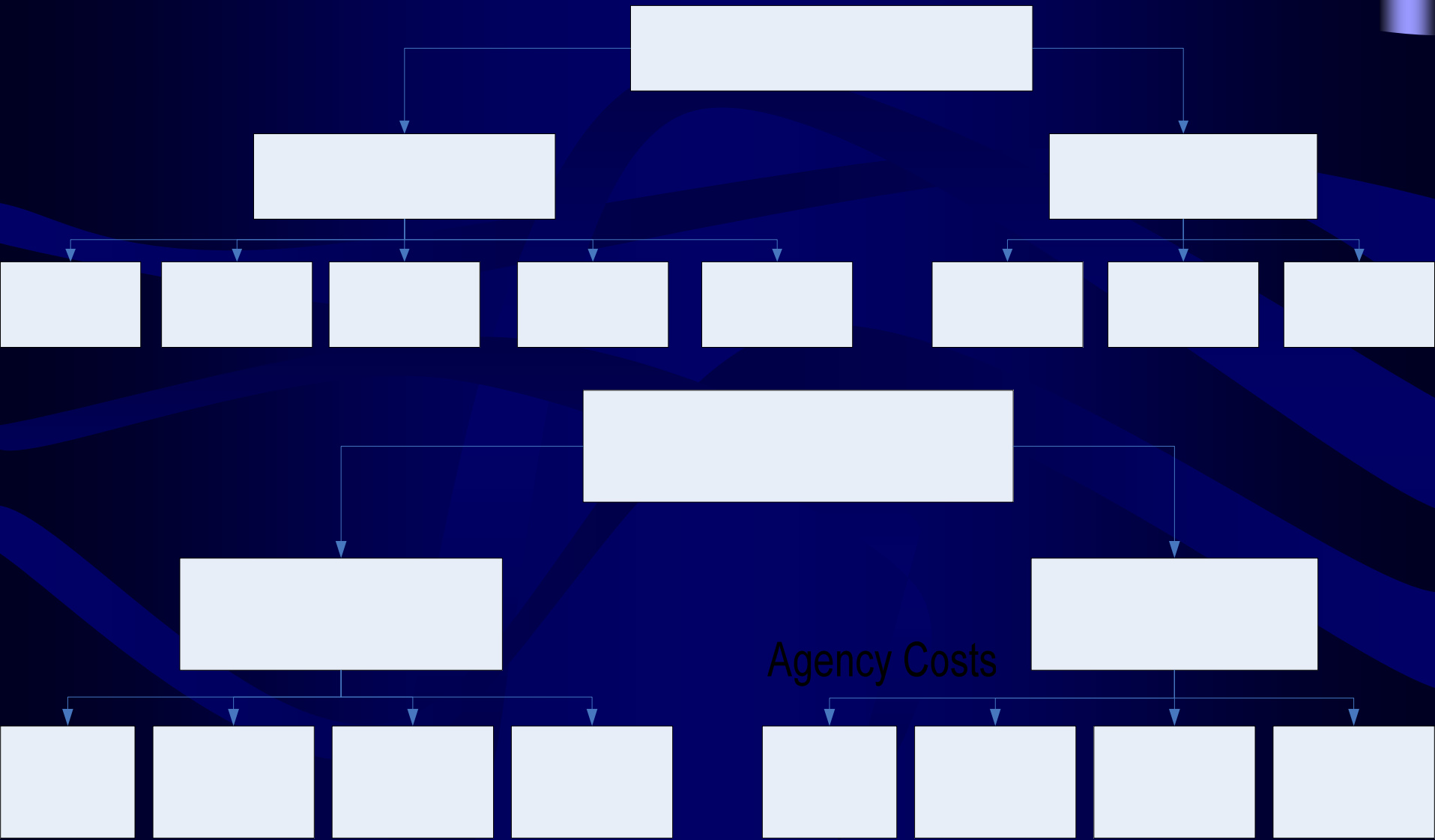
- Initial fabrication and erection costs
- Maintenance/Inspection/Repair costs
- Disposal costs

CONSTRUCTION

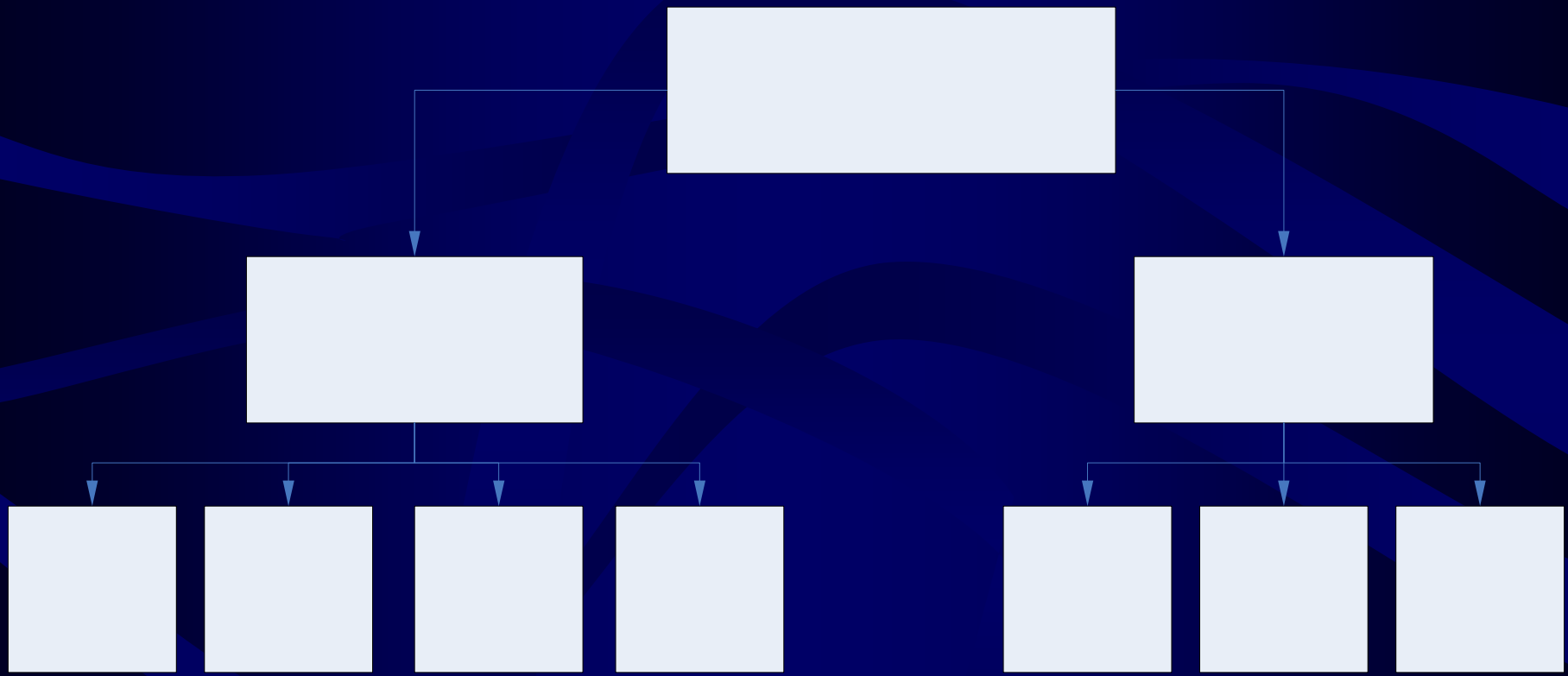
Life Cycle Cost Model



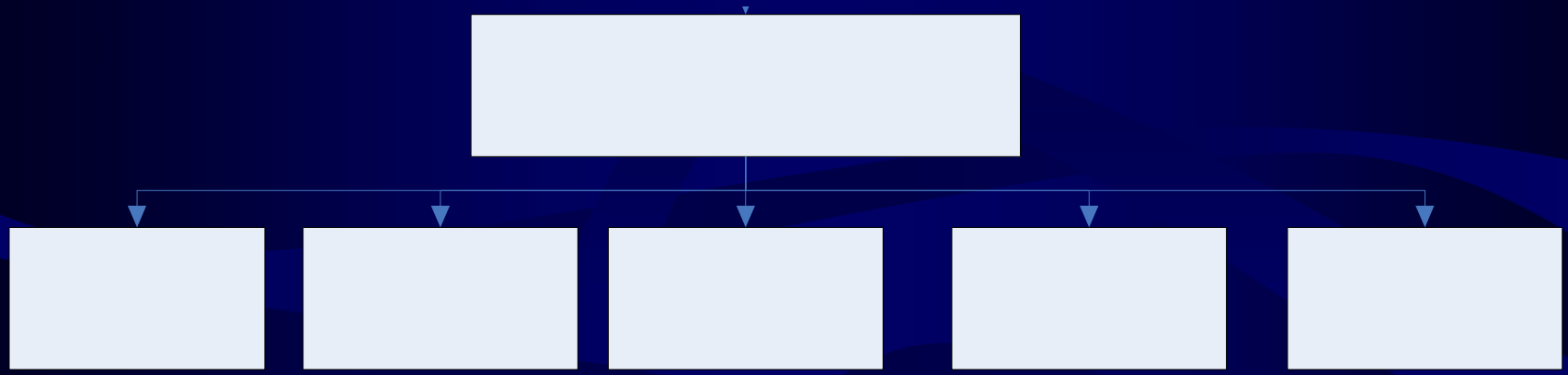
LCC Breakdown



LCC Breakdown



Initial – Agency Costs



Manufacturing cost = f (manufacturing cost/sq ft, deck area)
Transportation costs = f (distance between manufacturer and project site)
Installation costs = f (installation cost/ sq ft, deck area)
Safety costs = f (construction time, labor cost)

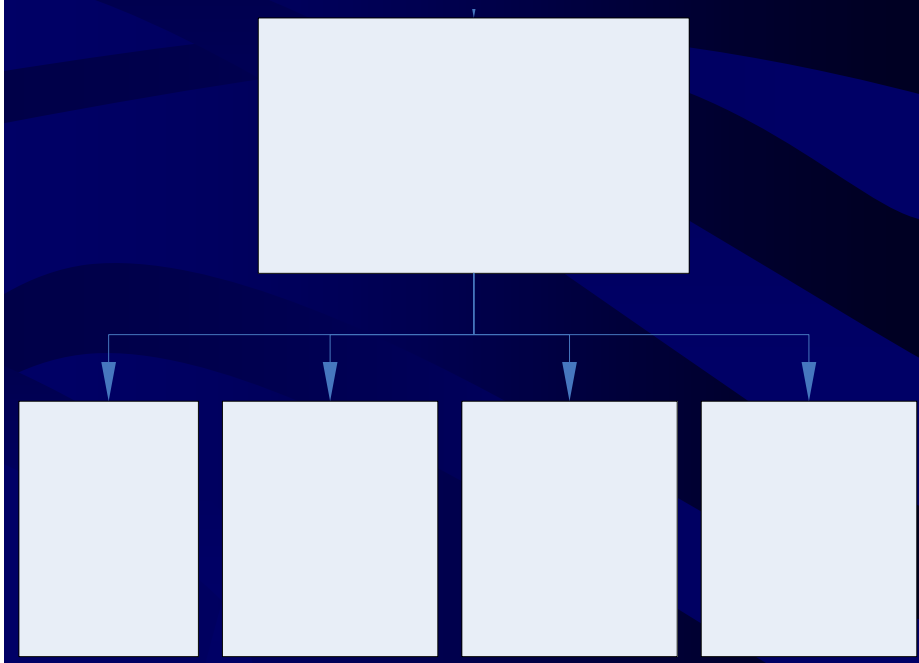
Agency

User Costs

Driver Delay Costs= (RL/CS – RL/NS) * ADT * N * HC (Equation 3-10)
Vehicle Operating Costs=(RL/CS – RL/NS) * ADT * N * VC (Equation 3-11)
Increased Accident Costs=RL * ADT * N * (CA – NA) * AC (Equation 3-12)

Maintenance,Inspection,Repair

INSPECTION/MAINTENANCE SCHEDULE			
Concrete Bridge Deck	start year	end year	time between
Periodic Inspection	2nd	28th	2 yrs
In Depth Period Inspection	6th	24th	6 yrs
Anticipated Repairs	20th	29th	3 yrs
Deck Replacement	30th	30th	
FRP Bridge Deck			
Periodic Inspection	2nd	58th	2 yrs
In Depth Period Inspection	6th	54th	6 yrs
Repair	20th	59th	3 yrs
Overlay Replacement	30th	30th	



MIR Agency Costs

FRP Maintenance/Inspection/Anticipated Repair Costs

Basic Inspection $= \sum SIC * (1+DR)^{-n}$

n=2,4,8,10,14,16,20,22,26,28,32,34,38,40,44,46,50,52,56,58

Supplemental Inspection $= \sum PIC * (1+DR)^{-n}$

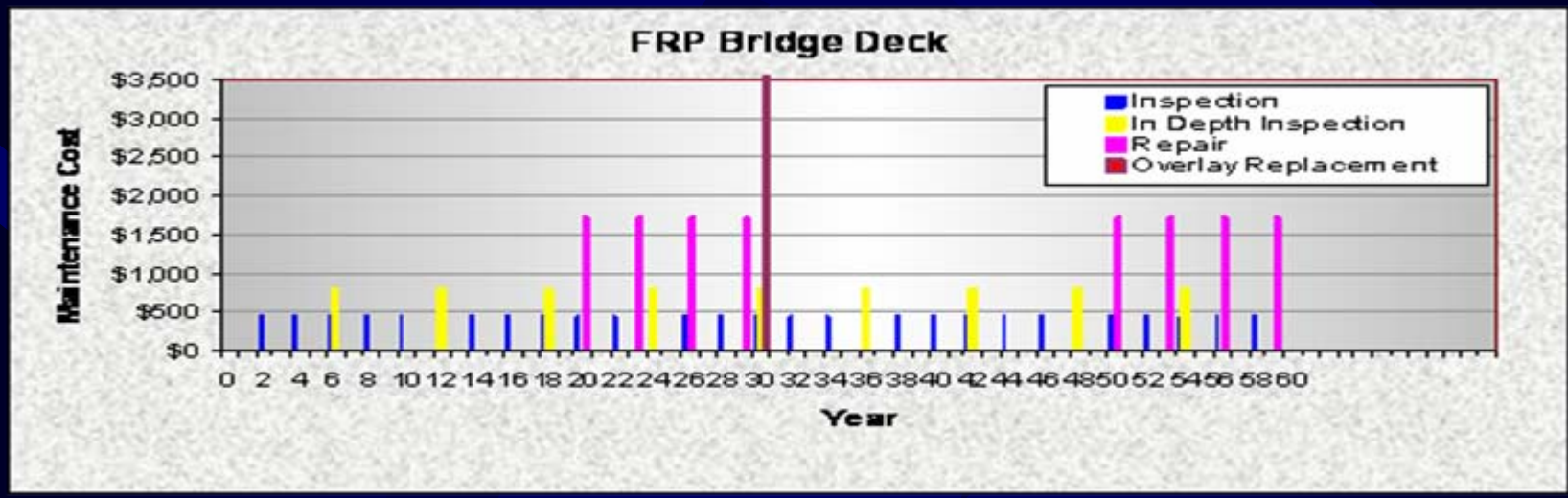
n=6,12,18,24,30,36,42,48,54

Anticipated Repair $= \sum DRC * (1+DR)^{-n}$

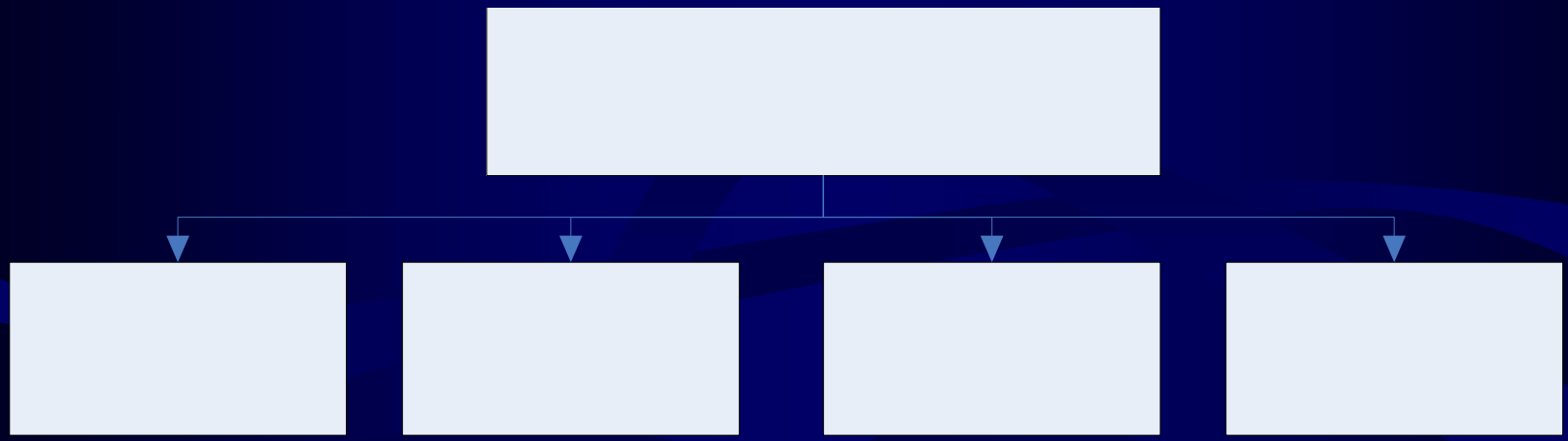
n=20,23,26,29,50,53,56,59

Overlay Replacement $= \sum WSC * DA * (1+DR)^{-n}$

n=30



Disposal – Agency Costs



Deconstruction Cost = f (deconstruction time, labor cost/hr)
Safety cost = f (deconstruction time, labor cost/hr)
Transportation Cost = f (number of truck trips required, distance between project site and disposal site)
Landfill Cost = f (landfill fee and number of truck loads)

Microsoft Excel - SS_LCC_KATYTRUSS_FINALM09 [Read-Only] [Compatibility Mode]

Katy Truss(Year 2000)

INPUT PARAMETERS

BRIDGE GEOMETRY

Span of Bridge	91.3	ft
Out to Out Bridge Width	14.3	ft
Number of Span	1	
Deck Overhang	10	in

TRAFFIC AND ACCIDENT INFORMATION

Average Daily Traffic (=ADT)	700	
Normal Traffic Speed	55	mph
Normal Accident Rate	0.268	per million-vehicle-miles
Traffic Speed during Construction	45	Default
Accident Rate during Construction	0.463	Default
Average Cost per Accident	$29,018	$
Hourly Vehicle Operating Cost	8.40	$/hr
Hourly Time Value of Driver	13.98	$/hr

DETAIL OF STEEL STRINGER FOR FRP BRIDGE DECK

OK Design Check

Stringer Properties (Choose :)	W27 x 217		
Number of Stringers	4		
Spacing of Stringers	4	ft	2 in
Cross Sectional Area	63.8	in^2	
Flange Width	14.115	in	
Web Thickness	0.83	in	
Stringer Depth	28.43	in	
Moment of Inertia	8870	in^4	
Stringer Weight	0.217	k/ft	
Section Modulus	624	in^3	
Young's Modulus of Elasticity	2.90E+07	psi	

DETAIL OF STEEL STRINGER FOR CONCRETE DECK

OK Design Check

Stringer Properties for Concrete (Choose:)	W30 x 235	
Stringer Cost	1.29	$/lb

DETAIL OF FRP DECK

Yr the Bridge Deck is Built (choose:)	2000		
Thickness of Deck	8	in	
Self weight of Deck	16	psf	Default
Cost of Deck	67.47	$ psf	67.469
Manufacturer	BRP		

DETAIL OF WEARING SURFACE

Material	polymer concrete overlay		
Weight	3	psf	Default
Wearing Surface Cost	$3.25	psf	

FRP DECK INSTALLATION

Labor cost per hour	$10.97

DISCOUNT AND INFLATION RATES

Discount Rate	3.0%

ENVIRONMENTAL CONDITIONS

Freeze Thaw Cycles	moderate

OVERALL TRAFFIC

ADT	low

OTHER COST INFO

Gasoline	$1.50	/ gallon
Landfill	$33.29	/ton
Federal Minimum Wage	$5.15	/hr
Inspection cost	$397	
In Depth Inspection Cost	$706	
Repair Cost	$32	

DETAIL OF CONCRETE DECK

Thickness of Deck	8	in
Self weight of Deck	100	psf
Cost of Deck	26.49	$ psf

PROJECT SITE

County

COUNTY

Marion Co

STUDY PERIOD

60

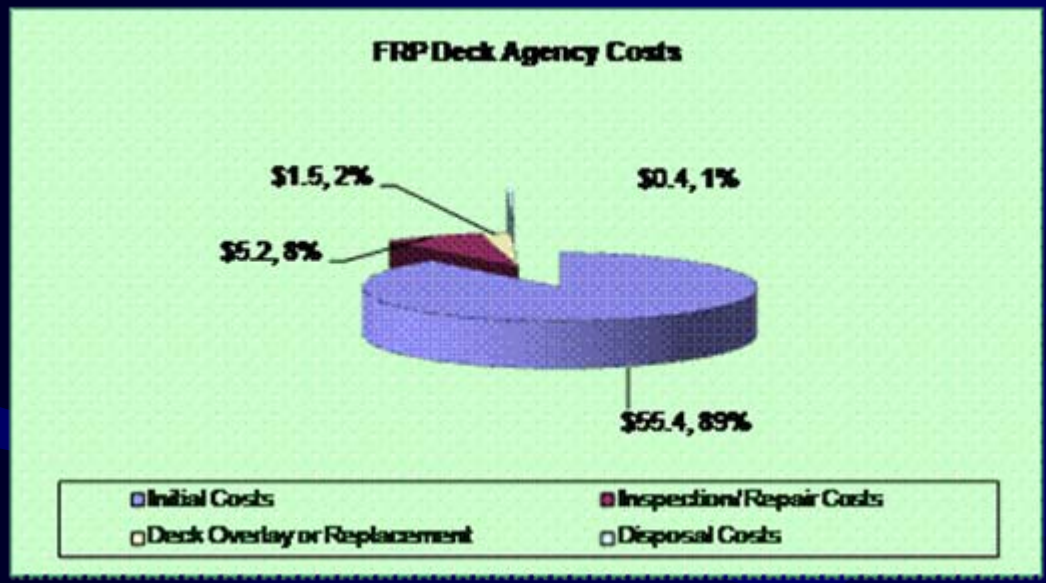
set=service life FRP

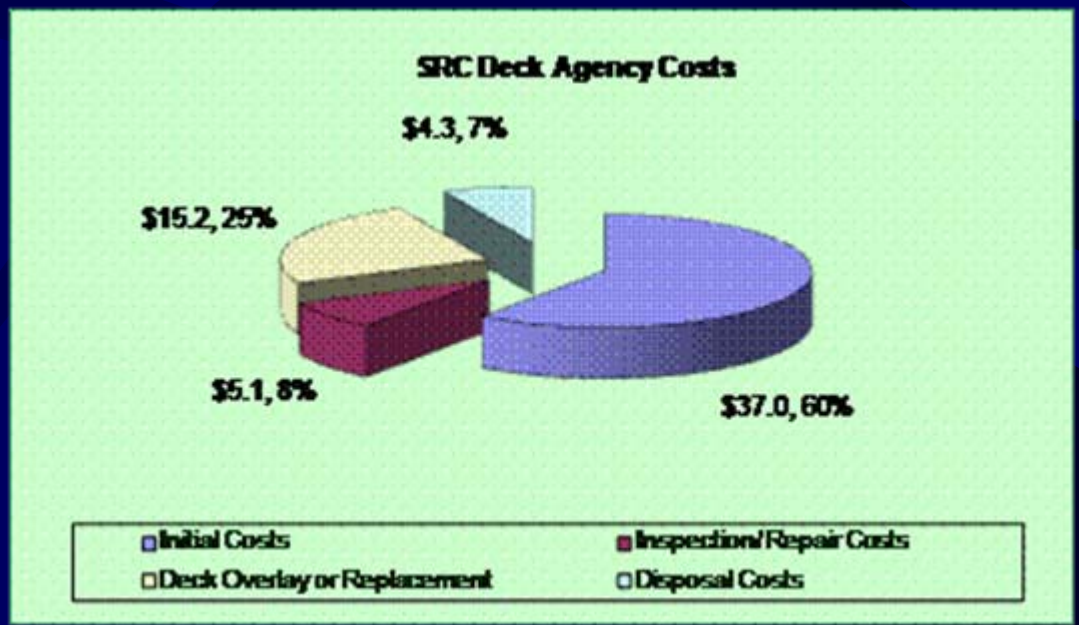
REF SERVICE LIFE

70 yrs

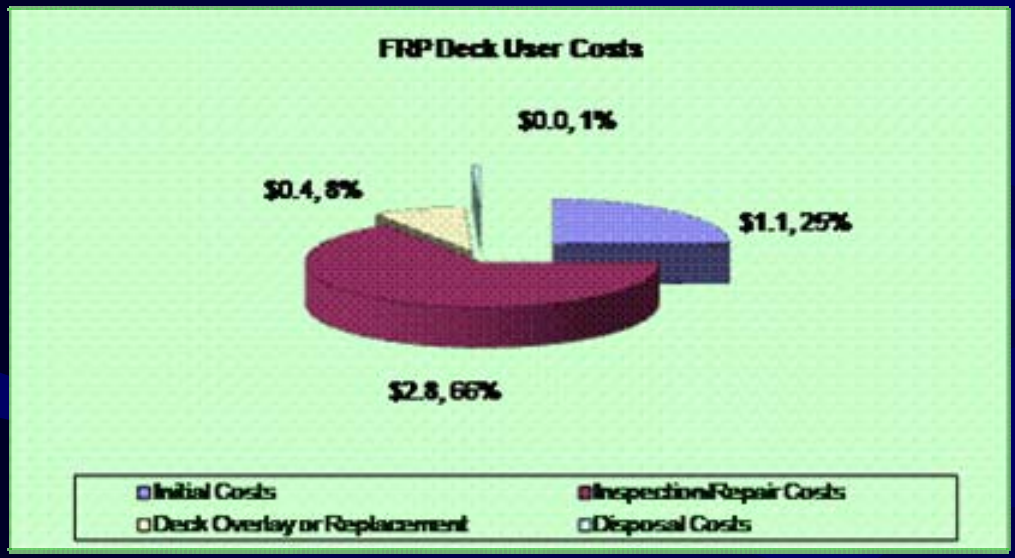
Maintenance Inputs | Calculate LCC | Sensv Analysis

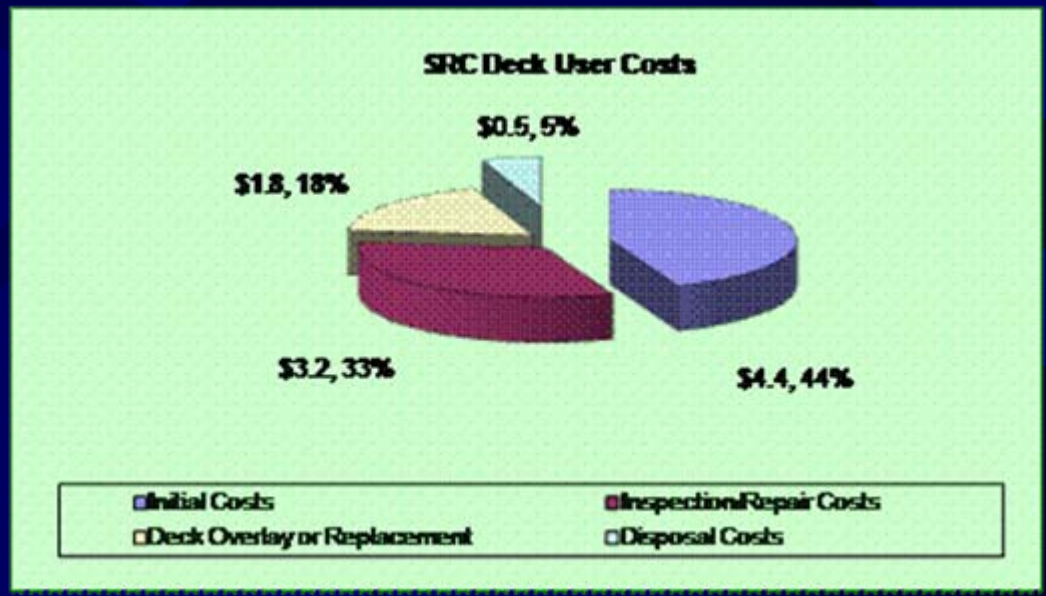
Agency Costs – Pie Charts





User Costs – Pie Charts

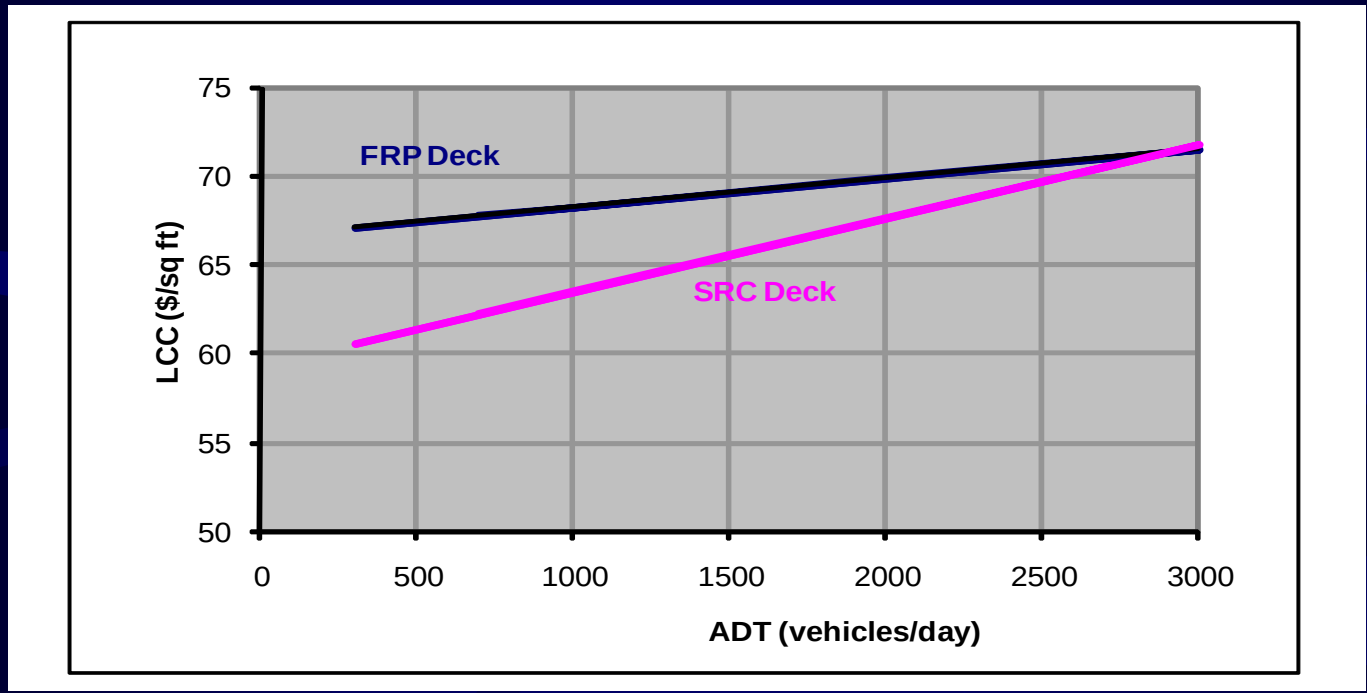




Bridge Deck Project	Katy Truss	Katy Truss
Yr	2000	2000
Bridge Deck Alternative	FRP	SRC
ADT (vehicles/day)	700	700
Study Period (yrs)	60	60
Service Life (yrs)	60	30
Deck Cost ($/sq ft)	$67.5	$26.5
Initial Costs		
Agency Costs		
Total Agency Costs	$69.3	$33.6
User Costs		
Total User Costs	$0.2	$1.3
Structural Savings		
Total Structural Savings	$11.4	$0.0
Total Initial Costs	$58.1	$34.9
Maintenance/Repair Costs		
Agency Costs		
Inspection/Repair	$6.9	$6.6
Deck Overlay or Replacement	$1.3	$13.9
Total Agency Costs	$8.2	$20.5
User Costs		
Total User Costs	$0.9	$1.5
Total Maintenance/Repair Costs	$9.1	$21.9
Disposal Costs		
Agency Costs		
Total Agency Costs	$0.3	$5.1
User Costs		
Total User Costs	$0.0	$0.1
Total Disposal Costs	$0.3	$5.2
LIFE CYCLE COST		
Total Agency Costs	$66.4	$59.1
Total User Costs	$1.2	$2.9
Total Life Cycle Costs	$67.6	$62.0

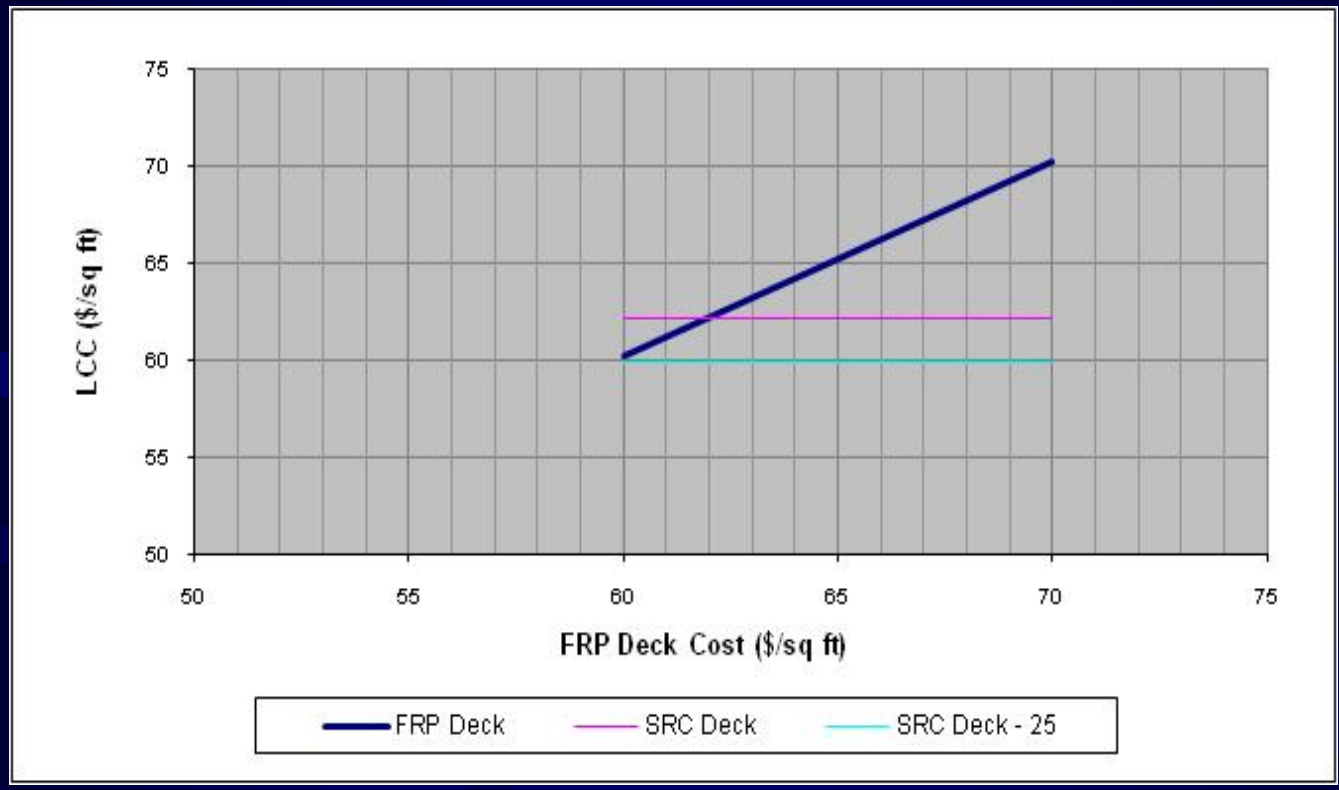
Example of Life Cycle Cost Breakdown

General Findings :
ADT and LCC

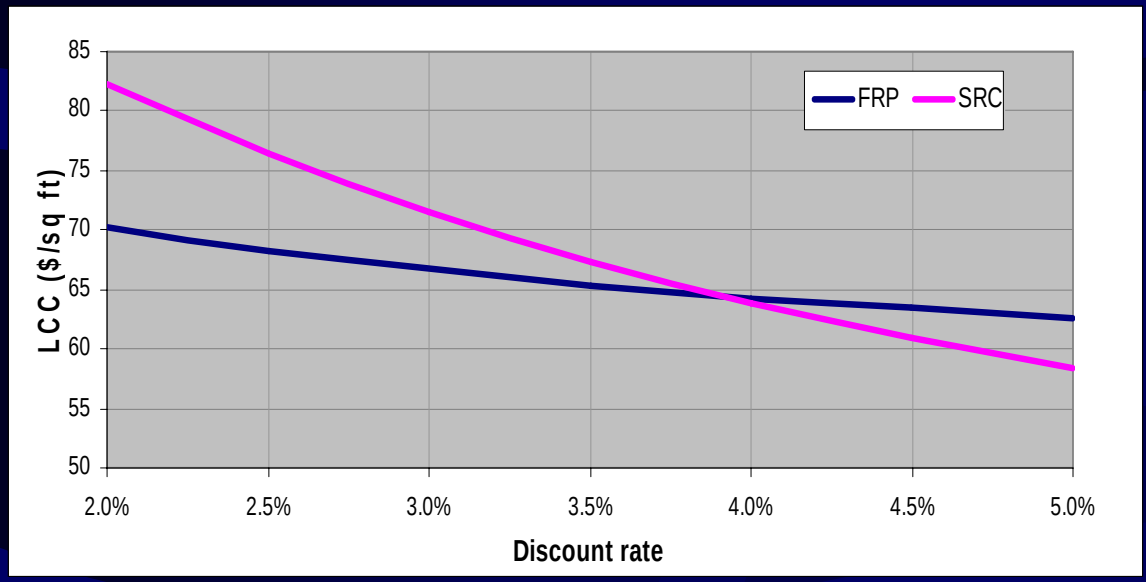


The higher the ADT, the better competitiveness of FRP deck to SRC deck

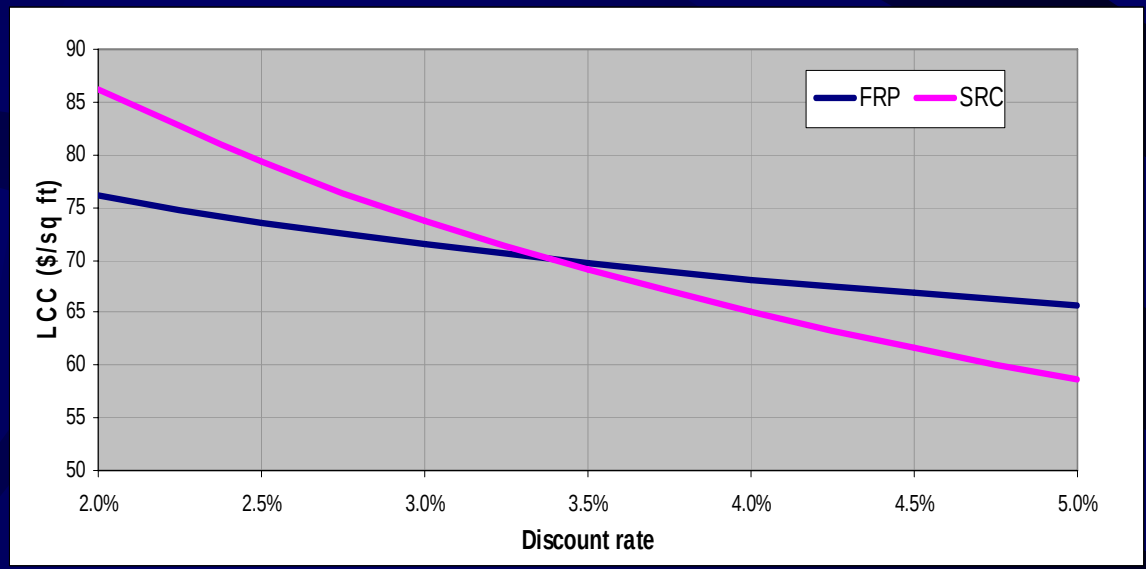
Deck Cost and LCC



FRP deck manufacturing cost has significant effect on LCC



Discount Rate and LCC



The higher the discount rate, the less likely FRP deck be a viable alternative to SRC deck.

Conclusions

- Fiber reinforced polymer (FRP) bridge decks have higher initial costs than traditional steel reinforced concrete (SRC) bridge decks. The improved corrosion resistance of FRP decks increases the deck life over that of SRC bridges, but this by itself does not offset the effect of the higher initial costs.
- The weight reduction would have an effect on the initial costs, as the structure to support the deck would be reduced because the weight of an FRP deck is approximately 20 to 25 percent that of a SRC deck.
- The higher the ADT, the more competitive the FRP deck becomes.
- The higher the discount rate, the less competitive the FRP deck is.
- FRP deck viability is a function of its service life, initial price ratio, ADT and discount rate.
- Overall, the results suggest that a $61/sq ft FRP deck is a viable alternative to a $30/sq ft SRC deck.

Acknowledgment

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