Technical Monograph: Estimating Maintenance Costs for Mixed High-Speed Passenger and Freight Rail Corridors

Unpublished

U.S. Department
of Transportation
**Federal Railroad
Administration**

Technical Monograph: Estimating Maintenance Costs for Mixed High Speed Passenger and Freight Rail Corridors

Office of Railroad Development
Washington, D.C. 20590

DOT/FRA/ORD-

Final Report
August 2004

This document is available to
the public through the National
Technical Information Service,
Springfield, Virginia 22161

1. Report No. FRA/ORD-	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Technical Monograph: Estimating Maintenance Costs for Mixed High Speed Passenger and Freight Rail Corridors		**5. Report Date** August 2004
		6. Performing Organization Code
7. Authors: **For the engineering contractor**: Dr. Allan M. Zarembski, President Randolph R. Resor, Project Manager **For the sponsoring agency**: John F. Cikota, Richard U. Cogswell, Donald Plotkin		**8. Performing Organization Report No.**
9. Performing Organization Name and Address **Engineering Contractor:** ZETA-TECH Associates, Incorporated 900 Kings Highway North, Suite 208 Cherry Hill, NJ 08034 **Sponsoring Agency (see below)**		**10. Work Unit No. (TRAIS)**
		11. Contract or Grant No. **DTFR53-01 D-0028, Task Order#:0020**
12. Sponsoring Agency Name and Address U.S. Department of Transportation Federal Railroad Administration Office of Railroad Development 1120 Vermont Avenue N.W., Mail Stop 20 Washington, DC 20590		**13. Type of Report or Period Covered** Technical monograph on Estimating High Speed Rail Maintenance Costs
		14. Sponsoring Agency Code See (1) Report No.
15. Supplemental Notes		

16. Abstract

Several states have indicated a desire to upgrade existing railroad corridors between well-populated cities for improved passenger rail service that is time competitive with air and/or auto on a door-to-door basis for trips in the approximate range of 100 to 500 miles. Once a corridor is upgraded for higher-speed operation, this monograph presents a number of matrices of "steady state" infrastructure maintenance costs to meet varying traffic, track and operating conditions. "Steady state" costs are defined here as amounts that must be spent annually to keep a particular railroad track at a defined level of service (operating speed) indefinitely. This monograph presents examples of track segment specific maintenance cost ranges and corresponding maintenance costs per passenger train mile that may be of assistance to States that are contemplating similar rail passenger service projects.

17. Key Words Railroad corridors, high speed rail maintenance costs, transportation planning, rail passenger service, high-speed rail, high speed rail corridors		**18. Distribution Statement** This document is freely available through the FRA's web site, www.fra.dot.gov. A limited printing will be available from the Sponsoring Agency at the address shown.	
19. Security Classification (of the report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No of Pages** 100	**22. Price** See (18) Distribution Statement

TABLE OF CONTENTS

I. Purpose

The Rail Planner's Handbook is intended as an aid to planners of new high speed rail operations. It seems most likely that future high speed rail operations will make use of trackage shared, at least in part, by freight trains. Since most railroad trackage in North America is privately owned, it will be necessary to negotiate access agreements with the private owners. These agreements will also have to specify how costs are to be shared.

To provide guidance to planners of high speed rail systems, the Planner's Handbook includes a number of matrices of "steady state" infrastructure maintenance costs. Steady state costs are defined here as amounts that must be spent annually to keep a particular railroad track at a defined level of service (operating speed) indefinitely. Since the components of railroad track are long-lived, annual expenditures may fluctuate for a particular track segment, but over an entire network, the annual level of investment should remain constant if components are replaced as they wear out. If the replacement rate is less, track condition will deteriorate. Infrastructure costs presented here include track, bridge and building (B&B), and communications and signal (C&S) costs. The one-time costs of upgrading for high speed operation are not included.

The costs are presented both in terms of a total cost per track mile and in terms of cost per passenger train mile. To develop a cost per passenger train mile, costs must first be allocated between passenger and freight traffic sharing a rail line. There are a number of methods for allocating costs. The costs presented here have been allocated through the use of one specific cost allocation model. All costs are in 2003 dollars.

In practice, operation of publicly-funded passenger trains on private freight railroads will require negotiation of access charges, and the negotiated charges may not be (in fact, probably will not be) the same as costs shown in the matrices. However, the cost matrices do indicate the expected total spending that will be required (on a "steady state" basis), as well as providing an example allocation of costs.

The cost matrices cover a range of combinations of traffic and track configuration. Minimum and maximum costs were developed for each cell in the cost matrices. The minimum costs are based on maintenance standards geared to FRA minimum track safety standards, while the maximum costs reflect maintenance of higher track standards to ensure good ride quality. The minimum costs are for typical Class I freight railroad practice, such as where passenger trains currently operate on a freight railroad right of way, while the maximum costs reflect maintenance practices on existing high speed railroad track such as Amtrak's Northeast Corridor.

The following sections of the Planner's Handbook provide a description of the analytic models used to generate the costs, and the process by which those models were calibrated to actual cost data to develop costs for a wide range of traffic and track combinations.

.

Operating Scenarios for High Speed Rail

The Federal Railroad Administration (FRA) defines “high speed rail” as operation at above 90 MPH. Overseas, the definition of high-speed rail generally means operation at more than 125 MPH, and new high-speed rail lines in Europe and Asia are being designed for maximum speeds of 180 or even 200 MPH. These lines, however, are dedicated for passenger train use. Operation in mixed traffic (i.e., with freight and commuter trains) typically occurs at much lower maximum speeds.

The highest speed operation in North America occurs on Amtrak’s Northeast Corridor, where speeds of 150 MPH are permitted on two short stretches of FRA Class 8 track. Simultaneous operation of freight and passenger trains is prohibited on FRA track classes 8 and 9 (maximum speeds of 160 and 200 MPH, respectively). Most of the rest of the NEC is FRA Class 7 track (125 mph), which passenger trains share with freight and commuter trains. The railroad is almost entirely grade separated and entirely electrified, and consists of multiple main tracks at most locations.

Recognizing that any likely high-speed rail in the United States will at least share a right of way, and may share track with, freight operations, planners elsewhere in the United States have set more modest goals than the emulation of the NEC. Rather than attempting 150 MPH, or even 125 MPH, speeds, planners have proposed the construction or upgrade of tracks to a maximum of FRA Class 6, for operation at up to 110 MPH. In some cases, this Class 6 track will be dedicated for passenger operations, but at many locations, particularly routes into major cities, freight and passenger trains will have to share tracks.

Future high-speed rail projects in the U.S. will probably look much like the network proposed by the Midwest Regional Rail Initiative (MWRRI). MWRRI contemplates a network of routes linking Chicago with other Midwest cities such as St. Louis, Detroit, and Cleveland. These routes will be partially single track, they will have grade crossings, and on some portions of each route, tracks will be shared with freight trains. Total passenger train volume is expected to be relatively modest, in the range of 16 to 20 daily trains. Other mixed passenger and freight operations include corridors such as the Seattle-Portland corridor, which has recently seen the introduction of a new generation of Talgo passenger trains on a heavy-traffic BNSF freight line.

Several scenarios are envisioned for mixed passenger and freight traffic corridors:

- Heavy freight routes where passenger trains share trackage to reach city terminals or where right-of-way constraints exist, but at maximum speed of 79 MPH for passenger trains (FRA Class 4)
- Moderate to heavy freight corridors with superimposed high speed passenger trains on the same track
- Lighter density freight routes, with passenger trains sharing trackage with minimal to moderate freight traffic (up to about 15 MGT annually), at passenger speeds of 110 MPH (FRA Class 6)
- Heavy-tonnage freight routes between cities with passenger trains operating at 110 MPH on a parallel single track with passing sidings. Interconnections to the freight

trackage will permit reciprocal use of tracks in emergencies, and local freight trains may use the passenger track to access yard and industrial tracks.

- Very low density freight corridors with superimposed high-speed passenger trains on the same tracks.

The purpose of the Planner's Handbook is to provide a reference for planners of high-speed rail service that will enable them to estimate the costs of right of way maintenance associated with the operation of high-speed passenger trains. As used in this handbook, right of way maintenance costs include "cyclic capital" costs such as rail replacement, tie renewals, surfacing, ballast replacement, etc., which are normally capitalized for accounting purposes as well as the expensed maintenance costs such as inspections, spot repairs, routine maintenance, etc.

Included in these right of way maintenance costs are:

- Track maintenance costs
- Bridge and Building (B&B) maintenance costs
- Signal maintenance costs

Capital upgrade costs, which are not cyclic in nature, but represent a one time upgrade costs are excluded from this handbook. The focus of the costs presented here are annual maintenance costs which are ongoing in nature. All costs are "steady state"; that is, the presumption is that track has been upgraded for high-speed operation, and what is required is to maintain it in adequate condition to carry the expected volumes of traffic.

This handbook presents a series of matrices which have been constructed to illustrate the costs associated with the operation of defined volumes of passenger traffic on tracks shared with freight trains. These matrices of right of way maintenance costs includes sensitivity to the following key factors:

- Annual tonnage (MGT) by tonnage categories
    - Light < 5 MGT
    - Low 5-15
    - Medium 15- 30,
    - High > 30 MGT
- Track geometry by broad curvature category
    - Light
    - Moderate
    - Severe
- Maximum operating speed
    - FRA Class 4 (80 passenger)
    - FRA Class 5 (90 passenger)
    - FRA Class 6 (110 passenger)
- Mix of passenger and freight
    - Predominantly passenger
    - Equal passenger and freight tonnage
    - Predominantly freight

- Tie type
    - Wood
    - Concrete

In this handbook matrices have been developed for:

- Total right of way maintenance costs
    - Track, B&B and signal maintenance costs
- Passenger share of cost per train mile

The purpose of these matrices is to allow a transportation planner to estimate the annual right of way maintenance costs by building up these costs using the individual elements of the matrices.

As noted above, costs have been generated for three operating scenarios, covering a range of tonnage and traffic mix, as follows:

1. Predominantly freight
    a. 80% of annual tonnage is freight, 20% passenger
    b. A maximum of 50 passenger trains per day[1]

2. Mixed traffic
    a. Tonnage divided 50/50 between passenger and freight
    b. A maximum of 60 passenger trains per day

3. Predominantly passenger
    a. Tonnage 80% passenger, 20% freight
    b. A maximum of 60 passenger trains per day

Each of these scenarios has been applied to a range of annual gross tonnages, from five million gross tons (MGT) per track mile per year to 50 MGT[2] per track mile per year. In each case, passenger train weight has been fixed at 550 tons total, including cars and locomotives, and freight train weight at 5,900 tons. The cost models used in this analysis take account both number of trains and total tonnage. In each scenario, the number of trains operating is driven by tonnage. Thus, in the "predominantly freight" category, at 5 MGT there are 4 MGT of freight traffic (2 freight trains) and one MGT of passenger traffic (5 passenger trains) per day. Higher annual gross tonnages will result in more trains of each type.

For each scenario, costs have been generated for the four ranges of annual tonnage noted above, using two proprietary track maintenance cost models described in subsequent sections of this report. Costs are "steady state" costs, the costs of maintaining the track at a specified FRA class

[1] Where this volume of passenger service is operated, freight trains are assumed to operate primarily at night, to avoid interference with passenger traffic. Note, at this volume of traffic, there may be difficulty in gaining track access for MoW activites, with a resulting increase in unit MoW costs.
[2] Several elements of the matrix which represent an unrealistic combinations of tonnage and high-speed passenger trains have been intentionally left out. These include predominantly passenger operations with tonnage levels above 15 MGT and equal passenger-freight operations with tonnage levels above 30 MGT.

once any required upgrades have been completed. A total cost per track mile has been calculated, including:

- MOW operating expenses
- Cyclic capital expenditures for track
- Bridge & building costs (maintenance and capital)
- Communications and signals costs (maintenance and capital)

These costs have been allocated between passenger and freight trains, allowing for the calculation of a cost per passenger train mile.

The results of the model applications are provided in the form of matrices, appended to this handbook, that allow planners to select the appropriate maintenance/capital cost for any segment of proposed high speed passenger railroad. This is expected to be a significant aid in the planning of high-speed rail service throughout the United States.

The following sections describe the models employed, and the process of developing costs for each of 216 combinations of track, topology, traffic mix, and operating speed. The process of calibrating these costs to five actual track corridors (four on the MWRRI network and one-Seattle-Portland corridor) is described, and finally the costs are presented.

II. Development of Cost Estimates

In order to determine the range of right of way maintenance costs (to include both maintenance and cyclic capital costs) for these mixed high-speed passenger-freight operations, two ZETA-TECH models were utilized:

- ZETA-TECH's Work Unit Model, which calculates the level of "work" required to maintain a defined segment of track or territory and which is used here to estimate non-capital track maintenance expenditures associated with specific track segments and territories

- ZETA-TECH's Steady State Capital Model, which uses standard lives and costs for track components to estimate future or "steady state" spending required to replace components as they wear out. This is used to calculate the cyclic capital costs.

Minimum and maximum costs were developed for each cell in the cost matrices. The minimum costs are based on maintenance standards geared to FRA minimum track safety standards, while the maximum costs reflect maintenance of higher track standards to ensure good ride quality. The minimum costs are for typical Class I freight railroad practice, such as where passenger trains currently operate on a freight railroad right of way, while the maximum costs reflect maintenance practices on existing high speed railroad track such as Amtrak's Northeast Corridor.

The Work Unit Model

The Work Unit Model is an engineering based model designed to calculate the equivalent level of work required to maintain different and dissimilar segments of track. As such it addresses and incorporates each of the key work effort drivers such as miles of track, class of track (speed of operation), number of turnouts, traffic density (MGT and number of trains), number of passenger trains, curvature, climate, accessibility, etc. The Work Unit Model addresses only "maintenance of way operating expenses", the expensed costs for track inspection and minor maintenance.

The Work Unit Model was developed in cooperation with a large U.S. freight railroad, and has been applied on both freight and high speed passenger railroad systems. It quantifies the maintenance effort required on any segment of track in terms of "work units", which represent a "level of effort" required to maintain a segment of track. The number of work units assigned to a particular part of the track structure (a turnout, for example) varies according to its characteristics and also according to the volume of traffic it carries. Main track is assigned more work units per track mile than branch line or yard track. The number of work units is determined both by tonnage and by the number of trains per day (more trains per day make access more difficult), as well as by various other track, traffic, and environmental factors.

Summing across all track territories, a total for all work units on the railroad is obtained. MOW operating expenses are then divided by these work units to obtain a cost per work unit. Applying this cost per work unit to the number of work units calculated for individual line segments, the appropriate level of expenditure for each line segment can be determined. The focus is on the level of effort required of local track maintenance forces to maintain a particular piece of railroad.

The Work Unit Model is used to allocate maintenance budget across defined territories. Work units are calculated per track segment as a function of track and traffic characteristics that include:

- Track miles: Main Line, Sidings, Branch Line, Yard
- Miles of curves; by severity (tangent, moderate, severe)
- Traffic: Both annual MGT and trains/day
- Number of turnouts, diamonds, road crossings
- Miles of concrete ties, CWR
- Rail defects/mile, TQI[3] (Condition)
- Road crossings/mile (Accessibility)
- Climate (rain, snow, heat, cold)

<u>Work Unit Equations</u>

There are four individual work unit equations based on track type:

- Main line track

[3] Track geometry measurement cars usually employ software to generate a single scalar number to indicate the overall geometric condition of the track. This is called a track quality index (TQI).

- Sidings
- Branch Lines
- Yard Track

Each equation is sensitive to key maintenance factors associated with that type of track. The Work Unit equations reflect results of field audits and sensitivity analyses. Field verification was performed on all key input data. This was done by auditing 13 Roadmaster territories on a major US Class 1 railroad and surveying work effort distribution. ZETA-TECH also compared earlier Work Unit Model equations with other "work unit" type models:

- AREA[4]
- Canadian National[5]
- Other ZETA-TECH maintenance models[6]

Note, these models were precursors to the ZETA-TECH work unit model, and provided input into the Work Unit Model, which deals more extensively with the key parameters of interest here. Neither the AREA model nor the CN model was actually used in this analysis.

A 1999 audit found the overall model format to be fundamentally sound in concept and approach. Equations realistically reflect work effort based on surveys, audits, and comparative studies. Quantitative terms such as, Condition, Climate, and Accessibility, provide a quantitative rather than qualitative way to distinguish between territories.

Various other factors were "fine tuned" through review of available data. These included:

- Curvature effect
- MGT vs. train effect
- Yard effect
- Turnout effect

The model has also been modified to improve ease of use. In many cases, look up tables were replaced with continuous functions, and the generation of consolidated and summary reports was automated. The model can import supplemental data from various sources (e.g. TQIs). Please note however that TQI data was not used in the analysis described here.

<u>Territory Characteristics</u>

Territory characteristic parameters were implemented to replace more subjective factors. "Condition" is based on TQI (TQI actual vs. TQI desired). The higher the ratio the poorer the track condition. Desired TQI can be set as function of class of track; in most railroad

---

[4] The American Railway Engineering Association (AREA) Committee 16 introduced "Equated Mileage" parameters in 1994 that were intended to provide a basis for comparison of track maintainability. This methodology may be found in *Manual for Railway Engineering 2003,* American Railway Engineering and Maintenance Association (Washington, DC: 2003), Chapter 16, Part 11, page 16-11-1

[5] CN's model is proprietary.

[6] These include RaiLife© and TieLife©

applications and in generating the costs included in this report, it has been set to one value system wide. Alternately, a TQI Ratio (TQIR) can be calculated separately (based on TQI desired) for high speed and conventional track.

Climate characteristics include:

- Rainfall, annual inches
- Snowfall, annual inches
- Excessive heat (# of days above 90 degrees)
- Excessive cold (# of days below 0 degrees)

Accessibility is based on number of road crossings per mile (rcpm). The value varies between high, medium and low degrees of accessibility (rcpm) The overall Territory Characteristic Factor is calculated as a function of the three factors: condition, climate and accessibility.

<u>Main Line Track Equation</u>

The primary work unit equation for main line track is:

Work Units (Main Line) = [MGT Factor * Train Factor * Territory Factor]*
[Track Mile Term + Curve Term + Special Track Work Term + Crossing Term]

where:

- **MGT Factor** is function of Annual MGT
- **Train Factor** is function of Number of Trains/Day
- **Territory Factor** is a function of Condition (TQI), Climate (rain, snow, heat, cold), Accessibility (road crossings/mile)
- **Track Mile Term** is function of Track Miles, defects/mile and % CWR
- **Curve Term** is function of miles of moderate curves (2-6º), miles of sharp curves (> 6º), and miles of concrete ties
- **Special Track Work Term** is function of number of turnouts and crossing diamonds
- **Crossing Term** is a function of number of road crossings (public > 40', public < 40', and private)

Table 1 provides an example of a model application to main track.

Table 1: Work Unit Model Application to Main Track

Term	Value	Factor
MGT (annual)	8.8	1.18
# of Trains	3	1.00
Territory (cond./access/climate)	2.4+2.6+2	1.13
Track miles	222	269.73
Miles of Curves/Mi. of severe curves	34+1	58.39
Number of turnouts and crossings	45	59.85

Number of Rail/Highway Crossings (>40 ft. + ≤40 ft. + private)	1+65+54	21.3

Taking MGT first, it can be seen that the segment carries 8.8 MGT. This is more than the system average tonnage, so a factor of 1.18 is used. The number of trains is at the system average, so the factor is 1.0.

The "territory" term combines three variables. The first is condition, and is set to 2.4 in this example. The second is accessibility (defined as the number of rail/highway crossings). This is set to 2.6. Finally, the climate variable is set to 2.0. This produces a weighting factor of 1.13

The track mile term is affected by number of defects and percent of CWR. There are 222 actual track miles in this example, but they are increased to 269.73 to reflect a relatively high defect rate and a smaller than average percentage of CWR.

The curve term accumulates the miles of curves. Here there are 34 miles of moderate curves and one mile of sharp curves, equating to an equivalent 58.39 tangent track miles.

There are 45 turnouts and crossing diamonds, equating to 59.85 track miles. Finally, there is one public crossing with a width greater than 40 feet, 65 public crossings with a width of less than 40 feet, and 54 private crossings (width not recorded).

Thus, Work Units (ML) = (1.18*1.00*1.13)*(269.73+58.39+59.85+21.3) or 547.27 for this territory.

<u>Branch Line Track Equation</u>

Work Units (Branch Line) = k * [Territory Factor] *[Track Mile Term + Curve Term + Special Track Work Term + Crossing Term]

where:

- **Territory Factor** is a function of Condition (TQI), Climate (rain, snow, heat, cold), Accessibility (road crossings/mile)
- **Track Mile Term** is function of Track Miles, defects/mile and % CWR
- **Curve Term** is function of miles of moderate curves (2-6º), miles of sharp curves (> 6º), and miles of concrete ties
- **Special Track Work Term** is function of number of turnouts and crossing diamonds (constants differ from Main Line equation)
- **Crossing Term** is a function of number of road crossings (public > 40', public < 40', and private)

and k is the branch line weighting factor (0.49 in this application)

The Work Unit Model also contains equations for siding and yard tracks similar to those shown above. However, in the generation of cost numbers for this handbook, only main tracks were modeled. No branch lines, sidings, or yards were included in the analysis.

However, in the calibration of Work Unit Model results to two actual segments (Buffington Harbor to Ft. Wayne and Watertown to Madison, WI) all existing industry turnouts and diamond crossings were modeled. This will be described more fully in the Calibration section of this report.

Sensitivity Analysis

Extensive sensitivity analyses have been performed to examine relationship between key factors. Among these analyses were:

- Annual MGT
- Trains/Day (passenger and freight)
- Miles of Track
- Curvature

which are presented here.

Sensitivity to traffic volume (MGT and Freight trains/day) is shown in Table 2. Here the system average number of trains per day is 22, and the system average tonnage is 37.4, producing a total of 644 work units on the territory. As the table shows, changing the number of trains can increase or decrease work units, but the increase/decrease is a step function reflecting the change in accessibility. The relationship between work units and annual tonnage (holding trains per day constant) is a continuous function.

Table 2: Work Units as a Function of Traffic Volume

Annual MGT	Trains/Day							
	10	15	20	**22**	30	40	50	60
10	496	496	496	496	546	546	645	645
20	552	552	552	552	607	607	717	717
30	605	605	605	605	666	666	787	787
37.4	644	644	644	**644**	709	709	837	837
40	658	658	658	658	723	723	855	855
50	709	709	709	709	780	780	922	922
60	761	761	761	761	837	837	989	989
70	811	811	811	811	892	892	1054	1054
80	861	861	861	861	947	947	1120	1120
90	911	911	911	911	1002	1002	1184	1184
100	961	961	961	961	1057	1057	1249	1249
110	1010	1010	1010	1010	1111	1111	1313	1313
120	1059	1059	1059	1059	1164	1164	1376	1376
130	1107	1107	1107	1107	1218	1218	1439	1439
140	1156	1156	1156	1156	1271	1271	1502	1502
150	1204	1204	1204	1204	1324	1324	1565	1565

Table 3 illustrates the non-linear relationship between work units and miles of track maintained. Here the average territory consists of 160 track miles (which is likely a mix of main tracks, sidings, branch lines, and yards).

If track mileage is doubled, for example, work units increase 82%. In the same way, a reduction of 75% in track mileage maintained produces only a 53% reduction in work units. This reflects the nonlinearities in track maintenance, where there is not a one-to-one correspondence between the size of a territory and the labor required to maintain it.

Table 3: Work Units as a Function of Miles of Track Per Territory

Miles of Track	Work Units	% Change
20	424	-34%
40	455	-29%
60	486	-24%
80	517	-19%
100	548	-15%
120	579	-10%
140	610	-5%
160	641	0%
180	712	11%
200	780	22%
220	847	32%
240	912	42%
260	977	52%
280	1040	62%
300	1103	72%
320	1166	82%
340	1228	91%
360	1289	101%
380	1351	111%
400	1412	120%

Maintenance effort is increased in high curvature territory where degradation in increased. Thus curvature plays a significant role in determining the number of work units in each territory. Re-gauging of track is required more frequently on curves of two degrees and greater, so one of the drivers in the work unit calculation is the miles of curves greater than two degrees in each territory.

Again, the typical territory, with 644 work units, includes 17.4 miles of curves greater than 2 degrees Table 4 shows work units as a function of the miles of curves > two degrees.

Again, it must be remembered that the Work Unit Model addresses only track maintenance, and not the renewal of rail in curves. Rail renewal is capitalized; minor curve maintenance is not.

Table 4: Work Units as a Function of Miles of Curvature

Miles of Curves > 2 Degrees	Work Units	% Change from Avg.
5	617	(4%)
10	627	(3%)
17.4	644	0%
20	652	1%
30	713	6%
40	740	11%
50	767	15%
60	793	19%
70	820	23%
80	832	27%
90	849	32%
100	879	37%
110	909	41%
120	938	46%
130	968	50%
140	997	55%
150	1027	59%

Finally, Table 5 shows the relationship between work units and track class. If track class is increased from FRA Class 4 to FRA Class 6, work units increase by about 40%, reflecting the added maintenance burden of maintaining to a higher track standard.

Table 5: Work Units as a Function of Track Class

FRA Track Class	Work Units (at 15 MGT)
1	538
2	605
3	690
4	803
5	939
6	1100

Summary

The Work Unit Model calculates the "level of effort" required to maintain a segment of track, exclusive of component replacement (capital) costs. It has been used on several Class 1 railroads to determine and allocate maintenance budget for different territories. As noted above, the model has been validated based on field audits and comparison to other related models.

However, since the Work Unit Model calculates only work units, it was necessary to determining the proper cost per work unit to be used in developing the cost matrices. This was done by calibrating the work unit model to several sets of maintenance expenses, to include actual railroad maintenance budgets and a dedicated "bottom up" cost analysis for two Midwestern routes that have been proposed for high speed rail use. The bottom-up costs were developed by subcontractor HNTB, Inc. The process of calibrating the Work Unit Model is described in the Calibration section of this handbook.

It should be noted that, while the Work Unit Model can include many different categories of maintenance cost, the cost of pole line maintenance has not been included in this analysis. It has been assumed that any upgrade of railroad track for high speed operation would include replacement of any existing pole line with radio frequency control of signals and switches.This revised and validated model was applied to generate the cost matrices presented in the Planner's Handbook. In this application here, the model includes only main tracks and passing sidings. No yard or industry trackage has been included.

The Steady State Capital Model

Predicting "steady state" capital requirements is a somewhat different process than estimating MOW operating expenses. Many capital costs are driven by traffic volume (in MGT), while many MOW operating expenses (such as track inspection) have at best an indirect relationship with traffic volume. Also, capital costs are less affected by differences in local conditions than MOW operating expenses.

The critical step in formulating a capital model is the development of appropriate life expectancies for track components. The ZETA-TECH capital model includes the following components:

- Rail
- Ties (concrete and wood)
- Turnouts
- Surfacing/ballasting (surfacing cycle in years)

In this analysis, ZETA-TECH also considered bridge capital costs and communications and signals (C&S) capital costs. These costs are also related to traffic volume, since bridge lives are determined in part by the frequency of loadings by train traffic. C&S costs may initially appear unrelated to traffic, but are in fact are a function of "relay events". Each time a signal changes to a different aspect, or grade crossing gates and flashers activate, there is wear on components. The heavier the rail traffic, the more frequent the relay events, and the shorter the lives of installed components. Furthermore, a significant portion of C&S capital costs involve the installation and replacement of grade crossing components, where again, operations (and component lives) are directly related to traffic, specifically number of trains.

Model Application

The Steady State Capital Model was originally developed by ZETA-TECH for a Class I railroad to calculate steady state (condition independent) annual track capital costs. The objective was to provide the railroad with a neutral and scientific method of programming track capital renewals for rail, ties, and ballast/surfacing. To do this, the model had to properly account for the physical and environmental characteristics that determined track component degradation.

For each of the three component categories (rail, ties, ballast) the model incorporates a relationship between traffic density and environment, expressed mathematically, that allows the model to predict component life in years (and therefore the required date of replacement) under a defined set of conditions. Environmental factors dominate at low tonnages, while traffic (measured in MGT) dominates at higher tonnage levels

In addition to the density/environment relationship, the model also addresses curvature, a very important determinant of rail life. Data on the length and degree of curves was available from the MWRRI database and BNSF track charts. However, in order to reduce the level of complexity of the analysis, three levels of curvature were defined and used in the model:

- Tangent (curves of less than 2°)
- Moderate (2° to < 6°)
- Severe (≥ 6°)

The model uses standard component lives (in MGT) and adjusts them upwards or downwards according to the mathematical relationships included in the model, to obtain an expected life on each segment for each combination of traffic density and curvature.

In this application of the Capital Allocation Model, lives are calculated for each track component on each segment, taking into account total tonnage over each segment, curvature, operating speed, and other factors such as environment. For example, the relationship between rail life and tonnage is linear, since general practice in the rail industry is to express rail life interchangeably in either cumulative tonnage (MGT) or years. However, annual tonnage on many segments is low enough (1 MGT or less) to produce improbably long life for rail. At some point, rail must be replaced due to technological obsolescence or environmental decay (rust and corrosion) even if no traffic uses a rail line. Therefore, the Steady State Capital Model caps rail life at 100 years even on low-tonnage segments.

For turnouts, a similar relationship is used. However, maximum life of turnouts in main track is set at 30 years.

For ties and ballast, relationships are nonlinear due to the substitution of traffic damage for environmental decay as traffic increases. This substitution of mechanisms leads to a less-than-linear decrease in the life of these components as traffic increases. Again, however, a maximum life in years is established, due to the effects of environment on low-tonnage lines.

The model addresses high-speed operation in several ways. First, of course, the dynamic impact of vehicles on the track varies with speed. Second, the lives of turnouts (in MGT) are reduced on Class 5 and Class 6 track from the Class 4 "base case." Finally, surfacing cycles are more frequent at higher track classes (surfacing frequency depends not only on traffic, but also on FRA track standards-and therefore on maximum operating speed.)

The model then uses component life relationships and traffic data to predict a life for each of the component categories (rail, ties, ballast/surfacing, and turnouts) on each line segment under analysis. Using these component lives, and standard unit costs, the model produces the following:

- Steady state renewal requirements for each component (in units)
- Steady state capital budget requirements (in $), by component category
- A total capital cost for steady state track component renewal

Note that the effect of current component condition or maintenance history is not taken into account, since this is a "steady state" analysis.

Track Component Lives Used in the Model

Lives used in this analysis for each component are shown in the following tables:

For surfacing, the cycle is reduced at higher track classes, to account for the need to maintain a higher track geometry standard. For turnouts, component life in MGT is reduced, again to reflect the dynamic impacts generated at higher speeds as well as the need to maintain tighter standards.

At low annual tonnages, the lives of many capital components are capped. Maximum life of rail was set at 100 years. Concrete tie life was capped at 60 years, and turnout life was limited to 30 years. This life limit produced some anomalies. The capital cost of concrete-tie track is higher than for wood tie track, so at low annual tonnages and high track class (where turnout and surfacing costs also are high), the annualized cost for concrete is higher, producing a higher total cost when maintenance and capital costs are added together.

Table 6: Rail

Component	**Cost per Mile**		**Life in MGT**	
	Low	High	Low	High
Rail (CWR)	$350,000	$420,000	800	1200
Rail (jointed)	$320,800	$360,000	600	960
Rail (curve)	$388,500	$480,000	400	800
Rail (sharp curve)	$388,500	$480,000	200	400

Note: Maximum life capped at 100 years

Table 7: Ties

Component	Cost per Tie		Life in Years	
	Low	High	Low	High
Ties	$80	$90	30	36
Ties (curve)	$80	$90	24	27
Ties (sharp curve)	$80	$90	16	18
Ties (concrete)	$130	$160	50	60

Note: Concrete tie life capped at 60 years.

Table 8: Turnouts, Crossings+

Component	Cost per Each		Life in MGT	
	Low*	High*	Low	High
Turnout (Class 4)	$70,000	$90,000	400	800
Turnout (Class 5)	$70,000	$90,000	375	750
Turnout (Class 6)	$70,000	$90,000	350	700

Note: Maximum life of mainline turnout capped at 30 years

+These are wood-tie, #20 to #24 turnouts

* This cost does not include C&S costs (see below).

For #16 turnouts and larger, an additional $50,000 C&S cost has been added to account for the fact that these are generally power-operated turnouts with associated signals. See the section on calibration of the Steady State Capital Model.

Table 9: Surfacing

Component	Cost per Mile		Cycle in Years	
	Low	High	Low	High
Surfacing	$10,000	$12,000	3.0	4.0
Surfacing (curve)	$10,000	$12,000	2.5	3.4
Surfacing (sharp curve)	$10,000	$12,000	2.2	2.9

Note: Cycle based in 30 MGT and FRA Class 4 Track

Table 10: Surfacing Cycle by Track Class (Tangent Track)

Component	Cost per Mile		Cycle in Years	
	Low	High	Low	High
Surfacing (Class 4)	$10,000	$12,000	3.0	4.0
Surfacing (Class 5)	$10,000	$12,000	2.6	3.4
Surfacing (Class 6)	$10,000	$12,000	2.0	2.6

As with the Work Unit Model, results of the Steady State Capital Model were calibrated to actual costs on several Class I railroads. This is discussed further in the Calibration section.

The TrackShare® Model

ZETA-TECH's TrackShare model is an engineering based cost allocation model, designed to allocate track maintenance costs between different traffic types, including both freight and passenger trains. TrackShare is a direct descendent of the Weighted System Average Cost (WSAC) model, which has been extensively applied both in North America and overseas to determine the passenger train share of MOW cost. WSAC has been used before, and accepted by, the Interstate Commerce Commission as the "best available" method for determining the incremental costs of passenger train operation[7].

TrackShare makes use of engineering damage equations to calculate the portion of track damage (component life consumption) due to each defined traffic type operating over a specific track segment. This calculated cumulative damage is then used to allocate track maintenance costs in an auditable and accountable manner.

A. Track Data Development

To use TrackShare for MOW costing, the rail network under analysis must be divided into a network of unique track segments, without overlapping. For each of these segments, data must be obtained on the following parameters:

- Grade
- Curvature
- Track characteristics (e.g. weight of rail, tie type, type of rail, etc.)
- Track miles per route mile
- Traffic density per track mile, in MGT, for each defined traffic type

Track segments may be of any length permitted by data availability. Values for curvature may be averaged over the length of segments.

B. Traffic Data Development

Traffic types are defined by axle load, operating speed, and suspension characteristics. Any number of traffic types may be defined -- a typical number might be four types of freight traffic and a passenger category that includes both Amtrak and commuter rail services (if their operating speeds are the same). For each segment, a weighted average operating speed is calculated for each traffic type based on speed limits, geographic speed restrictions, and any special restrictions applying to particular traffic types. For example, passenger trains may operate at up to 150 m.p.h., while the freight maximum speed may be limited to 40 m.p.h.

---

[7] INTERSTATE COMMERCE COMMISSION DECISION, Finance Docket No. 32467, "National Railroad Passenger Corporation and Consolidated Rail Corporation: Application under Section 402(a) of the Rail Passenger Service Act for an order fixing just compensation". Decided December 29, 1995.

Not all traffic types need operate on every track segment. Costs are only assigned to traffics which actually operate on each segment. The sum of all assigned costs for any track segment is the total variable MOW cost for the segment.

C. Costs

In many U.S. applications, ZETA-TECH has used cost data from R-1 reports filed by the Class I freight railroads with the Surface Transportation Board. For commuter rail operators and Amtrak, internal financial reports are the usual data source. Here, TrackShare has been applied to track mile costs developed through use of the Work Unit and Steady State Capital models, to apportion costs between passenger and freight trains.

D. Some Caveats

Although TrackShare has been widely used, it is only one of many possible methods for allocating track maintenance costs between traffics. Actual payments by passenger train operations for use of privately owned freight tracks will be determined by negotiation. The numbers shown in the Planner's Handbook may be used for guidance, but should not be considered definitive.

III. Model Calibration

All track maintenance cost models must be calibrated against actual costs in order to ensure that their estimates are correct. The calibration exercise consists of applying the model to a track segment – or multiple segments – for which costs are known, and making adjustments until the model can properly predict the costs of the known segments. Then the model, if properly specified, should be able to accurately predict costs for segments with very different track and traffic characteristics.

The model calibration was carried out separately for the Work Unit Model and for the Capital Model. For the Work Unit Model, the primary analysis issue was the determination of an appropriate cost per work unit. This was done through calibration of the model with:

- A "bottom up" estimation of maintenance costs on two line segments[8].
- Known Class 1 railroad maintenance costs (to include non-capital maintenance expenses are reported on R-1 reports to the Surface Transportation Board)

For the Steady State Capital Model, model predictions were compared to average capital cost per track mile for several Class I railroads from R-1 reports to the STB.

The following sections describe the process of calibration for the two models.

[8] These costs (including B&B and C&S) were developed for ZETA-TECH by HNTB Inc. as a subcontractor. HNTB assigned an engineer to the task who had formerly worked for Amtrak, and was thus familiar with maintenance practices on high-speed rail lines.

Calibration of Work Unit Model

The primary calibration of the Work Unit Model was to costs developed on two track segments, both in the Midwest (and parts of the MWRRI):

- Buffington Harbor to Ft. Wayne, IN
- Watertown to Madison, WI

The first of these segments has five freight trains per day, for a total of about 15 MGT annually, and an operating speed of 40 MPH. The second has two freight trains per day, for a total of less than five MGT, and an operating speed of 25 MPH.

For the purposes of the "bottom-up" costing exercise, it was assumed that both segments would be upgraded to FRA Class 4, with 60 MPH freight operation and 79 MPH passenger train operation, and Class 6, with 60 MPH freight operation and 110 MPH passenger train operation. The bottom-up cost estimate was prepared by HNTB Inc. as a subcontractor to ZETA-TECH. HNTB, which was familiar with these two segments from its MWRRI support activities, conducted a field inspection of the Indiana line. HNTB then used available data to inventory all the track, signals, bridges, grade crossings, and structures to be maintained on these two routes, and then developed a table of organization for the staff required to inspect and maintain the railroad in each case. The bottom-up cost estimate covered maintenance of way operating expenses only.

Costs were built up based on activities necessary to keep the railroad in safe condition for operations. For example, a force of signal maintainers would be required to maintain train control equipment and grade crossing protection. Track would have to be inspected twice per week. Forces would need to be available to perform minor maintenance and spot surfacing.

In performing an exercise of this kind, there are a number of issues that tend to increase estimated costs. One is indivisibility: working with a track segment as short as Watertown to Madison, for example (36.1 miles), the planners must assign at least one track inspector even if he/she could, in theory, cover more territory. There are similar issues for other maintenance activities. Another issue is the increment in labor required to maintain track at a higher class. In the capital model, this is fairly straightforward – higher speeds mean, among other things, that surfacing cycles must be more frequent. But the estimation of the additional spot surfacing required, or how frequently track must be re-gauged on curves, is mostly a judgment call.

Notwithstanding these caveats, the bottom-up cost estimates provided a starting place for the calibration of the work unit model. Perhaps the single most valuable output of this "bottom up" costing exercise was the estimation of the incremental additional cost of maintaining a Class 6 railroad. This cost turned out to be substantial. Table 11 presents the summary bottom up results for the Buffington Harbor to Ft. Wayne, IN segment. Table 12 shows the costs for the same segment maintained to FRA Class 4 standards. These numbers can be directly compared, and it can be seen that expenditures for Class 6 track on the Buffington Harbor – Ft. Wayne segment are 66% higher than for Class 4 track.

Track expenditures are only about 50% higher for Class 6 than for Class 4; most of the remaining cost increase is due to higher C&S costs. Specifically, all public highway crossings are assumed to have been fitted with four-quadrant gates. This will double the number of units to be maintained if the crossing already has gates. A number of public crossings on the line do not have any kind of active protection at present, and of course no private crossings have active protection. For operation at Class 6, all public crossings will have four-quadrant gates, with the exit gate descent delayed to prevent vehicles from becoming “trapped”. ` All private crossings will have active protection (two-quadrant gates, flashers, and bells). The differential cost is clearly evident from comparison of the C&S columns on Table 11 and Table 12.

Finally, Table 13 shows costs for Watertown, WI to Madison. The short length of this segment, plus the use of concrete ties, produces even higher costs for Class 6 operation. However, as noted earlier, this is also due in part to the short length of the segment. A breakdown of C&S and B&B costs was not available for this segment.

TABLE 11: Bottom Up Cost Analysis: Maintenance Expense for Buffington Harbor to Ft Wayne

MWRRI – Buffington Harbor to Ft. Wayne
Maintenance Cost Model FRA Class 6
Wood Tie System (CSX) - Single Track

Low Volume Freight (5 to 15 MGTs)

Total Number of Passenger Trains Per Day	16
Total Number of Route Miles	128.5
Total Number of Track Miles	153.7

Maintenance Category	Maintenance Item	Budgeted Cost	Comments / Notes	TRACK Class 6	B&B Class 6	C&S Class 6	TOTAL Class 6
Management	Service Delivery	$512,000.00	4 managers on the line	$256,000		$256,000	$512,000
Professional Services	Engineering	$125,000.00	BP Estimates	$57,500	$21,600	$45,900	$125,000
Roadway Maintenance Services	Infrastructure Services	$313,965.00	Detailed Estimate	$313,965			$313,965
Labor	Straight Time	$2,349,776.00	Labor to maintain class #6	$1,281,696	$308,100	$759,980	$2,349,776
	Overtime	$422,960.00	At 18% of Straight Time	$230,705	$55,458	$136,796	$422,960
	Overhead	$1,802,278.00	At 65% of Straight Time & Overtime	$983,061	$236,313	$582,905	$1,802,278
Materials	Track	$382,400.00	Detailed Listing of materials	$382,400			$382,400
	C&S	$83,700.00	Detailed Listing of materials			$83,700	$83,700
	Structures	$100,000.00	BP Estimates		$100,000		$100,000
	Electric Traction	NA					
	Work Equipment	$115,000.00	BP Estimates	$80,500	$17,250	$17,250	$115,000
Small Tools & Safety Equipment	Service Delivery	$83,397.00	At $1,458.00 Per person	$45,490	$10,935	$26,973	$83,398
Roadway Equipment	Rental	$25,000.00	Assume, Vehicles are leased	$5,000	$10,000	$10,000	$25,000
Vehicle	Rental						
	Maintenance	$72,450.00	At 3,150 Per Vehicle	$37,674	$17,388	$17,388	$72,450
	Administration	$18,000.00	BP Estimates	$9,360	$4,320	$4,320	$18,000
Support & Other	Service Delivery	$152,501.00	Percentage of labor with detailed description	$83,182	$19,996	$49,323	$152,500
Extraordinary Maintenance	Storms and Wrecks	$215,000.00	BP Estimates	$111,800	$33,024	$70,176	$215,000
Communications	Phone	$6,360.00	Detailed Estimate	$7,285	$2,152	$4,573	$14,010
	Radio	$7,650.00	Detailed Estimate				
Environmental	Compliance and Safety	$75,000.00	BP Estimates	$20,000	$17,600	$37,400	$75,000
Training	Safety and Technical	$85,800.00	BP Estimates	$44,616	$13,179	$28,005	$85,800
	Grand Total:	**$6,948,237.00**		$3,950,234	$867,314	$2,130,689	$6,948,237

Note: BP = ballpark estimate

Table 12: Bottom Up Cost Estimate, Buffington Harbor to Ft. Wayne
FRA Class 4
Wood Tie System (CSX) - Single Track

Low Volume Freight (5 to 15 MGT's)	
Total Number of Passenger Trains Per Day	16
Total Number of Route Miles	128.5
Total Number of Track Miles	153.7

Maintenance Category	Maintenance Item	Total Cost	Track Only	B&B	C&S
Management	Service Delivery	**$256,000**	$128,000		$128,000
Professional Services	Engineering	**$50,000**	$50,000		
Roadway Maintenance Services	Infrastructure Services	**$148,640**	$148,640		
Labor	Straight Time	**$1,495,312**	$879,112	$246,480	$369,720
	Overtime	**$164,484**	$96,702	$27,113	$40,699
	Overhead	**$1,078,868**	$634,279	$177,835	$266,753
Materials	Track	**$229,400**	$229,400		
	C&S	**$73,700**			$73,700
	Structures	**$100,000**		$100,000	
	Work Equipment	**$80,000**	$80,000		
Small Tools & Safety Equipment	Service Delivery	**$53,071**	$31,201	$13,122	$8,748
Roadway Equipment	Rental	**$25,000**	$25,000		
Vehicle	Maintenance	**$53,550**	$31,595	$8,568	$13,388
	Administration	**$15,000**	**$8,850**	$2,400	$3,750
Support & Other	Service Delivery	**$91,289**	$53,670	$15,048	$22,571
Extraordinary Maintenance	Storms and Wrecks	**$165,000**	$97,350	$26,400	$41,250
Communications	Phone and Radio	**$9,560**	$5,640	$1,530	$2,390
Environmental	Compliance and Safety	**$50,000**	$29,500	$8,000	$12,500
Training	Safety and Technical	**$54,600**	$32,214	$8,736	$13,650
	Grand Total:	**$4,193,474**	$2,561,153	$635,231	$997,089

Note: BP = ballpark cost estimate

Table 13: Bottom Up Cost Estimate Watertown to Madison
FRA Class 6
Concrete Tie System - Single Track
Predominantly Passenger (Freight < 5 MGT)

Total Number of Passenger Trains Per Day	20
Total Number of Freight Trains Per Day	2
Total Number of Track Miles	37.5

Maintenance Category	Maintenance Item	Budgeted Cost	Comments / Notes
Management	Service Delivery	**$229,500.00**	2 management employees
Professional Services	Engineering	**$ 30,000.00**	BP Estimate
Roadway Maintenance Services	Infrastructure Services	**$106,490.00**	Detailed Estimate
Labor	Straight Time	**$915,200.00**	Labor to maintain a class #6 single track
	Overtime	**$ 91,520.00**	At 10% of straight time & overtime
	Overhead	**$352,352.00**	At 35% of total straight time & overtime
Materials	Track	**$ 119,575.00**	Detailed listing of materials
	C&S	**$45,700.00**	Detailed listing of materials
	Structures	**$30,000.00**	BP Estimate
	Work Equipment	**$ 65,000.00**	BP Estimate
Small Tools & Safety Equipment	Service Delivery	**$28,440.00**	At $1,200.00 per person
Roadway Equipment	Rental	**$12,000.00**	Assumes equipment is primarily owned
Vehicle	Rental	**$172,800.00**	Assumes vehicles are leased
	Maintenance	**$31,500.00**	Fuel, PM, Misc. BP estimate
	Administration	**$18,000.00**	BP assume, already in place
Support & Other	Service Delivery	**$55,370.00**	Percentage of labor with detailed description
Extraordinary Maintenance	Storms and Wrecks	**$60,000.00**	BP Estimate
Communications	Phone	**$ 3,300.00**	Detailed Estimate
	Radio	**$3,150.00**	Detailed Estimate
Environmental	Compliance and Safety	**$ 30,000.00**	BP Estimate
Training	Safety and Technical	**$28,440.00**	BP Estimate
	TOTAL	**$ 2,428,337.00**	

Using the bottom-up cost analysis performed by HNTB, ZETA-TECH was able to determine a cost per work unit for the calculated number of work units on each line, such that the total maintenance cost predicted by the Work Unit Model matched the bottom-up cost calculation. This is presented in Table 14 together with the corresponding costs per track mile.

TABLE 14: Calculation of Cost per Work Unit

	Track Cost	B&B	C&S	TOTAL
	Class 6	**Class 6**	**Class 6**	**Class 6**
Total maintenance cost (Operating)	**$3,950,234**	$867,314	$2,130,689	$6,948,237
Work Units	716			
$/Work Unit	$5,517	$1,211	$2,976	$9,704
Maintenance cost (Operating) $/Trk Mile	$25,785	$5,661	$13,908	$45,354

However, it was noted that the resulting cost per mile was noticeably higher than the cost per mile on several Class I railroads examined. This is in fact consistent with maintenance costs on Amtrak and on foreign high-speed lines, which show significantly higher costs than on typical US Class 1 freight operations. However, all the available data for U.S. railroads indicated that costs should be lower.

In order to address this issue, it was decided to present a range of costs in each cost matrix, with the minimum cost representing a number calibrated to U.S. freight railroad "average" costs and the maximum a number matching the bottom-up cost calculations. The result was a "low" value based on available railroad data, and a "high" value based on the HNTB bottom up analysis. Noting that the minimum cost was based on predominately freight traffic and the maximum cost was based on predominately passenger traffic, a range of cost/work unit values was developed for the three passenger/freight traffic distributions and the corresponding operating speeds (classes of track). Table 15 presents the minimum and maximum work unit values used.

TABLE 15: Minimum and Maximum Cost per Work Unit

	Track	B&B	C&S
Minimum	$3000	$650	$1600
Maximum	$5500	$1200	$3000

This produced reasonable agreement with costs on the Buffington Harbor to Ft. Wayne segment, but continued to understate costs on the Watertown – Madison segment. HNTB suggested that, because of the short length of Watertown – Madison, there were issues of divisibility, and the workforce could probably maintain an additional 20 track miles without additional resources. This brought the cost per mile into the range predicted by the work unit model.

The resulting costs were then used to develop a series of costs per mile for individual matrix elements for maintenance costs. These cost elements were then calibrated against a full model application for five specific segments:

- Chicago to Buffington Harbor, (MWRRI)
- Buffington Harbor to Ft. Wayne, IN (MWRRI)
- Delta Junction, OH to Cleveland, OH (MWRRI)
- Watertown, WI to Madison, WI (MWRRI)
- Seattle WA to Portland OR (BNSF)

In each case, the values for MGT, number of trains, operating speeds, and other factors were input into the two models, and the results were compared with numbers obtained from the cost matrices. These calibration costs are presented in Appendix A together with the corresponding "handbook" costs (after calibration) for the same five segments.

After calibration a full set of maintenance unit cost elements was developed and applied to a range of combinations of traffic volume, traffic mix, and track configuration. These results are presented in Appendix B.

In using these cost matrices, planners should take cognizance of the conditions prevailing on specific track segments. The costs presented in the matrices cover a broad range. However, in calibrating the values in the matrices, ZETA-TECH adjusted for the difference in maintenance cost between passenger and freight by reducing the maximum costs in the "predominantly freight" matrices, and by increasing the minimum costs in the "predominantly passenger" matrices. This reflects the extra inspection and maintenance activity on high-speed passenger railroads, and also the difficulty of access when large numbers of trains per day operate. This means that the analyst need only select the correct matrices for a particular situation, and both minimum and maximum expected costs will accurately reflect operating conditions.

Calibration of the Steady State Capital Model

Since the Steady State Capital Model is based on the predicted life of the key track capital components (e.g. rail, ties, ballast, etc.), this model was calibrated against observed lives of track components under traffic, together with actual railroad capital costs from Class 1 railroad sources Although actual component condition will effect the schedule of component capital replacement, since track assets are long-lived, and replacements are highly cyclical in nature, if a long enough time series covering a large enough number of track miles is used, a steady state analysis can be used to develop cyclic capital maintenance costs for planning purpose.

Current traffic levels and track geometry are used in the track component life models within the Steady State Capital Model to calculate steady state requirements for rail, ties, and ballast. For the case of the five calibration track segments, presented in Appendix A, the actual traffic levels, curvature, and other key data was input into the ZETA-TECH Steady State Capital Model, together with industry average costs (as noted previously) to calculate the annual cyclic capital cost per mile for maintaining railroad track.

Annual bridge and signal expenditures were likewise calculated using a steady state approach and calibrated to Class 1 railroad data. In the case of bridges, a design life of 80 years was used together with unit costs (cost per foot) as shown in Table 13. In the case of signals, a design life of 80 years was again used (based on industry standards for treating very long life assets) together with unit costs (cost per track mile) as shown in Table 16.

TABLE 16: Minimum and Maximum Capital Cost for Bridges and Signals

	B&B Cost/foot	C&S Cost/mile[9]
Minimum	$4000	$220,000
Maximum	$6000	$320,000

As with the MOW operating expense matrices, care should be taken in selecting costs within these ranges. The minimum cost is typical of U.S. Class I freight railroad practice[10]. The maximum cost is more appropriate for high-speed passenger rail lines, and will cover additional active protection at grade crossings, four-quadrant gates, and more sophisticated signal systems.

.

IV. Production of Cost Matrices

To obviate the need for planners to actually run the Work Unit and Steady State Capital models, ZETA-TECH generated two sets of matrices (one for wood ties, one for concrete ties). Each matrix is composed of 108 cells, each of which provides a value (cost per track mile) for both operating and capital expenditures for some combination of tonnage, traffic mix, operating speed, and curvature. All segments assumed use of heavy CWR and good quality ballast. Ties, as noted above, were either wood or concrete.

The key variables used to make up these matrices are:

Annual Tonnage (MGT)

- ≤ 5 MGT per track mile per year
- 5 – 15 MGT
- 15 – 30 MGT
- > 30 MGT

Traffic Mix:

- Predominantly freight traffic
- Traffic equal between freight and passenger
- Predominantly passenger traffic

Curvature

- Light
- Moderate
- Severe

---

[9] Note, this cost per mile includes al $50,000 per turnout C&S costs to reflect the cost of switch machines and signals associated with remote-control turnouts. Based on an averhge of 0.4 turnouts per mile, this represents an turnout C&S capital cost of $20,000 per mile. Note, the C&S costs represents costs with different lives, which are annualized separately later in this report.

[10] Based on Class 1 freight railroads on which passenger trains operate.

Class of Track

- FRA Class 4
- FRA Class 5
- FRA Class 6

Tie Type

- Wood
- Concrete

The final matrices contain a set of 108 values for wood tie track, and another 108 for concrete tie track.

Table 17 shows the traffic mixes used in generating the matrices.

Table 17: Traffic Mixes

Traffic Mix	% of MGT	
	Passenger	Freight
Predominantly freight	20	80
Equal	50	50
Predominantly passenger	80	20

Note: Number of daily passenger trains capped at 50 for the first two cases, 60 for the third. In the predominantly freight case, at 50 passenger trains per day, freight is assumed to operate predominantly (only) at night.

The number of trains of each type was calculated for the following annual gross tonnages:

- ≤ 5 MGT per track mile per year
- > 5 – 15 MGT
- > 15 – 30 MGT
- > 30 MGT

[Note that in the calculation of the costs in the matrices, values of 5, 15, 30, and 50 MGT respectively were used for these four tonnage categories.]

Passenger trains were assigned a gross weight of 550 tons, freight trains a gross weight of 5,900 tons.

Note, however, that several elements of the matrix would have produced unrealistic combinations of passenger and freight track and as such were excluded (and are so indicated by an * in the matrix element). These unrealistic cases included:

- Equal 50/50 passenger/freight traffic and annual tonnage >30 MGT
- Predominantly passenger traffic and 15 – 30 MGT
- Predominantly passenger traffic and > 30 MGT

Note also that traffic densities are per track. It is extremely unlikely that any predominately passenger operation will ever exceed 15 MGT per track mile. As a comparison, the most heavily used portion of Amtrak's Northeast Corridor, between Newark and New York's Penn Station, carries about 150 trains per day on two tracks, for a total of about 40 MGT annually or 20 MGT on each track. There is no freight traffic. The heaviest segment with freight traffic is between Perryville, MD and Baltimore, where the 20 MGT of total traffic (split 50/50 between freight and passenger) runs on two or three main tracks depending on location.

In addition to traffic mix and annual gross tonnage, ranges of curvature were also used as shown in Table 18.

Table 18: Ranges of Curvature

Category	% of Total Distance in Each Category		
	< 2 deg.	2 – 6 deg.	> 6 deg.
Light curvature	96%	4%	0%
Moderate curvature	90%	8%	2%
Severe Curvature	82%	12%	6%

Finally, costs are provided for three track classes:

Table 19: Track Classes

FRA Class of Track	Maximum Speed	
	Passenger	Freight
Class 4	80	60
Class 5	90	80
Class6	110	80

However, it should be noted that while the maximum posted freight speed for Classes 5 and 6 is 80 mph, most freight cars can not travel faster than 60 mph and as such 60 mph was used as the practical maximum freight train speed for all three classes of track.

The combination of all these factors produced a matrix of 108 cells for wood-tie track. A second 108-cell matrix was run for concrete-tie track. Minimum and maximum costs are presented for each element, thus providing a range of costs to account for variations in operations, track characteristics, local costs, environmental effects, topographical variations and other such factors.

Cost Per Track Mile

The matrices for Annual Total Maintenance Cost Per Track Mile[11] are presented in Tables 17, 18, 19, and 20 (corresponding to Matrices 19, 20, 37, and 38 in Appendix B). Matrices for the individual elements that make up these total costs are presented in Appendix B.

Costs included in the matrices (and presented in Appendix B) are:

- Track maintenance (MOW operating expenses)
- Track cyclic capital
- Signal maintenance

[11] Includes both cyclic capital and expensed maintenance costs.

- Signal capital
- B&B maintenance
- B&B capital

These costs are further summed as follows:

- Maintenance Cost per Track Mile [Minimum and Maximum]
- Capital (Cyclic) Cost per Track Mile [Minimum and Maximum]

Finally, a single set of total (Maintenance + Cycle Capital) costs per track mile are developed; again with a minimum-maximum range of values. These are presented in Tables 21, 22, 23, and 24 below.

Adjustment to Account for Upgrading

One other adjustment should be considered by users of the cost matrices included in this Planner's Handbook. The assumption in developing costs has been that of "steady state", the expenditures (both capital and maintenance) required to keep each line in service at a defined operating speed (track class).

Prior to the start of high speed rail operations, any routes included in a high speed rail network will have to be upgraded. In many cases, this will involve complete replacement of rail, ties, and ballast. Such a "new" railroad of this kind will require maintenance, but little or no renewal of track components for a number of years. Therefore, costs shown in the matrices may be adjusted downward during the first few years of operations to account for this fact. Maintenance costs are unaffected, since even new track requires maintenance. But some cyclic capital costs can be deferred. Table 20 shows the suggested adjustment to costs to account for new construction.

Table 20: Cost Adjustments Following Upgrade of a Rail Line

Year	% of Cyclic Capital	Year	% of Cyclic Capital
0	0%	11	50%
1	0%	12	50%
2	0%	13	50%
3	0%	14	50%
4	20%	15	75%
5	20%	16	75%
6	20%	17	75%
7	35%	18	75%
8	35%	19	75%
9	35%	20	100%
10	50%		

This table is a recommendation based on the relative percentage of costs accounted for by rail, ties, and ballast, and by the average life of each component. Note that these percentages apply only to capital costs, such as those shown in Matrices 40, 42, 46,and 48 in Appendix B. Maintenance costs are unaffected.

Using the Matrices

To use the matrices, a planner need only select a value from the appropriate cell for each segment of track and multiply the per mile cost by the number of miles in the segment. For long segments with different combinations of traffic and tonnage, the costs are built up by dividing the long segment into shorter segments corresponding to an individual matrix element, multiply the cost per mile for each element by the corresponding mileage, and then summing up these costs to obtain a cost for the line segment. Section V presents an example to illustrate how the matrices are used to build up costs for a complex line segment containing different traffic mixes, tonnages, curvatures, etc.

Using these elements the actual cost of maintaining the infrastructure can be calculated for any defined line segment or route by building up the elements of the route and using the appropriate cost per track mile multiplied by the number of miles corresponding to each element.

Selection of the correct matrices is important. The range of costs is higher for the "predominantly passenger" matrices, to reflect the need for more complex highway crossing protection, more limited track time for maintenance work and a higher level of inspection and maintenance. Costs are lower for "predominantly freight" matrices, reflecting the efficiencies achieved by the freight railroads in maintaining heavy-tonnage but moderate-speed trackage. Within each matrix, the minimum cost may be considered to reflect current Class I freight railroad practice[12]. The maximum cost reflects the maintenance of good ride quality for high speed passenger trains, along with a higher level of grade crossing protection and more sophisticated C&S.

The range of costs shown is based on calibration both to actual freight railroad spending and to the "bottom up" costs developed by subcontractor HNTB.

[12] Based on Class 1 freight railroads on which passenger trains operate.

Table 21: Annual Total Cost[13] Per Track Mile (Minimum) for Wood Tie Track

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$26,554	$31,046	$42,008	$60,833	4	$27,107	$32,007	$43,460	$63,136	4	$27,918	$33,503	$45,763	$66,784
Pred. Frght	5	$29,172	$34,408	$46,816	$68,778	5	$29,846	$35,523	$48,484	$71,442	5	$30,826	$37,231	$51,086	$75,592
	6	$32,962	$39,329	$53,833	$80,265	6	$33,808	$40,662	$55,807	$83,442	6	$35,026	$42,672	$58,836	$88,304
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$29,393	$38,149	$54,725	*	4	$30,084	$39,457	$56,797	*	4	$31,087	$41,431	$59,958	*
	5	$31,500	$41,476	$59,946	*	5	$32,288	$42,935	$62,253	*	5	$33,425	$45,120	$65,741	*
	6	$35,816	$48,291	$70,573	*	6	$36,801	$50,060	$73,363	*	6	$38,211	$52,675	$77,521	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$31,879	$47,206	*	*	4	$32,691	$48,955	*	*	4	$33,861	$51,540	*	*
	5	$34,408	$52,073	*	*	5	$35,337	$54,049	*	*	5	$36,670	$56,948	*	*
	6	$37,543	$58,074	*	*	6	$38,612	$60,319	*	*	6	$40,139	$63,594	*	*

[13] Maintenance + Cyclic Capital

Table 22: Annual Total Cost[14] Per Track Mile (Maximum) for Wood Tie Track

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$38,748	$47,507	$66,570	$97,664	4	$39,632	$49,283	$69,464	$102,356	4	$40,986	$52,085	$74,111	$109,884
Pred. Frght	5	$42,189	$52,331	$73,422	$108,988	5	$43,255	$54,323	$76,619	$114,189	5	$44,864	$57,425	$81,688	$122,424
	6	$47,849	$59,930	$84,192	$126,621	6	$49,184	$62,253	$87,856	$132,603	6	$51,165	$65,816	$93,574	$141,921
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$42,842	$57,976	$85,400	*	4	$43,926	$60,262	$89,212	*	4	$45,557	$63,771	$95,129	*
	5	$45,750	$63,042	$93,287	*	5	$46,990	$65,556	$97,452	*	5	$48,839	$69,380	$103,861	*
	6	$52,215	$73,532	$109,567	*	6	$53,763	$76,518	$114,467	*	6	$56,039	$80,998	$121,897	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$46,640	$71,721	*	*	4	$47,909	$74,677	*	*	4	$49,796	$79,113	*	*
	5	$50,194	$79,124	*	*	5	$51,650	$82,421	*	*	5	$53,799	$87,331	*	*
	6	$54,822	$88,301	*	*	6	$56,497	$92,006	*	*	6	$58,949	$97,482	*	*

[14] Maintenance + Cyclic Capital

Table 23: Annual Total Cost[15] Per Track Mile (Minimum) for Concrete Tie Track

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$27,002	$30,808	$40,377	$58,218	4	$27,436	$31,622	$41,621	$60,169	4	$28,084	$32,913	$43,636	$63,330
Pred. Frght	5	$29,598	$34,145	$45,149	$66,101	5	$30,120	$35,069	$46,549	$68,312	5	$30,889	$36,514	$48,780	$71,835
	6	$33,359	$39,029	$52,114	$77,501	6	$34,006	$40,112	$55,060	$80,083	6	$34,947	$41,776	$56,278	$84,122
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$29,816	$37,851	$52,986	*	4	$30,350	$38,912	$54,672	*	4	$31,134	$40,545	$57,300	*
	5	$31,907	$41,152	$58,166	*	5	$32,510	$43,323	$60,023	*	5	$33,391	$44,108	$62,887	*
	6	$36,189	$47,914	$68,711	*	6	$36,934	$49,309	$72,240	*	6	$38,013	$51,405	$74,264	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$32,280	$46,616	*	*	4	$32,900	$47,984	*	*	4	$33,804	$50,043	*	*
	5	$34,790	$51,407	*	*	5	$35,494	$52,938	*	*	5	$36,515	$55,221	*	*
	6	$37,901	$57,319	*	*	6	$38,706	$59,044	*	*	6	$39,869	$61,597	*	*

[15] Maintenance + Cyclic Capital

Table 24: Annual Total Cost[16] Per Track Mile (Maximum) for Concrete Tie Track

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$38,387	$47,330	$65,072	$94,860	4	$39,090	$48,881	$67,648	$99,015	4	$40,800	$52,128	$72,922	$107,601
Pred. Frght	5	$41,798	$52,118	$71,872	$106,096	5	$42,636	$53,825	$74,668	$110,618	5	$44,474	$57,213	$80,140	$119,534
	6	$47,413	$59,662	$82,564	$123,596	6	$48,448	$61,608	$87,000	$128,683	6	$50,332	$65,049	$91,245	$137,712
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$42,446	$57,710	$83,742	*	4	$43,292	$59,625	$86,973	*	4	$44,846	$63,014	$92,703	*
	5	$45,329	$62,738	$91,567	*	5	$46,291	$64,817	$95,054	*	5	$48,050	$68,500	$101,243	*
	6	$51,743	$73,147	$107,722	*	6	$52,929	$75,567	$113,041	*	6	$54,704	$79,264	$117,946	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$46,211	$71,014	*	*	4	$47,189	$73,395	*	*	4	$48,675	$77,036	*	*
	5	$49,734	$78,303	*	*	5	$50,851	$80,928	*	*	5	$52,530	$84,907	*	*
	6	$54,327	$87,345	*	*	6	$55,604	$90,264	*	*	6	$57,505	$94,651	*	*

[16] Maintenance + Cyclic Capital

Cost Per Passenger Train Mile

In addition to the total cost matrices presented, a series of matrices for Cost per Passenger Train Mile were calculated (see Appendix C). These costs were determined by first separating passenger and freight costs using the following methodology:

1. ZETA-TECH's TrackShare® Model is used to allocate Class 4 costs between passenger and freight trains (based on a maximum freight speed of 60 mph and a passenger speed of 80 mph).

2. 100% of the calculated incremental cost of Class 5 or Class 6 track (over Class 4) is assigned to passenger trains, since it is only the passenger trains that benefit from the higher track class.

As in the case of the Total Cost per Track Mile, two sets of 108 cell matrices are generated, for wood-tie and concrete tie track respectively. Again, minimum and maximum costs are presented for each element, thus providing a range of costs to account for variations in operations, track characteristics, local costs, environmental effects, topographical variations and other such factors.

The matrices for Total Maintenance Cost Per Passenger Train Mile[17] are presented in Tables 21, 22, 23, and 24 (corresponding to Matrices 43, 44, 49, and 50 in Appendix C). Matrices for the individual elements that make up these total costs are presented in Appendix C.

Again, costs included in the matrices (and presented in Appendix C) are:

- Track maintenance (MOW operating expenses)
- Track cyclic capital
- Signal maintenance
- Signal capital
- B&B maintenance
- B&B capital

These costs are further summed as follows:

- Maintenance Cost per Passenger Train Mile [Minimum and Maximum]
- Capital (Cyclic) Cost per Passenger Train Mile [Minimum and Maximum]

Finally, a single set of total (Maintenance + Cycle Capital) costs per passenger train mile are developed; again with a minimum-maximum range of values. These are presented in Tables 25, 26, 27 and 28 below.

[17] Includes both cyclic capital and expensed maintenance costs.

Some Comments on Cost Allocation

There are a number of ways to allocate costs between passenger and freight trains, or between different types of freight trains, sharing the same track. ZETA-TECH's TrackShare is only one of these.[18] Amtrak is, by law, guaranteed access to freight railroad tracks at "avoidable" cost – the cost the railroads incur solely due to the operation of Amtrak trains. Freight railroads pay each other trackage rights fees based on track maintenance and communications and signal (C&S) costs, plus some allowance for train dispatching cost and overhead. Shippers have used methodologies such as the Speed Factored Gross Tonnage (SFGT) model and "stand alone costing" to determine the cost of particular train movements in rate disputes.

It is also possible to allocate costs based solely on gross ton miles of each traffic type.

Access fees for use of private railroad tracks by publicly operated trains will be determined by negotiation between the parties, ultimately. While the allocations presented attempt to apportion costs based on engineering relationships, they are intended as examples only. As such, they may serve as a starting point for negotiations between passenger service providers and the private railroads.

[18] In its 1995 decision, the Interstate Commerce Commission found TrackShare "best available" method to determine incremental track maintenance cost in a dispute between Conrail and Amtrak over payments by Amtrak to use Conrail tracks.

Table 25: Total Cost Per Passenger Train Mile (Minimum) for Wood Tie Track

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$1.97	$0.77	$0.52	$0.45	4	$2.01	$0.79	$0.54	$0.47	4	$2.08	$0.83	$0.57	$0.50
Pred. Frght	5	$3.41	$1.39	$0.96	$0.89	5	$3.52	$1.44	$1.00	$0.93	5	$3.67	$1.51	$1.05	$0.98
(80% Frght. 20% Pass.)	6	$5.50	$2.29	$1.60	$1.52	6	$5.70	$2.38	$1.67	$1.59	6	$5.98	$2.51	$1.77	$1.68
	No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	4	$2.49	$1.08	$0.96	*	4	$2.55	$1.11	$1.00	*	4	$2.63	$1.17	$1.06	*
(50% Frght. 50% Pass.)	5	$2.95	$1.32	$1.20	*	5	$3.03	$1.37	$1.25	*	5	$3.14	$1.44	$1.32	*
	6	$3.90	$1.82	$1.69	*	6	$4.02	$1.89	$1.76	*	6	$4.20	$1.99	$1.86	*
	No. of Pass. Train	20	60			No. of Pass. Train	20	60			No. of Pass. Train	20	60		
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Pred. Pass.	4	$3.13	$1.55	*	*	4	$3.21	$1.60	*	*	4	$3.33	$1.69	*	*
(20% Frght. 80% Pass.)	5	$3.48	$1.77	*	*	5	$3.57	$1.84	*	*	5	$3.71	$1.94	*	*
	6	$3.91	$2.04	*	*	6	$4.02	$2.12	*	*	6	$4.19	$2.24	*	*

Table 26: Total Cost Per Passenger Train Mile (Maximum) for Wood Tie Track

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$2.88	$1.18	$0.82	$0.73	4	$2.95	$1.22	$0.86	$0.76	4	$3.05	$1.29	$0.92	$0.82
Pred. Frght	5	$4.77	$2.06	$1.45	$1.35	5	$4.94	$2.15	$1.52	$1.41	5	$5.18	$2.27	$1.61	$1.51
(80% Frght. 20% Pass.)	6	$7.89	$3.45	$2.44	$2.32	6	$8.20	$3.60	$2.55	$2.42	6	$8.64	$3.81	$2.70	$2.58
	No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	4	$3.63	$1.64	$1.51	*	4	$3.72	$1.70	$1.57	*	4	$3.86	$1.80	$1.68	*
(50% Frght. 50% Pass.)	5	$4.27	$2.01	$1.87	*	5	$4.39	$2.09	$1.95	*	5	$4.58	$2.21	$2.08	*
	6	$5.69	$2.78	$2.61	*	6	$5.88	$2.89	$2.73	*	6	$6.16	$3.06	$2.90	*
	No. of Pass. Train	20	60			No. of Pass. Train	20	60			No. of Pass. Train	20	60		
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Pred. Pass.	4	$4.58	$2.35	*	*	4	$4.71	$2.44	*	*	4	$4.89	$2.59	*	*
(20% Frght. 80% Pass.)	5	$5.07	$2.69	*	*	5	$5.22	$2.80	*	*	5	$5.44	$2.97	*	*
	6	$5.71	$3.11	*	*	6	$5.89	$3.24	*	*	6	$6.15	$3.43	*	*

Table 27: Total Cost Per Passenger Train Mile (Minimum) for Concrete Tie Track

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	**5**	**15**	**30**	**50**	**No. of Pass. Train**	**5**	**15**	**30**	**50**	**No. of Pass. Train**	**5**	**15**	**30**	**50**
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
	4	$2.01	$0.76	$0.50	$0.43	**4**	$2.04	$0.78	$0.52	$0.45	**4**	$2.09	$0.82	$0.54	$0.47
Pred. Frght.	**5**	$3.44	$1.38	$0.94	$0.87	**5**	$3.52	$1.42	$0.97	$0.90	**5**	$3.63	$1.48	$1.01	$0.94
(80% Frght. 20% Pass.)	**6**	$5.50	$2.27	$1.58	$1.49	**6**	$5.65	$2.34	$1.75	$1.54	**6**	$5.86	$2.44	$1.70	$1.61
	No. of Pass. Train	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**	
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
Equal Frght.	**4**	$2.52	$1.07	$0.93	*	**4**	$2.57	$1.10	$0.96	*	**4**	$2.63	$1.14	$1.01	*
(50% Frght. 50% Pass.)	**5**	$2.98	$1.31	$1.17	*	**5**	$3.04	$1.35	$1.21	*	**5**	$3.13	$1.40	$1.27	*
	6	$3.92	$1.81	$1.65	*	**6**	$4.02	$1.86	$1.77	*	**6**	$4.15	$1.94	$1.79	*
	No. of Pass. Train	**20**	**60**			**No. of Pass. Train**	**20**	**60**			**No. of Pass. Train**	**20**	**60**		
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
Pred. Pass.	**4**	$3.17	$1.53	*	*	**4**	$3.23	$1.57	*	*	**4**	$3.32	$1.64	*	*
(20% Frght. 80% Pass.)	**5**	$3.52	$1.75	*	*	**5**	$3.59	$1.80	*	*	**5**	$3.69	$1.88	*	*
	6	$3.94	$2.02	*	*	**6**	$4.03	$2.08	*	*	**6**	$4.15	$2.17	*	*

Table 28: Total Cost Per Passenger Train Mile (Maximum) for Concrete Tie Track

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	**5**	**15**	**30**	**50**	**No. of Pass. Train**	**5**	**15**	**30**	**50**	**No. of Pass. Train**	**5**	**15**	**30**	**50**
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
	4	$2.85	$1.17	$0.81	$0.71	**4**	$2.91	$1.21	$0.84	$0.74	**4**	$3.03	$1.29	$0.90	$0.80
Pred. Frght	**5**	$4.73	$2.05	$1.43	$1.32	**5**	$4.86	$2.12	$1.48	$1.37	**5**	$5.05	$2.22	$1.57	$1.46
(80% Frght. 20% Pass.)	**6**	$7.82	$3.43	$2.41	$2.29	**6**	$8.05	$3.54	$2.61	$2.37	**6**	$8.28	$3.66	$2.58	$2.46
	No. of Pass. Train	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**	
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
Equal Frght	**4**	$3.59	$1.63	$1.48	*	**4**	$3.66	$1.68	$1.53	*	**4**	$3.79	$1.78	$1.63	*
(50% Frght. 50% Pass.)	**5**	$4.23	$2.00	$1.84	*	**5**	$4.32	$2.06	$1.90	*	**5**	$4.50	$2.18	$2.03	*
	6	$5.64	$2.76	$2.58	*	**6**	$5.78	$2.85	$2.73	*	**6**	$5.96	$2.97	$2.79	*
	No. of Pass. Train	**20**	**60**			**No. of Pass. Train**	**20**	**60**			**No. of Pass. Train**	**20**	**60**		
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
Pred. Pass.	**4**	$4.54	$2.32	*	*	**4**	$4.63	$2.40	*	*	**4**	$4.78	$2.52	*	*
(20% Frght. 80% Pass.)	**5**	$5.02	$2.66	*	*	**5**	$5.14	$2.75	*	*	**5**	$5.31	$2.88	*	*
	6	$5.65	$3.07	*	*	**6**	$5.79	$3.18	*	*	**6**	$5.99	$3.33	*	*

V. Example Application

Two hypothetical examples are presented here to illustrate how the handbook and its matrices are used to calculate a route segment's total maintenance cost and passenger train cost. Note, to use the matrices, a route must first be defined.

Example A.

Example A is illustrative of a 100-mile route that begins in an urban area, representative of a major city terminal area. The first ten miles are shared with heavy freight traffic on a Class 4 railroad. The passenger trains then enter a primarily passenger track (minimal freight traffic) for 50 miles, transitioning to a 30 mile segment on a secondary freight line, still at Class 6 but carrying 15 MGT or perhaps five trains per day of freight. Finally, the line enters another terminal in the destination city, sharing a heavy freight line at FRA Class 4. The entire route is wood tie track.

Table 29: Route Characteristics, Hypothetical Case A

Segment Length (Miles)	Characteristics			
	Traffic	FRA Class	MGT Range	Curvature
10	Pred. Freight.	4	> 30	Moderate
50	Pred. Passenger.	6	< 5	Light
30	50/50	6	5 – 15	Moderate
10	Pred. Freight.	4	> 30	Severe

To estimate a cost per track mile, the analyst need only choose the appropriate cost per mile for each segment, and multiply by the number of track miles to obtain the total cost of maintenance plus cyclic capital. Minimum costs are from Table 21 and maximum costs are from Table 22. Costs include Track, C&S and B&B. Note, if separate maintenance and cyclic capital costs are desired they can be built up by using individual maintenance (expensed) and capital cost tables from Appendix B.

Table 30: Total Steady-State Maintenance[19] Cost Calculation Using Minimum Cost (From Table 21)

Segment Length (Miles)	Costs	
	Cost per Mile	**Total Segment Cost**
10	$63,136	$631,360
50	$37,543	$1,877,150
30	$50,060	$1,501,800
10	$66,784	$667,840
Total Annual Route Cost		**$4,678,150**

[19] Includes both cyclic capital and expensed maintenance costs.

This is the minimum total expenditure a high-speed rail authority might expect to make on this route. The corresponding maximum cost is obtained by using the maximum value for each cost element in exactly the same manner, as shown in Table 31.

Table 31: Total Maintenance Cost Calculation Using Maximum Cost (From Table 22)

Segment Length (Miles)	Costs	
	Cost per Mile	**Total Segment Cost**
10	$102,356	$1,023,560
50	$54,822	$2,741,100
30	$76,518	$2,295,540
10	$109,884	$1,098,840
Total Annual Route Cost		**$7,159,040**

As noted earlier, the analyst will have to make a judgment as to whether to use minimum, maximum, or mean costs in the analysis. Tables 32 and 33 show the calculations for minimum and maximum costs respectively. Costs include track, B&B, and C&S.

Table 32: Cost per Passenger Train Mile Using Minimum Cost (from Table 25)

Total Segment Cost	Costs	
	Cost per Passenger Train Mile	**Total Segment Cost**
10	$0.47	$4.70
50	$3.91	$195.50
30	$1.89	$56.70
10	$0.50	$5.00
Total Passenger Train Cost per One-Way Trip		**$261.90**

Note that this is the minimum total expenditure a high-speed rail authority might expect to make on this route. The corresponding maximum cost is obtained by using the maximum value for each cost element in exactly the same manner.

Table 33: Cost per Passenger Train Mile Using Maximum Cost (from Table 26)

Segment Length (Miles)	Costs	
	Cost per Passenger Train Mile	**Total Segment Cost**
10	$0.76	$7.60

50	$5.71	$285.50
30	$2.89	$86.70
10	$0.82	$8.20
Total Passenger Train Cost per One-Way Trip		**$388.00**

Example B.

Example B is illustrative of a somewhat longer (150 mile) route that again begins in an urban area, representative a major city terminal area. These first twenty miles are conventional wood tie track shared with heavy freight traffic on a Class 4 railroad. The passenger trains then enters mixed freight and passenger segment (wood ties) of Class 5 track, 30 miles in length. The next 50 miles are primarily passenger track (minimal freight traffic) on concrete ties, transitioning to 30 mile severe curvature concrete tie segment of Class 6 track carrying 15 MGT of traffic equally divided between passenger and freight. Finally, the line enters another terminal in the terminating city, sharing a heavy freight line on wood tie track.

Table 34: Route Characteristics, Hypothetical Case B

Segment Length (Miles)	Characteristics				
Length	Traffic	FRA Class	MGT	Curvature	Ties
20	PRED. Freight.	4	>30	Severe	W
30	50/50	5	15-30	Moderate	W
50	PRED. Passenger	6	<5	Moderate	C
30	50/50	5	5-15	Severe	C
20	PRED. Freight.	4	>30	Moderate	W

As in the case of the earlier example A, to estimate a cost per track mile, the analyst chooses the appropriate cost per mile for each segment, and multiplies this cost by the number of track miles to obtain the total cost of maintenance plus cyclic capital, as shown in Tables 35 and 36 for minimum and maximum costs respectively. Since this route has both wood and concrete tie track, values must be taken from both sets of matrices. Thus, minimum costs are from Tables 21 and 23 while maximum costs are from Tables 22 and 24. Costs include Track, C&S and B&B. Again, if separate maintenance and cyclic capital costs are desired they can be built up by using individual maintenance (expensed) and capital cost tables from Appendix B.

Table 35: Total Maintenance[20] Cost Calculation Using Minimum Cost (from Tables 21 and 23)

Segment Length (Miles)	Costs	
	Cost per Mile	**Total Segment Cost**
20	$66,784	$1,335,680
30	$62,253	$1,867,590

[20] Includes both cyclic capital and expensed maintenance costs.

50	$38,706	$1,935,300
30	$44,108	$1,323,240
20	$63,136	$1,262,720
Total Annual Route Cost		**$7,724,530**

This is the minimum total expenditure a high-speed rail authority might expect to make on this route. The corresponding Maximum cost is obtained by using the maximum value for each cost element in exactly the same manner, as shown in Table 36.

Table 36: Total Maintenance Cost Calculation Using Maximum Cost (from Tables 22 and 24)

Segment Length (Miles)	**Costs**	
	Cost per Mile	**Total Segment Cost**
20	$109,884	$2,197,680
30	$97,452	$2,923,560
50	$55,604	$2,780,200
30	$68,500	$2,055,000
20	$102,356	$2,047,120
Total Annual Route Cost		**$12,003,560**

Determining the cost per passenger train mile is equally easy. Tables 37 and 38 show the calculations for minimum and maximum costs respectively. Minimum costs are from Tables 25 and 27 and maximum costs are from Tables 26 and 28. Costs include Track, C&S and B&B.

Table 37: Cost per Passenger Train Mile Using Minimum Cost (from Tables 25 and 27)

Segment Length (Miles)	**Costs**	
	Cost per Passenger Train Mile	**Total Segment Cost**
20	$0.50	$10.00
30	$1.25	$37.50
50	$4.03	$201.50
30	$1.40	$42.00
20	$0.47	$9.40
Total Passenger Train Cost per One-Way Trip		**$300.40**

Note that this is the minimum total expenditure a high-speed rail authority might expect to make on this route. The corresponding maximum cost is obtained by using the maximum value for each cost element in exactly the same manner.

Table 38: Cost per Passenger Train Mile Using Maximum Cost (from Tables 26 and 28)

Segment Length (Miles)	**Costs**	
	Cost per Passenger Train Mile	**Total Segment Cost**
20	$0.82	$16.40
30	$1.95	$58.50
50	$5.79	$289.50
30	$2.18	$65.40
20	$0.76	$15.20
Total Passenger Train Cost per One-Way Trip		**$445.00**

Thus, using the tables presented in this Handbook, transportation planners can estimate the range of Right of Way maintenance costs for a proposed passenger corridor sharing freight right of ways together with the corresponding passenger train trip cost for a range of track and traffic conditions and operations.

VI. A Simplified Method for Calculating Costs

Purpose

The purpose of this section is to describe a simplified method for estimating track maintenance costs. This method relies on costs from the ZETA-TECH matrices, but provides an easier format for planners to use, with less judgment required as to which factors to select for a particular analysis case.

To use this process, the planner must divide the route into more-or-less homogeneous segments, with segment boundaries located wherever a significant change occurs in one of the route characteristics. Characteristics included are those which make a significant difference in cost:

- Annual gross tonnage
- Mix of passenger and freight trains
- Curvature (a single value for the segment)
- FRA track class
- "Maintenance difficulty" (a combined factor that accounts for traffic volume, complexity of the infrastructure, difficulty of access, and environmental factors)

Although the ZETA-TECH matrices calculate costs separately for track with concrete and wood ties, no concrete vs. wood factor is used here due to the small difference in cost between concrete and wood.

Segmenting is done by assessing one variable at a time, and then the process is repeated for each variable until the route has been assessed for all of the variables. Each defined segment should have at least one different characteristic (or significantly different variable value) from either of the adjacent segments.

With each round of segmenting, the milepost boundaries for any further division of segments are recorded on the Cost Calculation Table (Appendix D, Table D.1), along with the cost factor or variable category for the route characteristic being assessed. Cost factors and variable categories are given in these instructions. When all the cost factors and variable categories for a segment have been recorded on the Cost Calculation Table, the total track maintenance cost for that segment will be automatically calculated and shown in the table.

This process permits the analyst to quantify the effect of adding (or subtracting) individual trains (passenger or freight), or of incremental changes in other cost-determining variables. Working with a route map or diagram will help in determining where route characteristics change, and in keeping track of segment boundaries during the process.

In the Cost Calculation Table, Columns with headings and entries in *italics* are automatically calculated from other entries.

Specific instructions for determining the values for each of the variables are provided in the next section.

Process Instructions

Mileposts

Enter the beginning and ending mileposts for each segment in Columns 1 and 2 of Table D-1. Enter the number of tracks in Column 3. Total track mileage for the segment will be automatically calculated in Column 4. For routes that are partially double track, create a new segment whenever the number of tracks changes.

FRA Track Class

Beginning at the low-numbered milepost end of the route, make a mark on the route map, and note the milepost, wherever the FRA track class changes. The FRA track classes are shown in Table 39. The higher of passenger or freight maximum speed for the segment will govern the choice. (Choose Class 4 also for locations where maximum speed is lower than 60 MPH).

Enter the mileposts where changes occur in Columns 1 and 2 of the Cost Calculation Table. In Column 8 enter the FRA track class.

Table 39: FRA Track Class

Maximum Allowable Speed (MPH)		FRA Track Class
Passenger	Freight	
80	60	4
90	80	5

110	80	6

Number of Trains and Tonnage

This data should be obtained from the owner of the railroad, or from the planners of future higher-speed train service. The analyst should obtain information for both:

- Number of freight and passenger trains per day; and
- Total annual gross tonnage

If both these data elements are unavailable, the number of trains may be estimated, and total annual tonnage calculated through use of an average weight of 550 tons for passenger trains and 5,900 tons for freight trains.

In the Cost Calculation Table for each segment, enter the number of passenger trains per day (average over the 7-day week) in Column 5 and number of freight trains in Column 6 that pass in either direction over the segment track being evaluated. Once entered, the Ratio of Passenger to Freight Trains will be automatically calculated and entered into Column 7. If actual annual gross tonnage is known, it may be directly entered into column 10. If annual tonnage is not known, the spreadsheet will calculate it from the numbers of trains entered and default values of 550 tons and 5,900 tons for passenger and freight trains, respectively. (These two values will be used later to determine Base Cost Factors).

Where the number of trains per day (either passenger or freight) changes within an existing segment, make a mark on the route map, note the milepost, and create a new segment line in the Cost Calculation Table where that milepost fits into the route sequence. To create an intermediate (new) segment in the Cost Calculation table, copy the whole table line with the next higher milepost directly above that line. Then change the entry for Ending Milepost to the correct new number. Now add the number of trains in the corresponding columns for this newly-created segment.

Maintenance Difficulty Factor

This factor is intended to capture a number of factors that influence track maintenance costs. These include:

- Complexity of the infrastructure to be maintained (frequency of highway crossings, turnouts, bridges, diamond crossings)
- Difficulty of access (due both to train volume and to the number of access points)
- Environmental factors (warm and wet vs. cold and dry)

Beginning at the low-numbered milepost end of the route, for each segment, note the relative amount of track and roadway infrastructure present, and relative ease of access for its maintenance. This infrastructure includes the number and size of bridges, turnouts, interlockings, crossings, signal system equipment, drainage structures, and other roadway infrastructure present.

Select the most descriptive infrastructure category from the table below, and use the Total Tonnage shown in Column 10 of the Cost Calculation Table (Appendix D, Table D-1) to determine the appropriate Maintenance Difficulty Factor. Enter this factor in Column 11 of the Cost Calculation Table.

Table 40: Maintenance Difficulty Factor

Infrastructure Concentration and Difficulty of Access for Maintenance		Total Annual Traffic (Million Gross Tons/Year: MGT)			
Category	**Description**	**≤ 5**	**5-15**	**15-30**	**≥30**
High	Frequent turnouts, bridges, crossings, some interlockings etc. Some areas have difficult maintenance access. Typical of urban centers.	1.46	1.53	1.59	1.62
Medium	Frequent crossings, but fewer than 3 bridges and turnouts per mile. Only occasional short sections with impeded maintenance access. Typical of smaller cities or metropolitan suburbs.	1.23	1.26	1.29	1.31
Low	Rural: mostly open track. Maintenance access rarely impeded.	1.00	1.00	1.00	1.00

Where the infrastructure density and ease of maintenance access changes within an existing segment, make a mark on the route map, note the milepost, and create a new segment line in the Cost Calculation Table where that milepost fits into the route sequence. Now add the Infrastructure Density Factor in the corresponding column for this newly-created segment.

Track Curvature

For each segment, add the length of track (mileage) which has a curvature greater than 2° and divide that by the total segment length, to find the % of track in each segment with curvature greater than 2°. Use Table 41 to find the Curvature Category that most closely matches each segment and enter the Curve Factor in Column 9 of the Cost Calculation Table (Table D-1).

At this point, the segmenting process is done. After two more factors (below) are added to each segment in the Cost Calculation Table, the maintenance costs will be calculated.

Table 41: Curvature Category

% of Track with Curvature > 2^0	Curvature Category	Curve Factor
≤ 4%	Low	1.00

10%	Medium	1.04
≥ 18%	High	1.09

Base Case Cost Factors

Use the table of Base Case Track Maintenance Cost Factors (Table 42) to determine two base case factors for each segment – one factor for cost per track mile and one for cost per train mile. Referring again to Table D.1, use the Ratio Pass/Frt (from Column 5) and the FRA Track Class (from Column 6) to determine the appropriate reference row in the Base Case table (Table 42). Again from the Cost Calculation Table, use the Total Tonnage (from Column 8) to then determine the appropriate reference columns in the Base Case table, and enter the resulting Base Case Factors in the Cost Calculation Table: in Column 12 for Cost Per Track Mile and in Column 15 for Cost Per Train Mile.

The costs in Table 42 are from Tables 21 (Annual Total Cost Per Track Mile (Minimum) for Wood Tie Track) and 25 (Annual Total Cost Per Passenger Traink Mile (Minimum) for Wood Tie Track) in Section IV.

Annual Track Maintenance Costs

Once all the entries for a segment are filled in the Cost Calculation Table (Table D-1), the annual track maintenance costs are automatically calculated: cost per track mile in Column 13 and total cost for the segment in Column 14, and cost per train mile in Column 16 and total cost for one trip through that segment in Column 16. Total annual cost for the route (sum of the segments) is shown at the bottom of Column 14, and total annual cost corresponding to a one-way trip over the route is shown at the bottom of Column 16.

Equations used in Table D-1 are shown in Table D-2, Appendix D.

An Example Application

Route Segmentation

Table D-1 in Appendix D contains an example application of the simplified methodology. The example consists of three segments. The first of these begins at milepost 13.4 and extends to MP 38.1, so these numbers are entered in Columns 1 and 2 of the Cost Calculation Sheet. This segment is double track, so “2” is entered in Column 3. The total track mileage of 49.4 is calculated by the spreadsheet.

There is a milepost “equation” at MP 38.1 (perhaps the route runs onto a different railroad line). The next segment begins at MP 248.3 and extends to 259.5. It is single track, so a “1” is entered in Column 3. Again, total track mileage is calculated. If there was a passing siding on this segment, it would have been entered as a separate, double-track segment.

Finally, there is a segment from MP 259.5 to MP 272.7, also single track. The mileposts are entered into columns 1 and 2, the number of tracks is set at “1”, and again a track mileage is calculated.

Table 42: Base Case Track Maintenance Cost Factors

Ratio of Passenger to Freight Trains	FRA Track Class	Cost Per Track Mile ($1,000) Total Tonnage (MGT) 5 or Less	5-15	15-30	30 or More	Cost Per Train Mile ($) Total Tonnage (MGT) 5 or Less	5-15	15-30	30 or More
2 Pass: 1 Frt	4	26.6	31.0	42.0	60.8	1.97	0.77	0.52	0.45
	5	29.2	34.4	46.8	68.8	3.41	1.39	0.96	0.89
	6	33.0	39.3	53.8	80.3	5.50	2.29	1.60	1.52
10 Pass: 1 Frt	4	29.4	38.1	54.7	***	2.49	1.08	0.96	***
	5	31.5	41.5	59.9	***	2.95	1.32	1.20	***
	6	35.8	48.3	70.6	***	3.90	1.82	1.69	***
40 Pass: 1 Frt	4	31.9	47.2	***	***	3.13	1.55	***	***
	5	34.4	52.1	***	***	3.48	1.77	***	***
	6	37.5	58.1	***	***	3.91	2.04	***	***

Number of Trains and Tonnage

Numbers of trains are entered in columns 5 and 6. For the first segment, there are 16 passenger and 16 freight trains. For the second segment there are 16 passenger and 1 freight train. For the third segment there are 16 passenger and 10 freight trains per day. The ratio of passenger to freight trains, which will be used in selecting base cost (see Table 42) is calculated from these numbers and is shown in Column 7 of Table D-1.. Annual gross tonnage, if known, should be entered in column 10. In this example, annual tonnage is not known. In this case, no entry is made in column 10 and the tonnage is calculated from the entered numbers of passenger and freight trains and default gross tonnage of 550 tons and 5,900 tons, respectively.

FRA Track Class

This information is obtained for each segment and entered in Column 8. Two of the segments in this application are FRA Class 4 (79 MPH for passenger trains) and one is Class 6 (110 MPH).

Curvature Factor

Curvature for each of the three segments is obtained from track charts or condensed profiles. A review of data for the example segments indicates that two of the three have "medium" curvature (curve factor of 1.04 per Table 41), while the third has "low" curvature (curve factor of 1.00 per Table 41) .

Maintenance Difficulty Factor (MDF)

For all three of the segments, maintenance difficulty is determined to be "medium" as defined in Table 40. However, noting the differences in total tonnage (column 10), three different values for the Maintenance Difficulty Factor (MDF) are obtained for the three segments. Thus for the highest tonnage segment, segment 1 with an annual tonnage of 38 MGT, the MDF is 1.31. For the second segment, with a low tonnage of 5 MGT, the MDF is 1.23. For the third segment, with an annual tonnage of 25 MGT, the MDF is 1.29. These values are entered in column 11.

Base Case Costs

Base case costs are selected from Table 42 based on the ratio of passenger to freight trains and total annual tonnage.

As can be seen from Table D.1, the base case cost for the first of the three segments is $61,000 per mile, obtained from Table 42 as follows. The closest passenger to freight ratio is 2:1[21], the FRA track class is 4, and the total annual tonnage is greater than 30 MGT, so a cost of $60,800 per track mile is selected. This is then multiplied by the curvature factor and the maintenance difficulty factor to produce the cost per mile in column 13 of Table D.1.

For the second segment, where tonnage is lower, the ratio of passenger to freight is 16:1[22], the annual tonnage is 5 MGT, but track class is still FRA Class 4, so the base cost of $31,900 is selected from Table 42.

The third segment has a 2:1 ratio of passenger to freight, annual MGT of 25, and is FRA Class 6, resulting in the selection of a base case of $53,800 per track mile. A similar process is used to select base case costs per train mile.

Calculation of Costs

With values supplied for all variables, the spreadsheet will calculate a cost per track mile, a cost per train mile, a total track maintenance cost per segment, and a segment cost per train trip. For the example here the total annual route maintenance cost is $5,484,201 and the cost per train trip is $101.74.

[21] While the actual ratio is 1:1, the closest ratio in Table 42 is 2:1,

[22] This ratio of 16;1 is greater than the 10:1 category and less than the 40:1 category. However, to be conservative, the 40:1 category was selected.

Bibliography

American Railway Engineering and Maintenance Association, *Manual for Railway Engineering 2003*, Chapter 16, Part 11, page 16-11-1, 2003, Washington, DC.

Interstate Commerce Commission, Decision, Finance Docket No. 32467, "National Railroad Passenger Corporation and Consolidated Rail Corporation: Application under Section 402(a) of the Rail Passenger Service Act for an order fixing just compensation". Decided December 29, 1995.

Resor, R. R. and Michael E. Smith, "Track Maintenance Costs and Economies of Density: An Analysis of the Speed Factored Gross Tonnage Model" (Award: Best Transportation Costing Paper 1992), **Journal of the Transportation Research Forum,** Volume 33, No. 1, (1993).

Resor, R. R., "Track Maintenance Costing in the Uniform Railway Costing System (URCS): A User Perspective", **Proceedings**, 35th Annual Meeting of the **Transportation Research Forum,** (New York, NY: October 1993).

Resor, R.R., "Meeting the Need for Accurate MOW Costing", **Railway Track and Structures**, August 1994.

Resor, R. R., "Issues in Rail Passenger Service Costing and Operations", **Journal of the Transportation Research Forum,** Volume 35, No.2 (1995).

Resor, R. R. and Thompson, G. L., "Do North American Railroads Understand Their Costs? Implications for Strategic Decision-Making", **Transportation Research Record No. 1653,** (Washington, DC: 1999).

Resor, R, R and Blaze, J. R., "Private Operators, Public Tracks: Equitable Access to Public Railroad Facilities for Private Operators", **Proceedings,** "Passenger Trains on Freight Railroads", sponsored by Railway Age Magazine (Washington, DC 2002).

Resor, R. R. and Patel, P., "Allocating Track Maintenance Costs on Shared Rail Facilities", **Transportation Research Record**, No. 1785, (Washington, DC 2002), Paper No. 02-3812

Zarembski, A. M., "Track Maintenance Costing: Alternative Approaches", **Conference on Maintaining Railway Track; Determining Cost and Allocating Resources,** Arlington, VA, October 1993.

Zarembski, A. M., "Determining the Cost of Track Maintenance", **Railway Track and Structures**, April 1993.

Zarembski, A. M., "Incremental Costs Incurred for Track Maintenance", **Conference on High Speed Trains on Freight Railroads,** Washington, D.C., November 1994.

Appendix A: Analysis of Five Study Line Segments

Calibration

Corridors	Track Miles	Min Track Capital	Max Track Capital	Min B&B Capital	Max B&B Capital	Min C&S Capital	Max C&S Capital	Min Track Operating	Max Track Operating	Min B&B Operating	Max B&B Operating	Min C&S Operating	Max C&S Operating	Min Operating Trk+B&B+ C&S	Max Operating Trk+B&B+ C&S	Min Capital Trk+B&B+ C&S	Max Capital Trk+B&B+C&S
Chicago to Buffington Harbor (Tolleston)	48.50	$ 912,595	$1,569,617	$203,215	$304,629	$121,250	$181,875	$903,289	$1,342,727	$195,306	$292,959	$488,265	$732,397	$1,586,860	$2,368,083	$1,237,060	$2,056,121
Buffington Harbor (Tolleston) to Ft. Wayne (Mike)	152.20	$2,361,123	$4,009,765	$641,908	$962,249	$383,000	$574,500	$2,728,726	$4,056,214	$589,995	$884,992	$1,474,987	$2,212,480	$4,793,708	$7,153,687	$3,386,031	$5,546,514
Delta Junction to Cleveland	188.80	$3,829,920	$ 6,521,862	$791,072	$1,185,853	$472,000	$708,000	$3,430,317	$5,099,120	$741,690	$1,112,535	$1,854,225	$2,781,338	$6,026,232	$8,992,993	$5,092,992	$8,415,715
Madison to Watertown	36.10	$444,797	$629,204	$151,259	$226,744	$90,250	$135,375	$587,525	$873,348	$127,032	$190,549	$317,581	$476,372	$1,032,139	$1,540,269	$686,306	$991,323
Seattle to Portland	384.73	$8,157,984	$15,281,722	$1,508,316	$2,261,034	$899,950	$1,349,925	$6,199,636	$9,215,675	$1,340,462	$2,010,693	$3,351,155	$5,026,732	$10,891,252	$16,253,099	$10,566,250	$18,892,682

Matrix 1

Corridors	Track Miles	Min Track Operating	Max. Track Operating	Min B&B Operating	Max B&B Operating	Min C&S Operating	Max C&S Operating	MinTrack Capital	Max Track Capital	Min B&B Capital	Max B&B Capital	Min C&S Capital	Max C&S Capital	Min Operating Trk+B&B+ C&S	Max Operating Trk+B&B+ C&S	Min Capital Trk+B&B+ C&S	Max-Capital Trk+B&B+ C&S
Chicago to Buffington Harbor (Tolleston)	48.50	$911,688	$1,370,700	$197,537	$299,048	$486,227	$747,655	$983,796	$1,625,874	$203,215	$304,629	$121,250	$181,875	$1,595,451	$2,417,403	$1,308,261	$2,112,378
Buffington Harbor (Tolleston) to Ft. Wayne (Mike)	152.20	$2,966,764	$4,441,973	$642,821	$969,112	$1,582,272	$2,422,871	$2,418,526	$3,849,198	$641,908	$962,249	$383,000	$574,500	$5,191,857	$7,833,955	$3,443,434	$5,385,947
Delta Junction to Cleveland	188.80	$2,307,846	$3,475,016	$500,051	$758,191	$1,230,765	$1,895,483	$3,370,029	$5,283,751	$791,072	$1,185,853	$472,000	$708,000	$4,038,662	$6,128,690	$4,633,101	$7,177,604
Madison to Watertown	36.10	$550,308	$824,366	$119,238	$179,855	$293,493	$449,661	$501,068	$788,496	$151,259	$226,744	$90,250	$135,375	$963,040	$1,453,881	$742,577	$1,150,615
Seattle to Portland	384.73	$4,975,056	$7,536,830	$1,077,854	$1,644,899	$2,653,370	$4,110,810	$9,780,644	$17,176,206	$1,508,316	$2,261,034	$899,950	$1,349,925	$8,706,281	$13,292,539	$12,188,911	$20,787,165

Matrix 2

Appendix B: Handbook Cost Matrices for High Speed Passenger and Mixed Freight Corridors

Track Maintenance Cost per Track Mile Wood (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% - 2%)					Severe Curve (82% - 12% - 6%)			
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
	4	$4,851	$6,069	$8,548	$14,440	**4**	$5,087	$6,365	$8,965	$15,144	**4**	$5,414	$6,775	$9,541	$16,118
Pred. Frght	**5**	$6,243	$7,811	$11,002	$18,584	**5**	$6,547	$8,192	$11,537	$19,490	**5**	$6,968	$8,719	$12,280	$20,743
	6	$8,196	$10,255	$14,444	$24,399	**6**	$8,596	$10,755	$15,147	$25,587	**6**	$9,148	$11,447	$16,122	$27,233
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
Equal Frght	**4**	$6,473	$10,129	$15,816	*	**4**	$6,788	$10,622	$16,586	*	**4**	$7,225	$11,305	$17,653	*
	5	$7,574	$11,850	$18,504	*	**5**	$7,942	$12,428	$19,406	*	**5**	$8,453	$13,227	$20,654	*
	6	$9,827	$15,376	$24,010	*	**6**	$10,306	$16,125	$25,179	*	**6**	$10,968	$17,162	$26,799	*
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
Pred. Pass.	**4**	$7,893	$15,304	*	*	**4**	$8,278	$16,050	*	*	**4**	$8,810	$17,082	*	*
	5	$9,235	$17,906	*	*	**5**	$9,685	$18,778	*	*	**5**	$10,308	$19,986	*	*
	6	$10,814	$20,966	*	*	**6**	$11,341	$21,988	*	*	**6**	$12,070	$23,402	*	*

Matrix 3

Build. and Bridges Maintenance Cost per Track Mile Wood (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% - 2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$1,051	$1,315	$1,852	$3,129	4	$1,102	$1,379	$1,942	$3,281	4	$1,173	$1,468	$2,067	$3,492
Pred. Frght	5	$1,353	$1,692	$2,384	$4,027	5	$1,419	$1,775	$2,500	$4,223	5	$1,510	$1,889	$2,661	$4,494
	6	$1,776	$2,222	$3,129	$5,286	6	$1,862	$2,330	$3,282	$5,544	6	$1,982	$2,480	$3,493	$5,901
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$1,403	$2,195	$3,427	*	4	$1,471	$2,301	$3,594	*	4	$1,565	$2,449	$3,825	*
	5	$1,641	$2,568	$4,009	*	5	$1,721	$2,693	$4,205	*	5	$1,832	$2,866	$4,475	*
	6	$2,129	$3,332	$5,202	*	6	$2,233	$3,494	$5,456	*	6	$2,376	$3,719	$5,806	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$1,710	$3,316	*	*	4	$1,794	$3,477	*	*	4	$1,909	$3,701	*	*
	5	$2,001	$3,880	*	*	5	$2,098	$4,069	*	*	5	$2,233	$4,330	*	*
	6	$2,343	$4,543	*	*	6	$2,457	$4,764	*	*	6	$2,615	$5,070	*	*

Matrix 4

Comm. and Signal Maintenance Cost per Track Mile – Wood (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$2,587	$3,237	$4,559	$7,701	**4**	$2,713	$3,395	$4,781	$8,077	**4**	$2,888	$3,613	$5,089	$8,596
Pred. Frght	**5**	$3,330	$4,166	$5,867	$9,912	**5**	$3,492	$4,369	$6,153	$10,394	**5**	$3,716	$4,650	$6,549	$11,063
	6	$4,371	$5,469	$7,703	$13,013	**6**	$4,584	$5,736	$8,079	$13,647	**6**	$4,879	$6,105	$8,598	$14,524
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	**4**	$3,452	$5,402	$8,435	*	**4**	$3,621	$5,665	$8,846	*	**4**	$3,853	$6,029	$9,415	*
	5	$4,039	$6,320	$9,869	*	**5**	$4,236	$6,628	$10,350	*	**5**	$4,508	$7,054	$11,015	*
	6	$5,241	$8,201	$12,805	*	**6**	$5,496	$8,600	$13,429	*	**6**	$5,850	$9,153	$14,293	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	**4**	$4,210	$8,162	*	*	**4**	$4,415	$8,560	*	*	**4**	$4,699	$9,110	*	*
	5	$4,925	$9,550	*	*	**5**	$5,165	$10,015	*	*	**5**	$5,498	$10,659	*	*
	6	$5,767	$11,182	*	*	**6**	$6,048	$11,727	*	*	**6**	$6,437	$12,481	*	*

Matrix 5

Track Maintenance Cost per Track Mile – Wood (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
	4	$7,349	$9,195	$12,950	$21,876	**4**	$7,707	$9,643	$13,581	$22,942	**4**	$8,202	$10,263	$14,454	$24,417
Pred. Frght	**5**	$9,295	$11,630	$16,380	$27,670	**5**	$9,748	$12,197	$17,178	$29,018	**5**	$10,375	$12,981	$18,283	$30,884
	6	$12,244	$15,321	$21,578	$36,450	**6**	$12,841	$16,067	$22,629	$38,226	**6**	$13,667	$17,100	$24,084	$40,684
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
Equal Frght	**4**	$9,670	$15,131	$23,627	*	**4**	$10,141	$15,868	$24,778	*	**4**	$10,794	$16,889	$26,372	*
	5	$11,314	$17,703	$27,644	*	**5**	$11,865	$18,566	$28,990	*	**5**	$12,629	$19,760	$30,855	*
	6	$14,720	$23,033	$35,966	*	**6**	$15,437	$24,155	$37,718	*	**6**	$16,430	$25,709	$40,144	*
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
Pred. Pass.	**4**	$11,824	$22,925	*	*	**4**	$12,400	$24,042	*	*	**4**	$13,197	$25,588	*	*
	5	$13,834	$26,822	*	*	**5**	$14,508	$28,129	*	*	**5**	$15,441	$29,938	*	*
	6	$16,199	$31,407	*	*	**6**	$16,988	$32,937	*	*	**6**	$18,080	$35,056	*	*

Matrix 6

Build. and Bridges Maintenance Cost per Track Mile – Wood (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$1,603	$2,006	$2,825	$4,773	4	$1,681	$2,104	$2,963	$5,005	4	$1,790	$2,239	$3,154	$5,327
Pred. Frght	5	$2,028	$2,538	$3,574	$6,037	5	$2,127	$2,661	$3,748	$6,331	5	$2,264	$2,832	$3,989	$6,738
	6	$2,672	$3,343	$4,708	$7,953	6	$2,802	$3,506	$4,937	$8,340	6	$2,982	$3,731	$5,255	$8,877
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$2,110	$3,301	$5,155	*	4	$2,213	$3,462	$5,406	*	4	$2,355	$3,685	$5,754	*
	5	$2,469	$3,863	$6,031	*	5	$2,589	$4,051	$6,325	*	5	$2,755	$4,311	$6,732	*
	6	$3,212	$5,025	$7,847	*	6	$3,368	$5,270	$8,229	*	6	$3,585	$5,609	$8,759	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$2,580	$5,002	*	*	4	$2,705	$5,245	*	*	4	$2,879	$5,583	*	*
	5	$3,018	$5,852	*	*	5	$3,165	$6,137	*	*	5	$3,369	$6,532	*	*
	6	$3,534	$6,852	*	*	6	$3,706	$7,186	*	*	6	$3,945	$7,649	*	*

Matrix 7

C&S Main. Cost per Track Mile – Wood (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$4,008	$5,015	$7,064	$11,932	4	$4,204	$5,260	$7,408	$12,514	4	$4,474	$5,598	$7,884	$13,318
Pred. Frght	5	$5,070	$6,344	$8,935	$15,093	5	$5,317	$6,653	$9,370	$15,828	5	$5,659	$7,081	$9,973	$16,846
	6	$6,679	$8,357	$11,770	$19,882	6	$7,004	$8,764	$12,343	$20,850	6	$7,455	$9,327	$13,137	$22,191
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$5,275	$8,253	$12,887	*	4	$5,532	$8,655	$13,515	*	4	$5,887	$9,212	$14,385	*
	5	$6,171	$9,656	$15,078	*	5	$6,472	$10,127	$15,813	*	5	$6,888	$10,778	$16,830	*
	6	$8,029	$12,563	$19,618	*	6	$8,420	$13,176	$20,573	*	6	$8,962	$14,023	$21,897	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$6,449	$12,504	*	*	4	$6,764	$13,114	*	*	4	$7,199	$13,957	*	*
	5	$7,546	$14,630	*	*	5	$7,913	$15,343	*	*	5	$8,422	$16,330	*	*
	6	$8,836	$17,131	*	*	6	$9,266	$17,966	*	*	6	$9,862	$19,121	*	*

Track Cyclic Capital Cost per Track Mile – Wood (Minimum)

	Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%					Severe Curve (82% - 12% - 6%)			
	5	15	30	50		5	15	30	50		5	15	30	50
4	$10,709	$13,067	$19,692	$28,207	4	$10,848	$13,512	$20,415	$29,278	4	$11,087	$14,291	$21,709	$31,221
5	$10,890	$13,382	$20,207	$28,899	5	$11,032	$13,830	$20,937	$29,978	5	$11,275	$14,616	$22,241	$31,934
6	$11,262	$14,026	$21,200	$30,211	6	$11,409	$14,484	$21,942	$31,307	6	$11,660	$15,284	$23,266	$33,289

Build. and Bridges Cyclical Capital Cost per Track Mile Wood (Minimum)

Bridge Capital Cost				
Average Feet/Mile	Cost/feet	$/Mile	Life in years	$/Mile/Year
83.75	4000	$335,000	80	$4,190

Comm. and Signal Capital Cost per Track Mile – Wood (Minimum)

Signal Capital Cost		
$/Mile	**Life in years**	**$/Mile/Year**
$200,000	80	$2,500
$ 20,000[23]	30	$ 667
$220,000		$3,167

[23] Based on 0.4 turnouts per mile at $50,000 per turnout.

Track Cyclic Capital Cost per Track Mile – Wood (Maximum)

	Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
4	$14,756	$20,259	$32,700	$48,052	**4**	$15,009	$21,245	$34,481	$50,864	**4**	$15,489	$22,954	$37,588	$55,790
5	$14,765	$20,789	$33,502	$49,157	**5**	$15,032	$21,781	$35,292	$51,981	**5**	$15,535	$23,499	$38,413	$56,924
6	$15,223	$21,879	$35,106	$51,305	**6**	$15,506	$22,886	$36,916	$54,155	**6**	$16,030	$24,626	$40,066	$59,137

Build. and Bridges Cyclic Capital Cost per Track Mile – Wood (Maximum)

Bridge Capital Cost				
Average Feet/Mile	**Cost/feet**	**$/Mile**	**Life in years**	**$/Mile/Year**
Wood+Steel+Stone				
83.75	6000	$502,500	80	$6,281

Comm. and Signal Cyclic Capital Cost per Track Mile Wood (Maximum)

Signal Capital Cost		
$/Mile	**Life in years**	**$/Mile/Year**
$300,000	80	$3,750
$ 20,000[24]	20	$ 1,000
$320,000		$4,750

[24] Based on 0.4 turnouts per mile at $50,000 per turnout.

Total Maintenance Cost per Track Mile – Wood (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$8,489	$10,621	$14,959	$25,270	4	$8,902	$11,139	$15,688	$26,501	4	$9,475	$11,855	$16,697	$28,206
Pred. Frght	5	$10,925	$13,670	$19,253	$32,523	5	$11,457	$14,336	$20,191	$34,107	5	$12,194	$15,258	$21,489	$36,301
	6	$14,343	$17,947	$25,276	$42,698	6	$15,042	$18,821	$26,508	$44,778	6	$16,010	$20,032	$28,213	$47,658
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$11,328	$17,725	$27,677	*	4	$11,880	$18,588	$29,025	*	4	$12,644	$19,784	$30,892	*
	5	$13,254	$20,738	$32,382	*	5	$13,899	$21,748	$33,960	*	5	$14,793	$23,147	$36,144	*
	6	$17,197	$26,908	$42,017	*	6	$18,035	$28,219	$44,064	*	6	$19,195	$30,034	$46,898	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$13,813	$26,782	*	*	4	$14,486	$28,087	*	*	4	$15,418	$29,893	*	*
	5	$16,161	$31,335	*	*	5	$16,949	$32,861	*	*	5	$18,039	$34,975	*	*
	6	$18,924	$36,691	*	*	6	$19,846	$38,479	*	*	6	$21,122	$40,954	*	*

Matrix 15

Total Cyclic Capital Cost per Track Mile – Wood (Minimum)

	Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
4	$18,065	$20,424	$27,048	$35,563	**4**	$18,205	$20,868	$27,771	$36,634	**4**	$18,443	$21,647	$29,066	$38,578
5	$18,247	$20,738	$27,564	$36,255	**5**	$18,389	$21,187	$28,293	$37,335	**5**	$18,631	$21,973	$29,597	$39,291
6	$18,619	$21,383	$28,556	$37,567	**6**	$18,766	$21,841	$29,299	$38,664	**6**	$19,017	$22,640	$30,623	$40,645

Matrix 16

Total Maintenance Cost per Track Mile – Wood (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
	4	$12,960	$16,216	$22,839	$38,581	**4**	$13,592	$17,006	$23,952	$40,461	**4**	$14,466	$18,100	$25,492	$43,063
Pred. Frght.	**5**	$16,393	$20,511	$28,888	$48,800	**5**	$17,192	$21,511	$30,296	$51,177	**5**	$18,298	$22,894	$32,244	$54,469
	6	$21,595	$27,020	$38,055	$64,284	**6**	$22,647	$28,336	$39,909	$67,416	**6**	$24,103	$30,159	$42,476	$71,752
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
Equal Frght.	**4**	$17,055	$26,686	$41,670	*	**4**	$17,886	$27,986	$43,700	*	**4**	$19,036	$29,786	$46,510	*
	5	$19,954	$31,223	$48,753	*	**5**	$20,926	$32,744	$51,129	*	**5**	$22,272	$34,850	$54,417	*
	6	$25,961	$40,622	$63,430	*	**6**	$27,226	$42,601	$66,520	*	**6**	$28,977	$45,341	$70,799	*
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
Pred. Pass.	**4**	$20,853	$40,431	*	*	**4**	$21,869	$42,401	*	*	**4**	$23,275	$45,128	*	*
	5	$24,398	$47,304	*	*	**5**	$25,586	$49,609	*	*	**5**	$27,232	$52,800	*	*
	6	$28,568	$55,391	*	*	**6**	$29,960	$58,089	*	*	**6**	$31,887	$61,826	*	*

Matrix 17

Total Cyclic Capital Cost per Track Mile – Wood (Maximum)

	Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
4	$25,787	$31,290	$43,731	$59,083	**4**	$26,040	$32,276	$45,512	$61,896	**4**	$26,520	$33,985	$48,619	$66,821
5	$25,796	$31,820	$44,534	$60,188	**5**	$26,064	$32,812	$46,323	$63,012	**5**	$26,567	$34,531	$49,444	$67,955
6	$26,254	$32,910	$46,137	$62,337	**6**	$26,537	$33,917	$47,947	$65,186	**6**	$27,061	$35,657	$51,098	$70,168

Matrix 18

Total Cost per Track Mile – Wood (Minimum) - Maintenance + Cyclic Capital

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$26,554	$31,046	$42,008	$60,833	4	$27,107	$32,007	$43,460	$63,136	4	$27,918	$33,503	$45,763	$66,784
Pred. Frght	5	$29,172	$34,408	$46,816	$68,778	5	$29,846	$35,523	$48,484	$71,442	5	$30,826	$37,231	$51,086	$75,592
	6	$32,962	$39,329	$53,833	$80,265	6	$33,808	$40,662	$55,807	$83,442	6	$35,026	$42,672	$58,836	$88,304
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$29,393	$38,149	$54,725	*	4	$30,084	$39,457	$56,797	*	4	$31,087	$41,431	$59,958	*
	5	$31,500	$41,476	$59,946	*	5	$32,288	$42,935	$62,253	*	5	$33,425	$45,120	$65,741	*
	6	$35,816	$48,291	$70,573	*	6	$36,801	$50,060	$73,363	*	6	$38,211	$52,675	$77,521	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$31,879	$47,206	*	*	4	$32,691	$48,955	*	*	4	$33,861	$51,540	*	*
	5	$34,408	$52,073	*	*	5	$35,337	$54,049	*	*	5	$36,670	$56,948	*	*
	6	$37,543	$58,074	*	*	6	$38,612	$60,319	*	*	6	$40,139	$63,594	*	*

Matrix 19

Total Cost per Track Mile – Wood (Maximum) – Maintenance + Cyclic Capital

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$38,748	$47,507	$66,570	$97,664	4	$39,632	$49,283	$69,464	$102,356	4	$40,986	$52,085	$74,111	$109,884
Pred. Frght	5	$42,189	$52,331	$73,422	$108,988	5	$43,255	$54,323	$76,619	$114,189	5	$44,864	$57,425	$81,688	$122,424
	6	$47,849	$59,930	$84,192	$126,621	6	$49,184	$62,253	$87,856	$132,603	6	$51,165	$65,816	$93,574	$141,921
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$42,842	$57,976	$85,400	*	4	$43,926	$60,262	$89,212	*	4	$45,557	$63,771	$95,129	*
	5	$45,750	$63,042	$93,287	*	5	$46,990	$65,556	$97,452	*	5	$48,839	$69,380	$103,861	*
	6	$52,215	$73,532	$109,567	*	6	$53,763	$76,518	$114,467	*	6	$56,039	$80,998	$121,897	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$46,640	$71,721	*	*	4	$47,909	$74,677	*	*	4	$49,796	$79,113	*	*
	5	$50,194	$79,124	*	*	5	$51,650	$82,421	*	*	5	$53,799	$87,331	*	*
	6	$54,822	$88,301	*	*	6	$56,497	$92,006	*	*	6	$58,949	$97,482	*	*

Matrix 20

Track Maintenance Cost per Track Mile Concrete (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
	4	$4,809	$6,017	$8,475	$14,316	**4**	$4,978	$6,229	$8,772	$14,819	**4**	$5,212	$6,521	$9,184	$15,515
Pred. Frght	**5**	$6,189	$7,744	$10,907	$18,425	**5**	$6,407	$8,016	$11,290	$19,072	**5**	$6,708	$8,393	$11,820	$19,967
	6	$8,126	$10,167	$14,320	$24,190	**6**	$8,411	$10,524	$14,822	$25,039	**6**	$8,806	$11,018	$15,518	$26,214
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
Equal Frght	**4**	$6,418	$10,042	$15,680	*	**4**	$6,643	$10,394	$16,230	*	**4**	$6,955	$10,882	$16,992	*
	5	$7,509	$11,749	$18,346	*	**5**	$7,772	$12,161	$18,990	*	**5**	$8,137	$12,732	$19,881	*
	6	$9,743	$15,244	$23,804	*	**6**	$10,085	$15,780	$24,639	*	**6**	$10,558	$16,520	$25,796	*
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
Pred. Pass.	**4**	$7,826	$15,050	*	*	**4**	$8,100	$15,578	*	*	**4**	$8,481	$16,310	*	*
	5	$9,156	$17,609	*	*	**5**	$9,477	$18,227	*	*	**5**	$9,922	$19,083	*	*
	6	$10,721	$20,619	*	*	**6**	$11,097	$21,342	*	*	**6**	$11,618	$22,345	*	*

Matrix 21

Build. and Bridges Maintenance Cost per Track Mile Concrete (Minimum)

		Light Curve (96% - 4% - 0%					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$1,042	$1,304	$1,836	$3,102	4	$1,079	$1,350	$1,901	$3,211	4	$1,129	$1,413	$1,990	$3,361
Pred. Frght	5	$1,341	$1,678	$2,363	$3,992	5	$1,388	$1,737	$2,446	$4,132	5	$1,453	$1,818	$2,561	$4,326
	6	$1,761	$2,203	$3,103	$5,241	6	$1,822	$2,280	$3,212	$5,425	6	$1,908	$2,387	$3,362	$5,680
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$1,390	$2,176	$3,397	*	4	$1,439	$2,252	$3,517	*	4	$1,507	$2,358	$3,682	*
	5	$1,627	$2,546	$3,975	*	5	$1,684	$2,635	$4,114	*	5	$1,763	$2,759	$4,308	*
	6	$2,111	$3,303	$5,158	*	6	$2,185	$3,419	$5,339	*	6	$2,288	$3,579	$5,589	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$1,696	$3,261		*	4	$1,755	$3,375	*	*	4	$1,837	$3,534	*	*
	5	$1,984	$3,815	*	*	5	$2,053	$3,949	*	*	5	$2,150	$4,135	*	*
	6	$2,323	$4,467	*	*	6	$2,404	$4,624	*	*	6	$2,517	$4,841	*	*

Matrix 22

Comm. and Signal Maintenance Cost per Track Mile Concrete (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$2,565	$3,209	$4,520	$7,635	4	$2,655	$3,322	$4,679	$7,903	4	$2,780	$3,478	$4,898	$8,274
Pred. Frght	5	$3,301	$4,130	$5,817	$9,827	5	$3,417	$4,275	$6,021	$10,172	5	$3,577	$4,476	$6,304	$10,649
	6	$4,334	$5,423	$7,637	$12,901	6	$4,486	$5,613	$7,905	$13,354	6	$4,697	$5,877	$8,276	$13,981
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$3,423	$5,356	$8,363	*	4	$3,543	$5,544	$8,656	*	4	$3,709	$5,804	$9,063	*
	5	$4,005	$6,266	$9,784	*	5	$4,145	$6,486	$10,128	*	5	$4,340	$6,791	$10,603	*
	6	$5,196	$8,130	$12,695	*	6	$5,378	$8,416	$13,141	*	6	$5,631	$8,811	$13,758	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$4,174	$8,027	*	*	4	$4,320	$8,309	*	*	4	$4,523	$8,699	*	*
	5	$4,883	$9,391	*	*	5	$5,055	$9,721	*	*	5	$5,292	$10,177	*	*
	6	$5,718	$10,997	*	*	6	$5,919	$11,383	*	*	6	$6,196	$11,917	*	*

Matrix 23

Track Maintenance Cost per Track Mile Concrete (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$7,286	$9,116	$12,839	$21,688	4	$7,541	$9,436	$13,290	$22,450	4	$7,896	$9,879	$13,914	$23,504
Pred. Frght	5	$9,215	$11,531	$16,240	$27,433	5	$9,539	$11,935	$16,810	$28,396	5	$9,987	$12,496	$17,599	$29,729
	6	$12,140	$15,189	$21,393	$36,138	6	$12,566	$15,722	$22,144	$37,406	6	$13,156	$16,461	$23,183	$39,162
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$9,587	$15,002	$23,425	*	4	$9,924	$15,528	$24,247	*	4	$10,390	$16,257	$25,385	*
	5	$11,217	$17,552	$27,407	*	5	$11,611	$18,168	$28,369	*	5	$12,156	$19,021	$29,701	*
	6	$14,594	$22,836	$36,658	*	6	$15,106	$23,637	$36,909	*	6	$15,816	$24,747	$38,642	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$11,723	$22,545	*	*	4	$12,134	$23,336	*	*	4	$12,704	$24,432	*	*
	5	$13,715	$26,377	*	*	5	$14,197	$27,303	*	*	5	$14,863	$28,585	*	*
	6	$16,060	$30,886	*	*	6	$16,624	$31,970	*	*	6	$17,404	$33,471	*	*

Build. and Bridges Maintenance Cost per Track Mile Concrete (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$1,590	$1,989	$2,801	$4,732	4	$1,645	$2,059	$2,900	$4,898	4	$2,328	$2,913	$4,102	$6,930
Pred. Frght	5	$2,011	$2,516	$3,543	$5,985	5	$2,081	$2,604	$3,668	$6,195	5	$2,724	$3,408	$4,800	$8,108
	6	$2,649	$3,314	$4,668	$7,885	6	$2,742	$3,430	$4,831	$8,161	6	$3,189	$3,990	$5,620	$9,494
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$2,092	$3,273	$5,111	*	4	$2,165	$3,388	$5,290	*	4	$2,519	$3,941	$6,154	*
	5	$2,447	$3,829	$5,980	*	5	$2,533	$3,964	$6,190	*	5	$2,947	$4,611	$7,200	*
	6	$3,184	$4,982	$7,780	*	6	$3,296	$5,157	$8,053	*	6	$3,451	$5,399	$8,431	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$2,558	$4,919	*	*	4	$2,647	$5,091	*	*	4	$2,772	$5,331	*	*
	5	$2,992	$5,755	*	*	5	$3,097	$5,957	*	*	5	$3,243	$6,237	*	*
	6	$3,504	$6,739	*	*	6	$3,627	$6,975	*	*	6	$3,797	$7,303	*	*

Matrix 25

Comm. and Signal Maintenance Cost per Track Mile Concrete (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$3,974	$4,972	$7,003	$11,830	4	$4,114	$5,147	$7,249	$12,245	4	$4,307	$5,389	$7,589	$12,820
Pred. Frght	5	$5,027	$6,289	$8,858	$14,963	5	$5,203	$6,510	$9,169	$15,489	5	$5,447	$6,816	$9,599	$16,216
	6	$6,622	$8,285	$11,669	$19,711	6	$6,854	$8,576	$12,078	$20,403	6	$7,176	$8,979	$12,645	$21,361
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$5,230	$8,183	$12,777	*	4	$5,413	$8,470	$13,226	*	4	$5,667	$8,868	$13,847	*
	5	$6,119	$9,574	$14,949	*	5	$6,333	$9,910	$15,474	*	5	$6,631	$10,375	$16,200	*
	6	$7,960	$12,456	$19,450	*	6	$8,240	$12,893	$20,132	*	6	$8,627	$13,498	$21,077	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$6,394	$12,297	*	*	4	$6,619	$12,729	*	*	4	$6,929	$13,326	*	*
	5	$7,481	$14,388	*	*	5	$7,744	$14,893	*	*	5	$8,107	$15,592	*	*
	6	$8,760	$16,847	*	*	6	$9,067	$17,438	*	*	6	$9,493	$18,257	*	*

Matrix 26

Track Cyclic Capital Cost per Track Mile Concrete (Minimum)

	Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
4	$11,229	$12,921	$18,189	$25,808	4	$11,368	$13,365	$18,913	$26,879	4	$11,607	$14,144	$20,207	$28,823
5	$11,410	$13,235	$18,705	$26,500	5	$11,552	$13,684	$19,434	$27,580	5	$11,795	$14,470	$20,738	$29,536
6	$11,782	$13,880	$19,697	$27,812	6	$11,929	$14,338	$21,764	$28,908	6	$12,180	$15,137	$21,764	$30,890

Matrix 27

Build. and Bridges Cyclic Capital Cost per Track Mile Concrete (Minimum)

Bridge Capital Cost				
Average Feet/Mile	**Cost/feet**	**$/Mile**	**Life in years**	**$/Mile/Year**
83.75	4000	$335,000	80	$4,190

Comm. & Signal Cyclic Capital Cost per Track Mile Concrete (Minimum)

Signal Capital Cost		
$/Mile	**Life in years**	**$/Mile/Year**
$200,000	80	$2,500
$20,000[25]	30	$ 667
$220,000		$3,167

[25] Based on 0.4 turnouts per mile at $50,000 per turnout.

Track Cyclic Capital Cost per Track Mile Concrete (Maximum)

	Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
4	$14,506	$20,222	$31,398	$45,578	**4**	$14,758	$21,208	$33,179	$48,391	**4**	$15,239	$22,917	$36,286	$53,316
5	$14,514	$20,751	$32,200	$46,683	**5**	$14,782	$21,744	$33,990	$49,507	**5**	$15,285	$23,462	$37,111	$54,450
6	$14,972	$21,842	$33,804	$48,832	**6**	$15,255	$22,848	$36,916	$51,681	**6**	$15,780	$24,588	$38,764	$56,663

Matrix 30

Build. and Bridges Cyclic Capital Cost per Track Mile Concrete (Maximum)

Bridge Capital Cost				
Average Feet/Mile	**Cost/feet**	**$/Mile**	**Life in years**	**$/Mile/Year**
83.75	6000	$502,500	80	$6,281

Comm. and Signal Cyclic Capital Cost per Track Mile Concrete (Maximum)

Signal Capital Cost		
$/Mile	**Life in years**	**$/Mile/Year**
$300,000	80	$3,750
$20,000[26]	20	$1,000
$320,000		$4,750

[26] Based on 0.4 turnouts per mile at $50,000 per turnout.

Total Maintenance Cost per Track Mile Concrete (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$8,416	$10,531	$14,831	$25,054	4	$8,712	$10,900	$15,352	$25,933	4	$9,121	$11,412	$16,073	$27,150
Pred. Frght	5	$10,832	$13,553	$19,088	$32,244	5	$11,212	$14,028	$19,758	$33,376	5	$11,738	$14,687	$20,685	$34,943
	6	$14,221	$17,793	$25,060	$42,332	6	$14,720	$18,418	$25,939	$43,818	6	$15,411	$19,282	$27,157	$45,875
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$11,231	$17,573	$27,440	*	4	$11,625	$18,190	$28,403	*	4	$12,171	$19,044	$29,737	*
	5	$13,140	$20,560	$32,105	*	5	$13,601	$21,282	$33,232	*	5	$14,240	$22,281	$34,792	*
	6	$17,050	$26,678	$41,657	*	6	$17,648	$27,614	$43,119	*	6	$18,477	$28,911	$45,144	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$13,695	$26,338	*	*	4	$14,175	$27,262	*	*	4	$14,841	$28,542	*	*
	5	$16,023	$30,815	*	*	5	$16,585	$31,897	*	*	5	$17,364	$33,394	*	*
	6	$18,762	$36,083	*	*	6	$19,420	$37,349	*	*	6	$20,332	$39,103	*	*

Matrix 33

Total Cyclic Capital Cost per Track Mile Concrete (Minimum))

	Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
4	$18,585	$20,278	$25,546	$33,165	**4**	$18,725	$20,722	$26,269	$34,236	**4**	$18,963	$21,501	$27,564	$36,179
5	$18,767	$20,592	$26,061	$33,857	**5**	$18,909	$21,041	$26,791	$34,936	**5**	$19,151	$21,826	$28,095	$36,892
6	$19,139	$21,236	$27,054	$35,169	**6**	$19,286	$21,694	$29,121	$36,265	**6**	$19,537	$22,494	$29,121	$38,247

Matrix 34

Total Maintenance Cost per Track Mile Concrete (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$12,849	$16,077	$22,644	$38,251	4	$13,300	$16,642	$23,438	$39,593	4	$14,530	$18,180	$25,605	$43,254
Pred. Frght.	5	$16,253	$20,336	$28,641	$48,382	5	$16,823	$21,050	$29,646	$50,080	5	$18,158	$22,719	$31,998	$54,053
	6	$21,410	$26,789	$37,729	$63,734	6	$22,161	$27,729	$39,053	$65,971	6	$23,521	$29,430	$41,449	$70,017
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght.	4	$16,909	$26,457	$41,313	*	4	$17,502	$27,386	$42,763	*	4	$18,576	$29,066	$45,386	*
	5	$19,783	$30,955	$48,336	*	5	$20,478	$32,042	$50,032	*	5	$21,734	$34,007	$53,101	*
	6	$25,739	$40,274	$62,887	*	6	$26,642	$41,687	$65,094	*	6	$27,893	$43,645	$68,150	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$20,674	$39,761	*	*	4	$21,400	$41,156	*	*	4	$22,405	$43,089	*	*
	5	$24,189	$46,520	*	*	5	$25,038	$48,153	*	*	5	$26,213	$50,414	*	*
	6	$28,324	$54,472	*	*	6	$29,318	$56,384	*	*	6	$30,694	$59,031	*	*

Matrix 35

Total Cyclic Capital Cost per Track Mile Concrete (Maximum)

	Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
4	$25,537	$31,253	$42,429	$56,609	**4**	$25,789	$32,239	$44,210	$59,422	**4**	$26,270	$33,948	$47,317	$64,347
5	$25,546	$31,783	$43,232	$57,714	**5**	$25,813	$32,775	$45,021	$60,538	**5**	$26,316	$34,493	$48,142	$65,481
6	$26,004	$32,873	$44,835	$59,863	**6**	$26,286	$33,880	$47,947	$62,712	**6**	$26,811	$35,620	$49,796	$67,695

Matrix 36

Total Cost per Track Mile Concrete (Minimum) – Maintenance + Cyclic Capital

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
	4	$27,002	$30,808	$40,377	$58,218	**4**	$27,436	$31,622	$41,621	$60,169	**4**	$28,084	$32,913	$43,636	$63,330
Pred. Frght	**5**	$29,598	$34,145	$45,149	$66,101	**5**	$30,120	$35,069	$46,549	$68,312	**5**	$30,889	$36,514	$48,780	$71,835
	6	$33,359	$39,029	$52,114	$77,501	**6**	$34,006	$40,112	$55,060	$80,083	**6**	$34,947	$41,776	$56,278	$84,122
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
Equal Frght	**4**	$29,816	$37,851	$52,986	*	**4**	$30,350	$38,912	$54,672	*	**4**	$31,134	$40,545	$57,300	*
	5	$31,907	$41,152	$58,166	*	**5**	$32,510	$43,323	$60,023	*	**5**	$33,391	$44,108	$62,887	*
	6	$36,189	$47,914	$68,711	*	**6**	$36,934	$49,309	$72,240	*	**6**	$38,013	$51,405	$74,264	*
		<=5	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**		**<=5**	**5-15**	**15-30**	**>=30**
Pred. Pass.	**4**	$32,280	$46,616	*	*	**4**	$32,900	$47,984	*	*	**4**	$33,804	$50,043	*	*
	5	$34,790	$51,407	*	*	**5**	$35,494	$52,938	*	*	**5**	$36,515	$55,221	*	*
	6	$37,901	$57,319	*	*	**6**	$38,706	$59,044	*	*	**6**	$39,869	$61,597	*	*

Matrix 37

Total Cost per Track Mile Concrete (Maximum) – Maintenance + Cyclic Capital

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
	4	$38,387	$47,330	$65,072	$94,860	4	$39,090	$48,881	$67,648	$99,015	4	$40,800	$52,128	$72,922	$107,601
Pred. Frght	5	$41,798	$52,118	$71,872	$106,096	5	$42,636	$53,825	$74,668	$110,618	5	$44,474	$57,213	$80,140	$119,534
	6	$47,413	$59,662	$82,564	$123,596	6	$48,448	$61,608	$87,000	$128,683	6	$50,332	$65,049	$91,245	$137,712
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Equal Frght	4	$42,446	$57,710	$83,742	*	4	$43,292	$59,625	$86,973	*	4	$44,846	$63,014	$92,703	*
	5	$45,329	$62,738	$91,567	*	5	$46,291	$64,817	$95,054	*	5	$48,050	$68,500	$101,243	*
	6	$51,743	$73,147	$107,722	*	6	$52,929	$75,567	$113,041	*	6	$54,704	$79,264	$117,946	*
		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$46,211	$71,014	*	*	4	$47,189	$73,395	*	*	4	$48,675	$77,036	*	*
	5	$49,734	$78,303	*	*	5	$50,851	$80,928	*	*	5	$52,530	$84,907	*	*
	6	$54,327	$87,345	*	*	6	$55,604	$90,264	*	*	6	$57,505	$94,651	*	*

Matrix 38

Appendix C: Handbook Cost Matrices for High Speed Passenger and Mixed Freight Corridors -- Cost per Passenger Train Mile

Total Maintenance Cost per Passenger Train Mile Wood (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$0.63	$0.26	$0.19	$0.19	4	$0.66	$0.28	$0.19	$0.20	4	$0.70	$0.29	$0.21	$0.21
Pred. Frght	5	$1.97	$0.82	$0.58	$0.59	5	$2.07	$0.86	$0.61	$0.62	5	$2.20	$0.92	$0.65	$0.65
(80% Frght. 20% Pass.)	6	$3.85	$1.61	$1.13	$1.15	6	$4.04	$1.68	$1.19	$1.20	6	$4.30	$1.79	$1.26	$1.28
	No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	4	$0.96	$0.50	$0.49	*	4	$1.01	$0.52	$0.51	*	4	$1.07	$0.56	$0.54	*
(50% Frght. 50% Pass.)	5	$1.38	$0.72	$0.70	*	5	$1.45	$0.76	$0.74	*	5	$1.54	$0.80	$0.79	*
	6	$2.25	$1.17	$1.15	*	6	$2.36	$1.23	$1.20	*	6	$2.51	$1.31	$1.28	*
	No. of Pass. Train	20	60				20	60				20	60		
	Trk Class/MGT	<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30		<=5	5-15	15-30	>=30
Pred. Pass.	4	$1.36	$0.88	*	*	4	$1.42	$0.92	*	*	4	$1.51	$0.98	*	*
(20% Frght. 80% Pass.)	5	$1.68	$1.09	*	*	5	$1.76	$1.14	*	*	5	$1.87	$1.21	*	*
	6	$2.06	$1.33	*	*	6	$2.16	$1.40	*	*	6	$2.30	$1.49	*	*

Matrix 39

Total Cyclic Capital Cost per Passenger Train Mile – Wood (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$1.34	$0.51	$0.34	$0.26	4	$1.35	$0.52	$0.34	$0.27	4	$1.37	$0.54	$0.36	$0.29
Pred. Frght	5	$1.44	$0.56	$0.38	$0.30	5	$1.45	$0.58	$0.39	$0.31	5	$1.47	$0.60	$0.41	$0.33
(80% Frght. 20% Pass.)	6	$1.65	$0.68	$0.47	$0.37	6	$1.66	$0.70	$0.48	$0.38	6	$1.69	$0.72	$0.50	$0.40
	No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	4	$1.53	$0.58	$0.48	*	4	$1.54	$0.59	$0.49	*	4	$1.56	$0.61	$0.51	*
(50% Frght. 50% Pass.)	5	$1.57	$0.60	$0.50	*	5	$1.58	$0.61	$0.51	*	5	$1.60	$0.63	$0.54	*
	6	$1.65	$0.65	$0.55	*	6	$1.66	$0.66	$0.56	*	6	$1.69	$0.68	$0.58	*
	No. of Pass. Train	20	60			No. of Pass. Train	20	60			No. of Pass. Train	20	60		
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Pred. Pass.	4	$1.77	$0.67	*	*	4	$1.79	$0.68	*	*	4	$1.81	$0.71	*	*
(20% Frght. 80% Pass.)	5	$1.80	$0.68	*	*	5	$1.81	$0.70	*	*	5	$1.84	$0.72	*	*
	6	$1.85	$0.71	*	*	6	$1.87	$0.73	*	*	6	$1.89	$0.75	*	*

Matrix 40

Total Maintenance Cost per Passenger Train Mile Wood (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$0.96	$0.40	$0.28	$0.39	4	$1.01	$0.42	$0.30	$0.30	4	$1.08	$0.45	$0.32	$0.32
Pred. Frght	5	$2.85	$1.19	$0.84	$0.85	5	$2.99	$1.25	$0.88	$0.89	5	$3.18	$1.33	$0.93	$0.95
(80% Frght. 20% Pass.)	6	$5.71	$2.38	$1.68	$1.70	6	$5.99	$2.50	$1.76	$1.78	6	$6.38	$2.66	$1.87	$1.90
	No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	4	$1.44	$0.75	$0.73	*	4	$1.51	$0.79	$0.77	*	4	$1.61	$0.84	$0.82	*
(50% Frght. 50% Pass.)	5	$2.08	$1.09	$1.06	*	5	$2.18	$1.14	$1.11	*	5	$2.32	$1.21	$1.18	*
	6	$3.40	$1.77	$1.73	*	6	$3.57	$1.86	$1.82	*	6	$3.80	$1.98	$1.93	*
	No. of Pass. Train	20	60			No. of Pass. Train	20	60			No. of Pass. Train	20	60		
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Pred. Pass.	4	$2.05	$1.32	*	*	4	$2.15	$1.39	*	*	4	$2.29	$1.48	*	*
(20% Frght. 80% Pass.)	5	$2.54	$1.64	*	*	5	$2.66	$1.72	*	*	5	$2.83	$1.83	*	*
	6	$3.11	$2.01	*	*	6	$3.26	$2.11	*	*	6	$3.47	$2.24	*	*

Total Cyclic Capital Cost per Passenger Train Mile Wood (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$1.92	$0.78	$0.54	$0.44	4	$1.94	$0.80	$0.56	$0.46	4	$1.97	$0.84	$0.60	$0.50
Pred. Frght	5	$1.92	$0.87	$0.62	$0.50	5	$1.95	$0.90	$0.64	$0.52	5	$2.00	$0.94	$0.68	$0.56
(80% Frght. 20% Pass.)	6	$2.17	$1.07	$0.76	$0.62	6	$2.21	$1.10	$0.79	$0.64	6	$2.27	$1.15	$0.83	$0.68
	No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	4	$2.18	$0.88	$0.77	*	4	$2.20	$0.91	$0.80	*	4	$2.24	$0.96	$0.86	*
(50% Frght. 50% Pass.)	5	$2.18	$0.92	$0.81	*	5	$2.21	$0.95	$0.84	*	5	$2.25	$1.00	$0.89	*
	6	$2.28	$1.00	$0.88	*	6	$2.31	$1.03	$0.91	*	6	$2.36	$1.08	$0.97	*
	No. of Pass. Train	20	60			No. of Pass. Train	20	60			No. of Pass. Train	20	60		
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Pred. Pass.	4	$2.53	$1.02	*	*	4	$2.56	$1.06	*	*	4	$2.60	$1.11	*	*
(20% Frght. 80% Pass.)	5	$2.53	$1.05	*	*	5	$2.56	$1.08	*	*	5	$2.61	$1.14	*	*
	6	$2.60	$1.10	*	*	6	$2.63	$1.13	*	*	6	$2.68	$1.19	*	*

Total Cost per Passenger Train Mile Wood Maintenance + Cyclic Capital (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$1.97	$0.77	$0.52	$0.45	4	$2.01	$0.79	$0.54	$0.47	4	$2.08	$0.83	$0.57	$0.50
Pred. Frght	5	$3.41	$1.39	$0.96	$0.89	5	$3.52	$1.44	$1.00	$0.93	5	$3.67	$1.51	$1.05	$0.98
(80% Frght. 20% Pass.)	6	$5.50	$2.29	$1.60	$1.52	6	$5.70	$2.38	$1.67	$1.59	6	$5.98	$2.51	$1.77	$1.68
	No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	4	$2.49	$1.08	$0.96	*	4	$2.55	$1.11	$1.00	*	4	$2.63	$1.17	$1.06	*
(50% Frght. 50% Pass.)	5	$2.95	$1.32	$1.20	*	5	$3.03	$1.37	$1.25	*	5	$3.14	$1.44	$1.32	*
	6	$3.90	$1.82	$1.69	*	6	$4.02	$1.89	$1.76	*	6	$4.20	$1.99	$1.86	*
	No. of Pass. Train	20	60			No. of Pass. Train	20	60			No. of Pass. Train	20	60		
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Pred. Pass.	4	$3.13	$1.55	*	*	4	$3.21	$1.60	*	*	4	$3.33	$1.69	*	*
(20% Frght. 80% Pass.)	5	$3.48	$1.77	*	*	5	$3.57	$1.84	*	*	5	$3.71	$1.94	*	*
	6	$3.91	$2.04	*	*	6	$4.02	$2.12	*	*	6	$4.19	$2.24	*	*

Matrix 43

Total Cost per Passenger Train Mile Wood – Maintenance + Cyclic Capital (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$2.88	$1.18	$0.82	$0.73	4	$2.95	$1.22	$0.86	$0.76	4	$3.05	$1.29	$0.92	$0.82
Pred. Frght	5	$4.77	$2.06	$1.45	$1.35	5	$4.94	$2.15	$1.52	$1.41	5	$5.18	$2.27	$1.61	$1.51
(80% Frght. 20% Pass.)	6	$7.89	$3.45	$2.44	$2.32	6	$8.20	$3.60	$2.55	$2.42	6	$8.64	$3.81	$2.70	$2.58
	No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	4	$3.63	$1.64	$1.51	*	4	$3.72	$1.70	$1.57	*	4	$3.86	$1.80	$1.68	*
(50% Frght. 50% Pass.)	5	$4.27	$2.01	$1.87	*	5	$4.39	$2.09	$1.95	*	5	$4.58	$2.21	$2.08	*
	6	$5.69	$2.78	$2.61	*	6	$5.88	$2.89	$2.73	*	6	$6.16	$3.06	$2.90	*
	No. of Pass. Train	20	60			No. of Pass. Train	20	60			No. of Pass. Train	20	60		
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Pred. Pass.	4	$4.58	$2.35	*	*	4	$4.71	$2.44	*	*	4	$4.89	$2.59	*	*
(20% Frght. 80% Pass.)	5	$5.07	$2.69	*	*	5	$5.22	$2.80	*	*	5	$5.44	$2.97	*	*
	6	$5.71	$3.11	*	*	6	$5.89	$3.24	*	*	6	$6.15	$3.43	*	*

Total Maintenance Cost per Passenger Train Mile Concrete (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass.Train	5	15	30	50	No. of Pass.Train	5	15	30	50	No. of Pass.Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$0.63	$0.26	$0.18	$0.19	4	$0.65	$0.27	$0.19	$0.19	4	$0.68	$0.28	$0.20	$0.20
Pred. Frght	5	$1.95	$0.81	$0.57	$0.58	5	$2.02	$0.84	$0.59	$0.60	5	$2.12	$0.88	$0.62	$0.63
(80% Frght. 20% Pass.)	6	$3.82	$1.59	$1.12	$1.14	6	$3.95	$1.65	$1.16	$1.18	6	$4.14	$1.73	$1.22	$1.23
	No. of Pass.Train	12	37	60		No. of Pass.Train	12	37	60		No. of Pass.Train	12	37	60	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	4	$0.95	$0.50	$0.48	*	4	$0.98	$0.51	$0.50	*	4	$1.03	$0.54	$0.52	*
(50% Frght. 50% Pass.)	5	$1.37	$0.71	$0.70	*	5	$1.42	$0.74	$0.72	*	5	$1.49	$0.77	$0.76	*
	6	$2.23	$1.16	$1.14	*	6	$2.31	$1.20	$1.18	*	6	$2.42	$1.26	$1.23	*
	No. of Pass.Train	20	60			No. of Pass.Train	20	60			No. of Pass.Train	20	60		
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Pred. Pass.	4	$1.35	$0.86	*	*	4	$1.39	$0.89	*	*	4	$1.46	$0.93	*	*
(20% Frght. 80% Pass.)	5	$1.67	$1.07	*	*	5	$1.72	$1.10	*	*	5	$1.80	$1.16	*	*
	6	$2.04	$1.31	*	*	6	$2.11	$1.35	*	*	6	$2.21	$1.42	*	*

Matrix 45

Total Cyclic Capital Cost per Passenger Train Mile Concrete (Minimum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$1.38	$0.50	$0.32	$0.25	**4**	$1.39	$0.51	$0.33	$0.25	**4**	$1.41	$0.53	$0.34	$0.27
Pred. Frght	**5**	$1.48	$0.56	$0.36	$0.28	**5**	$1.49	$0.57	$0.37	$0.29	**5**	$1.51	$0.59	$0.39	$0.31
(80% Frght. 20% Pass.)	**6**	$1.69	$0.68	$0.45	$0.36	**6**	$1.70	$0.69	$0.59	$0.37	**6**	$1.72	$0.71	$0.48	$0.38
	No. of Pass. Train	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**	
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
Equal Frght	**4**	$1.57	$0.57	$0.45	*	**4**	$1.58	$0.58	$0.46	*	**4**	$1.60	$0.61	$0.49	*
(50% Frght. 50% Pass.)	**5**	$1.61	$0.60	$0.47	*	**5**	$1.62	$0.61	$0.49	*	**5**	$1.65	$0.63	$0.51	*
	6	$1.69	$0.64	$0.52	*	**6**	$1.71	$0.66	$0.59	*	**6**	$1.73	$0.68	$0.56	*
	No. of Pass. Train	**20**	**60**			**No. of Pass. Train**	**20**	**60**			**No. of Pass. Train**	**20**	**60**		
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
Pred. Pass.	**4**	$1.83	$0.66	*	*	**4**	$1.84	$0.68	*	*	**4**	$1.86	$0.70	*	*
(20% Frght. 80% Pass.)	**5**	$1.85	$0.68	*	*	**5**	$1.86	$0.69	*	*	**5**	$1.89	$0.72	*	*
	6	$1.90	$0.71	*	*	**6**	$1.92	$0.72	*	*	**6**	$1.94	$0.75	*	*

Matrix 46

Total Maintenance Cost per Passenger Train Mile Concrete (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	**5**	**15**	**30**	**50**	**No. of Pass. Train**	**5**	**15**	**30**	**50**	**No. of Pass. Train**	**5**	**15**	**30**	**50**
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$0.96	$0.40	$0.28	$0.28	**4**	$0.99	$0.41	$0.29	$0.29	**4**	$1.08	$0.45	$0.32	$0.32
Pred. Frght	**5**	$2.83	$1.18	$0.83	$0.84	**5**	$2.93	$1.22	$0.86	$0.87	**5**	$3.08	$1.28	$0.90	$0.92
(80% Frght. 20% Pass.)	**6**	$5.66	$2.36	$1.66	$1.69	**6**	$5.86	$2.44	$1.72	$1.75	**6**	$6.02	$2.51	$1.77	$1.79
	No. of Pass. Train	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	**4**	$1.43	$0.75	$0.73	*	**4**	$1.48	$0.77	$0.75	*	**4**	$1.57	$0.82	$0.80	*
(50% Frght. 50% Pass.)	**5**	$2.06	$1.08	$1.05	*	**5**	$2.14	$1.11	$1.09	*	**5**	$2.27	$1.18	$1.15	*
	6	$3.37	$1.76	$1.72	*	**6**	$3.49	$1.82	$1.78	*	**6**	$3.62	$1.89	$1.84	*
	No. of Pass. Train	**20**	**60**			**No. of Pass. Train**	**20**	**60**			**No. of Pass. Train**	**20**	**60**		
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Pred. Pass.	**4**	$2.03	$1.30	*	*	**4**	$2.10	$1.35	*	*	**4**	$2.20	$1.41	*	*
(20% Frght. 80% Pass.)	**5**	$2.51	$1.61	*	*	**5**	$2.60	$1.67	*	*	**5**	$2.72	$1.75	*	*
	6	$3.08	$1.98	*	*	**6**	$3.19	$2.05	*	*	**6**	$3.34	$2.14	*	*

Matrix 47

Total Cyclic Capital Cost per Passenger Train Mile Concrete (Maximum)

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50	No. of Pass. Train	5	15	30	50
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
	4	$1.90	$0.77	$0.53	$0.42	4	$1.92	$0.80	$0.55	$0.44	4	$1.95	$0.84	$0.59	$0.48
Pred. Frght	5	$1.90	$0.87	$0.60	$0.48	5	$1.93	$0.90	$0.62	$0.50	5	$1.98	$0.94	$0.66	$0.54
(80% Frght. 20% Pass.)	6	$2.15	$1.07	$0.75	$0.60	6	$2.19	$1.10	$0.89	$0.62	6	$2.25	$1.15	$0.81	$0.66
	No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60		No. of Pass. Train	12	37	60	
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Equal Frght	4	$2.16	$0.88	$0.75	*	4	$2.18	$0.91	$0.78	*	4	$2.22	$0.96	$0.83	*
(50% Frght. 50% Pass.)	5	$2.16	$0.92	$0.78	*	5	$2.19	$0.95	$0.82	*	5	$2.23	$1.00	$0.87	*
	6	$2.26	$1.00	$0.86	*	6	$2.29	$1.03	$0.95	*	6	$2.34	$1.08	$0.95	*
	No. of Pass. Train	20	60			No. of Pass. Train	20	60			No. of Pass. Train	20	60		
	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30	Trk Class/MGT	<=5	5-15	15-30	>=30
Pred. Pass.	4	$2.51	$1.02	*	*	4	$2.53	$1.06	*	*	4	$2.58	$1.11	*	*
(20% Frght. 80% Pass.)	5	$2.51	$1.05	*	*	5	$2.54	$1.08	*	*	5	$2.59	$1.14	*	*
	6	$2.57	$1.10	*	*	6	$2.60	$1.13	*	*	6	$2.65	$1.19	*	*

Total Cost per Passenger Train Mile Concrete (Minimum) – Maintenance + Cyclic Capital

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	**5**	**15**	**30**	**50**	**No. of Pass. Train**	**5**	**15**	**30**	**50**	**No. of Pass. Train**	**5**	**15**	**30**	**50**
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
	4	$2.01	$0.76	$0.50	$0.43	**4**	$2.04	$0.78	$0.52	$0.45	**4**	$2.09	$0.82	$0.54	$0.47
Pred. Frght.	**5**	$3.44	$1.38	$0.94	$0.87	**5**	$3.52	$1.42	$0.97	$0.90	**5**	$3.63	$1.48	$1.01	$0.94
(80% Frght. 20% Pass.)	**6**	$5.50	$2.27	$1.58	$1.49	**6**	$5.65	$2.34	$1.75	$1.54	**6**	$5.86	$2.44	$1.70	$1.61
	No. of Pass. Train	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**	
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
Equal Frght.	**4**	$2.52	$1.07	$0.93	*	**4**	$2.57	$1.10	$0.96	*	**4**	$2.63	$1.14	$1.01	*
(50% Frght. 50% Pass.)	**5**	$2.98	$1.31	$1.17	*	**5**	$3.04	$1.35	$1.21	*	**5**	$3.13	$1.40	$1.27	*
	6	$3.92	$1.81	$1.65	*	**6**	$4.02	$1.86	$1.77	*	**6**	$4.15	$1.94	$1.79	*
	No. of Pass. Train	**20**	**60**			**No. of Pass. Train**	**20**	**60**			**No. of Pass. Train**	**20**	**60**		
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
Pred. Pass.	**4**	$3.17	$1.53	*	*	**4**	$3.23	$1.57	*	*	**4**	$3.32	$1.64	*	*
(20% Frght. 80% Pass.)	**5**	$3.52	$1.75	*	*	**5**	$3.59	$1.80	*	*	**5**	$3.69	$1.88	*	*
	6	$3.94	$2.02	*	*	**6**	$4.03	$2.08	*	*	**6**	$4.15	$2.17	*	*

Matrix 49

		Light Curve (96% - 4% - 0%)					Moderate Curve (90% - 8% -2%)					Severe Curve (82% - 12% - 6%)			
	No. of Pass. Train	**5**	**15**	**30**	**50**	**No. of Pass. Train**	**5**	**15**	**30**	**50**	**No. of Pass. Train**	**5**	**15**	**30**	**50**
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
	4	$2.85	$1.17	$0.81	$0.71	**4**	$2.91	$1.21	$0.84	$0.74	**4**	$3.03	$1.29	$0.90	$0.80
Pred. Frght	**5**	$4.73	$2.05	$1.43	$1.32	**5**	$4.86	$2.12	$1.48	$1.37	**5**	$5.05	$2.22	$1.57	$1.46
(80% Frght. 20% Pass.)	**6**	$7.82	$3.43	$2.41	$2.29	**6**	$8.05	$3.54	$2.61	$2.37	**6**	$8.28	$3.66	$2.58	$2.46
	No. of Pass. Train	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**		**No. of Pass. Train**	**12**	**37**	**60**	
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
Equal Frght	**4**	$3.59	$1.63	$1.48	*	**4**	$3.66	$1.68	$1.53	*	**4**	$3.79	$1.78	$1.63	*
(50% Frght. 50% Pass.)	**5**	$4.23	$2.00	$1.84	*	**5**	$4.32	$2.06	$1.90	*	**5**	$4.50	$2.18	$2.03	*
	6	$5.64	$2.76	$2.58	*	**6**	$5.78	$2.85	$2.73	*	**6**	$5.96	$2.97	$2.79	*
	No. of Pass. Train	**20**	**60**			**No. of Pass. Train**	**20**	**60**			**No. of Pass. Train**	**20**	**60**		
	Trk Class/MGT	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**	**Trk Class/MGT**	**<=5**	**5-15**	**15-30**	**>=30**
Pred. Pass.	**4**	$4.54	$2.32	*	*	**4**	$4.63	$2.40	*	*	**4**	$4.78	$2.52	*	*
(20% Frght. 80% Pass.)	**5**	$5.02	$2.66	*	*	**5**	$5.14	$2.75	*	*	**5**	$5.31	$2.88	*	*
	6	$5.65	$3.07	*	*	**6**	$5.79	$3.18	*	*	**6**	$5.99	$3.33	*	*

Appendix D: Simplified Example Application

Table D-1: Track Maintenance Cost Calculation Sheet

1	2	3	4	5	6	7	8	9	10	11
				No. of Trains Per Day						
Start Milepost	Ending Milepost	# of Tracks	*Segment Length (Miles)*	Passenger	Freight	*Ratio Pass/Frt*	FRA Track Class	Curve Factor	*Total Tonnage (MGT)*	Maintenance Difficulty Factor
13.4	38.1	2	*49.4*	16	16	***1***	**4**	1.04	***38***	**1.31**
248.3	259.5	1	*11.2*	16	1	***16***	**4**	1	***5***	**1.23**
259.5	272.7	1	*13.2*	16	10	***2***	**6**	1.04	***25***	**1.29**
	Route Length		*73.8*							

Cost Per Track Mile		
12	*13*	*14*
Base Case Cost (000)	***Cost Per Track Mile***	***Segment Cost/Yr***
$61	*$82,834*	*$4,091,996*
$32	*$39,237*	*$439,454*
$54	*$72,178*	*$952,751*
	Total Route Cost	*$5,484,201*

Cost Per Train Mile		
15	*16*	*17*
Base Case Cost	***Cost Per Train Mile***	***Segment Cost/Trip***
0.45	*$0.61*	*$30*
3.13	*$3.85*	*$43*
1.60	*$2.15*	*$28*
	Total Cost Per Trip	*$101.74*

Table D.2: Track Maintenance Cost Calculation -- Equations

Column #	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
	A	***B***	***C***	***D***	***E***	***F***	***G***	***H***	***I***
Row #			No. of Trains Per Day						
	Ending Milepost	*Segment Length (Miles)*	Passenger	Freight	*Ratio Pass/Frt*	FRA Track Class	Curve Factor	*Total Tonnage (MGT)*	Maintenance Difficulty Factor
6	0.0	*A6*			*C6/(D6 + 0.025)*			*((C6*550 + D6*5900)*365)/1000000*	
7		*A7-A6*			*C7/(D7 + 0.025)*			*((C7*550 + D7*5900)*365)/1000000*	
8		*A8-A7*			*C8/(D8 + 0.025)*			*((C8*550 + D8*5900)*365)/1000000*	
9		*A9-A8*			*C9/(D9 + 0.025)*			*((C9*550 + D9*5900)*365)/1000000*	
10		*A10-A9*			*C10/(D10 + 0.025)*			*((C10*550 + D10*5900)*365)/1000000*	
	Route Length	*SUM(B6:B10)*							

Cost Per Track Mile				Cost Per Train Mile		
10	*11*	*12*		*13*	*14*	*15*
K	***L***	**M**	***N***	***O***	***P***	***Q***
Base Case Cost	***Cost Per Track Mile***	***Segment Cost/Yr***		Base Case Cost	***Cost Per Train Mile***	***Segment Cost/Trip***
	*G6*I6*K6*1000*	*B6*L6*			*G6*I6*O6*	*B6*P6*
	*G7*I7*K7*1000*	*B7*L7*			*G7*I7*O7*	*B7*P7*
	*G8*I8*K8*1000*	*B8*L8*			*G8*I8*O8*	*B8*P8*
	*G9*I9*K9*1000*	*B9*L9*			*G9*I9*O9*	*B9*P9*
	*G10*I10*K10*1000*	*B10*L10*			*G10*I10*O10*	*B10*P10*
	Total Route Cost	*SUM(M6:M10)*			*Total Cost Per Trip*	*SUM(Q6:Q10)*