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CONTENTS

ABSTRACT

This synthesis documents agency practices, innovations, and lessons learned in track maintenance costs. Its purpose is to identify the factors that influence these costs. Foundation information is presented here for transit agency managers, maintenance and operations staffs, and other professionals involved in developing a program for practitioners to actively manage track maintenance costs.

The synthesis includes findings from a literature review. It incorporates survey responses from select rail transit agencies, east and west coast, old and new in age. Furthermore, it closely examines organization, practice, and budgeting at three transit agencies in more in-depth case studies to further development of a matrix of factors that influence costs.

SUMMARY

This synthesis offers survey information, as reported, on agency practices, innovations, and lessons learned in programmed track maintenance costs to identify influences on maintenance costs, such as the following:

- Track maintenance activities, listed and defined;
- Labor and material costs;
- Work windows;
- Track inspection and maintenance policies;
- Operating characteristics;
- Budgeting/accounting practices;
- Availability of capital and operating funds;
- Recordkeeping procedures;
- Etc.

This report presents the results of a limited survey and interviews on track maintenance costs, and includes a literature review related to track maintenance costs.

The limited survey and interview results indicate that transit agency maintenance is composed of and defined as activities that are conducted on all railroads: rail maintenance, track geometry maintenance, tie and fastener maintenance, ballast maintenance, track inspection, and emergency services (derailment repairs, storm repair, etc.). Survey results show that transit agency track maintenance costs, practices, and policies are primarily influenced by track access; that is, available maintenance windows and site access. The results show that the transit's track access cost adds to the direct cost of accomplishing a track maintenance task. The survey asked for the direct and indirect costs of three tasks: a 39-ft rail replacement, a switch point replacement, and a frog replacement.

Most responding agencies reported work windows of 4 h, of which 50% may be expended traveling to a work site (2 h net work time daily). Vehicle traffic during track maintenance periods (such as testing vehicle repairs, implementing new vehicle and control systems, or dead-heading bad-ordered cars to home yards for repairs) allows single track access during many track maintenance work windows. Track maintenance windows reported were nearly exclusively at night, which adds a measure of difficulty and therefore cost to the track maintenance access issue.

Track maintenance access requires an additional level of planning costs, which are not reflected in this survey, to coordinate the work windows to accommodate maintenance crews (structures, stations, traction power, and train control), as well as vehicle testing and shuttling. Limited survey results suggest that the transit agency's direct cost (labor and material) to perform a maintenance task is as efficient as or more efficient than that of a freight railroad or contracted service, and that higher track maintenance costs can be attributed almost solely to track access costs.

The second largest influence on transit track maintenance cost reported here is unquantifiable: replacement of inappropriate or underperforming component designs installed during original construction. Interviews suggest that maintenance of underperforming track systems is substantial and eventual replacement is costly.

Other than underperforming track designs, the survey results report that the primary maintenance cost is from normal wear and fatigue. No agency believes that track damage from other sources such as corrosion, geotechnical issues, derailments, human error, vandalism, or environmental causes has significant adverse influences on track maintenance budgets.

The interviews suggest that deferred track maintenance has a cost in the sense that minor, preventive maintenance repairs are supplanted by more costly repairs. However, it is difficult to quantify the cost of deferred maintenance outside of the specific contexts of each case.

Based on synthesis survey information, all agencies use a pragmatic approach when budgeting for track maintenance. Funding sources are universally from a variety of public sources, local, state, and federal, with transit funding levels that are subject to tax revenue generation each year. A consistent survey comment appeared to be that maintenance cost-efficiency would be served if uniform annual funding was available.

Younger agencies believe their budgets are based on maintenance demand and are reasonably adequate. Older agencies appear to believe that their budgets are inadequate. The differences in these opinions appear to correlate with a 20- to 30-year aging of systems, speculated as the inherent life-cycle benchmark of a system.

The pragmatic budgeting of track maintenance balances the longer view of maintenance with the realities of annual budgets. A guiding concept across those offering opinions is to maintain a base level of in-house resources, meaning highly experienced personnel, useful level of appropriate maintenance equipment, and stores of at least emergency materials. The budgeting process therefore attempts to retain experienced personnel and to assess the short- and long-term technical needs of a system. The funding streams apparently require maintenance managers to make overt choices between these necessities on occasion. Although maintenance costs for corrosion repair and other non-wear forms of track degradation are not considered significant, track personnel are aware of the mechanics and possibilities that neglecting those mechanics will result in adverse maintenance.

In the past 10 years, rail transit agencies have begun to implement track standards, with at least one agency publishing its track standards for all future new extensions and any retrofit application. In 2002, the APTA Rail Transit Task Force developed a Standard for Transit Track Inspection and Maintenance (RT-S-FS-002-02) to be used in conjunction with the most recent versions of Federal Title 49 CFR 213—Track Safety Standards (2003) and American Railway Engineering and Maintenance-of-Way Association *Manual for Railway Engineering*, Volume 1, Chapter 5. The purpose of this standard was to act as a safety guideline; a model for transit to verify that tracks are operated safely and as designed through periodic inspection and maintenance. Individual rail paratransit systems are allowed to modify practices in the standard to accommodate their specific equipment and mode of operation.

Track inspection records for safety are publicly available documents, and therefore receive due attention. However, reports on track conditions that are routine maintenance but do not invoke safety standards are treated differently.

Some agencies have instituted project cost tracking, creating an objective database for budget estimating and planning. This survey showed that reliable maintenance cost information would be most useful to agency staff as a tool to explain budget proposals, and to document for management as well as funding sources, validity of budget requests.

The literature indicates that track maintenance costs are beneficially affected by technology implementation (materials as well as monitoring and detection devices).

The economic modeling efforts identified in the literature review conducted during this study did not show any strong links between maintenance costs and the amount of rail traffic. This is likely because the modeling efforts identified used statistical methods relying on general characteristics of the track and vehicles rather than specific rail vehicle characteristics, track characteristics, and local rail traffic characteristics. Models do exist, however, that relate track maintenance cost to the specific characteristics of track, vehicles, and traffic. These models and the results of their specific applications are usually propriety and not available to the public.

The survey respondents reflect a limited cross section of young and old agencies from across the United States.

This report also contains information on the following topics:

- Unit costs (as level of effort) for three common tasks: changing a rail, changing a switch point, and changing a frog. This report focuses on cost factors. The level of efforts provided by agencies show that indirect costs are 50% to 200% of the transit agency maintenance direct (i.e., productive) effort, and these costs are predominately the cost of limited track access.

- Unit costs from contract bids as insight on the range of unit costs beyond the few tasks selected above. Although reflecting contractor overheads and, occasionally, bid strategy effects, average bid unit costs have a comparative benchmark value to agency direct effort (without indirect effort), with overheads and profit margins between contractors and agencies approximately equal.

- Routine maintenance practices. These practices reflect individual system age, hindering any universal characterization of industry practices. Most agencies practice life-extending methods such as rail grinding and rail lubrication, details varying with system characteristics.

- Agency improvements to future maintenance costs, such as implementing track standards and eliminating poorly performing designs and components.

- Examples of designs that responding agencies reported as challenging:
  - U-69 guard rail (short life), and Direct Fixation rail clip bolts and anchor bolts (susceptible to loosening and corrosion-freezing).
  - Welding frogs to running rail. Most agencies have terminated this practice, one agency reluctantly. The reason for mechanically joining frogs to running rail is for expedient replacement. Some agencies use bonded mechanical joints for frog connection to running rail.

CHAPTER ONE

INTRODUCTION

PURPOSE

This synthesis offers limited survey and interview response information on rail transit industry track maintenance costs and practices.

BACKGROUND

Track maintenance, in the broadest sense, is a product of resources, judgments, experience, skills, tools, and policies that are exercised in a range of service environments and within every conceivable type of organizational structure.

Rail transit agencies' maintenance costs vary widely among agencies, even though agency size, age, and operating conditions appear similar at first. This synthesis offers examples of bottom-up (needs-based) budgeting and attempts to identify factors that cause significant variation in costs.

This synthesis's assignment was to collect data from older and newer track structure designs, vehicles, and operating characteristics to report on factors that influence costs.

Factors that influence maintenance costs include the following:

- Track maintenance activities—listed and defined,
- Labor and material costs,
- Work windows,
- Track inspection and maintenance policies,
- Operating characteristics,
- Budgeting and accounting practices,
- Availability of capital and operating funds, and
- Recordkeeping procedures.

This project reports on elements of track maintenance costs and maintenance practices in rail transit, and provides some indications of cost variations by regions and system length. More robust documentation of specific agency track maintenance costs and relationships to traffic are kept for a follow-on TCRP effort.

REPORT ORDER

The report is presented in the following order:

- Summary
- Literature review on track maintenance costs in transit
- Transit agency survey data
- Case studies
- Conclusion.

CHAPTER TWO

LITERATURE REVIEW

GENERAL

This literature review presents selected information available from published and public sources on track maintenance costs and the influences on track maintenance cost within the United States rail transit industry.

The topics of this section are presented in the following order:

- Defining track maintenance
- Size and shape of the rail transit industry
- Literature review.

DEFINING TRACK MAINTENANCE

At the most fundamental level, track maintenance costs reflect track maintenance practices. Track maintenance is well understood by its practitioners, as evidenced by continuing success (and resurgent growth) of the wheel/rail technology.

This report does not include structures maintenance; for example, bridges and tunnels. Track maintenance definitions and understandings are as follows:

1. Track
2. Maintenance demand
3. “Acceptable” track conditions
4. General maintenance approaches
5. Life-cycle costs
6. Direct and indirect costs
7. Light rail, heavy rail

Track

Track is the system of materials from the subgrade to top of rail in ballasted track or from the bottom of a rail support device (fastener, block tie) to the top of rail in ballast-less track.

Maintenance Demand

Maintenance demand is the level of effort, materials, and equipment to provide acceptable track.

Acceptable Track Conditions

Acceptable track conditions are as defined by APTA and American Railway Engineering and Maintenance-of-Way Association (AREMA) track safety standards. Track is properly maintained or "acceptable" when the track condition is acceptable for the designed operating parameters over that track. Any length of track that meets the applicable standards for the designed operation on that track is considered to be "acceptable." Any flaw in the track that causes it not to comply with the track standards for the designed operation is an unacceptable track condition.

General Maintenance Approaches

The execution of track maintenance varies by maintenance philosophies or budget realities. Approaches to track maintenance range from *preventive maintenance*, where developing conditions are corrected as they occur, and *crisis maintenance*, where corrections occur at failure (service degradation by slow order for a track condition is, by the foregoing definition, a failure), as well as "spot" or "programmed" maintenance. Most if not all maintenance practitioners adhere to preventive maintenance as a goal, although budget constraints require a balanced approach somewhere between ideal maintenance and crisis maintenance.

Life-Cycle Costs

Life-cycle costs are the sum of all costs of a specified track throughout its economic life, from first installation through removal or replacement. These costs include the material purchase and initial track construction, routine track inspections, and periodic maintenance to the end of its economic life, as well as disposal or recycle costs; for example, tie disposal, disposal of spikes and anchors, and including costs to collect and sell to scrap dealers. The nature of track requires the definition of life cycle to be stated for an arbitrary period, often assumed to be on the order of 25 years, within which the all the track performance cross-influences are adequately captured.

Economic life is defined as a point in time where the trend of annual maintenance costs of an existing component or system of components exceeds a threshold value. Technically, a threshold value for identifying useful economic life is when repair costs have reached some percentage of the replacement and future maintenance costs. A key criterion for economic life is track that meets the definition of acceptable track conditions, described previously. Track with deferred maintenance requires "temporary" slow orders in place until repairs or maintenance is performed are one level, whereas "slow orders" to continue service occur when track has exceeded its economic life.

Direct and Indirect Maintenance Costs

The definitions of direct maintenance effort and the supporting organizational effort/cost to implement productive maintenance are fundamental for this project. For this report, direct maintenance is an effort to perform a specific maintenance task, such as replacing a frog or a rail. The effort and costs of direct maintenance are defined as those functions directly involved in the maintenance task that should be common to all rail applications.

For this report only, the following are direct maintenance efforts/costs for specific maintenance tasks:

- Labor and material to perform a task. This does not include the effort to assemble crews, material, and equipment; travel to a site; or management overheads. Labor for direct maintenance includes all craftsmen (track laborers, welders, machine operators, and any helpers) and their direct supervision (the crew foremen for most organizations). Material costs are the direct cost of components, including delivery of the material to the receiving point in the system;
- Expendables (fuel, etc.);
- Track inspection and reporting;
- Employee fringe benefits; and
- Premiums for constraints such as working in tunnels or other constricted areas, at night, etc.

Indirect maintenance efforts are the costs of preparing crews and materials for a task, travel from a staging area to a site, delays for example resulting from limited track access, mid-level supervision, material stores costs (material stock-pile efforts, including purchasing activities, inventory, etc.), equipment procurement and maintenance, clothing allowances, training, and organization overheads that are not captured in the direct costs or other category.

Heavy Rail, Light Rail

A heavy rail system usually has an exclusive right-of-way (ROW) with no other intervening transportation form, including road crossings. A light rail system shares the ROW in some manner with other transportation forms, largely road crossings and in-street operation. The term light rail, despite its implications, has nothing to do with weight. The vehicles and track for light rail have weights similar to heavy rail configurations. Hearsay suggests that the term "light rail" was devised as a political euphemism for streetcars and trolleys to allow funding consideration over objections that the latter were considered obsolete. Both modes may be operated in transit commuter services that shape ROW with freight railroads.

RAIL TRANSIT INDUSTRY

Track included in this literature review encompasses heavy rail, light rail, and commuter rail transit service, each producing somewhat different track performance, maintenance, and costs. It is useful to introduce, at least, the size of the industry (Table 1), its costs (Table 2), and cost by size and ridership (Table 3).

The following data were reported to and audited by the FTA. The data are from the 2004 National Transit Database, the most recent year available. The cost data in Tables 2 and 3 are from a single year, using aggregates. The aggregates combined by the author, are offered as loosely indicative of industry means.

TABLE 1
TRANSIT RAIL INDUSTRY SYSTEMS AND RIDERSHIP 2004

	Heavy Rail	Light Rail	Commuter Rail	Totals
Number of Rail Transit Systems	14	27	20	61
Annual Ridership (unlinked trips)	2,747,616,634	349,915,503	413,898,363	3,511,430,500
Annual Vehicle Train Miles	94,025,617	41,969,242	49,988,272	185,983,131
Length				
Route miles (main lines only, double track = 1 route mile)	878.81	681.19	3,793.20	5,353.20
Track miles, including each direction of multiple tracks, yards, and sidings				
At-grade				
exclusive ROW (track miles)	736.70	294.80	3,312.10	4,343.60
ROW with crossings (track miles)	32.20	544.90	3,253.70	3,830.80
Number of crossings	27	1,386	2,661	4,074
shared ROW (track miles)	0.00	248.00	85.70	333.70
Number of crossings	0	2,279	66	2,345
subtotal at-grade (track miles)	768.90	1,087.70	6,651.50	8,508.10
Above grade				
aerial structures (track miles)	485.90	62.90	66.80	615.60
track on elevated fills	100.50	57.80	458.70	617.00
subtotal above grade track	586.40	120.70	525.50	1,232.60
Below grade				
tunnels (track miles)	794.40	66.10	39.00	899.50
track in open cuts (track miles)	59.80	46.70	68.10	174.60
subtotal below grade (track miles)	854.20	112.80	107.10	1,074.10
Total track miles (including double track, yard, sidings)	2,209.50	1,321.20	7,284.10	10,814.80

(Reference: National Transit Database, the FTA).

The rail transit industry is composed of 61 transit systems, predominantly under public management, that receive subsidies from local, state, and federal grants, formula distributions, and agreements. In 2004, these agencies expended a little more than $10 billion on rail transit system maintenance and improvements of the FTA-reported total $44 billion expenditures for public transportation (includes buses, rail, and paratransit).

TABLE 2
RAIL TRANSIT INDUSTRY COSTS

Cost	Heavy Rail	Light Rail	Commuter Rail	Totals
Capital Expense				
Guideway	$1,398,244,515	$1,413,882,577	$936,633,072	$3,748,760,164
Systems	$495,753,019	$149,530,198	$83,501,424	$728,784,641
Stations	$977,821,226	$240,246,591	$389,902,370	$1,607,970,187
Maintenance facilities	$349,769,250	$126,473,275	$155,947,263	$632,189,788
Revenue vehicles	$329,551,033	$380,843,591	$726,291,642	$1,436,686,266
Other capital	$174,862,274	$115,533,225	$259,839,969	$550,235,468
Other vehicle amount	$18,472,816	$3,597,565	$4,177,254	$26,247,635
Administration buildings	$11,910,417	$660,499	$4,407,005	$16,977,921
Fare collection equipment	$39,391,281	$10,498,514	$16,158,436	$66,048,231
Total capital expense	$3,795,775,831	$2,441,266,035	$2,576,858,435	$8,813,900,301
Operating Expense (facilities only = "non-vehicle")	$1,224,234,345	$156,016,534	$623,914,117	$2,004,164,996
Total (Capital + Operating)	$5,020,010,176	$2,597,282,569	$3,200,772,552	$10,818,065,297

TABLE 3
RAIL TRANSIT INDUSTRY UNIT COSTS

	Heavy Rail	Light Rail	Commuter Rail	Average of Modes
Average guideway cost per mile (guideway capital expense/total track miles)	$632,833	$1,070,150	$128,586	$346,632
Average guideway cost per rider (guideway capital expense/annual riders)	$0.51	$4.04	$2.26	$1.07
Average total cost per mile (total cost/total track miles)	$2,272,012	$1,965,851	$439,419	$1,000,302
Average total cost per rider (total cost/annual riders)	$1.83	$7.42	$7.73	$3.08

Guideway (that portion of the transit line included between all outside lines of curbs or shoulders, etc., and all appurtenant structures) costs represent about one-third of the total rail transit expenses; the FTA data include new extensions as well as maintenance funds. The industry maintains more than 5,000 route miles (almost 11,000 track miles, including double track, sidings, and yards), serving about 3.5 billion riders per year.

For the following data presentations:

- Commuter rail is presented in this literature review for perspective. The panel chose not to include it in the scope of this project. Cog railroads, excursion (generally historic) railroads, cable car operations, and trams are other acknowledged rail-based systems that are not covered in this report.

- Ridership is shown as the number of individual boardings, meaning that an individual passenger may be counted multiple times in traveling to a destination if the traveler transferred to a separate transit system, and separately for a return trip on the same route.

- Transit industry configurations (track sections, stations, etc.) are from industry infrastructure databases, such as the FTA and APTA. (See the Bibliography for sources.)

Heavy Rail, Light Rail, and Commuter Rail

Tables 1–3 show the three major forms of rail transit: heavy rail, light rail, and commuter rail. These forms have many things in common, but they also have many differences that affect track maintenance.

A heavy rail system is completely separate from public vehicles and other rail modes, and operates on its own “exclusive” ROW. It is 100% electrified, with power typically delivered by a “third rail.”

Light rail is also separated from other rail modes, but does having street crossings (“at-grade crossings”). In many cases, it shares traffic lanes in streets with automobiles. Light rail is generally electrified, with power delivered by an overhead catenary.

Commuter rail shares track with freight rail operators, using passenger cars that are very similar to traditional intercity passenger coaches. (Some operations successfully use refurbished passenger coaches.) Many commuter rail trains use either diesel locomotives or overhead catenary electrified power.

TABLE 4
RAIL MODE COMPARISON

	Heavy Rail	Light Rail	Commuter Rail
			
Right-of-Way	Exclusive, not shared with any other rail or auto facilities. No grade crossings.	Not shared with other rail modes. Has street crossings and shares traffic lanes.	Shared with freight
Typical Motive Power	Third rail	Catenary	Diesel locomotives
Axle Load (maximum or "crush" load)	30,000 lb	30,000 lb	70,000 lb (locomotive)
Speeds (route dependent): • Maximum • Typical	 80 mph 50 to 75 mph	 60 mph 35 mph (or street speed)	 79 mph* 60 mph
Train Traffic Density (average trains/year, over maximum density route)	~38,000 trains/year	~26,000 trains/year	~6,000 trains/year (commuter trains only)
Ridership (annual trips)	2,747,616,634	349,915,503	413,898,363

*100+ mph permissible under special FRA dispensation.

Third rails and insulators are normally mounted on cross ties, often maintained by track departments. Overhead catenary equipment is separated from the track structure and typically is not a track maintenance responsibility.

Table 4 offers the attributes of the three major transit modes, with emphasis on the differences that affect track maintenance costs. In this table, heavy rail operates at higher speeds with higher train density than the other rail modes.

Light rail can approach the operating speeds of heavy rail where the system route is used exclusively by the trains (i.e., without grade crossings). However, these systems largely operate within city centers. When the alignment is along or within roadways, some states require the train speed to be the same as the posted automobile speed.

Commuter rail service is a lighter density form of transit, with the track usually shared with mainline freight operations. The allocation of track maintenance costs between the freight and commuter trains is somewhat difficult to define objectively.

The principal point of this review is to illustrate that different rail modes produce differences in track maintenance demand resulting from different track loads, track configurations, and traffic. Track configurations are the subject of the following section.

Track Standards and Configurations Affecting Maintenance

Track maintenance costs can vary with system configurations. Light rail systems' general deployment within city infrastructure inherently limits speeds. Light rail, by definition, has a far greater percentage of track within city streets. Light rail systems typically allow shorter permissible radii in curves and more severe vertical curves than the other modes, to accommodate street constraints.

Heavy rail's dedicated ROWs allow higher speeds but negotiate inner cities by means of elevated guideways and tunnels in greater percentages of route length than light rail. These configurations introduce more specialty track, such as Direct Fixation track, than other rail modes.

Light rail and heavy rail systems are nearly universally electrified, adding catenary or third rail facilities as a significant asset for maintenance compared with non-electrified railroads. Added maintenance costs from electrification are additional track components (primarily in third rail systems), corrosion of track components as well as structures and utilities surrounding the track, and added safety work rules.

Track design standards and track maintenance standards significantly affect the cost of track maintenance. Track maintenance standards for rail transit have a basis in the broader industry standards of AREMA, with some exceptions for track gauge and curvature (noted earlier). However, light rail and heavy rail transit agencies' track materials installations appear to lack uniformity. The lack of standardization adds a significant premium to track material delivery times, component unit costs, agency spare parts stocking costs, and maintenance processes (including training to recognize differences among similar components, costs of errors related to component incompatibility, and train delays associated with errors).

TECHNOLOGY INFLUENCE ON TRACK MAINTENANCE COSTS

Track maintenance costs vary dramatically over time, usually beneficially. In the early days of railroads, it was usual to replace cross ties each year (*1*); today, the expected life of a timber cross tie is on average 40 years (*2*).

Figure 1 shows unit costs for major track cost components in the U.S. freight industry. They are based on the Association of American Railroad's (AAR) Total Right-Of-Way Analysis and Costing System (TRACS), an empirically calibrated model of freight railroad maintenance-of-way (MOW) costs from 1970 to 2000.

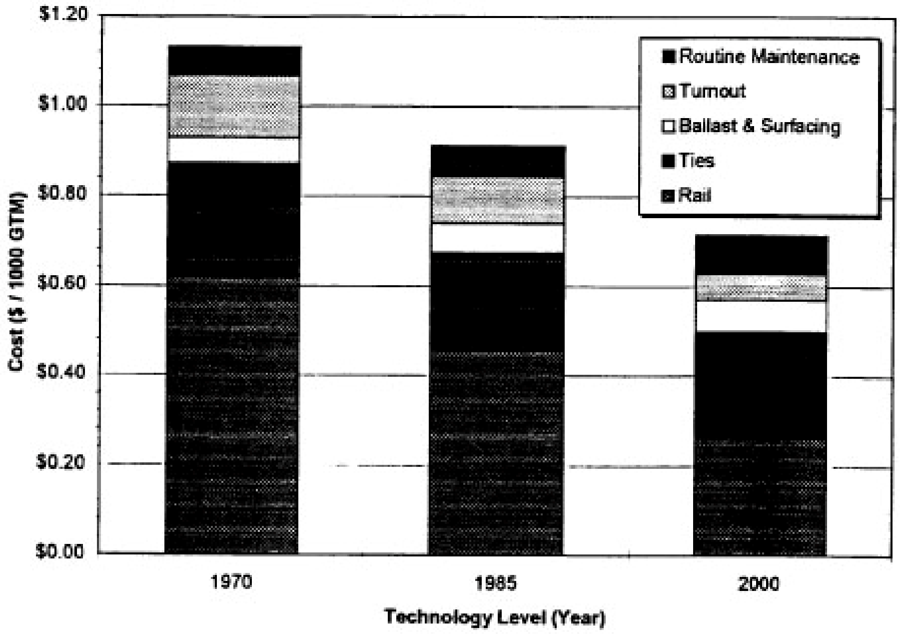

FIGURE 1 MOW cost breakdown by maintenance component for eastern 30 MGT mainline.

The improvements in maintenance costs are attributed to improvements in technology and practices.

Rail cost improvements contributed the most to the overall cost savings. Rail costs fell 58%. From $0.62/1000 GTM under 1970 steady-state conditions to $0.26/1000 GTM in 2000. This dramatic cost improvement was due to the introduction and refinement of rail grinding and lubrication techniques and due to the replacement of old rail by much more durable, higher quality rail, especially on curves. The total MOW costs fell 37% under the assumptions of this scenario, from $1.13/1000 GTM to $0.71/1000 GTM. Rail costs were the largest component of MOW costs, comprising 55% of the total in 1970 and 37% in 2000. Ties were the second largest contributor, consisting of 22% of total costs in 1970 and 34% in 2000. Routine maintenance, ballast and surfacing, and turnout costs all contributed approximately equally to the overall costs. Turnout costs did improve slightly more than the ballast and surfacing and routine maintenance costs due to more widespread use of better quality turnouts that have lower angles of incidence and also due to the elimination of underutilized turnouts from the network. Tie costs rose from 1985 to 2000 due to the introduction of premium fastenings on track with high degrees of curvature, despite a reduction in plate cutting and spike kill by using larger tie plates in 2000 (3).

These trends would be expected to be available in transit. The unit costs from freight are useful in suggesting probable upper limits for what may occur in transit if it is assumed that the maximum axle load density or frequency of maximum load occurrence is greater in freight than in rail transit.

MODELING ATTEMPTS TO ESTIMATE MAINTENANCE COSTS

Past track maintenance cost-estimating methods generally use statistical techniques (which we will refer to as models) that analyze various factors to associate past costs with influence parameters such as rail traffic characteristics, component age, and resources, to predict maintenance demand and costs. The models in this review have different purposes that range from establishing rail rates (for freight railroad regulatory and legal issues) to attempting maintenance planning (for budgeting, rehabilitation assessment, public funding evaluation, and railroad projections). The different purposes have led to different models that at best should be used with caution and at worst can be misleading for other purposes.

General Track Maintenance Modeling Concepts

It is useful to define a basis for a model's assumptions, constructions, and underlying data.

Track maintenance "models" presume that railroad traffic produces track maintenance. The presumption fails to capture yard track, as an example, even though yards certainly are a significant system track maintenance cost.

Track maintenance modeling also presumes that track maintenance is predictable; that is, there are quantifiable, mathematical relationships between influence factors (e.g., size of loads, number of wheels, curvature, and weather) and maintenance effort.

This premise requires encapsulating two types of processes. The first process is a rate of degradation for track and its components. To predict maintenance demand, the degradation mechanics (wear, settlement, etc.) must be known sufficiently to develop accurate predictions. The second process is track management, or the management of the track degradation process through maintenance. Philosophies (i.e., preventive maintenance or crisis maintenance), cyclic budget resources, changes in public officials effect funding, and execution of track maintenance often vary dramatically. Maintenance management processes are absent in any discrete form from all track maintenance prediction models.

In addition, most transit cost modeling efforts depend on past documentation (maintenance records, expenditure records, etc.) that may be incomplete, and may use varying accounting systems. Models based on maintenance data should have data over multiple economic cycles and parallel information on funding streams to understand the data.

A competent track maintenance model would have a database of the full system, including alignment, components, traffic by specific location (route, track, and engineering station), and the dates of installation of each component. Ideally, maintenance costs are then assigned to each track segment as the maintenance occurs. Predictions can then be based on site-specific traffic and maintenance conditions.

Track Maintenance Models

The following track maintenance models included in this literature review are indicative of past and current approaches:

1. AAR HAL Phase II Economic Analysis (1997)
2. Total Right-of-Way Analysis and Costing System (TRACS—1994)
3. Degradation Cost of Track (2004) (*4*)
4. Cost Sharing Allocation Models:
   a. Speed Factored Gross Tonnage (SFGT—AAR)
   b. Weighted System Average Cost (WSAC—AAR)
   c. Commercial Feasibility Study (FRA)
   d. TrackShare (Zeta-Tech)
   e. Swedish Railway Marginal Costs (2006)

The routine maintenance component (i.e., daily routine of inspections, spot repairs, adjustments, minor repairs) is described as a differential between a base maintenance demand and the demand from increased axle loads (*5*):

$$NRM = \left(\frac{NAL^{DFE}}{33} \right) BRM * MGT$$

Where:

NRM = new axle load routine maintenance (hours), 33 = 263,000-lb freight car axle load (tons),

NAL = new axle load (tons),

DFE = estimated damage factor exponent,

BRM = base (33-ton) routine maintenance (hours/MGT/mile), and

MGT = traffic density (MGT/mile/year).

Compared with freight rail operations, train operations increase transit maintenance costs. Train operations in transit either interfere with maintenance operations or restrict track access to narrow time periods. The cost amplification from traffic interference may be 50% of the basic cost of maintenance (Figure 2) (*5*) based on European data.

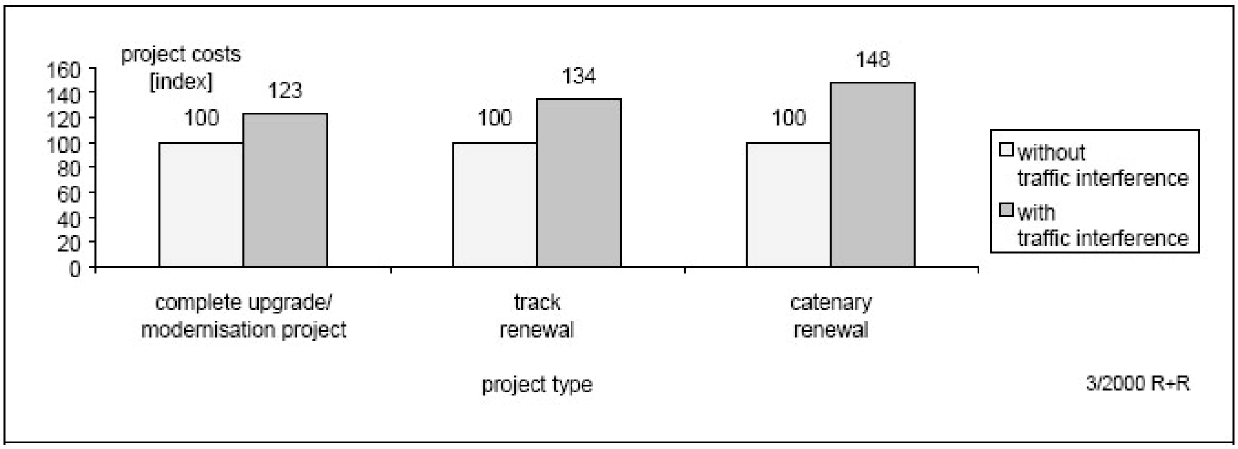

FIGURE 2 Effects of train interference on maintenance costs. (*Source:* AREMA 2001 Annual Conference.)

Consideration of track renewals as an investment has merit, predicated on savings from technology gains (see preceding section, Technology Influence on Track Maintenance Cost). The Massachusetts Bay Transportation Authority took this approach, suggesting that track rehabilitation, in part, is an investment (*6*) with a measurable return in system efficiencies, including track maintenance cost. The system was evaluated to consider the current age of components, life expectancy, and rate of return on reductions in maintenance for a system in an "ideal" state of repair. The results suggest that timely replacement of aging components has a positive influence from technology implementation on long-term cost trends.

Among others, Keeler (*7*) and Caves et al. (*8*) used aggregate data on U.S. Class I railroads with a focus on scale economies (i.e., economies with increasing railroad size) and productivity to generate cost-function estimates for the railway industry. The results suggest that system size reduces unit maintenance costs (i.e., cost per mile); however, whether those benefits are from efficiency of scale or spreading overhead costs is not clear.

Other studies have attempted to discern whether costs of track (a "marginal" or influencing cost) have measurable influence on a system's overall cost performance. Recently, Bitzan (*9*) and Bereskin (*10*) conducted studies using aggregate U.S. post-deregulation data, with the latter study estimating marginal costs for MOW among different railroad organizations. European studies that focus on marginal costs and use micro-level data include those by Daljord (*11*), Tervonen and Idstrom (*12*), and Gaudry and Quinet (*13*). Johansson and Nilsson (*14*) estimated marginal costs using Sweden's railway network, but this study does not backtrack data from 1994 to 1996, and no analysis has been undertaken on data network changes over time. The study was inconclusive on track maintenance costs. Lack of data resulting from such factors as mergers and acquisitions (eliminating sufficiently long time series) and a focus on day-to-day operations has often restricted micro-level analyses in the railway sector (*15*).

In these modeling efforts, the relationship of track costs to exposure to traffic appeared to be weak. The studies that had variables for specific track costs found that railroad traffic had little or no effect (i.e., was not statistically significant) on track costs.

In this vein, Anderson (*16*) used statistical modeling to estimate the track cost per train and per gross tonne (tonne = metric ton) for track and operating influence parameters using Swedish Rail Agency data from 1999 to 2002. The track parameters in the model include track length, rail lubrication, rail weight, tunnels, bridges, track alignment (curves, grade, superelevation), rail joining (mechanical joints, CWR), and the ages of track components (rail, ties, ballast, switches). Line segment tonnage is used as the independent variable. The model provides a base or constant maintenance cost with added premiums (or marginal) costs for each of the track parameters in the model.

Anderson found a significant interaction among track parameters. As might be expected, the results show that rail weight and age affect switch costs. Similarly, track length and alignment affect the other parameters. The track maintenance costs were modeled to a reasonable statistical reliability by including these interactive influences between parameters in the model. However, the statistical relationship between rail traffic and track maintenance was statistically weak, bordering on insignificant. Anderson also found that the results support the concept of economy of scale, implying that efficiencies in track maintenance cost are available as the rail system size (length) increases.

LITERATURE SUMMARY

The literature on track maintenance costs in this review touches on four points:

- Track maintenance costs can be viewed as investments to leverage the benefits of advancing technology, with benefits to system performance and costs as well as to track maintenance unit costs.
- Rail transit maintenance costs are higher as a result of train interference (i.e., lack of track access due to train operations, as well as points of entry to the track) compared with rail operations with permissive track maintenance access.
- Unit costs may scale inversely with system size, with costs declining as the system size increases. However, the literature is not consistent on whether the benefit exists and does not quantify the amount of the benefit.
- Statistical models of rail system costs reviewed appear to have difficulty discerning the influence of rail traffic on modeling results.

The last point reflects flaws in past modeling efforts for track issues, including costs. Estimating or predictive models might include the following details:

- Route-specific configurations, such as distance, alignment, and turnouts;
- Track component details, such as type of switches, frogs, ties, and rails;
- Mechanics of vehicle-track interaction (dynamic and kinematic motion) and wheel-rail interaction (curving mechanics);
- Track geometry (alignment and support deviations);
- Traffic characteristics by location; and
- Cost/maintenance documentation by the above parameters to validate the model.

However, that the economic modeling efforts identified in the literature review conducted during this study did not show any strong links between maintenance costs and the amount of rail traffic is likely because the modeling efforts identified used statistical methods relying on general characteristics of the traffic and vehicles rather than specific rail vehicle characteristics, track characteristics, and local rail traffic characteristics. Models do exist, however, that relate track maintenance costs to the specific characteristics of track, vehicles, and traffic. These models and the results of their specific applications are usually proprietary and not available to the public.

CHAPTER THREE

TRANSIT AGENCY SURVEY DATA

Transit agencies and industry regulators, engineers, and administrators were asked to participate in a survey, and selected agencies were interviewed.

The survey response is an industry cross section, including agencies from representative regions (East Coast, mid-continent, and West Coast), mode (light rail and heavy rail), and age (established systems and new systems). The survey responses represent 50% of the North American installed track facilities from responding agencies. The response rate was 19%, including agencies with facilities considered representative of North American practice.

The identities of the responding agencies are withheld in the following assessment, but the context of responding agencies is included (heavy or light rail, system age, system size, and regional location).

INTEREST IN TRACK MAINTENANCE COST INFORMATION

This synthesis topic addresses the concerns of those directly involved in track maintenance, such as track supervisors and their immediate managers, as well as those responsible for administration and regulation. Each of these interests looks for differing characteristics in the data, or presentation of data in varying manners. This report focuses on a level most directly useful to the practitioners, but is cognizant of the broader constituency with varying perspectives and applications of the information.

To assess the expectations of the broader constituency, respondents were asked their views on the use of track maintenance cost information. This survey received responses from transit agencies only. The broader constituency interest remains for a future study. The responses are summarized in Table 5 in which a common interest is to use the track maintenance cost information to justify budgets to state and federal funding sources. There is also high interest in using cost information as a reference in budget preparations. Opinions on other reasons for track maintenance cost information were mixed.

TABLE 5
USE OF TRACK MAINTENANCE COST DATA—AGENCY RANKING SCALED 1 TO 10 ON IMPORTANCE

Question		Agency A	Agency B	Agency C		Agency D	Agency E	Agency F	
		Hvy and Lt Rail, 100+ yr, 270 mi, EC	Hvy Rail, 30 yr, 100+ mi, WC	Lt Rail, 20 yr, 40 mi, WC		Lt Rail, 10 yr, 45 mi, C	Lt Rail, 20 yr, 37 mi, WC	Hvy Rail, 100+ yr, 656 mi, EC	
		Ranking	Ranking	Ranking	Notes	Ranking	Ranking	Ranking	Notes
II.1	Resource for Preparing or Justifying Maintenance Programs or Budgets	5	1	3		1	6	1	Critical and needed for monitoring inspection, trends and production activities
II.2	Reference for Evaluating Maintenance Program or Budget Proposals	5	10	2		2	5	1	Weekly/monthly, production, service performance reports
II.3	Reference for Track Upgrade Cost Assessments, Life-Cycle Cost Assessments	5	1	4		3	5	1	Data collected by quadrennial Track Condition Surveys form the basis for the formulation of our annual track reconstruction goals
II.4	Resource for Estimating (construction estimates, maintenance manpower estimates)	5	1	4		4	6	1	Historical costs
II.5	Benchmark Reference for Internal Assessments (compare to industry norms)	5	10	8	For new construction only	5	5	5	
II.6	Allocate Maintenance Costs (for multiple traffic modes, cost centers, etc.)	5	10	7	Only allocate track maintenance	10	7	1	Personnel and material resources

					cost				budgeting
II.7	Justify funding requests (federal, state budgeting)	1	1	2		2	7	1	Necessary capital programs
II.8	Evaluate submittals (bid submittals, etc.):	5	10	5		3	5	1	
II.9	Other				Design review: Maintenance plays a major role in future project design review making sure future construction project will not increase maintenance cost.	6			

Ranking: 1 = greatest importance to responder.
Hvy Rail = Heavy Rail System; Lt Rail = Light Rail System; XX yr = approximate system age; NN mi = approximate system main line route miles;
WC = West Coast; C = Central United States; EC = East Coast.

BUDGET PROCESSES

Table 6 presents results of opinions on a series of statements regarding the effectiveness of transit budget processes to meet track maintenance realities. Opinions were mixed, except on two questions where newer and older transit agencies differed. The survey offered the choice of agreeing, partially agreeing, or disagreeing with statements. The proposed statements and answers should not be construed as preferred management policy.

The key question (III.2.e in Table 6) is whether budgets are adequate for routine track maintenance. Newer systems appeared to differ markedly from the older systems on this question; older systems appear to believe that budgets are partially or completely inadequate. It appears from these responses that these opinions differ at a system age between 20 and 30 years. A marked difference in opinion here appears to exist between the new and old systems on the question (III.2.c) whether budgets are preset without considering the maintenance demand.

Unit Costs

This section contains responses on labor and costs to perform basic tasks common to any maintenance operation.

The point of this survey question is more to understand cost factors in common tasks, rather than the unit costs. The interest is in the cost (effort) ratio of (1) the direct manpower to perform tasks (within constrained work windows and often constrained ROW) to (2) the indirect cost required for preparation and track access delays in rail transit environments.

Respondents were asked to provide the level of effort for three common maintenance tasks: rail replacement, frog replacement, and switch point replacement. The direct and indirect hours are requested separately for each task, along with cost for expendables. To avoid regional or bargained wage rate differences, the level of effort (hours) is used rather than cost.

TABLE 6
BUDGET PROCESSES

Question		Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
		Hvy & Lt Rail, 100+ yr, 270 mi, EC	Hvy Rail, 30 yr, 100+ mi, WC	Lt Rail, 20 yr, 40 mi, WC	Lt Rail, 10 yr, 45 mi, C	Lt Rail, 20 yr, 37 mi, WC	Hvy Rail, 100+ yr, 656 mi, EC
		Ranking	Ranking	Ranking	Ranking	Ranking	Ranking
III.2.a	Budgets Generally Implement an Internal Long-Term Maintenance Plan	Partially Agree	Partially Agree	Partially Agree	Agree	Partially Agree	Partially Agree
III.2.b	Budget Construction Strategically Uses Capital Funds for Maintenance Purposes	Agree	Agree	Agree	Disagree	Partially Agree	Partially Agree
III.2.c	Maintenance Budget Amounts Are Dictated Prior to Assessing Annual Maintenance Needs	Agree	Agree	Partially Agree	Disagree	Agree	Partially Agree
III.2.d	Maintenance Budgets Include Investments in Improved Efficiency, Technology, or Equipment	Partially Agree	Partially Agree	Partially Agree	Agree	Partially Agree	Partially Agree
III.2.e	Maintenance Budgets Are Adequate for Routine Maintenance	Partially Agree	Disagree	Agree	Agree	Agree	Agree (see comment)
III.2.f	Budgets Are Adequate for Contingencies	Disagree	Partially Agree	Agree	Partially Agree	Partially Agree	Partially Agree

III.2.g	Comments on Budget Processes:		Operating budget does not include long-term cost planning, except for recurring expenses (i.e., power/water bills, rail testing contracts, etc.). All long-term maintenance expenses are requested through the capital budget.	2-year budget cycle "smoothens the ripples." Separate budgets for routine maintenance and capital projects, but lines are blurred between the two categories, and criteria have changed over time.	Maintenance budget can absorb minor contingencies.		Funding levels have not been adequate for maintenance contingencies to minimize long-term replacement costs.

Hvy Rail = Heavy Rail System; Lt Rail = Light Rail System; WC = West Coast; C = Central United States; EC = East Coast

Rail Replacement

This question requested an estimate of the hours required to replace one piece of 39-foot defective rail in mainline tangent track. Table 7 shows agency comments from responders.

TABLE 7
QUALIFYING COMMENTS ON RAIL REPLACEMENT HOURS

Agency A	Agency B	Agencies C, E, and F	Agency D
Heavy and Light Rail, 100^{+} Years, 270 mi, EC	Heavy rail, 30 yr, 100 mi, WC		Light Rail, 10 yr, 45 mi, C
No Qualifying Comments	Other direct expenses for rail, frog, and switch replacements typically include two electrical personnel for one 8-hour shift (for third rail safe clearance, rail bonds, and ground cable connections) and two train control personnel for 4 hours (wire removal/reinstallation and train control testing)	No qualifying comments	Agency D has not experienced any failures related to Items A.2 and A.3. No resources are available for labor hours or pricing.

Abbreviations: EC = East Coast; WC = West Coast; C = Central United States.

Table 8 shows agency responses for the direct work to perform the rail replacement (Part A); the support labor such as preparation time, support by signals, and traction power (Part B). Additional costs (expendables, etc.) are Part C of the responders' entries (Table 9).

Frog Replacement

Tables 10 and 11 show the survey responses for frog replacement.

Switch Point Replacement

Table 12 shows the survey responses for a switch point replacement. See Table 13 for a summary of other direct expenses in switch point replacement.

TABLE 8
DIRECT AND INDIRECT LABOR (HOURS) RAIL REPLACEMENT

Part A

Direct Labor						
	Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
	Hvy and Lt Rail, 100+ yr, 270 mi, EC	Hvy Rail, 30 yr, 100+ mi, WC	Lt Rail, 20 yr, 40 mi, WC	Lt Rail, 10 yr, 45 mi, C	Lt Rail, 20 yr, 37 mi, WC	Hvy Rail, 100+ yr, 656 mi, EC
Supervisor Hours	4	6	est. 6	3	1	4
Operator Hours	4	6	N/A		1	0
Laborer Hours	8	27	est. 30	9	4	60
Welder Hours	4	12	N/A	6	3	4
Notes	May require 2nd visit to replace temporary joints with welds	Includes rail thermal adjustment and welding	No rail replacement to date for defects	Includes two thermit welds		Rail on site

Part B

Indirect Labor						
	Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
Supervisor Hours	8	10	4	1	1	4
Operator Hours	8	14	N/A		2	0
Laborer Hours	12	49	24	2	3	16
Welder Hours	4	20	N/A	2	1	0
Notes			see Note A.1			

Survey questions IV.A.1 and IV.B.1—Rail replacement. Replace 1 piece of 39-ft rail for a detected transverse mainline tangent track.

N/A = not available. Hvy Rail = Heavy Rail System; Lt Rail = Light Rail System; WC = West Coast; C = Central United States; EC = East Coast.

TABLE 9
OTHER DIRECT EXPENSES RAIL REPLACEMENT

	Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
Description		Third rail lockout/ Tagout + train control testing	Unknown	Fuel, saw blades, and two thermite weld kits	Saw blade, grinding wheel, two weld kits, fuel	Slotter blades, fuels for small equipment
Cost		$2,400	Unknown	<$300	$350	$100

Survey question IV.C.1—Rail replacement: Replace 1 piece of 39-ft rail for a detected transverse defect mainline tangent track.

TABLE 10
DIRECT AND INDIRECT LABOR (HOURS) FROG REPLACEMENT

Part A—Direct Labor						
	Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
	Heavy and Light Rail, 100+ yr, 270 mi, EC	Heavy Rail, 30 yr, 100+ mi, WC	Light Rail, 20 yr, 40 mi, WC	Light Rail, 10 yr, 45 mi, C	Light Rail, 20 yr, 37 mi, WC	Heavy Rail, 100+ yr, 656 mi, EC
Supervisor Hours	4	3	N/A		1	8
Operator Hours	4	3	N/A		1	0
Laborer Hours	8	12	N/A		8	80
Welder Hours		0	N/A		6	8
Notes		Replacement frogs typically not field welded	Agency C has not yet replaced any frogs	N/A		Frog on site
Part B—Indirect Labor						
	Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
Supervisor Hours	8	5	N/A		1	8
Operator Hours	8	9	N/A		2	0
Laborer Hours	12	24	N/A		3	30
Welder Hours		0	N/A		1	0
Notes			see Note A.2	NA		

Survey Questions IV.A.2 and IV.B.2 Frog Replacement: Replace a mainline No. 10 RBM (or similar) frog.
N/A = not available. Hvy Rail = Heavy Rail System; Lt Rail = Light Rail System; WC = West Coast; C = Central United States; EC = East Coast.

TRACK INSPECTION

Track inspection is one of the discrete overhead items of track maintenance that is readily understood and is allocated significant resources. Table 14 indicates how the different agencies approach this aspect of their systems.

TABLE 11
OTHER DIRECT EXPENSES FROG REPLACEMENT

	Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
Description		Third rail lockout/tagout + train control testing	N/A		Saw blade, grinding wheel, 4 weld kits, fuel	Fuel for small equipment
Cost		$2,400	N/A		$680	$20

Survey Question IV.C.2—Frog replacement: Replace a mainline No. 10 RBM (or similar) frog.
N/A = not available.

MATERIAL AND CONSTRUCTION BIDS

The survey requested agency contract bid results. The responses only contained material procurement unit costs.

Although the responses did not contain any results for material installation, the material procurements are followed by samples of contract unit prices for construction from the author's database.

Notes:

1. The contract bid results, while not generally for maintenance, reflect key transit cost influences such as agency track standards and specifications, as well as working constraints imposed by the physical configuration of the system—such as tunnels, aerial structures, awkward access, limited space, and distant staging areas—that are related to the constraints experienced by agency maintenance organizations.

2. Contract bid differences from in-house agency costs:

TABLE 12
DIRECT AND INDIRECT LABOR (HOURS) SWITCH POINT REPLACEMENT

Part A: Direct Labor						
	Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
	Hvy and Lt Rail, 100+ yr, 270 mi, EC	Hvy Rail, 30 yr, 100+ mi, WC	Lt Rail, 20 yr, 40 mi, WC	Lt Rail, 10 yr, 45 mi, C	Lt Rail, 20 yr, 37 mi, WC	Hvy Rail, 100+ yr, 656 mi, EC
Supervisor Hours	6	3	4		1	16
Operator Hours	6	3	N/A		1	24
Laborer Hours	18	12	16		3	120
Welder Hours		0	N/A		2	8
Notes		Replacement points typically not field welded	No stock rails replaced	N/A		
Part B: Indirect Labor						
	Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
	Hvy and Lt Rail, 100+ yr, 270 mi, EC	Hvy Rail, 30 yr, 100+ mi, WC	Lt Rail, 20 yr, 40 mi, WC	Lt Rail, 10 yr, 45 mi, C	Lt Rail, 20 yr, 37 mi, WC	Hvy Rail, 100+ yr, 656 mi, EC
Supervisor Hours	8	5	2		1	8
Operator Hours	12	9	N/A		2	0
Laborer Hours	22	24	10		3	32
Welder Hours		0	N/A		1	0
Notes			see Note in Part A	N/A		

Total Hours: Direct + Indirect	72	56	32		14	208
Ratio Indirect Hrs/Direct Hrs	1.4	2.111111	0.6		1	0.238095
Direct hr Pct of Total	41.67%	32.14%	62.50%		50.00%	80.77%
Indirect hr Pct of Total	58.33%	67.86%	37.50%		50.00%	19.23%

Survey Question IV.A.3—Switch point replacement: Replace a mainline 19 ft 6 in. switch point (or similar) and its stock rail.
Hvy Rail = Heavy Rail System; Lt Rail = Light Rail System; WC = West Coast; C = Central United States; EC = East Coast.
N/A = not available.

a. Contracted track construction information is from line extension projects (new track construction) where there is no train interference and there is immediate access throughout the work. Agency track maintenance generally has train interference and access only from distant points of system entry, or is conducted in constrained time windows without trains.

b. Material unit costs generally include shipping costs, which vary with the distance from the recipient agency.

c. Contract labor costs generally have a lower overhead than agency labor.

d. Contracted services include profit and other marginal costs.

e. Contractor bid strategies may vary. Occasionally, track construction and (more rarely) material bid unit costs do not reflect the design or specification. These costs are typically limited to one or two of the track line items in a bid. However, individual line item bids vary significantly (as much as 400%) for the same project by separate contractors without any indication of strategic bidding intent.

3. The cost reference date is April 15, 2007. All costs are normalized from the bid date to this reference date using an inflation rate established by the FOB bid cost of rail steel of a domestic manufacturer.

Material Unit Costs

Table 15 presents material procurement bid results from 10 contracts awarded between 1992 and 2006. All contracts were new construction (line extensions or other new track).

The unit costs for materials in these bids generally include transportation to each agency. The unit costs in these bids should be considered to be biased toward the low side of a true average because half of the tabulated bids in the survey responses only included the winning bid (i.e., low bid).

Full interpretation of the bids requires access to the original specification for each bid and each line item. Unit costs here may be considered only illustrative for common practice.

TABLE 13
OTHER DIRECT EXPENSES SWITCH POINT REPLACEMENT

	Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
	Hvy and Lt Rail, 100+ yr, 270 mi, EC	Hvy Rail, 30 yr, 100+ mi, WC	Lt Rail, 20 yr, 40 mi, WC	Lt Rail, 10 yr, 45 mi, C	Lt Rail, 20 yr, 37 mi, WC	Hvy Rail, 100+ yr, 656 mi, EC
Description		Third rail lockout/ tagout + train control testing	Welding, fuel, consumables		Saw blade, grinding wheel, 2 weld kits, fuel	Fuel for small equipment
Cost		$2,400	$500		$200	$20

[Survey Question IV.C.3] Switch Point Replacement: Replace a mainline 19 ft 6 in switch point (or similar) and its stock rail.
Hvy Rail = Heavy Rail System; Lt Rail = Light Rail System; WC = West Coast; C = Central United States; EC = East Coast.

TABLE 14
TRACK PERSONNEL

	Agency A	Agency B	Agency C	Agency D	Agency E	Agency F
	Hvy and Lt Rail, 100+ yr, 270 mi, EC	Hvy Rail, 30 yr, 100+ mi, WC	Lt Rail, 20 yr, 40 mi, WC	Lt Rail, 10 yr, 45 mi, C	Lt Rail, 20 yr, 37 mi, WC	Hvy Rail, 100+ yr, 656 mi, EC
V1a Inspectors	12	15	14	8	10	93
V1b Percent of Staff	8.00%	23.00%	100.00%	28.00%	100.00%	33.00%
Total Track Department Personnel	150	65	14	29	10	282
System Length (track miles)	273	268	72	96	62.6	1312
Inspectors per Track Mile	0.04	0.06	0.19	0.08	0.16	0.07
Total Track Department Personnel per Track Mile	0.55	0.24	0.19	0.30	0.16	0.21

Hvy Rail = Heavy Rail System; Lt Rail = Light Rail System; WC = West Coast; C = Central United States; EC = East Coast.

Construction Unit Costs

Table 16 shows results of tabulated construction bids.

TABLE 15
TRACK MATERIAL UNIT COSTS SE-04 CONTRACT BID SUMMARY

Work Description/Bid Item		Units	Average Unit Cost (4/15/07)	No. Bids in Average
Ballast Mat		SF	$22.85	1
Ballast				
	Ballast	CY	$45.71	1
	Sub-ballast	CY	$35.04	1
Bumper Posts				
	Bumper post	EA	$11,907.27	1
	Friction buffers	EA	$36,250.50	2
Concrete Ties				
	Concrete cross ties and standard rail fasteners, FOB destination	EA	$85.50	1
	Concrete crossties—Emergency guard rail	EA	$226.54	2
	Concrete crossties—Grade crossing (10 ft)	EA	$193.51	5
	Concrete crossties—Standard	EA	$150.50	8
Derails				
	Derail unit in existing track	E4	$13,712.89	1
	Derail unit in new track	EA	$11,427.41	1
Direct Fixation Fasteners				
	Direct fixation fastener assembly for restraining rail	Each	$463.87	1
	Direct fixation rail fasteners	EA	$68.21	2
	Direct fixation rail fasteners (captive to plate clips)	EA	$150.79	8
Floating Heel Blocks Including Joint Bars		Each	$185.86	4
Frogs				
	#8 self-guarded frog excluding tie plates	Each	$8,765.23	1
	#10 rail bound manganese frog, rail	Each	$10,772.90	2
	#8 rail bound manganese frog, rail	Each	$10,787.88	1
	#15 rail bound manganese frog	Each	$15,335.94	2
	#20 rail round manganese frog	Each	$18,803.54	1
Grade Crossing Panels		LF	$341.43	5
Insulated Rail Joints				
	Insulated joint rail joint kits	Each	$481.43	1
	Insulated rail joint plug	EA	$1,371.29	1
Rail				
	Non-welded rail blank ends	Ton	$1,159.25	4
	Continuous welded rail, standard	TON	$1,308.57	12
	Continuously welded rail, high strength	Ton	$1,395.40	5
	Pre-curved rail	TON	$2,064.96	2
Rail Lubricator		EA	$9,141.93	1
Shop Rail Welds		Each	$333.08	5

Work Description/Bid Item			Units	Average Unit Cost (4/15/07)	No. Bids in Average
Stock Rail—39 ft			Each	$1,230.04	17
Switch Points					
	19' 6" switch point rail, straight		EA	$1,413.39	4
	19' 6" switch point rail, curved		EA	$1,615.78	6
	33-ft switch point rail, straight		EA	$2,064.66	4
	33-ft switch point rail, curved		EA	$2,118.95	1
	26' 0" switch point rail, straight		EA	$2,309.53	5
	26’ 0" switch point rail, curved		EA	$2,422.87	5
	39' 0" switch point, straight		EA	$4,176.44	3
	39' 0" switch point rail, curved		EA	$2,326.66	1
	56' 3" curved switch point		EA	$7,331.45	1
Turnouts					
	No. 6 turnout (No. 12) rail bound manganese frog, ballasted track, concrete ties, fully guarded		EA	$104,480.99	10
	No. 6 turnout, self-guarded frog, ballasted track, concrete ties		EA	$69,399.47	64
	No. 8 equilateral turnout, direct fixation		EA	$98,954.94	4
	No. 8 turnout, rail bound manganese frog, ballasted track, concrete ties		EA	$95,036.66	4
	No. 8 turnout, rail bound manganese frog, concrete ties		EA	$103,349.27	4
	No. 10 turnout, rail bound manganese frog, concrete ties		EA	$112,133.44	6
	No. 10 turnout, rail bound manganese frog, direct fixation		EA	$105,520.39	4
	No. 15 turnout ballasted		EA	$74,420.44	3
	No. 20 turnout ballasted		EA	$59,536.35	1
	Crossovers				
		No. 10 crossover	EA	$76,182.72	2
		No. 10 double crossover, ballasted	EA	$193,493.14	2
		No. 10 single crossover, concrete ties	EA	$210,230.93	4
		No. 10 single crossover, direct fixation	EA	$215,713.02	4
		No. 15 single crossover, ballasted	EA	$137,188.13	8
		No. 20 single crossover, ballasted	EA	$163,724.96	1

Ten contracts from 1992 through 2006; unit costs escalated at 3% from bid date to 4/15/07.

TABLE 16
TRACK CONSTRUCTION UNIT COSTS SE-04 CONTRACT BID SUMMARY

Work Description/Bid Item	Units	Average Unit Cost (4/15/07)	No. Bids in Average
Concrete Crossties—Standard	EA	$335.46	2
Direct Fixation Installation—Owner Furnished Material	LF	$145.94	6
Direct Fixation Resilient Tie Track	LF	$449.48	1
No. 6 Double Slip Switch, Ballasted Track, Concrete Ties	EA	$218,576.91	2
No. 6 Double Crossover, RBM Frog, Ballasted Track, Concrete Ties	EA	$294,173.59	4
No. 8 Equilateral Turnout, Concrete Ties	EA	$154,476.42	1
No. 8 Equilateral Turnout, Direct Fixation	EA	$194,057.64	2
No. 10 Turnout, Railbound Manganese Frog, Direct Fixation	EA	$261,558.27	4
No. 10 Crossover	EA	$408,045.54	6
No. 10 Double Crossover, Concrete Ties, 33' 0" Track Centers	EA	$550,455.41	2
No. 15 Turnout, Owner Furnished Material	EA	$53,327.91	1

10 Contracts from 1992 through 2006; unit costs escalated at 3% from bid date to 4/15/07; contractor furnished material and installation unless noted.
RBM = rail-bound manganese.

CHAPTER FOUR

CASE STUDIES

Three agencies—identified here as A, B, and C—were interviewed on their maintenance organization, practices, and budgeting processes. This section presents the results of the interviews.

The interviews were intended to capture the practices, innovative approaches, and lessons learned in track components, planning, and budgeting that reflect general industry conditions and opinions. The following shows responses to the posed questions.

1. Organization and Budget
   i. What is the organizational relationship between track maintenance staff, engineering, and operations? Simple stick diagram.

A	Track & Structures/Systems Maintenance is under the Chief Operating Officer in Operations. Engineering is currently consolidated in a separate independent unit. There is a staff of 1,241 in the Track Structure System Maintenance Department, 54 in the Chief Engineer's office, and 50 in the Engineering and Architecture Department.
B	Maintenance and Engineering are under the Chief Engineer, who reports to the Operations Manager.
C	Engineering and maintenance for light and heavy rail track are under the Director of Track and Civil Engineering, who reports to the Director of Engineering and Maintenance (essentially the Chief Engineer). Capitol Construction is a parallel department to the Engineering and Maintenance department. Both the Engineering and Maintenance and the Capitol Construction departments report to the Assistant General Manager, Engineering, Maintenance, and Construction. Engineering, maintenance, and construction are within the overall operating arm of the organization. The track staff (engineering and maintenance) totals about 300 personnel, including 15 inspectors, 170 track personnel (foremen, laborers, welders, and equipment operators), and 30 managers and administrative personnel.

ii. Define track maintenance department as it is considered for budgeting purposes. What is the scope of defined departments? Are engineering and maintenance co-mingled for funding purposes? Is maintenance an operations responsibility? Are relationships too muddy to easily define?

A	Track maintenance department deals strictly with routine and replacement track maintenance. The budget is clearly defined. The agency has an entirely different department for all expansion, capital projects, reimbursable projects, and major equipment renewals or upgrades. Both departments' work is exclusive, with virtually no intermixing of capital funds and maintenance budgets.
B	Track maintenance and track engineering have discrete budgets from other departments and functions. Track engineering is a staff function within the Chief Engineer's budget. Track maintenance is a subordinate department with a separately defined budget.
C	The budget follows cleanly the organization chart, with budget for the track maintenance and engineering clearly delineated. Engineering is considered integral to track maintenance functions, and is budgeted with that intent. The track department does support capital programs. Capital program cost centers reimburse those support efforts; there is essentially a zero net effect from capital programs (or other department funds) on the track maintenance budget.

iii. What is the annual track maintenance budget?

a. Is there a discrete line item for track maintenance?

A	B	C
Included in the overall track maintenance budget	Track maintenance budgets are proprietary.	Yes. The funding stream and accounting system provide two sources of funds for the track and civil department. These are the general operating fund and the IRSP (Infrastructure Renewal Safety Program, a state program).

iv. What other items in the budgets will fund activities for track departments (in addition to any overt budget line items directly for track maintenance)?

A	B	C
Maintenance items are explicitly defined in the budget.		The capital programs have line items for the support mentioned earlier.

2. Are there capital items that will use or add to track department resources? If yes, what are typical annual percentages (of the total budget)? What is the nature of these expenditures (typically)?

A	Capital contribution
B	Capital programs (extensions, system improvements) are separate budget items from operations (including track maintenance). Capital program funds do not support track maintenance. Capital construction programs do procure spare parts, operator training, and manuals for use by maintenance. Maintenance personnel time for training and associated capital program activities is not compensated from capital programs.
C	Large maintenance equipment is capitalized; repairs to maintenance equipment are operating expenses. All other maintenance expenses (see preceding responses) are within the department's budget.

v. What are the general staff levels for budget line items that contain the track maintenance budget?

A	B	C
About 218 in total	There are 65 track maintenance staff positions.	Please see the response to question 1.b.i, above.

3. Direct track maintenance for normal wear and degradation
   b. Normal track upkeep—maintenance for expected wear and tear from operations. Provide average annual cost in man-hours (typical year) and percent of budget in 1.b.iii. for:
      i. Inspection
      ii. Rail maintenance
      iii. Turnout maintenance

iv. Surface and line maintenance
v. Ties and fasteners

A	Dedicated maintenance staff. See response to question 1.b., above, for overall manpower levels. No breakdown by trackwork component available.
B	Inspection is ~25% of the routine maintenance budget. Inspectors are required to perform minor maintenance (replace rail clips, tighten bolts, perform minor tamping, etc.) in the normal course of inspection. The remaining activities are on an as-needed basis, which roughly averages 30% for rail (grinding, welding, and replacement), 10% for turnout maintenance, 15% for surface and line, and 5% for ties and fasteners. The balance is for supervision and administration.
C	Inspection is approximately 10% of the effort. The balance of the effort varies between years, depending on needs and planned activity. A fair assessment is the level of effort is spread uniformly between items ii through v. Track inspectors perform inspections 3 days per week and 2 days of maintenance work (work that can be performed without power tools).

c. Non-wear and tear activities. Provide average annual cost (or percent of annual budget) due to (some of these overlap; include a cost burden only once): (opinions and estimates are OK)
i. ROW upkeep (trash removal, fences, site damage)
ii. Operating damage (run-through switches, derailments, clearance violations)
iii. Public complaints
iv. Vandalism, public damage
v. Weather, acts of God, imponderables that occur anyway

A	Closed system, this is a relatively small part of the budget.
B	These are a negligible portion of the actual annual expense. The physical design of the system controls external mishaps. There are a number of public complaints annually, of which 99% are for noise from rail corrugations. This provides time to accomplish rail grinding.
C	These are negligible costs.

4. Working in the transit environment. What is the level of effort for fielding a crew to perform a maintenance task as the percentage of the tasks direct cost? This question asks about the

overhead level of effort to plan, get operating time, get crews organized, and get to a site, before and after executing a task. The answer will be a percentage (such as 50% or 100%) of the cost of doing the task. Include typical waiting time and all other things that drag on direct maintenance productivity.

A	Routine night maintenance is performed in a 3-hour nightly work window (100% premium), major replacements get weekend or extended nightly outages (50% to 75% premium). Getting track outage time is a major difficulty, as is mobilizing from agency yards to the site.
B	The manpower to accomplish maintenance is on the order of 175% of the productive effort (the effort to change a rail or a frog, for example). A portion of the added expense is safety monitors (separate department) required by operating rules, training for maintenance staff in operating and safety rules, and administrative time to plan track access (track access is planned in the weeks prior to actual work, with two weeks minimum notice). Additional cost is required for any work supported by other departments, such as signal (switches, any excavation) and traction power (third rail maintenance activities).
C	The added effort to perform a task is about 50% of the productive time performing the task. The track maintenance access window is from 12:30 a.m. to 4 a.m. daily, with single track access beginning at 9 p.m. daily.

5. Perfect world budget. If you could construct an annual budget without constraints that would produce track performance to a uniform standard (acceptable to you), what would that budget look like?

A	Not sure that this is possible, as an unconstrained budget would still be restricted by the unavailability of track time. One item that might be provided in the budget would be programmed maintenance. For some of the older rail approaching 600–700 MGT and original tunnel fasteners at the 30-year mark, an accelerated replacement program (and budget) will be necessary.
B	An ideal budget would (a) be consistent over multiple years, (b) have a programmed maintenance component for replacing aging track material, and (c) acknowledge occasional support for out-of-face replacements or upgrades. The agency has adopted limited programmed replacement of Direct Fixation fasteners on an annual basis. The agency has implemented budget allocations for rail grinder, track

	geometry car, and other major investments to replace equipment that is long past its economic life. Even an ideal budget will have constraints, with train operations having priority for track time.
C	Within the framework of the agency, the current budget process usefully acknowledges maintenance ideals. While the ideals are not always met, the system has removed substantial deferred maintenance and now is a capable system, meaning that it is meeting track speed and reliability standards set forth in our annual program goals.

6. Budgeting. How is the budget established?

A	Budget is a function of staffing levels and funding.
B	Budgets reflect the available funding, which varies with the local economy. As example, recent source funding resulted in staff cuts, which now are in the process of being restored.
C	The budget process is based on last year's budget, with historical allocations. Head count is basic to the track department, and to each of the above defined categories of budget methods. The process, while not specifically demand-based, is sufficient to do normal planning. The budget is reliable enough to project activities into subsequent years. Budgets can have a 5% increase or decrease from that expected. The agency recognizes that catch-up maintenance has penalties to be avoided. Funding for the last 7 to 8 years is stable, reflecting recognition that the cost of severe deferred maintenance is lost ridership. The agency uses project cost tracking, providing a validated cost database for budget estimates.

7. Maintenance philosophy. Where is the maintenance philosophy for your system stand between extremes of uniform maintenance (preventive maintenance at its best) and crisis maintenance (wear out the track completely then replace, with absolute minimum annual maintenance)?

A	Maintenance philosophy is striving toward balance and usually results in a limited pursuit of program maintenance items.

B	The maintenance philosophy is reasonably balanced with a mind toward the ideal of preventive maintenance and accomplishments rooted in the reality of available resources. The system is free of chronic slow orders, immediately corrects any violations of the track safety standards, and vigilantly monitors (and plans to upgrade) locations with developing degradation.
C	The maintenance philosophy is guided by annual program goals to meet service reliability for on-time train performance, among other measurable parameters. Success in attaining these goals has been steadily improving, with current measures meeting expectations. The agency has a 5-year plan with some multiyear projects. Materials are purchased a year in advance.

8. Track Design. What are examples of good design details that have low maintenance demand? What are examples of lousy design details that have a higher than normal maintenance demand?

A	The agency has gone away from its original turnout geometries, commencing with delivery of rail cars with different (stiffer) suspensions, which increased track wear and derailments. Straight point turnouts were replaced with guarded turnouts (Nos. 6 and 8 TO's), low switch angle/uniform radius turnouts (Nos. 10 and 15 TO's). Unguarded No. 8 TO's are retained for non-revenue service vehicle tracks. Much like Amtrak, the agency has gone with multi-tie plates on its frog and switch areas for both ballast and DF track to control movement. Stray current is a problem. Initial installation of Foster H-series fasteners in line extension has exhibited bolt fractures and alignment problems in the switch and frog areas. The agency uses a high restraining rail (115-132RE with 1/4" stepped plate), which seems to control restraining rail wear. Design is a bolted split block with shims. One installation with U69 discrete bracket restraining rail that failed after 8 years. Biggest criteria for our track design are to replace components quickly where necessary. Many of the rail welds have been removed in frog heel and toe joints for ease of replacement. We use Pandrol 'e' clips. Fastclips were rejected as requiring special tools for removal. We have a simple third rail expansion joint that tends to wear in the slotted holes and create a joint profile offset and loss of third rail shoes. We have a program to

	replace third rail expansion joints in tunnels with air gaps (two end ramps). Study continues on discrete plinth construction vs. the current practice of using DF grout pad construction. Over the years, TSSM has developed a multi-fastener pad that is far more durable than the single plate counterpart. Plinth construction was used on one extension; evaluation is underway. One anomaly is the use of zero-cant DFF.
B	The system was generally designed with sound characteristics, such as generous curvatures, and constructed for endurance. The system pioneered Direct Fixation fastening systems (Long Island RR was the first implementer as a result of our construction schedule), which had bolts for rail fastenings and for anchor bolts. The first generation bolts are being replaced with elastic rail clips and new construction will use resilient ties to remove anchor bolts. We have now instituted Facility Standards that include track design criteria, track standards, and standard track specifications. These standards are already making a difference in designs and procurements that will significantly reduce future maintenance. The Standards are aiding inter-departmental communication, with signals and traction power engineers and maintenance personnel able to integrate requirements with the track engineers.
C	

9. Maintenance limits. What are the condemnation wear limits for replacing rail in curves, switch points, and stock rail? What criteria are used for track condition (such as FRA track classes)? Is the agency planning to adopt the APTA Track Safety Standards? (obtain copy of Track Safety Standards).

A	Agency uses a simple lateral condemnation limit for rail. It does not follow FRA maintenance standards, and is not planning on adopting APTA Track Safety Standards, but developed its own Track Maintenance Manual.
B	We will adopt the APTA Track Safety Standards, while reserving judgment where the Standards may not be compliant with our safety rules or not suitable for a circumstance. Condemnation limits are similar to AREMA. Criteria for track condition uses the FRA approach, with track class speeds modified for our signal system speed increments.

C	

10. Design Criteria. What are the Design Criteria values for the following parameters?

Parameter	A	B	C
Maximum superelevation imbalance	4 ½'	4.5”	
Minimum curve radius	755' main track, 300' yard	1000’	
Use of guard rail	800' R main track, 500' R yard tracks	along the outside edges of aerial structure crossover locations	
Standard mainline turnouts	No. 8 guarded, No. 10, No. 15, with No. 15’s used only at major junctions	numbers 10, 15, and 20	
Maximum grade	4.0%	3%, except 1% in stations	

11. Maintenance practices: Which of the following are employed and what are the criteria for applying the practice?

Parameter	A	B	C
Rail lubrication	Manual rail gauge lubrication on unguarded No. 8 turnouts, wayside lubricators on most restraining rails. Wayside lubrication is limited on high rail of curves due to braking concerns.	Rack curves with a radius of 3,000 ft or less, ahead of high wear turnout location, on restraining rails, and in all tracks in the throats of yards	

Parameter	A	B	C
Rail grinding (including turnout grinding)	Limited top of rail grinding for corrugation only, very little rail profile grinding, virtually no turnout grinding	As required. Use in-house 5-stone grinder	
Rail flaw and track geometry inspection	Minimum six times a year for each unit, with the rail flaw detector getting priority	Two times annually using in-house inspection rail vehicles, with additional inspections for special occurrences	
Curve rail transposition	None	Not done	

12. Maintenance Equipment. Describe in-house maintenance equipment (number of locomotives, flats, grinding trains, rail flaw cars, track geometry cars, tampers, mobile cranes, speed swings, etc.).

A	B	C
Equipment housed in eight yards—grinding, rail flaw, and geometry cars are all by contract)	Dedicated track maintenance equipment includes rail grinder, track geometry car, and several versions of tampers and tamper-liners. Inter-departmentally shared maintenance equipment includes self-propelled flats with integral crew compartment and boom cranes.	

13. Track material stocks. What is the level of spare rail, frogs, switches, fasteners, ballast, ties?

A	B	C
About 30 turnouts and about 2,000 LF of track.	Stocks include supplies for approximately 3 years maintenance demand for turnout components and approximately ½ track mile of open track components.	

14. Multiple types of track material designs. What are the cost inefficiencies of lack of standards or for having to stock spares for multiple product design for the same function (switch points, frogs, fasteners, etc.)?

A	Track standards being finalized: Cost is mostly in spare parts and the high cost to maintain unique components. Premium is approximately 50% whenever this occurs + lost time. New DFF and ballasted track components are standardized.
B	The cost of multiple designs from various extensions has created stocking, inventory tracking, and lost crew time. Recently implemented track standards will curtail and eventually eliminate this source of cost.
C	

CHAPTER FIVE

CONCLUSIONS

BUDGETS

The limited survey responses here appear to indicate differences in opinions on adequacy of budgets between newer and older systems, with an apparent demarcation point in those opinions for system age between 20 and 30 years. Older systems believe that budgets are preset before assessing maintenance demand, whereas newer systems believe that budgets are based on needs.

These results suggest that funding sources perpetuate maintenance levels that are present at the initiation of a transit's life cycle. Although this may be suitable as a baseline reference for funding, aging systems require different annual funding assessments to help through system life-cycle transitions. The life-cycle transitions appear to occur at 20- to 30-year intervals, according to limited synthesis information here.

The older agencies appear to believe that budgets are based on available funding and maintaining staff levels. The common comment is that budgets lack long-term programmed maintenance items.

TRACK STANDARDS

The interviewed agencies either have or are on the verge of having true track standardization. The cost of lack of uniform standards is reportedly significant, suggested as 50% premium on the basic cost of maintenance from errors (caused by similar but wrong parts on a job), lost time, and extra stocking costs.

Those interviewed highlighted additional benefits of standardization to enhance the system with proven components and curtail entry of untried or undesirable components. Standardization further provides a means for communicating the correct concepts to other departments, to consultants and managers, resulting in compliant designs and maintenance. Standardization removes unproductive time of key personnel in educating staff, consultants, and managers on expected results.

The interviewees also implied that track performance is achieved by adjusting track standards to the vehicles on their system. Solutions are being implemented through track standards.

A comprehensive review of track maintenance costs might consist of documentation of industry agency construction and maintenance standards, along with an assessment of vehicle characteristics that affect track maintenance demand.

MAINTENANCE STRATEGIES

The interviews and survey appear to indicate that maintenance may tend more toward emergency response than most would prefer. One respondent stated succinctly that an “ideal” maintenance strategy must embody the realities of limited track access time. The lack of track access time appeared to be the factor most often cited as the major added cost of rail transit compared to other rail applications.

It appears from the limited survey and interviews that maintenance strategies are being tested and implemented as a routine responsibility, with some elements, such as rail lubrication, rail grinding, and advanced materials, advancing to the level of specified standards. The process is informal, but effective.

LIFE-CYCLE MAINTENANCE DEMAND

No information was received on this topic. A follow-on program is suggested to address issues of track component life expectancy and levels of maintenance required to attain or extend track component life.

AGENCY MAINTENANCE UNIT COSTS

This report asked about reasonable rail transit track maintenance costs, along with the factors that contribute to those costs.

Limited survey and interviews show that the lack of track access appears to double maintenance costs. The bid responses also provide an idea of contractor unit costs to perform tasks, generally without train interference.

Agencies report productively performing rail replacement under constrained conditions, measured by contractor rates from capital projects.

It appears that transit agencies perform maintenance tasks without the access afforded to contractors for most capital projects. Compared with a contractor, an agency may have an additional premium for unplanned occurrences such as broken rails, whereas contractors reportedly have the advantage of planning. Agencies do not always appear to have that option.

The practices to extend component life and increase reliability are partially documented in this report, and include rail lubrication, advanced rails, and rail grinding. A further study to benchmark current component life cycles would be appropriate to define the measures, technologies, and practices that will aid agencies’ efficiencies.

SUMMARY

This synthesis documents limited agency survey and interview information on agency practices, innovations, and lessons learned in track maintenance costs.

It includes a review of literature related to track maintenance costs. The literature indicates that track maintenance costs are beneficially affected by technology implementation in materials as well as in monitoring and detection devices.

A primary reason for replacement of track components is wear- and fatigue-based failures. The economic modeling efforts identified in the literature review conducted during this study did not show any strong links between maintenance costs and the amount of traffic. This is likely because the modeling efforts identified used statistical methods relying on general characteristics of the track and vehicles rather than specific rail vehicle characteristics, track characteristics, and local rail traffic characteristics. Models do exist, however, that relate track maintenance costs to the specific characteristics of track, vehicles, and traffic. These models and the results of their specific applications are usually proprietary and not available to the public.

The survey showed that reliable maintenance cost information would be most useful to agency staff as a tool to explain budget proposals, and to document for management as well as for funding sources the basis of budget requests. Younger agencies appear to believe that their budgets are based on maintenance demand and are reasonably adequate, whereas older agencies believe that their budgets are inadequate. The differences in these opinions appear to relate to a 20- to 30-year aging of system, among others factors at work.

Estimates of specific track maintenance tasks showed consistency among older system level-of-effort estimates. These estimates also illustrate the interview opinions that the largest component of track maintenance cost is lack of track access. The productive cost to conduct a task has at least an equal unproductive cost caused by lack of track access. The respondents also reported that agencies are removing unproductive constraints and improving maintenance costs by implementing track standards.

Limited survey and interview comments suggest that budgets are constructed more around maintaining staff levels than on maintenance demand. A consistent comment from agencies appears to be budget-related—the lack of programmed maintenance planning and a commitment to multiyear (budget) commitments to support programmed maintenance.

The report suggests that compared to contractor costs, the agencies are efficient in conducting maintenance tasks. The agencies have a significant cost premium, however, associated with lack of track access that normally is not a constraint on contractors.

FINDINGS: GAPS IN INFORMATION AND KNOWLEDGE

This report provides a limited view on factors that influence track maintenance costs. It should be considered a beginning. The gaps in information and knowledge are as follows:

- Clear understandings of resources (skill base, equipment, time) and needs (maintenance demand, operations, track access, etc.). The survey for this project failed to elicit responses from non-agency designers, researchers, regulators, and public funding sources on their interest in track maintenance costs. Framing track maintenance costs in a manner that is relevant to different uses is critical and might be explored in the future.
- Wear and degradation life-cycle mechanics. Based on this report's results, these mechanics appear to have periods of 20 to 25 years.
- Unit cost and unit levels of effort for specific track tasks, segregating productive effort from required indirect effort (preparation, waiting for access, etc.).
- Assembly of readily available costs into databases for agency use, such as contract bid results.

SUGGESTED RESEARCH NEEDS

Research needs for track maintenance costs include the following:

- Further development of demand-based maintenance budgeting tools, including a database system for collecting maintenance activity against specific track components, geometry, and traffic at specific locations
- Further development of mechanistic relationships of track component wear, degradation, and fatigue from traffic loads, frequencies, and vehicle behavior
- Further development of models that link the previous items specifically aimed at life-cycle cost planning with planning horizons greater than 30 years.
- Further exploration of agency- or industry-wide track standards.

REFERENCES

1. Camp, W.M., *Notes on Track*. Published by the author, 1904, 532 pp.

2. Gauntt, J., "Railroads Continue to Strengthen Market Position," *Crossties Magazine*, Sep./Oct. 2003, pp. 2–7.

3. Chapman, J.D. and C.D. Marland, *The Effects of Fixed Plant and Rolling Stock Technology on Railroad Track Costs*, American Railway Engineering and Maintenance of Way Association (AREMA) Annual Conference, Feb. 1998.

4. Larsson, D., *A Study of the Track Degradation Process Related to Changes in Railway Traffic*, Lulea Railway Research Center, Lulea University of Technology, Lulea, Sweden, 2004.

5. Stalder, O., *International Benchmarking of Track Cost*, American Railway Engineering and Maintenance of Way Association (AREMA) 2001 Annual Conference, p. 15.

6. Berrang, S.A., S. Zimmerman, and J. Gast, "Road Map to a State of Ideal Repair: Bringing the MTBA's Capital Assets to Ideal Standards and Sustaining Them over Time," *Proceedings of the 2001 APTA Rail Transit Conference*, June 2001, 13 pp.

7. Keeler, T., "Railroad Costs, Returns to Scale, and Excess Capacity," *Review of Economics and Statistics*, Vol. 56, No. 2, 1974, pp. 201–208.

8. Caves, D.W., L.R. Christensen, and J.A. Swanson, "Productivity in U.S. Railroads, 1951–1974," *Bell Journal of Economics*, Vol. 11, No. 1, 1980, pp. 168–181.

9. Bitzan, J.D., "Railroad Costs and Competition: The Implications of Introducing Competition to Railroad Networks," *Journal of Transport Economics and Policy*, Vol. 37, No. 2, May 2003, pp. 201–225.

10. Bereskin, C.G., "Estimating Maintenance-of-Way Costs for U.S. Railroads After Deregulation," *Transportation Research Record: Journal of the Transportation Research Board, No. 1707*, Transportation Research Board, National Research Council, Washington, D.C., 2000, pp. 13–21.

11. Daljord, O.B., *Marginalkostnader i Jernbanenettet*, Ragnar Frisch Centre for Economic Research, Oslo, Norway, 2003.

12. Tervonen, J. and T. Idstrorn, *Marginal Rail Infrastructure Costs in Finland 1997–2002*, Finnish Rail Administration, Helsinki, Finland, 2004.

13. Gaudry, M. and E. Quinet, *Rail Track Wear-and-Tear Costs by Traffic Class in France*, presented at the First Conference on Railroad Industry Structure, Competition and Investment, Toulouse, France, 2003.

14. Johansson, P. and J.-E. Nilsson, *An Economic Analysis of Track Maintenance Costs*, *Transport Policy*, Vol. II, No. 3, 2004, pp. 277–286.

15. *Railway Reform and Charges for the Use of Infrastructure*, European Conference of Ministers of Transport, Brussels, Belgium, Apr. 4, 2005.

16. Anderson, M., *Marginal Cost Pricing of Railway Infrastructure Operation, Maintenance, and Renewal in Sweden, From Policy to Practice through Existing Data*, *Journal of the Transportation Research Board, No. 1943*. Transportation Research Board of the National Academies, Washington, D.C., 2006, pp. 1–11.

BIBLIOGRAPHY AND OTHER RESOURCES

1. Larsson, D. and J. Gunnarsson, "A Model to Predict Track Degradation Costs," *Proc., 7th International Heavy Haul Conference*, Virginia Beach, Va., 2001, pp. 437–444.

2. Transit industry configurations (track sections, stations, etc.) and related data are available from Infrastructure Database Survey, American Passenger Transportation Association: www.ntdprogram.com/ntdprogram/data.htm.

3. *Manual for Railway Engineering*, American Railway Engineering and Maintenance of Way Association (AREMA), Lanham, Md., Chapter 16. See also the AREMA Annual Proceedings.

4. National Transit Database, maintained by the FTA in compliance with the Uniform System of Accounts (USOA) and associated laws for reporting by the transit industry. Transit industry data and reporting requirements may be found at www.ntdprogram.gov/ntdprogram/.

5. For an alternative damage factor relationship, see Zarembski, A.M., *The Implications of Heavy Axle Load Operations for Track Maintenance on Short Lines*, AREMA 2000 Annual Conference Proceedings.

6. Standard for Rail Transit Track Inspection and Maintenance, Vol. 6—Fixed Structures, APTA RT-5-FS-002-02, American Public Transportation Association, Washington, D.C., 2006.

Source Information on Industry Funding

The following are example Internet locations of transit funding information. Federal budgets and programs may be found under the auspices of the U.S. Department of Transportation and its member agencies (FTA, FHWA, FRA, etc.). State funds, comprising a significant share of transit funding, are typically available through each state's transportation budget. Local public funds at the city and county levels may be less consistently available. Major transit agencies publish their current budgets on their websites. All publicly funded agencies are required to publish their budgets.

The following are selected web locations of relevant regulatory and funding agencies information on rail transit matters. This list is not intended to be exhaustive.

www.fhwa.dot.gov/tea21/index.htm

www.dot.ca.gov/hq/transprog/stip.htm

www.dot.ca.gov/hq/transprog/index.htm

www.dot.ca.gov/

www.catc.ca.gov/

www.dot.gov/

APPENDIX A

AGENCY, INDUSTRY QUESTIONNAIRE

SURVEY FORM

Track Maintenance Cost

TCRP Project J-7 Synthesis Topic SE-04

I. Participant and Agency

Your primary responsibility: Agency Administrator

Name:

Title:

Affiliation:

Address:

City:

State/Province:

Zip/Postal Code:

Phone:

E-mail:

II. Interest in Track Maintenance Cost Information

Using a scale of 1 to 10 (1 being most important), indicate the following uses of track maintenance information in the order of importance to you. Use the "Notes" box for any clarifying comments you wish.

Rank Notes

II.1. Resource for Preparing or Justifying Maintenance Programs or Budgets

II.2. Reference for Evaluating Maintenance Programs or Budget Proposals

II.3. Reference for Track Upgrade Cost Assessments, Life-Cycle Cost Assessments

II.4. Resource for Estimating (construction estimates, maintenance manpower est.)

II.5. Benchmark Reference for Internal Assessments (compare to industry norms)

II.6. Allocate Maintenance Costs (for multiple traffic modes, cost centers, etc.)

II.7. Justify Funding Requests (federal, state budgeting)

II.8. Evaluate Submittals (bid submittals, etc.)

II.9. Other: Description:

III. Budgeting Processes

Please indicate your experience with track maintenance budget processes.

III.1. I typically participate in annual track maintenance budgeting processes or contribute information for annual budgets. ☐ Yes ☐ No

III.2. Select a response from the drop-down box to each statement that reflects your views of track maintenance budgeting processes and results.

III.2.a. Budgets generally implement an internal long-term maintenance plan. Agree

III.2.b. Budget construction strategically uses capital funds for maintenance purposes. Agree

III.2.c. Maintenance budget amounts are dictated prior to assessing annual maintenance needs. Agree

III.2.d. Maintenance budgets include investments in improved efficiency, technology or equipment. Agree

III.2.e. Maintenance budgets are adequate for routine maintenance. Agree

III.2.f. Budgets are adequate for contingencies. Agree

III.2.g. Comments on budget processes:

IV. Maintenance Unit Cost Estimate

(completed by agency track department personnel)

Part A. On-Site Labor (enter labor hours for each position)

Part A is the level of effort to execute the task once on-site with all the equipment, material, personnel, and track permissions in place.

Item	Description	Superv. Hours	Operator Hours	Laborer Hours	Welder Hours	Notes
A.1	**Rail Replacement:** Replace 1 piece of 39' rail for a detected transverse defect. Mainline tangent track					
A.2	**Frog Replacement:** Replace a mainline No. 10 RBM (or similar) frog					
A.3	**Switch Point Replacement:** Replace a mainline 19' 6" switch point (or similar) and its stock rail					

Part B. Support Effort (enter labor hours for each position)

Part B is the preparation for the work in Part A, including scheduling, assembly of material and equipment, travel to and from staging area, waiting for track access. Assume travel times are an average for the system.

Item	Description	Superv. Hours	Operator Hours	Laborer Hours	Welder Hours	Notes
B.1	**Rail Replacement:** Replace 1 piece of 39' Rail for a detected transverse defect. Mainline tangent track.					
B.2	**Frog Replacement:** Replace a mainline No. 10 RBM (or similar) frog					
B.3	**Switch Point Replacement:** Replace a mainline 19' 6" switch point (or similar) and its stock rail					

Part C. Other Direct Expenses (enter description and dollar amount of expenses)

Part C is an estimate of expendables (fuel, blades, etc.) and other direct expenses of performing the work in Part A. Include any third party expenses (such as testing) that is a normal expense. Do not include track material costs or equipment capital costs. Base distance–variable costs on an average systems distance.

Item	Description	Cost Description	Cost	Notes
C.1	**Rail Replacement:** Replace 1 piece of 39' rail for a detected transverse defect. Mainline tangent track			
C.2	**Frog Replacement:** Replace a mainline No. 10 RBM (or similar) frog			
C.3	**Switch Point Replacement:** Replace a mainline 19' 6" switch point (or similar) and its stock rail			

Part D. Comments of Maintenance Unit Costs

V. Track Inspection

(by operating agencies only)

V.1.a. Number of dedicated track inspectors _______

V.1.b. Track inspector percentage of total track staff (total staff of foremen, operators, inspectors, laborers) _______

Type of Inspection	Main Line	Yard	Switches
V.2.a. Rail Flaw Car			
V.2.b. Track Geom. Car			
V.2.c. On Foot			
V.2.d. Hi Rail			
V.2.e. Train			

VI. Material and Construction Bid Results

(by operating agencies only)

Please provide bid results from all public procurements and construction contracts that contained any track construction or track material. The preferred information is a copy of contract bid summaries showing bid line items, units of measurement for the bid line item, the line item quantity, and unit cost bids for each line item from all bidders (not just the winning bid). Please annotate the summary with the bid closing date (year is close enough), and the contract reference. If a line item description is vague, please add annotations to clarify the specification's scope for the line item. This request is for as many contract package results that can be assembled without excessive effort by participants. Please mail these materials to:

Larry Daniels

4222 Curragh Oaks Lane

Fair Oaks, CA 95628

E-mail: ledaniels@trackengineer.com

VII. Component Life Expectations

(completed by agency track department personnel)

VII.1 Replacement Quantities and Frequencies

On average, for mainline track only, how many of the following track components does your system replace annually and what is the estimated age (in years) of replacements.

VII.1.a. Rail (lineal feet) _______ Approx. Average Age _______

VII.1.b. Switch Point (ea) _______ Approx. Average Age _______

VII.1.c. Frogs (each) _______ Approx. Average Age _______

VII.1.d. Comments:

VII.2 Reasons for Replacements

Approximate Percentage of Replacements

(enter as decimal: enter ".0551" for 5.51%)

	Wear	Defect	Accident	Vehicle Caused	Other
VII.2.a. Rail					
VII.2.b. Switch Point					
VII.2.c. Frog					

VIII. Use of Contractors for Track Inspection and Maintenance

(completed by agency track department personnel)

Please select the frequency of use for each category and, if "other," a description. You may enter and select a different frequency of use if none of the responses fit your circumstances.

VIII.1. Inspection Services

Frequency of Use

VIII.1.a. Rail flaw ____________

VIII.1.b. Track geometry ____________

VIII.1.c. Other: ____________

Other description: ____

VIII.2. Specialty Maintenance Services

Frequency of Use

VIII.2.a Rail grinding ____________

VIII.2.b. Rail lubrication ____________

VIII.2.c. Other: ____________

Other description: ____

VIII.3. Emergency Maintenance ____________

Description of any contracted emergency track services:

VIII.4. Routine Maintenance ____________

Description of any contracted routine track services:

On completion of this form, please save the completed form to a location that allows you to transmit the file electronically. Then please e-mail the completed form to Larry Daniels, Project Consultant for SE-04, by clicking here.

APPENDIX B

Responding Agencies

Bay Area Rapid Transit District

Dallas Area Rapid Transit

Metropolitan Transportation Authority–New York City Transit

Sacramento Regional Transit District

Santa Clara Valley Transportation Authority

Southeastern Pennsylvania Transportation Authority