Cost-Effectiveness of Railway Infrastructure Renewal Maintenance

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Abstract: U.S. Class I railways maintain their infrastructure through a mix of ordinary maintenance and periodic renewal of infrastructure components. Different railways use different proportions of ordinary maintenance and periodic renewal with little consensus as to the best combination. Furthermore, the cost-effectiveness of emphasizing one method over the other has not been analyzed using empirical data. The objective of this research is to investigate the cost-effectiveness of renewal-based maintenance strategies using high-level financial data from industry sources. The results indicate that maintenance strategies that place more weight on renewal result in lower unit maintenance costs, at least within a specified observable range. The results imply that if railroads constrain renewal maintenance to reduce overall capital expenditures, increasing maintenance expenses will more than offset temporary reductions in capital spending.

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Introduction

Since the railway infrastructure investment boom of the mid-1980s, all Class I railroads have made significant efficiency gains in infrastructure maintenance that are the result of improvements in a number of areas. Technological advancements in infrastructure components such as cleaner and harder steel have reduced asset life-cycle costs. Improved component management has also reduced costs, for example, new developments in rail grinding and lubrication (IHHA 2001). Infrastructure maintenance delivery systems and maintenance equipment technology have changed considerably. Better measurement tools and cross-functional teamwork has transformed traditional engineering practices.

Railroads maintain their infrastructure using a combination of ordinary and renewal maintenance techniques. Ordinary maintenance generally includes the replacement of small quantities of infrastructure components using relatively small track gangs and small equipment, whereas renewal maintenance techniques involve the replacement of larger quantities of components with larger gangs and bigger, more sophisticated, and more expensive equipment. Ordinary maintenance activities are normally charged to operating expense and renewal maintenance programs to capital expenditures according to Surface Transportation Board (STB) accounting requirements (U.S. Senate 1995).

Over the past 20 years, all Class I railroads have increased their use of renewal-based compared to ordinary maintenance, but the degree to which they do so varies substantially (Fig. 1). A Class I railroad is one that met a revenue threshold of $277.7 million in 2004 in the United States (AAR 2005). For the purposes of this analysis we calculated renewal-based maintenance cost using a procedure (described in the section on methodology) that separates railroad capital expenditures into capacity- and maintenance-related components.

Using this definition, we found substantial variation in the way U.S. railroads allocated their maintenance-related expenditures relative to ordinary expense and capital expenditures. Renewal capital spending represents the largest single portion of the capital budget, with renewals accounting for 67% of total capital spending in 2002 (Fig. 2). There is also substantial variation in renewal regimes among international railroads (Burns 1983).

Both renewal capital expenditures and ordinary maintenance expenses represent costs incurred for maintenance of infrastructure, but the engineering management strategy of each differs substantially. Renewal-based maintenance results in better aver-

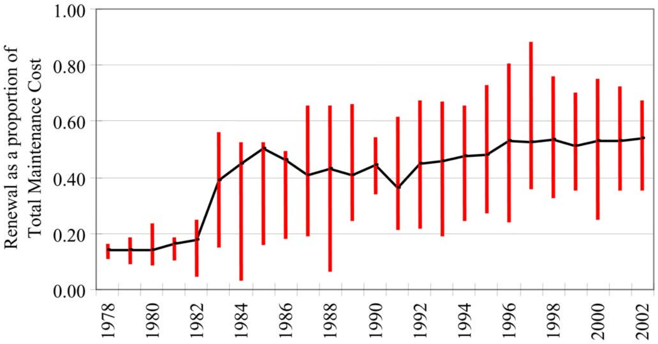

Fig. 1. Renewals as proportion of total maintenance cost (line indicates weighted average and bars indicate range among individual Class I railroads) as derived in this research. Weighted average was calculated on basis of total dollars expended by all Class I railroads.

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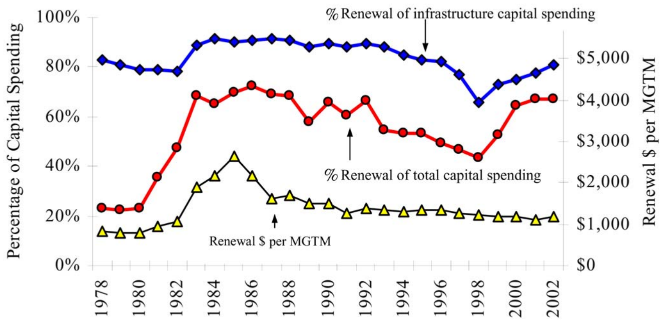

Fig. 2. Renewal capital expenditures as percentage of total and infrastructure capital expenditures, and per million gross ton miles (2001 dollars)

age track condition over the life-cycle of the track but also greater variation in track quality (Fig. 3). Selective ordinary maintenance, on the other hand, is generally used to maintain track to a consistent minimum standard (Burns 1980). Both are required, but an emphasis on one or the other can result in a wide variation of unit maintenance cost. Low-quality track might support relatively high axle loads with a high-maintenance regime; conversely, higher investment can mean higher axle loads and relatively low maintenance (Australian Government 2003). There are also substantial differences in the equipment employed and the schedule of work.

In general, renewals involve capital expenditures made to replace and/or improve infrastructure components in response to, or anticipation of, wear and tear caused by output (defined here as gross ton miles). By contrast, capital expenditures for expansion of facilities (terminals and yards, siding or mainline trackage, signal or dispatching systems, etc.) are made to accommodate rail traffic growth and are called additions. However, post facto railroad financial statements do not segregate capital expenditures into these categories. For the purposes of this study, ordinary maintenance is classified as maintenance that is expensed, renewal maintenance as maintenance activity that is capitalized, and additions as capacity expansion (Table 1).

The question addressed in this paper is whether a relationship can be demonstrated between the engineering management strategy and the overall cost effectiveness of the maintenance function using high-level financial data.

Background

Track maintenance by renewal is not new but was originally developed in the United States in the early 1900s, and even then it was believed to be less expensive (Burns 1981). Renewal was originally performed by hand or with relatively simple machines.

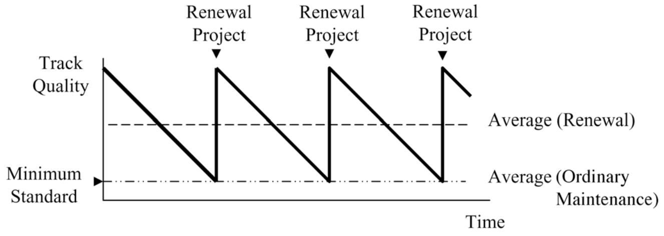

Fig. 3. Comparison of temporal relationship between renewal and ordinary maintenance and track quality

Table 1. Infrastructure Costs

Purpose	Study classification	Accounting category
Infrastructure maintenance	Ordinary Renewal	Operating expense[a] Capital expenditures
Capacity expansion	Additions	Capital expenditures

[a] Excluding depreciation.

Recent changes in technology and practice have led to improvements in overall efficiency for both ordinary and renewal-based maintenance techniques, but the efficiency difference between small section gangs performing selective maintenance (characteristic of ordinary maintenance) and large mechanized gangs (characteristic of renewal maintenance) has increased. This difference results, in part, from improvements in delivery technology including track renewal systems, tie-handling equipment, surface and lining equipment, rail laying equipment, and ballast delivery systems.

Newer maintenance-of-way equipment is safer, cleaner, easier to maintain, and easier to operate than earlier models (Judge 1999). Advances in computerization have improved the reliability of this equipment (Brennan and Kramer 1997). Although improvements have been made in all types of machinery, the high-end, high-production equipment has provided much of the recent productivity improvement (Kramer 1997). These advances and the larger scale of equipment and gangs permit greater economies of scale compared to ordinary maintenance.

Renewal programs also tend to have relatively long planning horizons so that track possessions can be coordinated with transportation operations to minimize service disruptions. These programs may target various track components for replacement, and the scope of individual programs may vary widely. For example, a tie program may target replacement of crossties without renewing the ballast section of the track structure, while a track surface and lining program may renew both crossties and ballast.

Maintenance “blitzes” or “jamborees” are an ultimate kind of renewal program involving most or all track components. The maintenance blitz is used to renew infrastructure in a manner intended to minimize track downtime (Stagl 2001). In North America, the maintenance blitz generally results in track closures between 4 and 12 days (Burns and Franke 2005). Engineering departments coordinate the large renewal projects with transportation and marketing departments (Foran 1997). Maintenance planning has improved through advancements in information technology (Brennan and Kramer 1997), and railroads have transformed material-handling systems as well as on-site production (Kramer 1997).

Renewal activities normally require significant track possession windows that can be difficult to obtain at high train densities. Spot or selective maintenance activities normally require shorter track possession times and thus are less difficult to obtain even at higher train densities. Consequently, high train densities can lead to a reduced reliance on renewal work (Kovalev 1988), although the nature of large Class I railroads today may permit alternative routings in certain regions. Additionally, renewal maintenance often involves high-cost, high-maintenance equipment that necessitates high utilization rates that are difficult to justify for small maintenance regimes. For this and other reasons, routine ordinary maintenance continues to be an important activity in conjunction with renewal regimes to minimize unit maintenance cost (Grassie and Baker 2000).

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Studies on railway maintenance costs do not provide information on the relative efficiency of emphasizing renewal-based maintenance in the United States. Over the period 1994 to 2000, maintenance costs in Europe decreased while expenditures for renewals increased, and enhanced renewal activity generally resulted in lower unit maintenance cost (UIC 2002). Another study found that maintenance and renewal practices on The Netherlands' railway system had a direct influence on its financial and operational performance and that the appropriate combination was critical to overall operational performance (Swier 2004). However, neither of these European studies provided data to support or quantify its conclusions.

These developments lead to the question: does reliance on renewal-based maintenance strategy reduce unit maintenance cost? Presumably the trend toward renewal-based maintenance reflects a belief that it is more efficient or effective in some manner. However, quantitative analyses of data evaluating this question have not previously been published. An analytical method is developed to evaluate this issue using a cross-sectional analysis of Class I railroad financial and operating data reported to the Association of American Railroads (AAR 1978–2002) under rules promulgated by the STB (U.S. Senate 1995).

Methodology

Financial and operating data for individual Class I railroads were modified to permit study of the maintenance components of these data. Railroad financial statements do not segregate capital expenditures into renewals and additions, and therefore a method was developed to estimate renewal capital expenditures so that total maintenance cost, including both renewal (capital expense) and ordinary maintenance (operating expense), could be combined to evaluate total unit maintenance cost. Because of consolidations in the industry during the study period, railroad financial and operating data were consolidated to reflect the 2001 industry structure. A series of standard linear regression analyses and joint hypothesis tests were conducted to compare several alternative models regarding the effect on unit maintenance cost, including the effect of renewal strategy, railroad size, percentage of light-density track miles, and average track density. If renewal strategy is a significant and influential variable in the best model, the hypothesis can be accepted.

Data Preparation

AAR financial data for individual Class I railroads were modified to permit study of the maintenance components of these data. A linear regression analysis was performed and standard statistical tests were conducted. Alternative hypotheses were tested, including the influence of railroad size, average density, and the percentage of light-density track miles.

Infrastructure Cost Index

A railroad infrastructure cost index was developed from components of the AAR cost recovery index (AAR RCR). This was termed the maintenance-of-way railroad cost recovery index (MOX RCR). The AAR RCR is based on data provided by all Class I railroads (AAR 1980–2002) and consists of 10 components, which are then combined into four groups: (1) labor, (2) fuel, (3) material and supplies, and (4) all other. Calculation of the infrastructure cost index considered these cost groups as follows:

1. The labor cost index (labor) reflects changes in the average unit price of wages and fringe benefits. The average wage for maintenance-of-way employees compared to all railroad employees has remained fairly constant over the period of study, and the overall labor index was therefore appropriate for an infrastructure cost index.
2. The fuel cost index (fuel) was not included in the MOW RCR because maintenance-of-way fuel expense is not separately identified in financial reports, and as a result the proportion of fuel cost to overall cost could not be calculated. Additionally, maintenance-of-way equipment is often fueled directly from locomotive diesel storage tanks that are not charged to maintenance. Fuel expenses represent a relatively small percentage of total maintenance-of-way expenditures, and this exclusion should not affect the overall results.
3. The material and supplies cost index (M&S) measures cost changes in a group of items that represent the preponderance of purchases by the largest railroads. This index component was included in the MOW RCR because M&S costs are a significant portion of total maintenance-of-way costs.
4. The other cost index (other) includes equipment rents, depreciation, purchased services, taxes other than income and payroll, and other expenses. This index component was included in the MOW RCR because these costs are a substantial portion of total maintenance costs.

The MOW RCR was then developed by multiplying each index (labor, M&S, and other) by the relative proportion of each component of total maintenance-of-way expense for each year. This calculation is shown below

$$\text{MOW RCR} = [\{R_L(M_L/M_T)\} + \{R_M(M_M/M_T)\} + \{R_O(M_O/M_T)\}]$$

where R_L=AAR labor index; M_L=Class I RR MOW labor expense; M_T=Class I RR total MOW expense; R_M=AAR M&S cost index; M_M=Class I RR MOW material and supply expense; R_O=AAR other cost index; and M_O=Class I RR MOW other expense.

This annual index was then calibrated with 2001 as the reference year (e.g., 2001 index=100%, 1978 index=36.22%) so that all expenses could be referenced in terms of relatively current prices. Maintenance-of-way nominal expenses and investments were then divided by each year's index to obtain constant 2001 dollars.

Defining Maintenance Cost and Renewal Strategy

Gross ton miles and track miles are standard units of measurement for U.S. railroads. Gross tonnage is the total weight of all locomotives, rail cars, and lading that pass over a particular location, and a gross ton mile is 1 gross ton moving over 1 mile of track. Unit maintenance cost was defined as the unit cost of maintaining track, that is, ordinary maintenance expenses plus renewal-based capital expenditures per million gross ton miles (MGTM) produced by railroads.

$$C_M = (E_O + C_R)/Q$$

where C_M=unit maintenance cost (cost per MGTM); E_O=ordinary maintenance operating expense; C_R=renewal capital expenditures; and Q=million gross ton miles (MGTM).

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Table 2. Comparison of Renewal Strategy and Unit Maintenance Cost

	Renewal strategy (%)					Unit maintenance cost (U.S. dollars)				
Road	1978–1982	1983–1987	1988–1992	1993–1997	1998–2002	1978–1982	1983–1987	1988–1992	1993–1997	1998–2002
US	19.3	44.5	41.9	49.6	52.8	5,803	4,737	3,499	2,662	2,217
UP	23.1	48.2	47.4	55.5	62.6	4,885	4,537	3,140	2,153	1,969
BNSF	20.9	44.7	34.8	54.3	62.7	4,966	3,982	2,908	2,565	1,875
CSX	16.3	41.5	40.8	40.6	40.2	6,349	4,815	3,376	2,547	2,589
NS	20.9	40.2	44.2	43.0	38.1	5,167	5,529	5,011	3,522	3,270
IC	19.2	46.0	58.2	74.5	69.1	7,330	3,520	2,118	2,341	2,053
KCS	21.5	44.7	48.9	54.2	53.5	6,659	4,329	4,543	4,079	2,639
SOO	11.5	21.5	35.4	36.5	41.7	7,228	4,730	3,985	4,221	3,255
GTW	15.2	20.7	24.0	26.4	50.9	7,747	5,115	5,159	4,217	2,698

Renewal strategy was defined as the percentage of unit maintenance cost that was allocated to renewal capital expenditures.

$$\mathrm{RS} = C_R/[(E_O + C_R)100]$$

where RS=renewal strategy.

Estimating Renewal-Based Capital Expenditures

Because railroad cost accounting systems do not itemize renewal capital expenditures, we used a modification of the procedure developed by Ivaldi and McCullough (2001) to estimate these expenditures. We compared the annual percentage of ties and rail laid in replacement track to the total amount of ties and rail laid. Railroad financial reports distinguish between ties and rail “laid in replacement track” versus “laid in additional track” from AAR reports (lines 344–372) (ARR 1978–2002). Although the annual capital program has other aspects, the largest portion of capital is for rail and ties (both purchase and installation). An additional step was taken to differentially weight rail and tie percentages because, on average, capital programs normally allocate a slightly higher budget for ties than for rail.

Railroad financial data segregate capital investment for road communications, road signals and interlocker, and road other, with the majority of investment categorized as road other. We assumed that capital expenditures for signals and communications systems were primarily for new technology and major system upgrades, such as replacing extant wire- and relay-based systems with fiber optic, wireless, and digital technologies and were appropriately classified as additions.

Renewal capital expenditures were calculated as follows:

$$P_T = T_E/(T_E + T_N)$$

where P_T=percentage renewal tie program; T_E=number of ties laid in existing track; and T_N=number of ties laid in new track.

$$P_R = R_E/(R_E + R_N)$$

where P_R=percentage renewal rail program; R_E=tons of rail laid in existing track; and R_N=tons of rail laid in new track.

$$P = [(0.6P_T) + (0.4P_R)]$$

$$C_R = C_O \cdot P$$

where C_O=road capital other; and P=overall percent renewal.

Railroad Groupings

The number of railroads reporting financial and operating data (in R1 standard format to the AAR) declined from 36 in 1978 to 8 in 2001. Most of this reduction occurred through mergers and combinations, although there were also several bankruptcies and deletions by changes in Class I railroad definition. Individual railroad data from 1978 through 2002 were combined into the 2001 industry structure. Data for 2002 for Grand Trunk Western and the Illinois Central are not included because these were merged with Canadian National Railway.

Renewal Strategy As Single Independent Variable

The study period (1978–2002) was divided into 5-year increments beginning in 1978. Each component (renewal capital expenditures, ordinary maintenance operating expense, MGTM) was averaged over each time period for each railroad. The model tested was

$$\text{Model 1:} \quad \mathrm{C_M} = a + b\mathrm{RS} + \varepsilon$$

where C_M=unit maintenance cost (dollars per MGTM); a=intercept; b=coefficient for RS; RS=renewal strategy; and ε=error term.

Renewal strategy and unit (infrastructure) maintenance cost were calculated for each railroad over each time period (Table 2). Data for all Class I railroads in the United States were aggregated and labeled (U.S.).

A series of linear regressions were conducted for each time period with renewal strategy as the independent variable and unit maintenance cost as the dependent variable (Model 1). The results indicate that there was a significant relationship only for the last time period, with an R^2 of 0.78, a p value of 0.003, and F/F_c of 3.62 with F_c calculated at a 95% confidence level (Table 3).

Only the last period (1998–2002) has an F-test result indicating significance; it also has the lowest p value and the strongest

Table 3. Influence of Renewal Strategy on Unit Maintenance Cost

Period	R^2	F/F_c	p	a	b
1978–1982	0.49	0.97	0.052	10,134	−20,674
1983–1987	0.23	0.30	0.227	5,637	−2,777
1988–1992	0.28	0.39	0.178	6,056	−5,455
1993–1997	0.42	0.72	0.083	5,105	−3,945
1998–2002	0.78	3.62	0.003	4,706	−4,130

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correlation. However, the R^2, F tests, and p values suggest a trend toward this relationship through the late 1980s and 1990s.

Why was this relationship significant only in the last period, and what could account for this apparent trend? Although track renewal systems have been employed by railroads for many years, a number of changes could explain why this relationship would be statistically significant only in the most recent period:

1. The relationship would not have been apparent in the period prior to depreciation accounting (1978 to 1982) because a large portion of renewal costs were accounted for as ordinary maintenance operating expense due to Betterment Accounting rules in effect during that period.
2. Delivery and information systems and planning technology have continued to improve in recent years, increasing the relative efficiency of renewal-based maintenance in relation to ordinary maintenance.
3. The unit cost differences between ordinary and renewal-based maintenance may not have been statistically apparent until reductions in ordinary maintenance gangs were gradually realized to their present level.
4. Increasing train densities may have increased the relative cost-effectiveness of renewal-based maintenance. From 1978 to 1987, average train density increased by less than 1% per year; from 1988 to 2001 train density increased by almost 6% per year. Reduction of light-density track through sale or abandonment may also have had an effect on the statistical relationships.
5. The railroads were consolidating to fewer and larger networks.

Plots of the data from the last three periods along with their trend lines are shown in Fig. 4.

Alternative Hypothesis: Influence of Size

Previous studies that evaluated the relationship between overall railroad costs and size yielded inconsistent results. Caves et al. (1985) found slightly increasing returns to scale while Barbera et al. (1987) and Lee and Baumol (1987) found constant returns to scale. To evaluate this possibility with respect to infrastructure maintenance costs, a statistical test was conducted comparing the original model to one including a new variable, track miles (TM). The results indicate that while railroad size had significant effect ($p=0.05277$), it had far less influence than renewal strategy ($p=0.00164$) on unit maintenance cost. The results of the joint hypothesis test ($p=0.02056$; $F/F_c=1.1589$) indicate that the interaction between the variables was positive, meaning that, in combination, these variables were better at predicting unit maintenance cost than they were individually. The results suggest that (1) a 10% increase in track miles for the average railroad (equal to an additional 2,091 track miles in 2001) would result in a reduction of $20 per MGTM total maintenance cost, and (2) an increase of 10% in renewal strategy would result in a reduction of $398 per MGTM total maintenance cost, or a 12 to 21% cost reduction, depending on the individual railroad. Furthermore, the results suggest that the track mile variable was significant only in combination with renewal strategy (at the 95% confidence level).

Two plausible explanations exist for the size effect. First, larger railroads may have been slightly more cost-effective in their maintenance programs because they could employ renewal systems more effectively. This could have resulted from more productive use of specialized equipment by optimizing component renewal cycles for any given piece of track, using equipment on a year-round basis (i.e., working south in winter and north in summer), and/or having more options to detour traffic, thereby permitting longer track possession windows. A second explanation for this effect is that a quasi-fixed overhead (engineering) cost may have been associated with maintaining infrastructure regardless of railroad size.

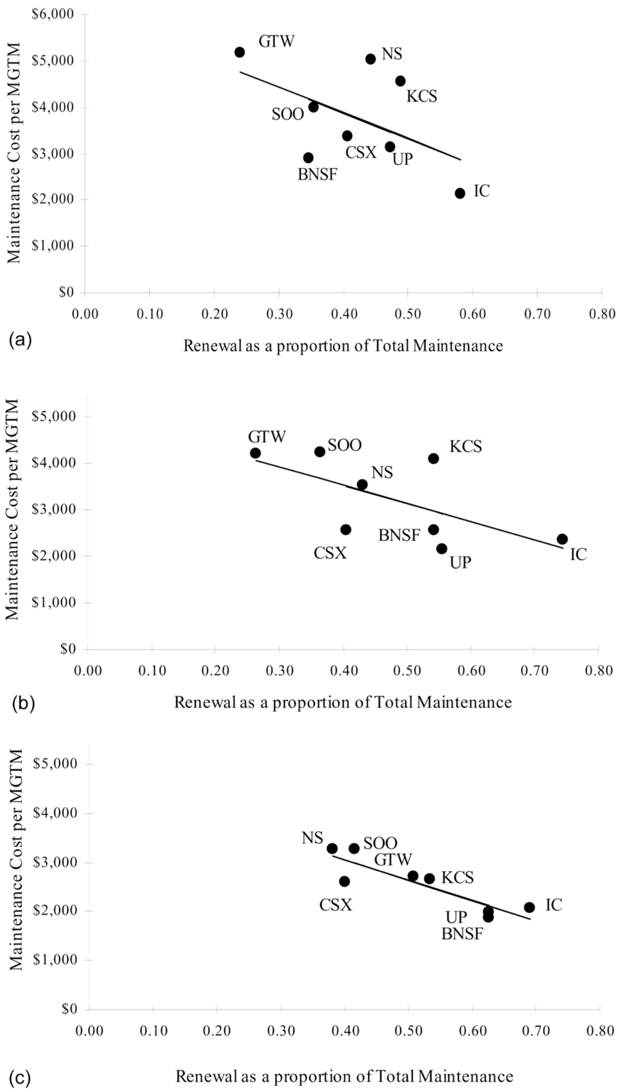

Fig. 4. Relationship of renewal strategy and unit maintenance cost (2001 dollars): (a) 1988–1992; (b) 1993–1997; and (c) 1998–2002

Alternative Hypothesis: Influence of Light Density Track Miles

Another hypothesis is that light-density lines are responsible for the variation in unit maintenance costs between railroads. Class I railroads have reduced the number of low-density routes through sale, abandonment, or lease in order to reduce the amount of low-performing routes. A number of studies found economies of density for railroads (Braeutigam et al. 1984; Caves et al. 1987; Barbera et al. 1987; Lee and Baumol 1987; Dooley et al. 1991), but differed as to the significance of the density effect. Although these studies considered overall railroad operating and maintenance costs, we considered whether a density effect might be applicable to infrastructure costs separate and apart from other operating costs. The theory is that each track mile has

Table 4. Comparison of Ordinary Maintenance Expense and Renewal Capital Expenditures per Million Gross Ton Miles (MGTM)

	Ordinary maintenance expense per MGTM					Renewal capital expenditures per MGTM				
Road	1978–1982	1983–1987	1988–1992	1993–1997	1998–2002	1978–1982	1983–1987	1988–1992	1993–1997	1998–2002
US	4,921	2,633	2,033	1,346	1,046	882	2,105	1,466	1,316	1,171
UP	4,044	2,356	1,653	958	738	841	2,181	1,488	1,195	1,231
BNSF	4,143	2,199	1,898	1,181	703	823	1,784	1,010	1,384	1,172
CSX	5,508	2,819	1,997	1,515	1,548	841	1,996	1,379	1,033	1,041
NS	4,316	3,315	2,798	2,007	2,018	851	2,214	2,213	1,515	1,251
IC	6,125	1,915	889	606	631	1,206	1,605	1,229	1,735	1,422
KCS	5,496	2,389	2,334	1,859	1,239	1,163	1,940	2,208	2,220	1,400
SOO	6,472	3,709	2,584	2,686	1,897	756	1,021	1,401	1,536	1,359
GTW	6,834	4,049	3,919	3,111	1,322	912	1,066	1,240	1,106	1,377

Note: MGTM are given in 2001 constant dollars.

a quasi-fixed cost associated with it that includes a maintenance-related component, and those roads that were able to shed more of these low-density lines may have had an inherent maintenance cost advantage.

To evaluate this possibility, a statistical test was conducted comparing the original model to one including a new variable, the percentage of light-density track miles (D_L). Light-density track was defined, for these purposes, as track with less than 10 million gross ton-miles per mile per year and was based on Bureau of Transportation Statistics data from 2000 (USDOT 2001).

Results from the joint hypothesis test ($p=0.2926$; $F/F_c=0.25444$) indicate that the inclusion of a variable for light-density track miles did not improve the original model (Model 1), and this new model was rejected.

Alternative Hypothesis: Influence of Average Density

We considered a third alternative hypothesis that average traffic density is responsible for the variation in unit maintenance costs between railroads. Similar to the hypothesis presented in the previous section, this hypothesis is related to the theory that each track mile has a quasi-fixed maintenance cost. To evaluate this possibility, a statistical test was conducted comparing the original model to one including a new variable, average density as measured in MGTM per Class I railroad track mile (line 343, AAR reports).

Results of the joint hypothesis test ($p=0.29891$; $F/F_c=0.25015$) indicate that the average density variable (D_A) did not improve the original model, and this new model was rejected.

Combining Strategy, Size, and Density Variables

A final test was conducted combining renewal strategy, average density, and size. Results of the joint hypothesis test ($p=0.10961$; $F/F_c=0.46501$) indicate that this combination of variables did not improve the original model (Model 1), and this new model was rejected.

Discussion

These results indicate that most of the variation in unit maintenance costs among Class I railroads can largely be explained by variation in the degree to which they emphasize renewal and deemphasize ordinary maintenance in their engineering strategies. Why is a renewal maintenance strategy cost-effective? As previously described, large mechanized track gangs are more productive, not only in terms of labor and materials, but also with use of limited track possession time. Their work is better planned and executed due to engineering management systems and can be programmed in advance so that traffic patterns can be adjusted to provide long track possession windows that maximize resource productivity.

It also appears that an emphasis on reducing ordinary maintenance expense was important. Ordinary maintenance expense was compared to renewal capital expenditures (per MGTM) for the four time periods between 1982 and 2002 for each railroad (Table 4). Some railroads made greater reductions in ordinary maintenance expense than others. Other than average density and system size, no obvious characteristics appeared to offer a satisfactory alternative explanation for overall unit maintenance cost other than renewal strategy. Although there was some appearance of an east–west geographic effect for the large roads, results for smaller roads were not consistent with this, and we are not aware of any a priori reason for such an effect.

This analysis necessarily made the supposition that rail infrastructure quality for each road over each time horizon was not declining substantially. Under Federal Railroad Association guidelines, track conditions can only vary within a predetermined range for a given class of track. Barkan et al. (2003) and Anderson and Barkan (2004) found that the safety record of these railroads improved over this time period, which would be unlikely if track conditions were deteriorating substantially. The increasing reliance on renewal maintenance may indicate that track quality has been improving. The analysis also makes the supposition that railroads use relatively similar accounting methods and that any differences are relatively minor and do not affect the overall results of the analysis.

Although a distinction was made between costs for capacity expansion and maintenance, capacity and unit maintenance cost are not entirely independent. As train densities increase, track possessions for maintenance may become limited in duration and frequency because track gangs must compete with trains for track time. Consequently, capacity limitations increase unit cost because of the more frequent need for gangs to get on and off track. Capacity expansion may thus have a secondary effect of decreasing unit maintenance cost.

This analysis focused only on maintenance costs. An important consideration for any railroad is the effect that different maintenance strategies have on transportation costs and service quality. Initial tests were inconclusive in regard to transportation cost, probably because of more influential effects of factors not related to maintenance, for example, reduction of crew size, changes in transportation labor work rules, improvements in motive power, and fuel efficiency. Service quality factors, such as coordination of maintenance windows with customer commitments, were not tested, and these relationships are suggested for future investigation.

This analysis is only valid for the range of data presented. Extending it beyond the limits of demonstrated values may lead to inappropriate conclusions. As mentioned previously, a 100% renewal strategy is neither attainable nor desirable based on current technology or maintenance and accounting practices. This analysis is intended for use by railroad engineering professionals as one tool (of many) in the determination of the appropriate balance between ordinary and renewal maintenance options.

Two final questions are proposed for further research and discussion. First, what are the real limits of cost efficiencies generated by renewal strategies? If UP, BNSF, and IC can achieve renewal levels in the 60% range, would a further shift from operating expense to renewal investment result in even lower unit cost? Second, what barriers exist for other railroads, such as CSX, NS, and SOO, from gaining the apparent benefits of shifting more ordinary maintenance to renewal regimes? Could these barriers be technical (i.e., infrastructure characteristics), financial (i.e., tight capital budgets), philosophical (i.e., safety, management), operational (i.e., train densities), or a combination?

Conclusions

The results are consistent with the hypothesis that an emphasis on renewal programs for track maintenance was cost-effective from an engineering viewpoint and provide an explanation for why railroads have consistently increased their use of renewal maintenance in relation to ordinary maintenance. Additionally, apparent differences in unit maintenance costs can be largely explained by the degree to which individual firms apply renewal strategies.

These findings have important implications for railroad financial planners. Since 1998, railroads have become more conservative with capital spending as investors have become increasingly skeptical about the industry's financial competitiveness (Flower 2003a,b; Gallagher 2004; Hatch 2004). Recalling that renewal capital expenditures comprise the largest share of overall capital spending, if railroads unduly constrain renewal maintenance in an effort to conserve capital resources, they will find that ordinary maintenance expenses will rise disproportionately in relation to the reductions in capital expenditures. Making such tradeoffs may improve free cash flow temporarily, but the effect will only be short lived as overall maintenance cost eventually increases.

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References

Association of American Railroads (AAR). (1978–2002). *Analysis of Class I railroads*, AAR, Washington, D.C.

Association of American Railroads (AAR). (1980–2002). *Railroad facts*, AAR, Washington, D.C.

Association of American Railroads (AAR). (2005). *Class I railroad statistics*, AAR, Washington, D.C., ⟨http://www.aar.org/PubCommon/Documents/AboutTheIndustry/⟩ (Jan. 15, 2005).

Anderson, R., and Barkan, C. P. L. (2004). "Railroad accident rates for use in transportation risk analysis." *Transportation Research Record. 1863*, Transportation Research Board, Washington, D.C., 88–98.

Australian Government Bureau of Transport and Regional Economics. (2003). *Rail infrastructure pricing: Principle and practice*, ⟨http://www.btre.gov.au/docs/r109/btre_r109.pdf⟩ (Jan. 6, 2004).

Barbera, A., Grimm, C. M., Philips, K. A., and Selzer, L. J. (1987). "Railroad cost structures—Revisited." *J. Transp. Res. Forum*, 28(1), 237–244.

Barkan, C. P. L., Tyler, C. T., and Anderson, R. (2003). "Railroad derailment factors affecting hazardous materials transportation risks." *Transportation Research Record. 1825*, Transportation Research Board, Washington, D.C., 64–74.

Braeutigam, R. R., Daughety, A. F., and Turnquist, M. A. (1984). "A firm specific analysis of economies of density in the railroad industry." *J. Ind. Econ.*, 33(1), 3–20.

Brennan, C., and Kramer, J. (1997). "High technology: M/W gains from software advances." *Railw. Track Struct.*, 93(12), 24.

Burns, D. (1980). "The case for total renewal." *Mod. Railroads*, 35(9), 38–42.

Burns, D. (1981). "Getting the best out of track renewal machines." *Railw. Gaz. Int.*, 137(3), 183–185, 189, 190.

Burns, D. (1983). "RT&S foreign scene: Track maintenance." *Railw. Track Struct.*, 79(3), 52–54, 56, 58.

Burns, D., and Franke, M. (2005). "Analyzing the blitz approach to M/W." *Railw. Track Struct.*, 101(10), 33–38.

Caves, D. W., Christensen, L. R., Tretheway, M. W., and Windle, R. J. (1985). *Network effects and the measurement returns to scale and density: Analytical studies in transport economics*, Cambridge University Press, Cambridge, Mass.

Dooley, F. J., Wilson, W. W., Benson, D. E., and Tolliver, D. D. (1991). "Post staggers productivity for Class I railroads." *MPC Rep. No. 91-6*, Mountain Plains Consortium, Fargo, S.D. ⟨http://www.mountain-plains.org/pubs/⟩ (Aug. 1, 2003).

Flower, S. (2003a). "Container volume is growing, but railroads' intermodal profit margins are marginal at best." *Progressive Railroading*, 46(5), 10.

Flower, S. (2003b). "UP focuses on maintaining operational discipline to lure long-term business, avoid unsustainable short term growth." *Progressive Railroading*, 46(6), 10.

Foran, T. (1997). "Re-engineering the engineering department." *Progressive Railroading*, 40(3), 47, 49, 52–55, 58, 59.

Gallagher, J. (2004). "Railing over rates: Railroad price increases anger shippers as record freight levels test track, cars, terminal capacity." *Traffic World*, 268(22), 36.

Grassie, S., and Baker, P. (2000). "Routine maintenance extends rail life and offers long-term savings." *Railw. Gaz. Int.*, 156(2), 88–89.

Hatch, T. (2004). "The capital question—Again." *Progressive Railroading*, 100(5), 10.

International Heavy Haul Association (IHHA). (2001). *Guidelines to best practices for heavy haul railway operations: Wheel and rail interface issues*, W. J. Harris, W. Ebersohn, J. Lundgren, H. Tournay, and S. Zakharov, eds., IHHA, Virginia Beach, Va.

International Union of Railways (UIC). (2002). *InfraCost: The cost of railway infrastructure*, UIC, Bern, Switzerland.

Ivaldi, M., and McCullough, G. (2001). "Density and integration effects on Class I U.S. freight railroads." *J. Regul. Econ.*, 19(2), 161–82.

Judge, T. (1999). "Standardizing coming to heavy equipment." *Railw. Track Struct.*, 95(11)17–19.

Kovalev, V. I. (1988). "Managing maintenance on the world's longest rail network." *Railw. Gaz. Int.*, 144(3), 159–61.

Kramer, J. (1997). "High-production maintenance: Looking for gains." *Railw. Track Struct.*, 93(12), 21–22.

Lee, T., and Baumol, C. P. (1987). “The cost structure of the U.S. railroad industry under deregulation.” *J. Transp. Res. Forum*, 28(1), 245–53.

Stagl, J. (2001). “Details: Class Is.” *Progressive Railroading*, 44(3), 40, 42, 44, 46, 47.

Swier, J. (2004). “Exposing the real infrastructure cost drivers.” *Railw. Gaz. Int.*, 160(1), 34–36.

U.S. Senate Committee on Commerce, Science, and Transportation. (1995). *ICC termination act of 1995*, 104th Congress, 1st Session, GPO, Washington, D.C.

U.S. Dept. of Transportation (USDOT). (2001). *National transportation atlas database*, National Railway Network, Bureau of Transportation Statistics, Washington, D.C.