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Analysis of Railroad Track Maintenance Expenditures for Class I Railroads 1962-1977

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16. Abstract

This study investigates the decision-making process for railroad track maintenance (T/M) expenditures. The objectives are to (1) describe how Federal track safety standards have influenced this process and (2) try to predict the impact of changes in safety regulations on T/M spending for all U.S. Class I railroads on selected groups of railroads. A related objective of this study was to use publicly available data to build models of track-related accidents and train speeds.

The approach used in this research included a literature search, field interviews, hypotheses testing through models and case analysis, and multivariate analysis of time series data in cross sections. The scope of the study was limited to the Class I railroads operating in 1978 and from 1962 to 1977.

The results suggest that imposition of FRA standards has had the predicted impacts on both T/M spending and on train speeds. Since the standards were imposed, railway revenues for T/M have increased. In addition, the standards appear to have has a negative influence on average train speeds, though they have not effected a reduction in track-related accidents.

17. Key Words
-Track Maintenance Expenditures, Track Safety Standards, Track-related Accidents, Train Speeds, Class I Railroads

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PREFACE

This study was performed under the auspices of the Pennsylvania Transportation Institute (PTI) at Pennsylvania State University and under Contract DOT-TSC-1675. The project's technical monitor was Mark Hollyer of the Transportation Systems Center (TSC). John E. Tyworth was the project supervisor and co-principal investigator.

Other individuals also contributed to this research. Albert J. Reinschmidt, co-principal investigator, was primarily responsible for guidance on technical railway engineering issues and data collection efforts; he also participated in the interviews of senior railroad officials. Ronald S. Koot was a key contributor to the development of the analytical framework and was primarily responsible for the computer programs used in the statistical analyses. John C. Spychalski participated in the survey of senior railroad officials and provided guidance and expertise throughout the course of the study. Likewise, Srikanth Rao contributed technical expertise; he also performed a major role in the identification and direction of additional research.

Project members spent considerable time with many senior executives at seven Class I railroads. Special thanks are due to these officials for their time, consideration, and valuable insights. In addition, the project team wishes to acknowledge TSC staff members, Mark Hollyer and Robert Smith, for providing valuable assistance with respect to the objectives and strategy of this research. Finally, special appreciation is due to the PTI staff, especially Linda Nigh, Vicki Spadaccio, Del Sweeney, Jean Smith, and Eileen Deihl.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha

MASS (weight)

Symbol	When You Know	Multiply by	To Find	Symbol
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

LENGTH

Symbol	When You Know	Multiply by	To Find	Symbol
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi

AREA

Symbol	When You Know	Multiply by	To Find	Symbol
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	

MASS (weight)

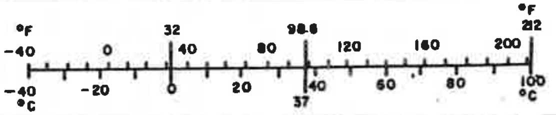
Symbol	When You Know	Multiply by	To Find	Symbol
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	

VOLUME

Symbol	When You Know	Multiply by	To Find	Symbol
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3

TEMPERATURE (exact)

Symbol	When You Know	Multiply by	To Find	Symbol
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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SYMBOLS AND ABBREVIATIONS

FRA	Federal Railroad Administration
T/M	Track Maintenance
TOFC	Trailer-on-Flat Car
IRR	Internal Rate of Return
RCR	random coefficients regression
TMEXP	track maintenance expenditures per track mile
TMRATIO	track maintenance ratio model
REV	revenue per track mile
ΔSPEED	change in average annual system train speed
DUMMY	Dummy Variable
$(ACC)_{t-1}$	Accidents lagged one period
ROI	Return on Investment
Weight	average system carload weight
PIR	price index ratio
CWRAIL	continuous welded rail
MGTs	million gross tons
TCM	track condition model
TCF	track condition factor
OT&R	Overtime and Recrew Costs
NPV	Net Present Value
ICC	Interstate Commerce Commission

EXECUTIVE SUMMARY

A. OVERVIEW OF TRACK MAINTENANCE PROJECT

The subject of deferred maintenance in railroad plants and equipment, and the consequences thereof, has received considerable national attention since the late 1960s. An issue of particular concern within this general subject area has been the frequency and impact of freight train accidents caused by deficient track conditions or inappropriate train speeds. Public reaction to this issue led Congress to direct the Federal Railroad Administration (FRA), in 1971, to establish track safety standards setting forth minimum safety requirements for specific track conditions. The promulgation of such regulations together with the passage of time since their enactment raises two interrelated questions: (1) Have the track safety standards contributed to the reduction of track-related accidents? and (2) Have the track safety standards encouraged the allocation of higher levels of resources for track maintenance with the purpose of reducing or eliminating deferred maintenance?

The purpose of this study was to investigate and, as far as possible, quantify the decision-making process for railroad track maintenance (T/M) expenditures in order to: (1) describe how federal track safety standards have influenced this process and (2) explore the possibility of predicting the impact of changes in safety regulations on T/M spending for all U.S. Class I railroads or selected groups of railroads. A related objective was to use publicly available data to build models of track-related accidents and train speeds.

FINDINGS

In spite of the limitations imposed by the use of publicly available data, this research has produced several interesting insights into the effects of the federal track safety standards. The standards were intended to reduce track-related accidents by imposing speed restrictions in accordance with track conditions. If the reduced speeds were imposed on high density lines, the increased operating costs associated with decreased car and locomotive utilization would provide the economic justification to increase maintenance expenditures. If, on the other hand, the increased operating costs were not sufficient to stimulate increased maintenance activity, the lower train speeds would enhance safety.

Track Maintenance Expenditures

The results do indicate that the imposition of the standards has had the predicted impacts on both track maintenance spending and on train speeds. In the years since the standards were imposed, there has been a statistically significant increase in the proportion of railway revenues which has been devoted to track maintenance. As might be expected, those railroads which operate trains at higher speeds appear to be more sensitive to the introduction of the safety standards than those which operate with lower system speeds. In contrast, the group of carriers which have very low system speeds were not affected by the standards, possibly because the speeds at which they operate were already lower than those which might be imposed by the federal standards. Profitable railroads were also found to be more sensitive to the standards, perhaps because they possess the resources to undertake rehabilitation efforts.

Train Speeds

Average train speeds have also been influenced by the imposition of the standards. The models indicate that the standards have had a statistically significant negative influence on average train speeds. However, this result must be considered in light of other influences, such as fuel conservation efforts, which may also have had negative influences on operating speeds.

Accidents

The major area in which the standards have not had the intended effect is in the reduction of the number of track-related accidents. In spite of the imposition of the standards, the accident rate has not decreased; rather, it has increased. It is possible, of course, that the imposition of the standards prevented a much larger increase in the accident rate, but it is not possible to investigate this hypothesis.

The industry, however, is sensitive to accident rates in the maintenance budgeting process. Carriers which are profitable at higher average speeds, or which have numerous high density lines, are more sensitive to the accident rate than are slow, unprofitable, or low density carriers.

STRUCTURE OF THE RESEARCH

In order to relate the objectives of this research to the general problem of reducing track-related accidents through safety standards, and in order to define the scope of this study, it is useful to conceptualize the interactions which are involved (see Figure ES-1). The operating speed limits and T/M expenditures have an effect on track-related accidents, income, market share, equipment utilization, etc., which in turn provide feedback to the decision-making processes, both directly and indirectly, through public track safety regulations.

The area of this study is encircled in Figure ES-1 and is limited to understanding the decision-making processes related to the selection of speed limits, the setting of track maintenance expenditure levels, and the direct and indirect feedback effects on these processes. The scope of the study was limited to the Class I railroads that operated in 1978 and the 16 year period from 1962 to 1977.

Finally, it is important to note that, in this study, the term "track maintenance" (or, simply, "maintenance") has a different meaning than the industry's standard notion of "maintenance of way"; track maintenance expenditures include expense and capital items primarily related to track and exclude expenditures for some structures.

Research Plan

The approach used to accomplish the objectives of this research included a literature search, field interviews with Federal Track Safety Inspectors and railroad officials, formulation and testing of hypotheses through conceptual models and case analysis, and multivariate analysis of time series data in cross sections. The specific tasks and the products from each are shown in Figure ES-2.

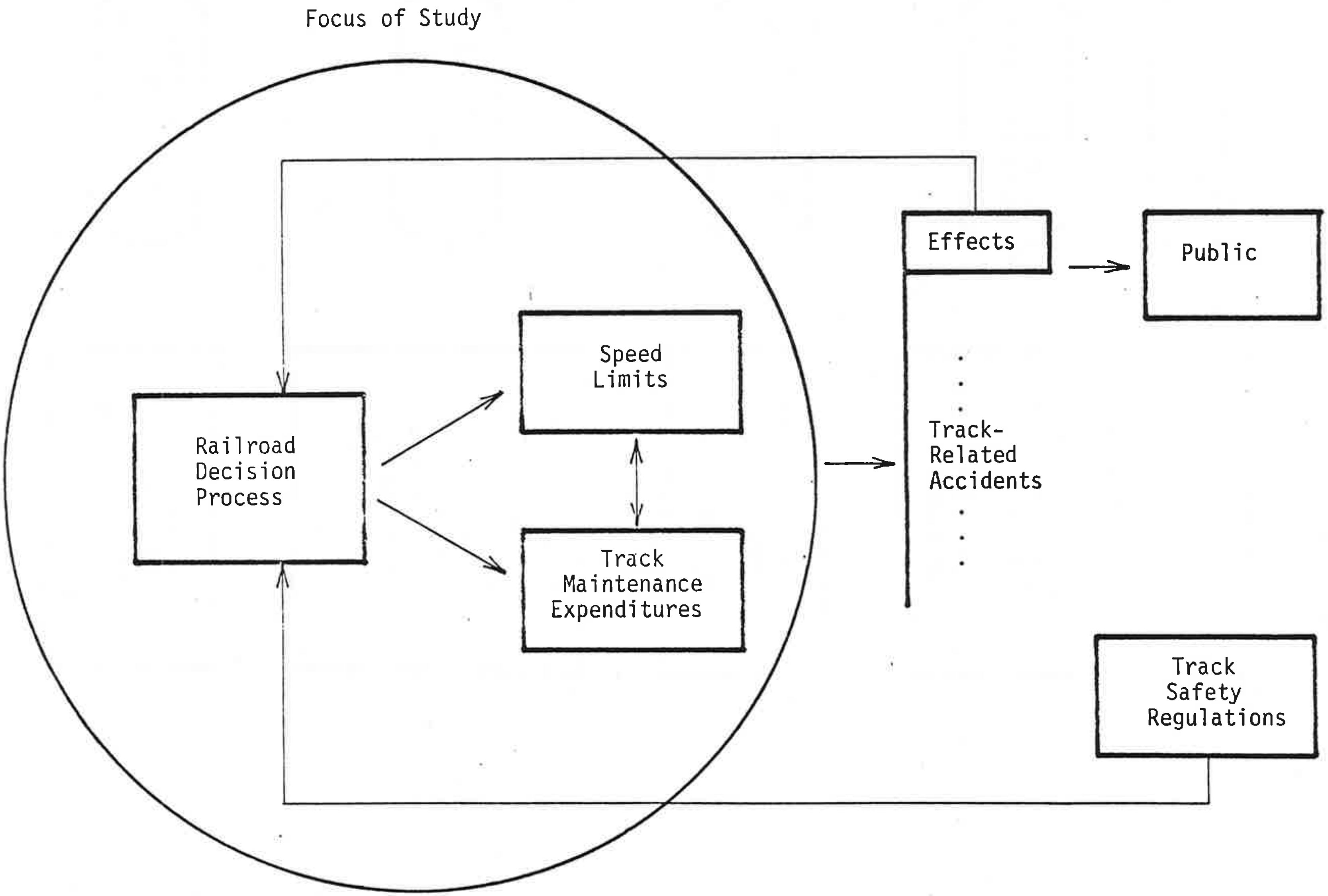


Figure ES-1. Focus of Study

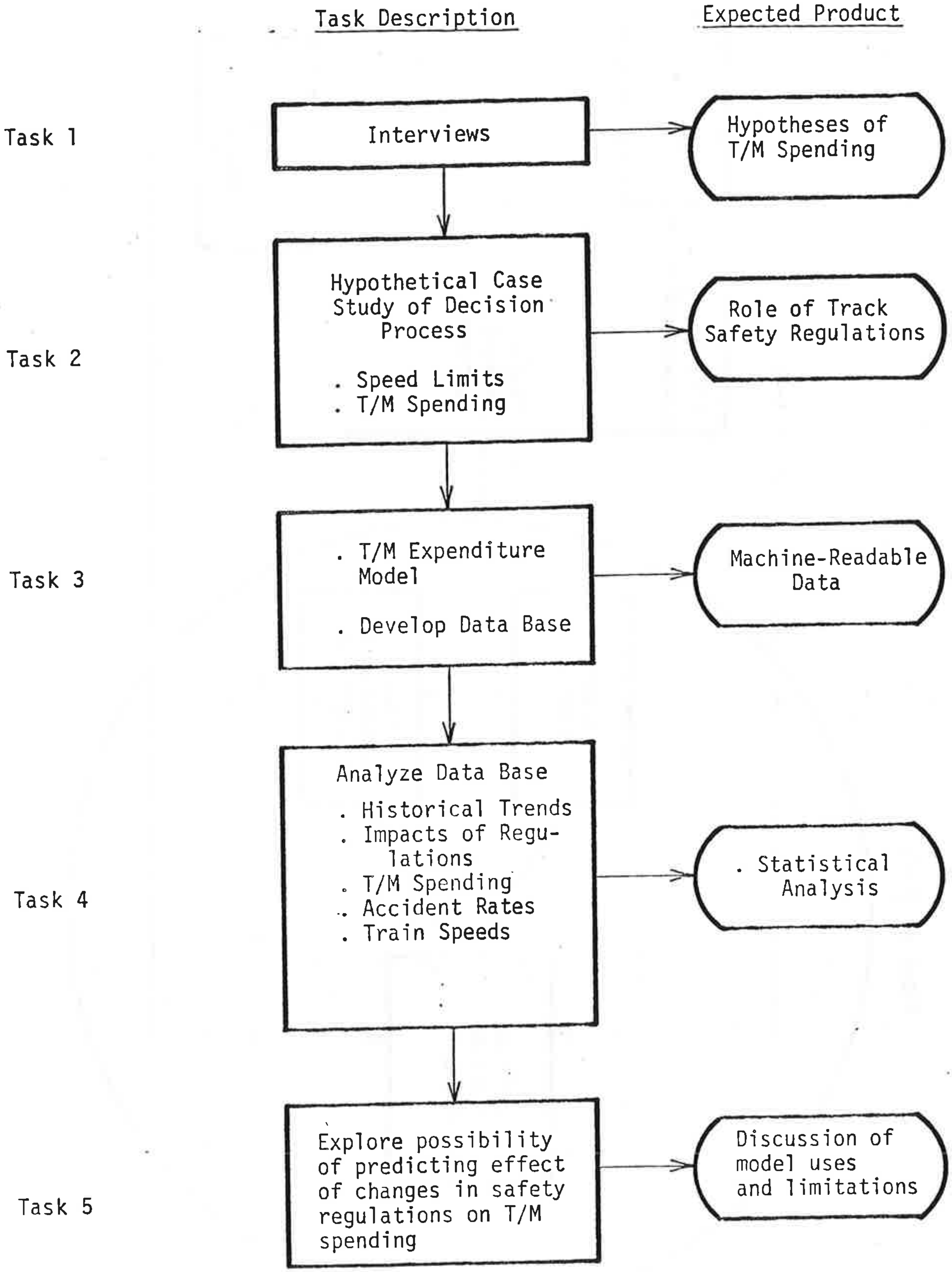


Figure ES-2. Project Tasks

Task 1--Interviews

The purpose of Task 1 was to explore the decision-making process for T/M expenditures, identify potential explanatory variables, and develop hypotheses to be tested. Task 1 was divided into two phases. The first phase, a literature search, was conducted to identify information available on railroad managerial processes, especially in relation to T/M expenditures, and to discover how these processes have varied over time.

In the second phase, a total of eight interviews were conducted, seven with senior officials of Class I railroads and one with a Federal Track Safety Inspector. The railroads which were chosen for interviews were selected by the project team with the advice and consent of the Technical Monitor.

The railroads that were selected for interviews were chosen on the basis of (1) size, (2) financial condition, (3) overall composition of lines (e.g., main vs. branch), (4) traffic characteristics, (5) maintenance philosophy or policy, and (6) method of organization (to the extent such characteristics were clearly discernible).

The main objective of these interviews was to characterize the railroad decision-making process for setting T/M expenditure levels and the role of federal track safety regulations in this process.

Important considerations in the selection of railroads include: (1) size, (2) financial condition, (3) overall composition of lines (e.g., main vs. branch lines--to the extent that overall composition is clearly distinguishable) and track miles, (4) basic traffic characteristics (e.g., coal in unit trains vs. [TOFC], (5) maintenance philosophy or policy and extent of mechanization, and (6) method of organization (to the extent such characteristics are clearly discernible). Many of these characteristics overlapped, so that even with a small sample, it was possible to obtain a fairly good cross section.

Task 2--Hypothetical Case Study

In Task 2, the research team formulated and parametrically solved a series of hypothetical railroad decision problems. These problems simulated railroad decision-making with regard to the selection of speed limits and associated levels of scheduled track maintenance expenditures on individual lines of road. Research questions of interest were: (1) How do railroad managers make decisions on operating speed limits on individual lines? and (2) How do they decide on the level of T/M spending which should be undertaken for given speed limits? In addressing these questions, a key parameter was the federal role (in the form of track safety regulations).

Task 3--Compilation of Data

In Task 3, hypotheses of T/M expenditure behavior and a list of explanatory variables were developed. In order to test these hypotheses, a data base was prepared consisting of historical T/M expenditures and physical quantities of rails and ties, as well as the explanatory variables.

Task 4--Analysis

This task required a statistical study, using the data developed in Task 3, of the level of track maintenance performed by the U.S. Class I railroads. Several explanatory variables were included: a measure of the railroad's need to perform maintenance, as determined by its level of traffic; amount of track; train speeds; the railroad's ability to perform maintenance, as measured by its financial condition; and the potential benefits of increased T/M investment, as measured by train speeds, accident levels, and costs.

Special attention was given to the period covering the imposition of the FRA track safety standards to determine what effect, if any, the standards have had on track maintenance. If, during this period, maintenance expenditures rose and train speeds and accident rates decreased (noting the time lag between maintenance expenditures and decreased accident rates), it could be assumed that the track standards achieved their objective. If, on the other hand, maintenance expenditures decreased and accidents and/or train speeds increased, it could be assumed that the standards failed to achieve the intended effect.

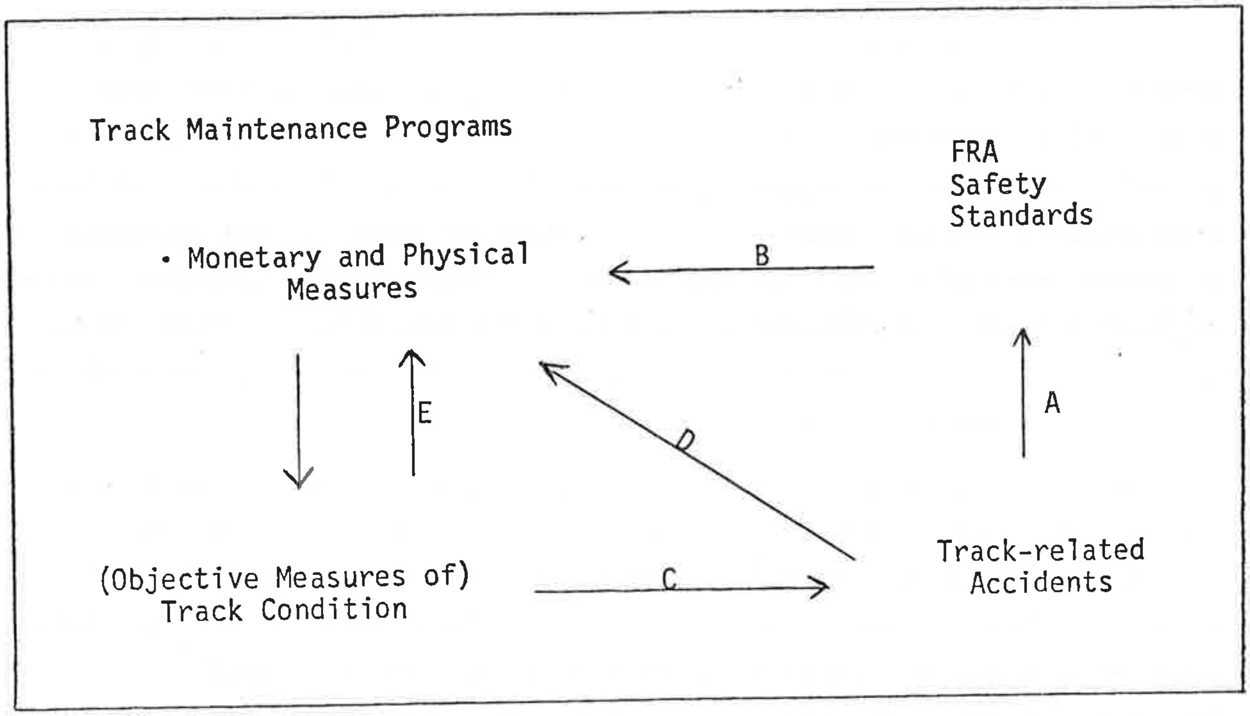
Task 5--Impacts of Changes in Safety Regulations

In Task 5, the research team explored the question of how the results of the preceding tasks might be used to predict the impacts which hypothetical changes in federal track safety regulations could have on T/M expenditures by Class I railroads.

THE NEXT STEP

While these findings have illuminated some of the effects of the FRA safety standards, they do not say anything about how the standards might be altered or improved to increase their effectiveness. This cannot be accomplished without an objective measure of track condition which has been statistically related either to the occurrence of track-related accidents or to the level of maintenance expenditures. Figure ES-3 illustrates the relationship between maintenance activities, track condition, accident rates, and safety standards. The research detailed in this report investigated the relationships labeled "A" and "B".

The next logical phase of research is noted as "C" and "D" in Figure ES-3. The collection of specific, disaggregate track condition data on specific railroad line segments, as well as the corresponding accident data, will permit a statistical analysis of the relationship between the two data sets. Alternative means of representing track condition should be explored, including the possible formulation of a weighted Track Quality and Use Index. The development of such an index would provide a meaningful basis on which to predict accident probability. Moreover, the index can provide the means to assess what maintenance expenditures would provide the greatest reductions in accident probability.



Note: A-B = research performed using aggregate data

C-E = proposed research using disaggregate, line-specific data

Figure ES-3. Relationships Between Maintenance, Track Condition, and Safety

B. METHODOLOGY

Besides a survey of the literature, two methods were used to explore the decision framework for T/M spending. Initially, project members interviewed FRA and senior railroad officials. After all interviews were completed, a comprehensive hypothetical case study was used to explore key relationships suggested in the literature and in the discussions with railroad managers and FRA safety officials.

Interviews

The basic purpose of the interviews was to investigate the role of the Federal Railroad Administration's track safety standards and the cost of track-related accidents in the overall decision-making process for railroad maintenance-of-way spending. Important research questions included:

1. What is the influence of FRA track standards on operating speed limits, and the influence of speed limits on the provision of maintenance funds?
2. Do FRA track standards cause railroads to increase maintenance-of-way expenditures for the improvement of deteriorated track conditions?
3. Have the track standards improved the safety experience of railroads?

To address these research questions, in-depth personal interviews were conducted with 40 senior officials of 7 Class I railroads. The selection of sample railroads was designed to encompass a full range of differences in climate, terrain, size, financial conditions, network characteristics, and traffic mix. Many carriers had overlapping characteristics, so that even with a small sample it was possible to obtain a fairly representative cross section.

Project Identification

Inspections, standard maintenance programs, and safety all play important roles in project identification. Section men, assistant track supervisors, roadmasters, and senior officers (sometimes including the company president) perform on-site inspections. Visual inspections concentrate on roadbed, ballast, rail sections, and ties. Section men usually perform detailed monthly inspections, while senior staff members inspect at least the principal line segments as often as three to four times per year. In addition, rail test car inspections are made two to three times per year over main lines and once per year over branch lines; some railroads also make track geometry car inspections.

Safety

Accident experience, hazardous materials routes, and FRA track safety standards are part of the project identification process. While accident experience is considered to be extremely important, no explicit "trigger levels" (in terms of cost per accident or number of accidents) guide project identification. Instead, management relies on a case-by-case approach and subjective judgment.

The general pattern of decision making also requires the identification of key hazardous materials routes. These routes usually receive greater attention in the work plan, particularly when the routes include lower density branch lines.

The imposition of FRA track safety standards has, in general, increased the number of visual inspections performed each year. The influence of track standards on cycle maintenance planning, however, varies inversely with the carrier's financial strength. For weak roads, it is often FRA standards that prescribe levels of required maintenance. For strong roads, track standards often do not significantly affect the work plan.

Project Evaluation

In general, decision making in the evaluation phase occurs on a system-wide basis within the framework of strategic objectives and long-range planning. Project evaluation, however, is highly centralized. While division-level decisions in both the identification and evaluation phases concentrate on replacement-in-kind projects, major capital programs and planning are part of the top-level review process. Most firms are pursuing more sophisticated and accurate methods for identifying and evaluating work requirements and capital programs. To a significant degree, however, the level of sophistication, as well as the length of the planning horizon, depends on the financial resources of the carrier.

Operations/Service Objectives

Consistent, on-time performance over strategic routes was cited by the railroads as the primary service objective. Train speeds depend primarily on the carrier's service strategy, which, in turn, is a function of the geographic, traffic, and financial profile of the carrier. For most of the carriers, operating speeds set in accordance with service priorities ranged from 35 to 50 mph on main lines and from 20 to 30 mph on branch lines. Where network and geographical conditions permitted, carriers that faced stiff competition for time-sensitive traffic operated trains at speeds of 60 mph or more.

For several carriers, the provision of specialized types of equipment for key market segments was also an important service goal. Although senior officials were aware that heavier cars would require considerably more track maintenance, a formal analysis of the relationship between increased maintenance costs and increased car size or weight was not undertaken.

Maintenance-of-Way Objectives

The objectives of the maintenance function are keyed to the achievement of strategic service goals and priorities. Generally, the goal was to provide an infrastructure capable of supporting the firm's service objectives. For carrier management teams which explicitly assumed a viable, profitable operation in the long run, i.e., over the next 30 years or more, preserving the structural integrity of the system was a top priority. Policies and programs were designed, therefore, to prevent substantial borrowing against the future. A long-term goal for most of the carriers, of course, was to abandon some line segments.

The basic short-term objective for the more prosperous railroads was to stay even, i.e., to maintain and preserve existing levels of plant integrity where the level of traffic or earnings justified normalized maintenance. More precisely, the typical policy was to recoup maintenance deferred during lean years on important lines (those experiencing ten million gross tons per year) and/or upgrade segments when estimated future earnings warranted new investment and funds were available. Low density or marginally profitable line segments, on the other hand, received only "adequate" maintenance--maintenance that met minimum safety standards.

For carriers that were confronted, after years of deferred maintenance, with deteriorated track and structures, the overall short-term goal was to restore main line track and yard to meet short-term objectives without compromising, if possible, short-term profitability. Although it was hard to make a mistake in project selection, priority was given to strategic routes with subsequent "cascading" of rail, replacing of defective rail, upgrading of crews (using fewer men with better equipment), and providing only minimum maintenance necessary to correct FRA inspection violations (thereby concentrating on the "really weak areas"). The immediate concerns were to maintain strategic routes above the minimum levels required by FRA standards for desired speeds, keep important traffic moving, and provide consistent deliveries. Slow orders on important line segments had to be removed in order to permit main line speeds in excess of 30 mph. The basic strategy was to establish financial viability, seek rate increases, expand maintenance programs, rebuild the system, and provide safe and dependable service.

Safety

Safety considerations had varying levels of influence on project evaluation and maintenance decisions. Although safety had little overall impact on the size of the total maintenance-of-way budget, accident experience and, sometimes, track safety standards significantly influenced the allocation of maintenance funds. While senior officials knew that derailments created "enormous" losses and that operating safety was an important objective, it was well known that causes of the derailments were difficult to assess. The prevailing viewpoint was that not much was known about the effects on track-related accidents of large cars and unit trains moving over well-maintained track at relatively high speeds (but consistent with maintenance conditions). It was argued, for example, that half of all accidents reported as track-related were not really caused by track problems. Unexplained accidents had occurred on strategic line segments with the highest maintenance standards. That accident experience led some carriers to reduce train speeds while still maintaining track at levels required for higher speed operations. The reduction in high train speeds on main lines, in turn, led to a dramatic reduction in unexplained accidents and has become an important part of the rationale for establishing consistent, rather than fast, delivery times as a strategic service objective.

For financially strong carriers, track safety standards had little effect on the amount or allocation of funds. Their view was that FRA standards prescribed minimal maintenance conditions. On high-density lines, company standards substantially exceeded FRA requirements, i.e., maintenance practices at least met the standards for the next higher class of track. On low density but important branch lines, the same practice was followed. When traffic or earnings did not support this maintenance policy, minimum safety requirements were essentially the only consideration; maintenance activity was placed in a holding pattern, and temporary slow orders were accepted. Eventually, the line segment was downgraded to the next lower class of track, and permanent slow orders were accepted. Minimum FRA standards then became the normal maintenance requirements.

On the other hand, FRA track safety standards often prescribed the maintenance-of-way requirements for financially weak carriers. In order to attain strategic service objectives, these firms had to eliminate slow orders or upgrade track to meet minimum standards for the class of track that permitted desired operating speeds over strategic routes. In this situation, the rail defect car test results generated considerable pressure to relay rail.

Finally, FRA regulations caused the carriers to devote additional (albeit minor) resources to administrative tasks (e.g., training) and, in some cases, to more frequent visual inspections. The prevailing view, however, was that additional inspections add little if anything to safety and are made only to comply with regulations. Senior executives of prosperous carriers, in particular, felt that track safety standards worked to dilute the effectiveness of ongoing programs. Managers pointed out, for example, that FRA regulations treat many defects identified by an inspection car as equally in need of corrective action. Although some defects are obviously worse than others, each must be repaired immediately. Often 10 mph slow orders are applied to defective rail that is not replaced, even if the repair adds nothing to safety. Such actions have caused resources to be diverted to repair track segments that were already scheduled for maintenance, thereby disrupting planned maintenance cycles and reducing the efficiency of mechanized maintenance gangs. Thus, a disincentive for inspecting more track than the law requires is created: the firm cannot afford to find minor defects that have little to do with actual safety but must be repaired immediately. Test car inspection instruments, moreover, are viewed as imprecise. Managers see safety more as a function of age (of rail), traffic density, equipment (axle loads, type and length of car, or load capacity), and speed rather than of technical specifications set forth in FRA track standards, e.g., the number of defective ties per line segment. Thus the prevailing viewpoint is that track standards mean fewer maintenance options and a less effective maintenance program.

Key Findings

- The level of maintenance expenditures is a function of several factors, the most important of which is the available operating revenue.

- Maintenance expenditures are frequently viewed from the perspective of the percentage of operating revenues devoted to maintenance.

- The percentage of operating revenues devoted to track maintenance is normally determined by the profit targets of the carrier.

- During periods of declining traffic and revenue, the track maintenance budget is often dealt a double blow since (1) the available revenues are reduced and (2) the percentage of revenues devoted to track maintenance is often reduced.

- Identification of maintenance projects is usually initiated in the field. At each successive level of review the scope of the work plan is reduced to conform with the budget limitations.

- Safety and accident experience are major considerations in both the project identification and project evaluation phases. Hazardous material routes frequently receive special considerations.

- The effect of the FRA safety standards on large railroads is minimal. The most severe problems stem from the disruption of planned maintenance activities to correct problem areas identified by inspectors, even if the area is scheduled for work at a later date. Additionally, the standards exerted pressure to limit rail inspections to the number of defects that can be replaced quickly.
- On financially weak carriers, the standards often served as goals that carriers attempt to meet in order to satisfy service objectives. The elimination of slow orders imposed by the standards is often a primary objective of the maintenance program.

Hypothetical Case Study

The hypothetical case study provided an effective vehicle for identifying and discussing the complex set of interactions among key factors. The purpose was to develop and refine further the conceptual foundation necessary for the construction of hypotheses about T/M decision-making behavior. The focus, in particular, was on the relationships between safety (track standards, accidents, and hypothetical policy options), train speeds (including the economic incentives that influence train speed), and levels of T/M spending.

Alternative track maintenance programs were evaluated for hypothetical main and branch line segments of a medium-sized and financially weak Class I railroad. Other than abandonment, the program levels of investment considered were minimum short-term, minimum long-term, and rehabilitation long-term. The short-term minimum level effort means the level of spending required only to meet present FRA track class requirements for the short-term. Accelerated track deterioration and increased risk and incidence of accidents will result. Eventually, temporary speed restrictions will become permanent when the track is downgraded to the next lower track class.

The minimum level long-term program will permit main line segments to stay in the same (Class 3) track status, and permit 30 mph train speeds on designated sections of the N branch line. This program, however, does not provide the spending necessary for normalized requirements. Consumption of the infrastructure will occur at a greater rate than maintenance replacements.

The long-term rehabilitation program will restore the track to normalized conditions at the end of 5 years. The substantial investment in property will assure train operations at Class 3 speeds ($\leq$ 40 mph) on main lines and 25 to 30 mph on both branch lines.

Besides initial project costs, increased track maintenance expenditures that result from increased track deterioration for different program levels of investment were included in the analysis. Benefits included savings in ordinary track maintenance and savings in train operations. Savings in train operations, in turn, were estimated for equipment, labor, fuel, and accident avoidance.

Several fundamental relationships emerged from the cost-benefit analyses. The following results, however, should not be viewed as generalized principles, but rather as illustrations of relationships and issues confronting the decision-maker.

- Speed-related benefits (labor and equipment savings) have the greatest impact on the IRR results for high density line segments. For example, for main lines, speed-related savings comprise from about one-half to two-thirds of the total dollar benefits, while corresponding savings for branch lines represent less than one-tenth of the total; the reason is that equipment and labor savings are a function of the reduction in time and the volume of traffic.

- Conversely, on low density lines, T/M or accident cost avoidance has the greatest influence on internal rates of return.

- Track safety regulations, at least to some extent, affect the decision process. If, as suggested in this case study, speed-related savings for high density line segments range from 50 to 67 percent of total savings and, as already noted, speed (length and consistency of transit time) is a key determinant of service and, ultimately, of freight revenues, then speed restrictions should provide a very effective incentive for railroads to meet corresponding track safety standards.

- On low density lines, however, the case analysis indicated that speed-related savings and service were not key factors in the investment decision. Instead, avoidable (accident and track maintenance) costs were dominant. Safety standards for the lowest track classification, therefore, will probably serve as a floor. Higher levels of investment will be made only when (1) the avoidable costs are sufficient to justify the decision; or (2) the actual or potential revenue generating capacity of low density line segments (individually or in the aggregate), when viewed as part of the entire system, justifies the investment.

STATISTICAL ANALYSES

The statistical analyses focused on three areas: track maintenance spending, track-related accidents, and system train speeds. To a considerable extent, the accuracy, aggregation, and availability of data from public sources restricted this task. Given publicly available data, the smallest unit of observation is the Class I railroad, while the unit of time is 1 year. Variable measurements, therefore, represent annual systemwide averages. This level of aggregation means that the study results provide only a general profile of track maintenance, accident, or train speed behavior in response to the multiplicity of overlapping influences on such behavior.

The analytical technique used to develop final statistical models and test hypotheses was random coefficients regression (RCR). The nature of the study (time series and cross sectional) made RCR essential from a statistical, theoretical, and logical point of view.

Track Maintenance Expenditure Models

Although statistical analyses were conducted in three related areas, the primary objective was to explain track maintenance behavior. Both financial and physical measures were used to represent track maintenance activity. For expenditure models, the research questions were:

- Which variables best explain how current operating revenues available to a railroad are allocated to track maintenance?
- Does a railroad devote a decreasing, constant, or increasing proportion of its available resources to track maintenance in response to key variables?

To answer these questions, regression models with track maintenance expenditures per track mile (TMEXP) and track maintenance expenditures as a proportion of total annual operating revenues (TMRATIO) were estimated. Both for a priori reasons and for purposes of regulation and control, variables representing speed (the change in average system train speed or Δ SPEED), accidents (the number of accidents per million gross ton miles, lagged one year $(\mathrm{ACC})_{t-1}$, and the frequency-severity accident indexes $(\mathrm{SI1})_{t-1}$ and $(\mathrm{SI2})_{t-1}$), and the introduction of FRA safety standards (DUMMY) were entered into models on an obligatory basis. Because measurements for accident indexes were available only for an eleven-year (1967-1977) period, models were developed for two time frames: (1) 1962-1977, where $(\mathrm{ACC})_{t-1}$ was used and (2) 1967-1977, where the indexes $(\mathrm{SI1})_{t-1}$ and $(\mathrm{SI2})_{t-1}$ were included.

In addition, analyses of track maintenance expenditure models were made for two different levels. Initially, industry models were developed and evaluated. Subsequently, final industry models were tested on six subgroups.

Key Findings

The results indicate that available operating revenues heavily influence industry track maintenance expenditures. Yet, operating revenue per track mile (REV) is highly collinear with other a priori variables of interest. Thus, the track maintenance ratio model (TMRATIO), which permits REV to be removed as an explanatory variable but keeps REV in the model equation and avoids the use of possibly deficient deflator data, was conceptually superior.

Safety-Related Variables

In TMRATIO models, safety-related variables are statistically significant predictors. In particular, the years since FRA standards were instituted are associated with a 1 percent increase in the proportion of revenues allocated to industry track maintenance expenditures. Also, track maintenance expenditure allocations showed a significant positive response to unit increases in accident rates. The link between safety standards and track maintenance expenditures, however, must be viewed with caution. The statistically significant upward shift in average track maintenance spending after 1972 may be the result of factors such as major renewal programs which, in turn, may have been the result of growing revenues or of anticipated growth--in coal or grain traffic for example--or of strategic goals that require upgrading service quality.

Furthermore, the analyses of railroad groups indicate that safety-related variables exhibit differential effects on various groups. Track maintenance decisions of railroad companies that operate trains at higher speeds appear to be more sensitive to accident rates and the introduction of FRA safety standards than similar decisions of companies that have slower average system train speeds. As one might intuitively expect, railroads with very low operating speeds seem not to be affected by FRA standards in their track maintenance allocations perhaps because the speeds are already so low that the standards do not serve as a disincentive to low track maintenance allocations, or perhaps because the carrier lacks the resources to undertake the major upgrading which would be required.

Large railroads appear to be more sensitive in their maintenance decisions to accident rates, perhaps because they possess the resources to undertake major rehabilitation. Profitable railroads appear to be more sensitive to accident rates and to the establishment of the FRA standards, while high density lines seem more sensitive to accident rates than low density lines.

For regional groups, the track maintenance expenditures of southern railroads appear more responsive than the expenditures of northern carriers to accident rates. Finally, for the passenger group, all models show accident variables with statistically significant coefficients that are larger for the passenger than for the nonpassenger groups. Not surprisingly, TMEXP and TMRATIO for railroads with passenger operations are more responsive to $(ACC)_{t-1}$ than carriers without such operations.

Train Speed and Car Weight

Overall, the change in average annual system train speed (Δ SPEED) was not a significant factor in the study of track maintenance spending. In regression equations for all railroads, Δ SPEED was not a statistically significant predictor of TMEXP or TMRATIO. In the analyses of subgroups, only TMEXP was responsive to Δ SPEED in medium size, low ROI, or low density railroad groups. For these groups, a reduction in average annual system train speed has a significant positive effect on the prediction of nominal track maintenance expenditures per track mile.

On the industry level, although average system carload weight (WEIGHT) has a significant direct effect on nominal track maintenance expenditures per track mile (TMEXP), it is not a significant predictor of real resources devoted to track maintenance (TMRATIO). For speed groups, although significant relationships are found in the low speed group, WEIGHT has a significant influence on the prediction of both track maintenance expenditure measures only in the medium speed group. Unlike speed groups, network-size groups show no significant relationships between WEIGHT and TMRATIO; when TMEXP is the dependent variable, statistically significant relationships occur only for the medium and the large network levels. For ROI groups, WEIGHT does have a significant effect on both track maintenance measures, but only at the low ROI level. The results for density groups are mixed; contrary results for medium and high groups as opposed to low density groups make interpretation difficult. The results are clear, however, for regional operations. Track maintenance expenditures of the northern group appear more sensitive to changes in average system carload weight. Finally, for passenger operation versus nonpassenger operation groupings, no patterns are apparent with respect to WEIGHT and track maintenance measures.

Tie and Rail Replacement Models

The second approach taken for the analysis of track maintenance activity was to estimate tie and rail replacement models. Besides the variables found statistically significant in the industry level study of track maintenance expenditures, a price index ratio (PIR) and the proportion of continuous welded rail (CWRAIL) were tested. Other operating variables such as DENSITY, SIZE, and LENGTH were not evaluated because they measure much of the same theoretical influences as WEIGHT.

Other than REV, no variable is significant in any regression equation for all railroads, and REV is significant only in the TIES model. In equations for carriers, other variables are significant, but changes in signs or in significance make interpretation difficult.

Accident and Speed Models

In developing final accident and speed models, variables considered essential (both a priori and from the point of view of regulation and control) as well as nonobligatory variables were tested. For accident models, the obligatory predictors were DUMMY, WEIGHT, and alternatively, $(\mathrm{TMRATIO})_{t-1}$, $(\mathrm{TMEXP})_{t-1}$, or $(\mathrm{REV})_{t-1}$; others tested were ROI, $(\mathrm{TIE})_{t-1}$, $(\mathrm{RAIL})_{t-1}$, LENGTH, and DENSITY. Regardless of the combination of variables, accident models did not give useful results, primarily because a meaningful measure of track condition could not be included in the models tested, and because the level of aggregation tended to blur the effects of the variables that were included.

Except for the substitution of LENGTH for WEIGHT, the same set of obligatory variables was specified for models of average system train speed. Nonobligatory variables, however, included only $(\text{TIES})_{t-1}$, $(\text{RAIL})_{t-1}$, DENSITY, and SIZE. The regression results for all railroads show that a significant reduction in average system train speed occurred after the introduction of FRA track safety standards. LENGTH, $(\text{REV})_{t-1}$, and the nonobligatory variables were not statistically significant. The results for lagged track maintenance measures are unclear and must be used cautiously. Although there are several possible explanations for the negative signs of the significant $(\text{TMRATIO})_{t-1}$ and $(\text{TMEXP})_{t-1}$ coefficients, the results were contrary to initial theoretical expectations. Finally, no other variables proved statistically significant in regression models for all railroads.

1. INTRODUCTION

The subject of deferred maintenance in railroad plants and equipment and the consequences thereof, has received considerable national attention since the late 1960s. An issue of particular concern within this general subject area has been the frequency and impact of freight train accidents caused by deficient track conditions or inappropriate train speeds. Public reaction to this issue led Congress to direct the Federal Railroad Administration (FRA), in 1971, to establish track safety standards setting forth minimum safety requirements for specific track conditions. The promulgation of such regulations together with the passage of time since their enactment raises two interrelated questions: (1) Have the track safety standards contributed to the reduction of track-related accidents? and (2) Have the track safety standards encouraged the allocation of higher levels of resources for track maintenance (T/M) with the purpose of reducing or eliminating deferred maintenance?

PURPOSE AND SCOPE

The purpose of this study was to investigate and, as far as possible, quantify the decision-making process for railroad track maintenance (T/M) expenditures in order to: (1) describe how federal track safety standards have influenced this process and (2) explore the possibility of predicting the impact of changes in safety regulations on T/M spending for all U.S. Class I railroads or selected groups of railroads. A related objective was to develop a data base and build statistical models of track maintenance spending that related T/M expenditures, both in dollar and physical terms, to significant explanatory variables such as traffic levels, train operation parameters, trackage, accident experience, financial and geographical characteristics, and track safety regulations.

In order to relate the objectives of this research to the general problem of reducing track-related accidents through safety standards, and in order to define the scope of this study, it is useful to conceptualize the interactions which are involved (see Figure 1). The operating speed

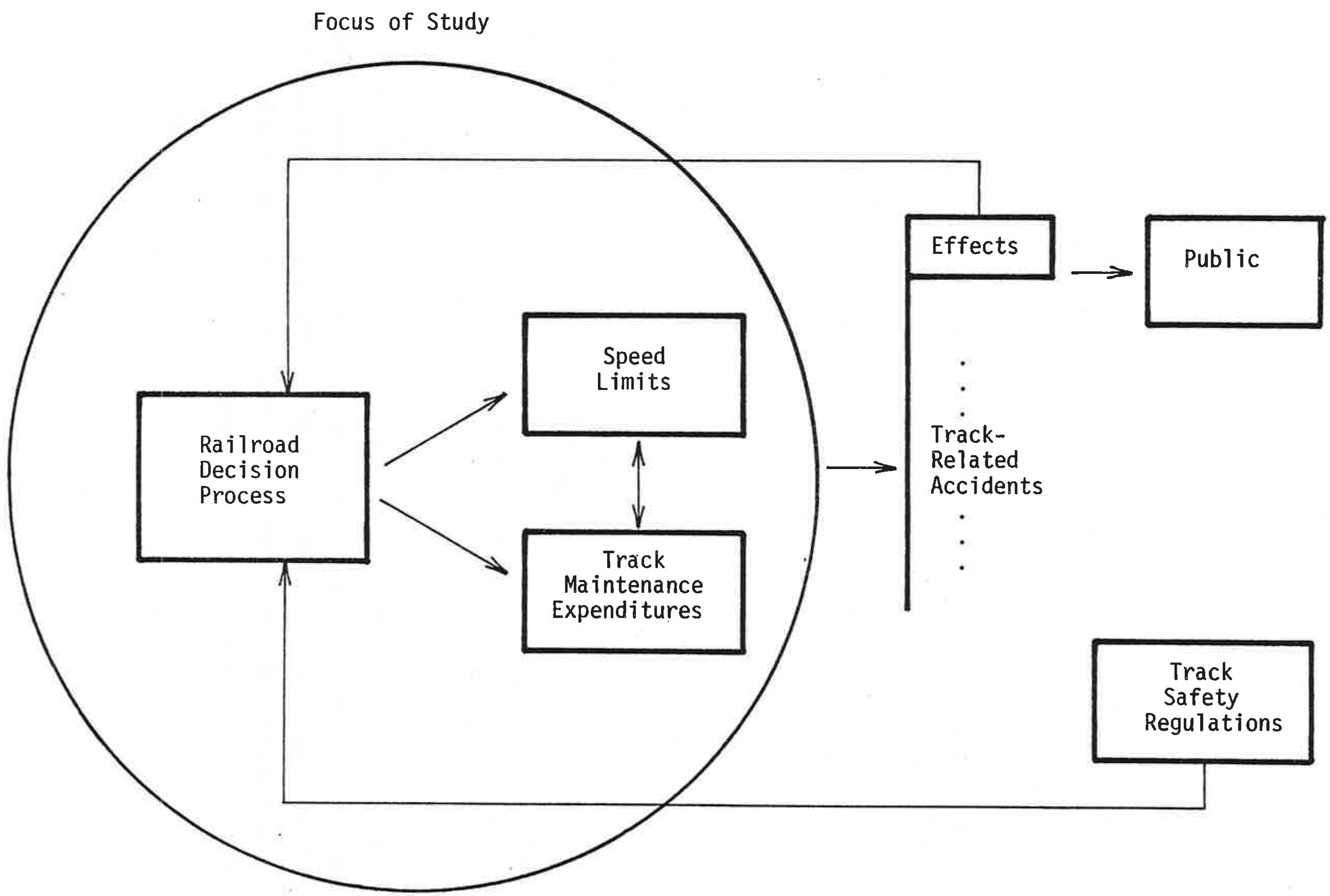


Figure 1. Focus of Study

limits and T/M expenditures have an effect on track-related accidents, income, market share, equipment utilization, etc., which in turn provide feedback to the decision-making processes, both directly and indirectly, through public track safety regulations.

The area of this study is encircled in Figure 1 and is limited to understanding the decision-making processes related to the selection of speed limits, the setting of track maintenance expenditure levels, and the direct and indirect feedback effects on these processes. The scope of the study was limited to the Class I railroads that operated in 1978 and the 16-year period from 1962 to 1977.

Finally, it is important to note that, in this study, the term "track maintenance" (or, simply, "maintenance") has a different meaning than the industry's standard notion of "maintenance of way"; track maintenance expenditures include expense and capital items primarily related to track and exclude expenditures for some structures. Specific details are highlighted in the Appendix.

RESEARCH PLAN

The approach used to accomplish the objectives of this research included a literature search, field interviews with Federal Track Safety Inspectors and railroad officials, formulation and testing of hypotheses through conceptual models and case analysis, and multivariate analysis of time series data in cross sections. The specific tasks and the products from each are shown in Figure 2.

Task 1--Interviews

The purpose of Task 1 was to explore the decision-making process for T/M expenditures, identify potential explanatory variables, and develop hypotheses to be tested. Task 1 was divided into two phases. The first phase, a literature search, was conducted to identify information available on railroad managerial processes, especially in relation to T/M expenditures, and to discover how these processes have varied over time.

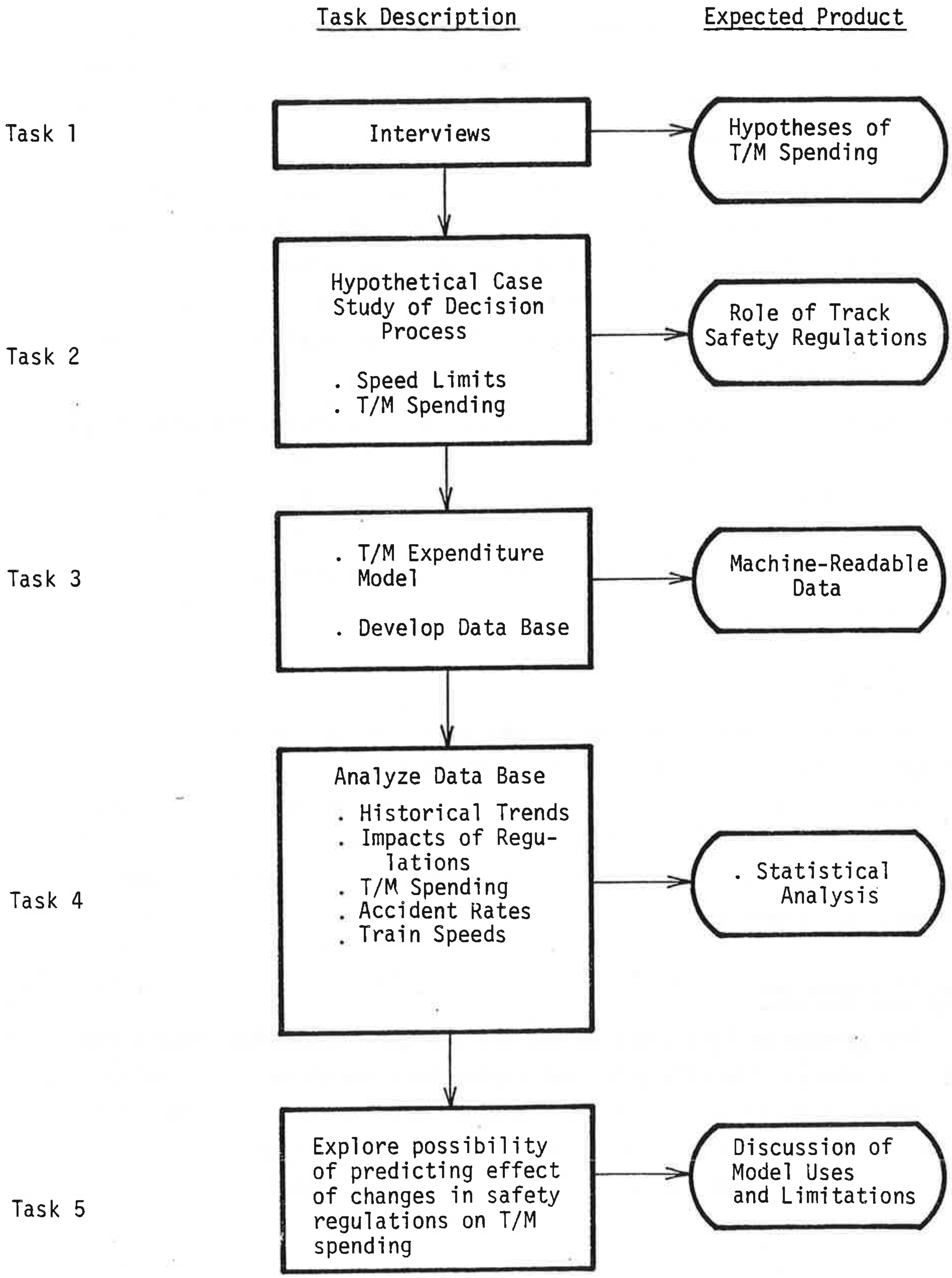


Figure 2. Project Tasks

In the second phase, a total of eight interviews were conducted, seven with senior officials of Class I railroads and one with a Federal Track Safety Inspector. The railroads which were chosen for interviews were selected by the project team with the advice and consent of the Technical Monitor.

Important considerations in the selection of railroads included: (1) size, (2) financial condition, (3) overall composition of lines (e.g., main vs. branch lines--to the extent that overall composition is clearly distinguishable) and track miles, (4) basic traffic characteristics (e.g., coal in unit trains vs. TOFC), (5) maintenance philosophy or policy and extent of mechanization, and (6) method of organization (to the extent such characteristics are clearly discernible). Many of these characteristics overlapped, so that even with a small sample, it was possible to obtain a fairly good cross section.

Task 2--Hypothetical Case Study

In Task 2, the research team formulated and parametrically solved a series of hypothetical railroad decision problems. These problems simulated railroad decision making with regard to the selection of speed limits and associated levels of scheduled track maintenance expenditures on individual lines of road. Research questions of interest were: (1) How do railroad managers make decisions on operating speed limits on individual lines? and (2) How do they decide on the level of T/M spending which should be undertaken for given speed limits? In addressing these questions, a key parameter was the federal role (in the form of track safety regulations).

Task 3--Compilation of Data

In Task 3, hypotheses of T/M expenditure behavior and a list of explanatory variables were developed. In order to test these hypotheses, a data base was prepared consisting of historical T/M expenditures and physical quantities of rails and ties, as well as the explanatory variables.

Task 4--Analysis

This task required a statistical study, using the data developed in Task 3, of the level of track maintenance performed by the U.S. Class I railroads. Several explanatory variables were included: a measure of the railroad's need to perform maintenance, as determined by its level of traffic; amount of track; train speeds; the railroad's ability to perform maintenance, as measured by its financial condition; and the potential benefits of increased T/M investment, as measured by train speeds, accident levels, and costs.

Special attention was given to the period covering the imposition of the FRA track safety standards to determine what effect, if any, the standards have had on track maintenance. If, during this period, maintenance expenditures rose and train speeds and accident rates decreased (noting the time lag between maintenance expenditures and decreased accident rates), it could be assumed that the track standards achieved their objective. If, on the other hand, maintenance expenditures decreased and accidents and/or train speeds increased, it could be assumed that the standards failed to achieve the intended effect.

Task 5--Impacts of Changes in Safety Regulations

In Task 5, the research team explored the question of how the results of the preceding tasks might be used to predict the impacts which hypothetical changes in federal track safety regulations could have on T/M expenditures by Class I railroads.

ORGANIZATION OF THE REPORT

This report is divided into five sections keyed to the tasks just described. Section 1 contains an introduction and overview of the report. Section 2 includes a review of the work accomplished in task 1 (Interviews) and task 2 (Case Study) and a comprehensive discussion of the decision framework for T/M spending. Section 3 describes the specific structural model, variable measurements and hypotheses, the data collection and editing procedures (task 3), and the analytical techniques. Section 4 presents the results of the work accomplished in the Statistical Analysis task. Section 5 explores the problem of how the model and supporting data might be used to predict the impact of changes in FRA track safety standards on T/M expenditures of Class I railroads (task 5). Finally, the appendix provides additional information relevant to this report.

2. DECISION FRAMEWORK

Besides a survey of the literature, two methods were used to explore the decision framework for track maintenance (T/M) spending. Initially, project members interviewed Federal Railroad Administration (FRA) and senior railroad officials. After all interviews were completed, a comprehensive hypothetical case study was used to explore key relationships suggested in the literature and in the discussions with railroad managers and FRA safety officials.

The basic purpose of the interviews was to investigate the role of the FRA track safety standards and the costs of track-related accidents in the overall decision-making process for railroad maintenance-of-way spending. Important research questions included:

1. What is the influence of FRA track standards on operating speed limits, and the influence of speed limits on the provision of maintenance funds?
2. Do FRA track standards cause railroads to increase maintenance-of-way expenditures for the improvement of deteriorated track conditions?
3. Have the track standards improved the safety experience of railroads?

To address these research questions, in-depth personal interviews were conducted with forty senior officials of seven Class I railroads. The selection of sample railroads was designed to encompass a full range of differences in climate, terrain, size, financial conditions, network characteristics, and traffic mix. Many carriers had overlapping characteristics, so that even with a small sample it was possible to obtain a fairly representative cross section.

Senior officials interviewed included the president or chief executive officer, the vice president of operations or the general manager, and the chief engineer. During some visits, financial officers and subordinate staff members of the engineering department were interviewed. Individual interviews generally lasted one hour. The format was flexible--to permit open-ended and candid discussion; a free response environment was considered essential to elicit desired information. It was the consensus of the interviewers that virtually every executive gave frank answers which provided valuable insights into the decision-making process.

DECISION-MAKING PROCESS

The interviews revealed a clear-cut pattern of decision making for maintenance-of-way spending. As shown in Figure 3, from an organizational perspective, the budget process is bi-directional. Top-level management establishes a ceiling for the annual operating budget after evaluating forecasted operating revenues, formulating strategic objectives, and specifying profit targets. Proposed budgets for maintenance-of-way expenditures are based on work plans which are developed initially at the division level and reviewed and refined at successively higher levels. During top-level review, management must reconcile the maintenance-of-way budget with the other departmental budget proposals and with the revenue ceiling.

Administrative Channels

The maintenance-of-way budget is developed within the framework of total operating budgets and strategic plans and programs. The work plan forms the basis of the budget request. A list of projects, developed initially at the division level, is reviewed and screened as it progresses through channels. In larger companies, roadmasters or section foremen initiate the work plan when they submit work requests through division and regional engineers to the chief engineer. Lower level requests concentrate on replacement-in-kind decisions, while major requests are normally identified and evaluated as part of the top-level review process. To a considerable extent, work plan requests at this level represent a "wish list" that must be carefully screened at each higher level of review. When the work plan reaches the chief engineer, it provides the basis for estimating maintenance-of-way expenses and budget proposals.

The procedural path leading to the final preparation and review of the budget request varied among the railroads studied. Most carriers use a formal budget committee to initiate the top-level review. Smaller roads (in terms of revenues and geographical extent), however, relied less on the formal budget committee structure and more on successive individual reviews by senior officials. In one case, a formal planning and costing model was developed which attempted explicitly to account for basic trade-offs. With this system, management felt little need for a formal committee review.

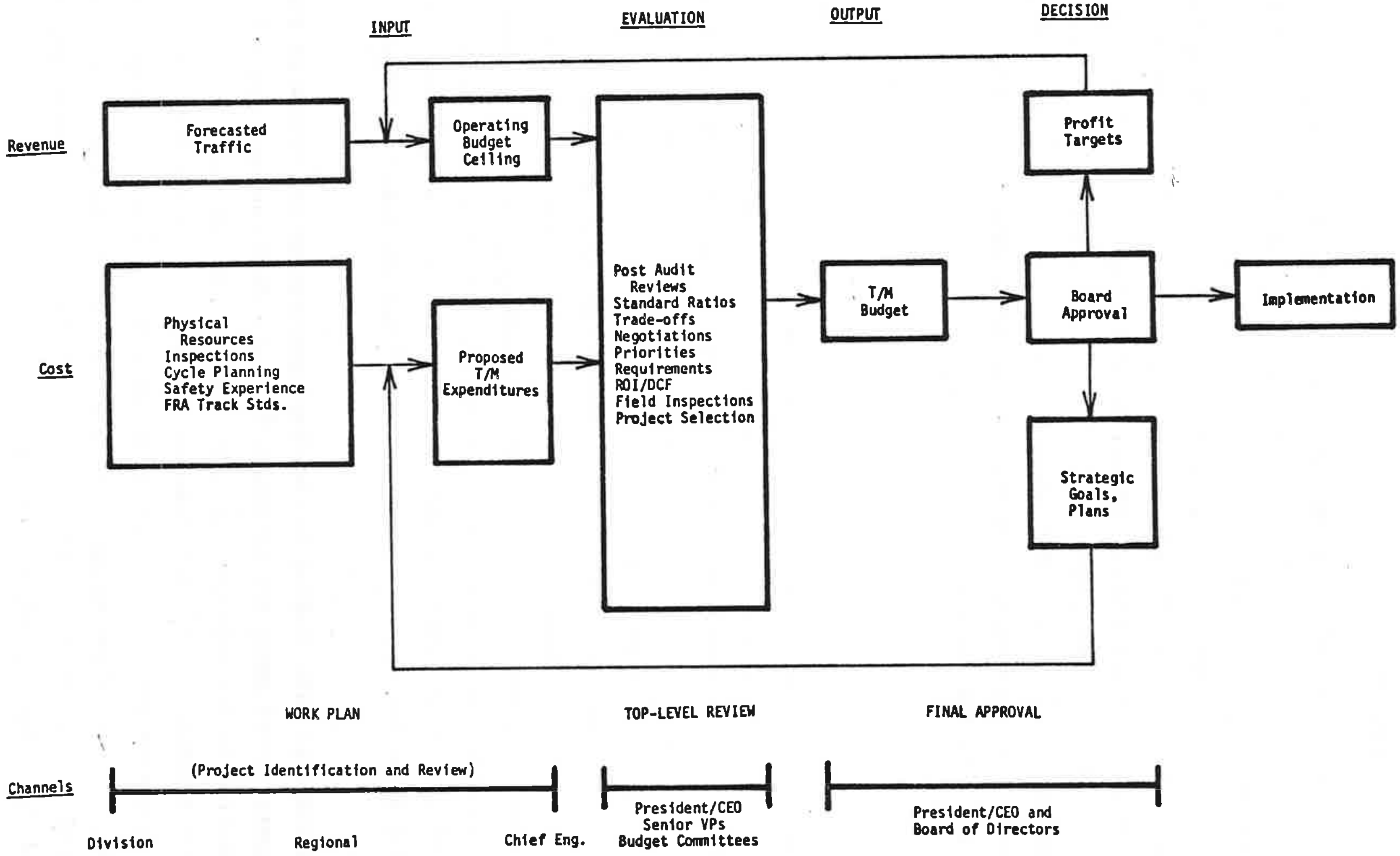


Figure 3. Maintenance-of-Way Decision Framework

Regardless of differences in the specific procedures for final budget review, the process requires an evaluation of trade-offs among major organizational units and a reconciliation of the maintenance budget request with other departmental budget requests, the established revenue ceiling, and the strategic objectives and plans. Ordinarily, carriers establish long-range plans (5 years or more) for capital programs. Such planning, however, is a function of financial viability. The planning horizon for a weak carrier is much shorter because the overriding concern simply is to survive.

In most cases, trade-offs are evaluated in budget committee meetings. Each officer defends his department's interests on the basis either of a return on investment or of need. Although several firms employ sophisticated planning tools, the results are typically determined by strong personalities, subjective judgments, and a recognition of the need "to come up with a figure the president can live with," rather than by any systematic modeling/planning information. Moreover, although trade-offs are formally addressed in committee, the resolution of conflicting functional objectives (particularly for small carriers) frequently is accomplished through informal meetings and discussions among senior executives. The chief executive officer is the final arbiter when conflicting objectives are not resolved informally or in committee. In most instances, the president or chief executive officer plays a strong, active role in the formulation of maintenance-of-way work plans and in the coordination of functional units in the organization. In one case, however, a coordinator was appointed to ensure cooperation between operations and engineering because the inability of the maintenance-of-way department to obtain sufficient track time from the operating department made it impossible to complete programmed maintenance.

The president and the board of directors make the final decision on the annual operating budget as well as on the maintenance-of-way and infrastructure capital expenditure budgets. The basic approach is that staff planners forecast traffic, estimate gross ton miles and, in turn, annual operating revenues, and establish the target profit. The size of the total budget is the difference between the expected total revenues and the annual profit target. The size of the maintenance-of-way budget is then calibrated to meet profit goals and other departmental requirements. Initially, the allocation of revenues to each functional unit is based on standard ratios ranging from 14 to 18 percent for maintenance of way and from 12 to 13 percent for mechanical operations. Subsequently, trade-offs are discussed, evaluated, and negotiated in high-level budget committee meetings as well as through informal channels. Ultimately, specific projects are selected on the basis of economic factors and subjective judgment. In addition, periodic reviews of projected revenues are used to modify planned expenditures. An adopted budget may be further modified to reflect actual business levels. Deletion or deferment of scheduled maintenance projects is common during an unexpected downturn in the economy.

The railroads considered an allocation of 17-18 percent of operating revenues to be standard for maintenance-of-way and structures expenditures, while an amount less than 14 percent was generally considered unsatisfactory. The assumption, of course, is that maintenance-of-way costs vary directly with the level of traffic. Little attention has been given to the economies that potentially can be derived from increased maintenance activity in slack periods, e.g., more track time and better maintenance productivity without service interruptions, as well as more favorable material prices. Instead, short-term profitability dominates the management philosophy of most companies. In some cases, this perspective apparently stems from board members who insisted on maintenance of earnings per share, even at the expense of maintenance of way.

In addition, maintenance-of-way expenditures suffer from the relatively fixed nature of planned expenditures in other departments. When traffic is declining, the operating department may be slow to reduce its expenditures by reducing the number of trains, switch engine hours, etc., and this delay increases the proportion of available funds spent by the operating department. Often, the source of these additional funds is the maintenance-of-way budget. Thus maintenance-of-way activities are reduced as a result of a reduction in the total budget and an increase in the share of the budget used by other departments. In "lean" years, the proportion of the budget allocated for maintenance-of-way expenditures may be reduced to 12-15 percent.

Since the primary objective is to meet the annual profit target established by the board, usually maintenance will be deferred in order to support the profit goal. In a recession, therefore, expensive projects are frequently postponed, for these projects represent the most dramatic changes in the annual budget and the most significant contributions to the profit target. In lean years, moreover, the carrier can mask deferred maintenance in order to retain proper levels of profit.

Project Identification

Inspections, standard maintenance programs, and safety all play important roles in project identification. Section men, assistant track supervisors, roadmasters, and senior officers (sometimes including the company president) perform on-site inspections. Visual inspections concentrate on roadbed, ballast, rail sections, and ties. Section men usually perform detailed monthly inspections, while senior staff members inspect at least the principal line segments as often as three to four times per year. In addition, rail test car inspections are made two to three times per year over main lines and once per year over branch lines; some railroads also make track geometry car inspections. Important inspection information, therefore, includes the track geometry car test results, the measurements of rail wear or defects, and the more subjective judgments of experienced inspectors.

Cycle Maintenance Planning. In the 1950s, large-scale mechanization of maintenance operations led to the development of cycle maintenance planning (CMP). CMP attempted to establish normalized conditions or standards for maintenance of way and, thereby, determine the minimum amount of maintenance required to prevent track conditions from falling below standard.

Although the comprehensiveness and the sophistication of cycle maintenance planning vary considerably among railroads, there is widespread recognition of the need for more precise and accurate indices, measurements, and methods to judge whether more is taken out of track than put into it. Both financially weak railroads and those that are financially strong used outside consultants to help develop cycle maintenance programs. The quality of in-house maintenance-of-way analysis is higher for stronger railroads, which understandably tend to use more sophisticated planning techniques. Some railroads, for example, use simulation and standard cost models that attempt explicitly to evaluate interactions among track structures, equipment, capacity, and speed. Most weaker carriers, however, do not have normalized maintenance programs in force. The property's most urgent arrearages must be overcome before such approaches can be implemented.

Safety. Accident experience, hazardous materials routes, and FRA track safety standards are part of the project identification process. While accident experience is considered to be extremely important, no explicit "trigger levels" (in terms of cost per accident or number of accidents) guide project identification. Instead, management relies on a case-by-case approach and subjective judgment.

The general pattern of decision making also requires the identification of key hazardous materials routes. These routes usually receive greater attention in the work plan, particularly when the routes include lower density branch lines.

Finally, the imposition of FRA track safety standards has, in general, increased the number of visual inspections performed each year. The influence of track standards on cycle maintenance planning, however, varies inversely with the carrier's financial strength. For weak roads, it is often FRA standards that prescribe levels of required maintenance. For strong roads, track standards often do not significantly affect the work plan.

Project Evaluation

In general, decision making in the evaluation phase occurs on a system-wide basis within the framework of strategic objectives and long-range planning. Project evaluation, however, is highly centralized. While division-level decisions in both the identification and evaluation phases concentrate on replacement-in-kind projects, major capital programs and planning are part of the top-level review process. As already indicated, most firms are pursuing more sophisticated and accurate methods for identifying and evaluating work requirements and capital programs. To a significant degree, however, the level of sophistication, as well as the length of the planning horizon, depends on the financial resources of the carrier.

Operations/Service Objectives.

Consistent, on-time performance over strategic routes was cited by the railroads as the primary service objective. Although, in a few instances, speed of delivery was ranked with consistency as a top service priority, on-time performance was generally considered more important. In addition, many carriers cited the provision of specialized equipment (car type, size, and availability) as an important service goal.

These transit performance priorities were based on a number of factors: network characteristics, geographical constraints, and traffic profile. For smaller networks, increasing train speeds would not significantly reduce delivery times between major nodes on strategic routes, i.e., major traffic lanes. For some carriers, an operating philosophy that called for long, heavy freight trains running at speeds of 60-65 mph was abandoned because the time saving from higher speeds was dissipated in yard and terminal activities, the consumption of fuel and the risk of derailments increased significantly, and the maintenance cycle was considerably shortened. A consistent service strategy, moreover, was viewed as better suited to networks characterized by (1) numerous nodes and relatively short distances between nodal pairs or (2) numerous and widely dispersed branch lines for gathering important traffic, because these characteristics limited the opportunities for, and thus the savings (e.g., in labor and per diem) from, higher operating speeds. Likewise, hilly terrain and numerous curves were geographical conditions that restricted opportunities for high-speed operations. Furthermore, in colder regions, winter weather may offset maintenance-of-way improvements designed to improve train speed.

Key aspects of the traffic profile were mix, volume, and competition. For some railroads, a small number of commodities were hauled over the strategic routes, but these commodities produced most of the operating revenues. When these commodities had relatively low dollar and weight densities, consistent rather than fast delivery better met shippers' needs. The primary objective, therefore, was to meet customers' delivery needs and to provide prompt return of empty cars to meet shippers' loading requirements. For other roads, intense intramodal and intermodal competition combined with a highly diversified traffic mix led to a service strategy of consistent and fast delivery time. In one case, senior executives considered that train speeds in excess of 60 mph were essential to maintain or to strengthen their competitive position. It was also believed that faster train speeds meant additional savings in crew and equipment costs; however, a formal analysis of incremental savings measured against additional costs (labor, maintenance cycles, fuel efficiency, or accidents) was not undertaken. The service strategy for financially troubled carriers was simply to restore consistent and safe service, at least over key traffic lanes. The implementation of this strategy meant the elimination of slow orders on strategic routes to provide minimum 30 mph service.

Thus, train speeds depend primarily on the carrier's service strategy, which, in turn, is a function of the geographic, traffic, and financial profile of the carrier. For most of the carriers, operating speeds set in accordance with service priorities ranged from 35 to 50 mph on main lines and from 20 to 30 mph on branch lines. Where network and geographical conditions permitted, carriers that faced stiff competition for time-sensitive traffic operated trains at speeds of 60 mph or more.

For several carriers, the provision of specialized types of equipment for key market segments was also an important service goal. Usually, this meant supplying shippers with 100-ton hopper cars. Although senior officials were aware that heavier cars would require considerably more track maintenance, a formal analysis of the relationship between increased maintenance costs and increased car size or weight was not undertaken. In at least one case, instead of increasing the maintenance budget to match the marketing effort (the provision of 100-ton cars), top executives expected the maintenance function to adjust by becoming more productive.

Maintenance-of-Way Objectives. The objectives of the maintenance function are keyed to the achievement of strategic service goals and priorities. Generally, the goal was to provide an infrastructure capable of supporting the firm's service objectives. For carrier management teams which explicitly assumed a viable, profitable operation in the long run, i.e., over the next 30 years or more, preserving the structural integrity of the system was a top priority. Policies and programs were designed, therefore, to prevent substantial borrowing against the future. A long-term goal for most of the carriers, of course, was to abandon some line segments.

The basic short-term objective for the more prosperous railroads was to stay even, i.e., to maintain and preserve existing levels of plant integrity where the level of traffic or earnings justified normalized maintenance. More precisely, the typical policy was to recoup maintenance deferred during lean years on important lines (those experiencing at least ten million gross tons per year) and/or upgrade segments when estimated future earnings warranted new investment and funds were available. Low density or marginally profitable line segments, on the other hand, received only "adequate" maintenance--maintenance that met minimum safety standards. It should be noted that, although the use of traffic density to identify important lines is almost universal, density cutoffs vary widely from one company to another; a "light density" line for a larger carrier, therefore, may be the "main line" of a small carrier.

For carriers that were confronted, after years of deferred maintenance, with deteriorated track and structures, the overall short-term goal was to restore main line track and yard to meet short-term objectives without compromising, if possible, short-term profitability. Although it was hard to make a mistake in project selection, priority was given to strategic routes with subsequent "cascading" of rail, replacing of defective rail, upgrading of crews (using fewer men with better equipment), and providing only minimum maintenance necessary to correct FRA inspection violations (thereby concentrating on the "really weak areas"). The immediate concerns were to maintain strategic routes above the minimum levels required by FRA standards for desired speeds, keep important traffic moving, and provide consistent deliveries. Slow orders on important line segments had to be removed in order to permit main line speeds in excess of 30 mph. The basic strategy was to establish financial viability, seek rate increases, expand maintenance programs, rebuild the system, and provide safe and dependable service.

The pattern of priorities for the allocation of maintenance expenditures is thus relatively straightforward. Not surprisingly, economic criteria, especially potential earnings, dominate priorities. In most cases, the volume of traffic is used as an indicator of potential earnings and to identify key line segments, defined as those on which there is a minimum of one million gross tons (MGTs) per year; usually, ten MGTs per year indicate a strategic route. One notable exception occurred when the actual earnings (traffic density and rate structure) on line segments were evaluated. This process led to a major renewal program for low-density branch lines that played a major role in gathering important traffic. All firms use discounted cash flow or rate of return methods to evaluate potential earnings and to allocate funds; minimum ROI requirements for projects ranged from 18 to 30 percent. But these firms frequently found it difficult to quantify savings related to conditions such as running time, equipment costs, crew costs, and shorter maintenance cycles. Occasionally, projects were completed without ROI analyses, because management deemed these projects necessary in order to "stay in business."

<u>Safety</u>. Safety considerations had varying levels of influence on project evaluation and maintenance decisions. Although safety had little overall impact on the size of the total maintenance-of-way budget, accident experience and, sometimes, track safety standards significantly influenced the allocation

of maintenance funds. While senior officials knew that derailments created "enormous" losses and that operating safety was an important objective, it was well known that causes of the derailments were difficult to assess. The prevailing viewpoint was that not much was known about the effects on track-related accidents of large cars and unit trains moving over well-maintained track at relatively high speeds. It was argued, for example, that half of all accidents reported as track related were not really caused by track problems. Unexplained accidents had occurred on strategic line segments with the highest maintenance standards. That accident experience led some carriers to reduce train speeds while still maintaining track at levels required for higher speed operations. The reduction in high train speeds on main lines, in turn, led to a dramatic reduction in unexplained accidents and has become an important part of the rationale for establishing consistent, rather than fast, delivery times as a strategic service objective. Thus, to a large extent, top-level management has relied upon subjective judgment and a case-by-case approach when evaluating accidents. No explicit numbers (either rate of incidence or costs of accidents) were used to guide maintenance-of-way expenditures; nonetheless, accident experience was an important element in the budget allocation process. The factors considered included statistical details, location, costs, and causes by road type and yard. Similarly, hazardous materials routes were identified and evaluated on a subjective basis, but these routes received special attention in the project evaluation phase.

The impact of FRA track safety standards on maintenance-of-way spending is largely a function of the carrier's financial condition. For financially strong carriers, track safety standards had little effect on the amount or allocation of funds. Their view was that FRA standards prescribed minimal maintenance conditions. On high-density lines, company standards substantially exceeded FRA requirements, i.e., maintenance practices at least met the standards for the next higher class of track. On low-density but important branch lines, the same practice was followed. When traffic or earnings did not support this maintenance policy, minimum safety requirements were essentially the only consideration; maintenance activity was placed in a holding pattern, and temporary slow orders were accepted. Eventually, the line segment was downgraded to the next lower class of track, and permanent slow orders were accepted. Minimum FRA standards then became the normal maintenance requirements.

On the other hand, FRA track safety standards often prescribed the maintenance-of-way requirements for financially weak carriers. In order to attain strategic service objectives, these firms had to eliminate slow orders or upgrade track to meet minimum standards for the class of track that permitted desired operating speeds over strategic routes. In this situation, the rail defect car test results generated considerable pressure to relay rail.

Finally, FRA regulations caused the carriers to devote additional (albeit minor) resources to administrative tasks (e.g., training) and, in some cases, to more frequent visual inspections. The prevailing view, however, was that additional inspections add little if anything to safety and are made only to comply with regulations. Senior executives of prosperous carriers, in particular, felt that track safety standards worked to dilute the effectiveness of on-going programs. Managers pointed out, for example, that FRA regulations treat many defects identified by an inspection car as equally in need of corrective action. Although some defects are obviously worse than others, each must be repaired immediately. This requirement has caused resources to be diverted to repair track segments that were already scheduled for maintenance, thereby disrupting planned maintenance cycles and reducing the efficiency of mechanized maintenance gangs. Thus, a disincentive for inspecting more track than the law requires is created: the firm cannot afford to find minor defects that have little to do with actual safety but must be repaired immediately. Test car inspection instruments, moreover, are viewed as imprecise. Managers see safety more as a function of age (of rail), traffic density, equipment (axle loads, type and length of car, or load capacity), and speed rather than of technical specifications set forth in FRA track standards, e.g., the number of defective ties per line segment. Thus the prevailing viewpoint is that track standards mean fewer maintenance options and a less effective maintenance program.

CASE STUDY

As indicated in the discussion of the decision-making process, many interrelated factors enter into the T/M decision. The following hypothetical case study provides an effective vehicle for identifying and discussing the complex set of interactions among key factors. The purpose is to develop and refine further the conceptual foundation necessary for the construction of hypotheses about T/M decision-making behavior. The focus, in particular, is on the relationships between safety (track standards, accidents, and hypothetical policy options), train speeds (including the economic incentives that influence train speed), and levels of T/M spending. The results, therefore, should not be viewed as generalized principles, but rather as illustrations of relationships and issues confronting the decision maker.

The conditions described characterize a medium-sized and financially weak Class I railroad. As already noted, top railroad executives at strong roads indicated that they do not believe track safety standards are a significant factor in project evaluation. The selection of a medium-sized railroad, moreover, reduces complexity, while still permitting identification and discussion of key relationships. The system conditions are derived (to the extent possible) from public sources. T/M requirements for selected line segments, however, are hypothetical but representative and generally consistent with information gathered from the literature (cited in subsequent sections of this report) and the interviews.

System Profile

Eighty-five percent of the route structure is main line, single track railroad. The remainder is classified as branch line. The main lines are divided into northern and southern territories. In the northern territory, lines are located in hilly terrain; gradients are frequently in excess of .5 percent but never exceed 1.5 percent. Heavy curvature is also encountered with two to three 1°-2° curves per mile, frequent (1-2 mile) curves in the 3°-5° range, and occasional curves up to 8°30'. Southern lines are much flatter, with grades seldom exceeding 0.5 percent, although grades approaching 1 percent can be found at several isolated locations. Curvature on the southern lines is also heavy with several miles of 8° curves.

Network Condition

Main Lines. As shown in Table 1, hypothetical but representative main line conditions vary from fair to poor. In both N and S territories, worn rail conditions prevail. In particular, the 112 lb jointed rail, rolled in the 1930s, is generally bent and has some rail-end batter. Furthermore, rail transposing is needed, insulated joints are in poor condition, and surface

Table 1. Line Segments

Line Segments	Track Section (miles)				Route Condition*			Operations			
	90 lb	112 lb	130 lb	132 lb	Rail	Ties	Surface	Speed (mph)	Traffic (MGT/mi)	Accidents (n)	Passenger (Yes, No)
Main											
N		50		150	F-P	F-P	F-P	≤ 30	25.0	5	No
S			100		F-P	F-P	F-P	≤ 30	10.0	5	Yes
Branch											
N		10	30		F-P	F-P	F-P	≤ 25	2.0	2	No
S	5	10			P	P	P	≤ 10	< 1.0	1	No

*F = fair
P = poor

grinding efforts are inadequate. Tie condition is fair to poor. Major tie renewals were performed in the early 1950s. Derailments, single shoulder plates, and lack of plate-holding spikes have contributed to the population of defective ties and the reduction of tie life.

Rail conditions, tie renewal requirements, and poor drainage are the primary factors, in turn, that have led to significant surface and alignment problems. During the recent work season, 10.3 miles of the main line were under 5 mph slow orders. In addition, numerous 10 mph slow orders existed on bridge approaches and at road crossings which were badly out of alignment.

The volume of traffic is considerably greater in the N than in the S territory. The 25 MGT moved annually over the N segment requires about 5,250 trains, with 3 locomotives and 70 cars per train. Only 1,000 trains per year handle the 10 MGT for the S segment, with a similar number of locomotives and cars per train. Despite the lower traffic density on the southern (S) main line, passenger operations over this route require maintenance to at least Class 3 standards.

Branch Lines. Like the main routes, the N branch line is in fair to poor condition. Most of the segment meets Class 2 standards. Temporary slow orders ($\leq$ 20 mph) are in effect at numerous locations. On the average, 350 trains per year, 2 locomotives per train, and 30 cars per train operate over this branch line.

The S branch line is in the worst condition, and some locations do not meet Class 1 standards. The 90 lb rail should be replaced because Sperry inspection car defects are very high--5.7 per mile per year. In addition, the tie condition is poor; defective ties exceed 1,000 per mile. Train speeds are restricted to 10 mph or less. The average train consists of 2 locomotives and 20 cars. About 150 trains move over this line each year.

Track Maintenance Programs

Alternative T/M programs for main and branch line segments are shown in Table 2. T/M investment cost is defined as the total expenditure to improve line segments from one set of conditions to another. Unit costs were derived primarily from interviews and industry sources [1-5].* The short-term minimum

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*Numbers in brackets refer to the list of references at the end of the report.

Table 2. Annual Track Maintenance Programs

Work Tasks	Unit	Minimum Level (Short Term)			Minimum Level (Long Term)			Rehabilitation (Long Term)		
			Cost			Cost			Cost	
		Qty	Unit	Total	Qty	Unit	Total	Qty	Unit	Total
Main Line										
(N)										
Rail	Trk-mi.	3	175,000	525,000	5	175,000	875,000	10	175,000	1,750,000
Ties	No.	25,000	30	600,000	40,000	30	1,200,000	50,000	30	1,500,000
Surface & Line	Miles	20	9,300	186,000	30	9,300	279,000	50	9,300	465,000
				1,311,000			2,354,000			3,715,000
(S)										
Rail	Trk-mi.	2	175,000	350,000	5*	63,000	315,000	10	**	1,505,000
Ties	No.	20,000	30	60,000	40,000	30	1,200,000	50,000	30	1,500,000
Surface & Line	Miles	10	9,300	93,000	25	9,300	232,500	40	9,300	322,000
				503,000			2,007,500			3,770,500
Branch										
(N)										
Rail	Trk-mi.	-	63,000	-	5*	63,000	315,000	5*	63,000	315,000
Ties	No.	5,000	30	150,000	8,000	30	240,000	10,000	30	300,000
Surface & Line	Miles	Spot		-	10	9,300	93,000	20	9,300	186,000
				150,000			648,000			801,000
(S)										
Rail	Trk-mi.	5*	63,000	315,000	5*	63,000	315,000	5*	63,000	315,000
Ties	No.	10,000	30	150,000	10,000	30	300,000	10,000	30	300,000
Surface & Line	Miles	5	9,300	46,500	5	9,300	46,500	5	9,300	46,500
				511,500			661,500			661,500

*Relay

**5 Relay

level ($L_{(Min-ST)}$) effort means the level of spending required only to meet present FRA track class requirements for the short term. Accelerated track deterioration and increased risk of accidents will result. Eventually, temporary speed restrictions will become permanent when the track is downgraded to the next lower track class.

The minimum level long-term ($L_{(Min-LT)}$) program will permit main line segments to stay in the same (Class 3) track status, and permit 30 mph train speeds on designated sections of the N branch line. This program, however, does not provide the spending necessary for normalized requirements. Consumption of the infrastructure will occur at a greater rate than maintenance replacements.

The long-term rehabilitation ($L_{(Rehab-LT)}$) program will restore the track to normalized conditions at the end of five years. The substantial investment in property will assure train operations at Class 3 speeds ($\leq$ 40 mph) on main lines and 25 to 30 mph on both branch lines.

In addition to the three program alternatives, a fourth option is to discontinue operations on the line segment. In summary, the four levels of spending are identified as follows:

1. $L_{(No)}$ - discontinuance
2. $L_{(Min-ST)}$ - minimum level, short-term program
3. $L_{(Min-LT)}$ - minimum level, long-term program
4. $L_{(Rehab-LT)}$ - long-term rehabilitation program

Problem

The problem to be studied is how managers determine the level of T/M spending for each line segment and what roles train speed, track safety standards, and accidents have in the spending decisions.

Costs

Besides initial project costs, it is necessary to estimate the subsequent increased T/M expenses that result from increased track deterioration for levels $L_{(No)}$ and $L_{(Min-ST)}$. The increased expenses will be a function of the relative change in track conditions and the unit costs for ordinary maintenance. The estimated annual unit cost for rail is $3,000 per track mile, while for ties, surface, and line the cost is $1,500 per track mile. The chief engineer, however, must assess track conditions before and after the initial investment in order to estimate the incremental level of ordinary maintenance required, i.e., to what extent the T/M stems from track deterioration. Frequently, this process, although supported by quantitative information, is largely subjective and is based on many years of experience in the field. In this regard, some of the larger or more profitable railroads are using more sophisticated information systems and modelling techniques to support decision making [6,7].

In order to understand this judgmental process and its complexity, as well as explore the effects of speed restrictions and safety standards on the decision process, a hypothetical track condition model, based on information gathered during interviews and derived from other industry sources and literature on the subject, is developed and discussed.

Track Condition Model. The objective of the track condition model (TCM) is to quantify the relative importance of major factors that affect track conditions and arrange the factors in a way that systematically yields reasonable estimates of relative differences. A multiplicative arrangement, where one is the base on a scale that measures relative importance, provides a method for attaining this objective. A value of one, of course, means no change, while values greater or less than one reflect the relative influence of various factors on the condition of track. With this approach, it is possible to quantify and better evaluate the subjective judgments in the decision process.

As shown in Table 3, important factors that affect track conditions include rail characteristics (physical attributes and track modulus), defective ties, surface and line (profile and end batter), and terrain (grade, curvature, and subgrade) [2,8,9,10,11]. Operating conditions (tonnage, axle loads, train length, and speed), of course, also affect track conditions [2,12,13,14]. The TCM combines these factors as follows to produce a track condition factor (TCF) measure:

Table 3. Track Condition Model Factors and Value Ranges

Factors (TCF)	Values (Range)
Network	
1. Modulus	
• Rail Weight	1.0-1.2
• Ballast	0.9-5.5
• Subgrade	0.5-1.0
2. Rail	
• Age	0.9-1.0
• Length	0.9-1.0
• Type	0.9-1.0
3. Ties	0.5-1.0
4. Surface and Line	
• Profile	0.9-1.0
• End Batter	0.9-1.0
5. Terrain	
• Curvature	0.9-1.0
• Grade	0.9-1.0
Operations	
• Tonnage	0.5-3.0
• Speed	1.0-1.5
• Axle Loads	0.8-1.5

$$\text{TCF} = \frac{\text{(Rail) (Modulus) (Ties) (S\&L) (Terrain)}}{\text{(Operations)}}$$

Thus, for network factors, larger values increase the TCF, while for operation factors, larger values greater than one indicate greater consumption of infrastructure and produce a downward influence on the TCF.

The values shown in Table 3, although hypothetical, are in general consistent with findings reported in the literature as cited below and the interviews. Obviously, for each of the factors, specific relationships between condition values and factor levels would have to be determined empirically and would vary, to some extent, from railroad to railroad. In this case, the condition values are calibrated to produce a standard of 4.00 to represent normalized conditions when train speeds approach 40 mph, when there are no unit train operations, when curvature and grade are not significant, and when traffic volume is about 25 MGTs. Specifically, values are based on the following rationale.

(1) Track Modulus

Track modulus is a measure of the track structure's ability to resist deflection under load. Traditional methods of track analysis often utilize modulus as the single measure of track strength. Deflection, in turn, greatly affects the rate of deterioration of the track [10,15,16]. The weight of rail, the type, depth, and condition of ballast, and the condition of the subgrade are important elements in the track modulus. Ballast and subgrade characteristics are usually the most significant elements in the modulus and are, therefore, important factors in the TCM.

(2) Rail

The age, type, and length of rail have much less influence on overall track condition than track modulus. The effects of age, in particular, are not well defined, although, generally, older rail is less serviceable. Most rail in main line use is adequate from a bending strength standpoint. Even assuming that the rail is approaching the maximum allowable headwear (25-30%), bending strength is not a problem [17]. If the rail has a history of being subjected to heavy wheel loads, however, the rate of internal defects may rise substantially as the rail ages [18,19,20]. Premium rails will wear more slowly and be subject to lower defect rates than standard rail [21-24]. Yet this does not substantially affect the condition of the track.

Finally, longer rails with fewer joints, or Continuous Welded Rail (CWR), with its elimination of joints, may represent substantial maintenance savings because rail joints represent a major expense item (joints must be tightened and inspected), and rail ties in the joint area are subjected to higher stress levels than rail and ties in other areas [11].

(3) Ties

Tie conditions affect the serviceability of track in several ways. Ties that have obviously failed (broken, rotted through, etc.) will not support the rail cross-level (horizontally or vertically) in a satisfactory manner. This can lead to surface bent rail, which increases the dynamic loads on the track and may render the rail unusable for high speed operations. Defective ties will also decrease the service life of adjacent ties [11,15]. Lack of horizontal support may give rise to wide-gauge-related derailments. The principal problem arises in determining the effect of a deteriorated, but not completely failed, tie. The performance of a tie which is partially rotted or is nearing the end of its serviceable life is not clear. Thus, only completely failed or missing ties can be seen as affecting the TCM.

(4) Surface and Line

The principal effect of surface and line conditions is the resultant dynamic forces generated in the track. As surface and line conditions deteriorate, cars moving over the track at any speed will induce significantly higher dynamic forces in the track structure [25]. The higher forces will decrease the life of most track components, as well as give rise to potential derailments.

Rail-end batter is a special case of localized surface irregularities. Excessive deformation in the rail joint area, together with the associated impact forces generated by moving wheels, can significantly shorten joint tie life and lead to ballast and subgrade degradation and vice versa. Rail cost may also be increased due to shortened rail life and an associated welding expense. CWR might eliminate the additional T/M expense from this condition.

(5) Terrain

Elements of terrain play a role in the life of the various components of the track structure. Curvature, and to a lesser extent gradient, will shorten the serviceable life of the components. Lateral forces generated during curve negotiation will: (1) cause the rail to wear faster as tonnage increases, (2) possibly give rise to more defects in the rail, (3) increase wear on ties and fasteners, and (4) require more alignment attention than tangent sections. Although the relative effect of curvature is directly related to the degree of curve, T/M costs are thought to be more dependent on the total central angle than on the relative sharpness of the curve [15]. Sharp curves may, however, require lower speeds and, thus, offset some of the expected costs.

Grades also affect the rate of consumption of track resources. The process of negotiating a grade requires that braking or traction forces be applied to the rail--forces that will shorten the life of track components. In addition, sand used to increase adhesion on grades will eventually reduce the drainage capabilities of the track structure, and additional track maintenance will be required to decrease the degradation rate of track components.

(6) Operations

Traffic volume, train speeds, and axle loads affect track conditions. The life cycle for most track components is directly related to the volume of traffic passing over the track [11,25,26]. Although several characteristics of the traffic are important, the volume, measured in terms of gross tons, is the most universally used and the easiest to measure. Since most track components deteriorate with use, the density measure plays a significant role in the TCM.

Speed primarily affects track maintenance in two ways. The dynamic forces that are imposed on the track by moving vehicles increase approximately linearly with speed [10,15,25]. Thus, trains moving at higher speeds will extract more from the track structure. On the other hand, to minimize such dynamic forces, high speed track is generally maintained to a higher degree of geometric quality, and, therefore, minor irregularities in line and surface must be corrected quickly.

Track deflection is often considered to vary linearly with axle load [25]. Laboratory tests, moreover, have shown that increases in axle load can cause significant reduction in the performance of such items as ballast and subgrade [27]. In addition, heavy axle loads may increase significantly the rate of defect formation in the rail [2,8,17,22].

Benefits

Benefits fall into two major categories: (1) savings in ordinary T/M and (2) savings in train operations.

Ordinary Track Maintenance. When track rehabilitation is performed, the annual increase in T/M expenses that results from increased track deterioration is avoided. The normalized track condition factor relative to the actual track condition factor can be used to estimate the annual increase in T/M expenses. For example, given a TCF of 4.00 that represents normalized conditions and an actual TCF of 1.00, the estimated annual increase ($ T/M) is:

$$\$\ T/M = \frac{4.00}{1.00} \times \text{annual unit costs.}$$

Specific estimates of such avoidable costs for main and branch lines are itemized in Table 4. As shown in this table, the southern territory main line (S) was given an actual TCF of 1.00, while the northern territory main line (N) was assigned a 1.50 TCF. The initial values indicated that actual track conditions were worse for (S) because deferred maintenance was assumed to be more extensive on this main line. Both branch lines, however, were given the same initial TCF of 1.25. Although the initial TCF value is greater for the branch lines than for the south main line, it still indicates comparably poor track conditions because, given similar track conditions, the much lower traffic volume on branch lines inflates the TCF.

In addition, it is assumed that replacing jointed rail with CWR generates T/M savings, for surfacing requirements are reduced, joint maintenance is often eliminated, and the life of track materials is extended. The amount of savings, of course, will depend on the level of traffic. The estimated annual saving per mile of CWR for main line segments N and S is $1,900 and $1,700, respectively. For the N and S branch lines, the figures are $1,500 and $1,200 per mile per year, respectively. When worn CWR is relayed, only 50 percent of the estimated savings per mile was assumed.

Train Operations. Train speed and accident avoidance are key elements in realizing savings in train operations. During interviews, senior railroad officials indicated that normally one-half to two-thirds of project savings were speed related.

Table 4. Increased Annual Ordinary T/M Expenses from Track Deterioration

	T/M PROGRAM							
	$L_{(Min-LT)}$				$L_{(Rehab-LT)}$			
Line Segment and Work Item	Net Change	Unit Cost	TCF Adjustment	Increased T/M	Net Change	Unit Cost	TCF Adjustment	Increased T/M
Main								
N								
Rail	2	$3,000	(4.0/1.5)	$ 16,000	7	$3,000	(4.0/1.5)	$ 56,000
Surface & Line	10	1,500	(4.0/1.5)	40,000	30	1,500	(4.0/1.5)	120,000
TOTAL				$ 56,000				$176,000
S								
Rail	3	$3,000	(4.0/1.0)	$ 36,000	8	$3,000	(4.0/1.0)	$ 96,000
Surface & Line	15	1,500	(4.0/1.0)	90,000	25	1,500	(4.0/1.0)	150,000
TOTAL				$126,000				$246,000
Branch								
N								
Rail	5	$3,000	(4.0/1.25)	$ 48,000	5	$3,000	(4.0/1.25)	$ 48,000
Surface & Line	10	1,500	(4.0/1.25)	48,000	20	1,500	(4.0/1.25)	96,000
TOTAL				$ 96,000				$144,000
S								
Rail	0	$3,000	(4.0/1.25)	$ 0	0	$3,000	(4.0/1.25)	$ 0
Surface & Line	5	1,500	(4.0/1.25)	24,000	5	1,500	(4.0/1.25)	24,000
TOTAL				$ 24,000				$ 24,000

(1) Equipment

Equipment costs are defined as the portion of locomotive and car costs which is allocated by management to the particular line. Investment in transportation equipment is clearly a function of equipment utilization. The latter is, in turn, a function of operating speed. Depending upon the volume and nature of traffic, low operating speeds could lead to low utilization and equipment shortages and thereby require additional investments in equipment. The task is to estimate the reduction (or difference) in running time (minutes per year) that will result from $L_{(Min-LT)}$ and $L_{(Rehab-LT)}$ levels of investment and the dollar savings per minute. Obviously, in practice, this is a complex and difficult task. Hypothetical train speeds for a 6-year decision horizon, each level of investment, and each line segment are shown in Figures 4 through 7. Based on system averages and utilization levels suggested during interviews, the assumed unit cost for locomotives is $.06 per locomotive per mile per minute and represents both ownership and maintenance costs. For freight cars, the estimated unit cost is $.0016 per car-mile minute. Given these conditions, the estimated annual equipment saving in the second year for program $L_{(Rehab-LT)}$ on main line N, for example, is computed as follows:

1. 15,750 locomotives/yr x 50 miles x 4.5 minutes x $.06/loco-miles per minute = $212,625.
2. 367,500 cars/yr x 50 miles x 4.5 minutes x $.0016/car-mile per minute = $132,300.

(2) Labor

Increased train speeds may reduce crew costs and overtime. The savings, however, are not likely to be great unless re-crewing and overtime are initially at relatively high levels and new investment reduces these levels significantly. The amount of savings is a function of the overtime and re-crew costs (OT&R) applicable to the line segment, the proportion of these costs attributable to slow orders, and the time saved from faster train speeds. OT&R costs are set at $5.00 per train mile for all line segments; this figure indicates a realtively high level of labor costs. The approximately 30 percent of the OT&R costs that are saved per minute are shown in Table 5.

(3) Fuel

Significant savings in fuel may be attained where slow orders for short segments are removed and so is the requirement for repeated deceleration and

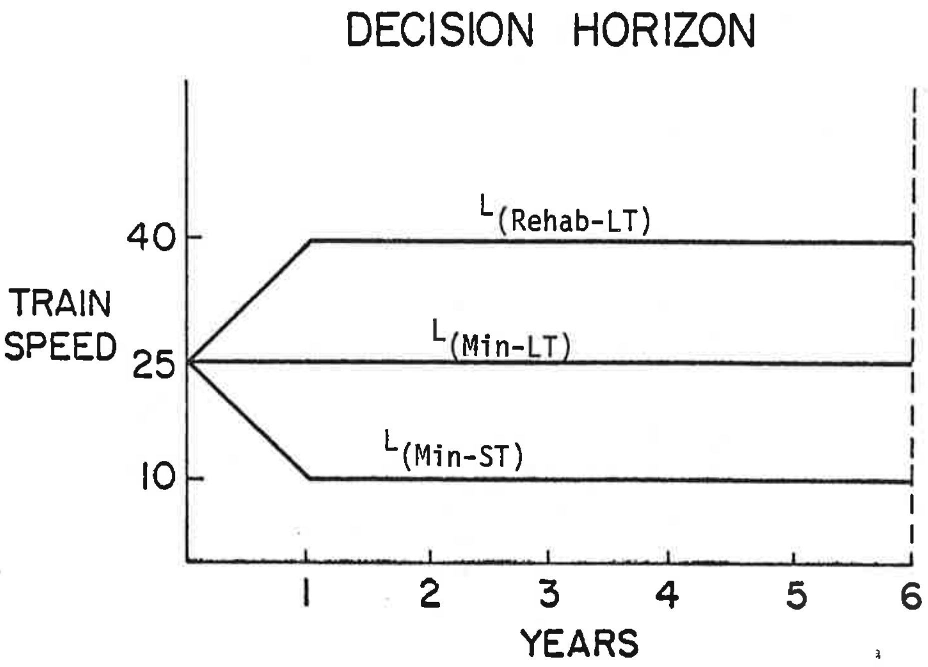

Figure 4. Main Line (N) Speed Deterioration Curves for Levels of Investment (L)

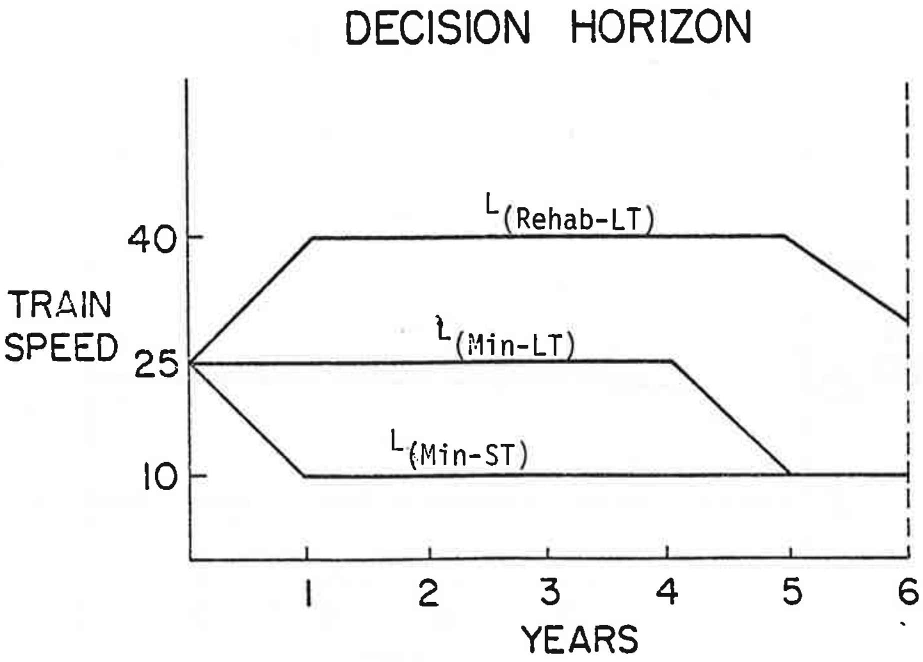

Figure 5. Main Line (S) Speed Deterioration Curves for Levels of Investment (L)

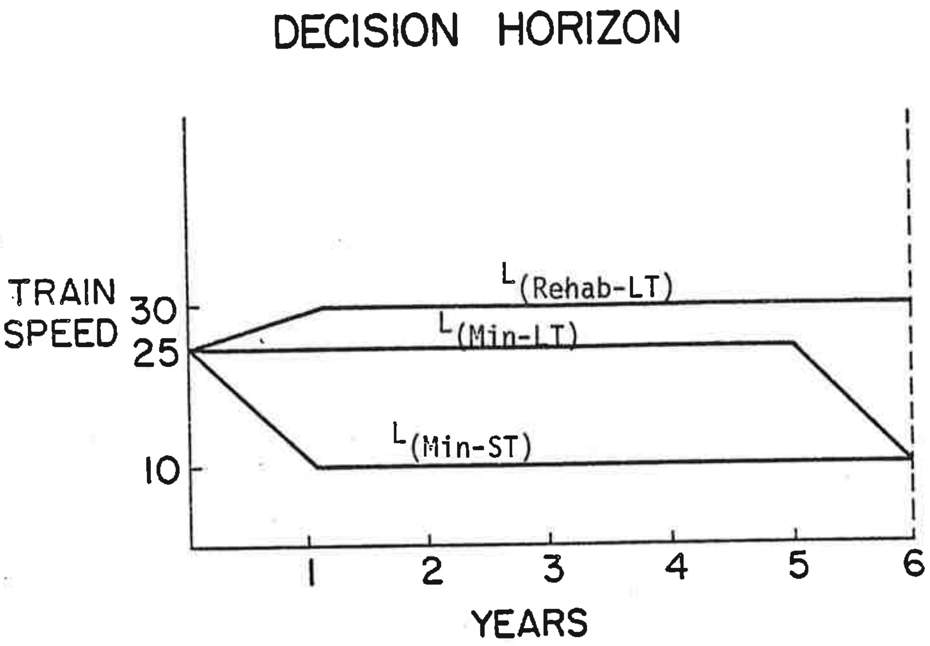

Figure 6. Branch Line (N) Speed Deterioration Curves for Levels of Investment (L)

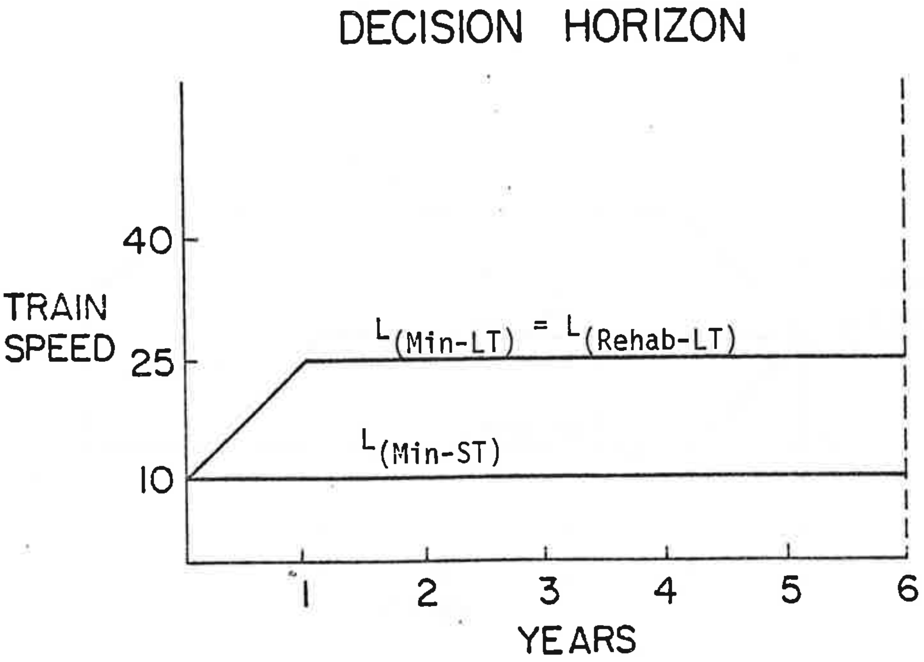

Figure 7. Branch Line (S) Speed Deterioration Curves for Levels of Investment (L)

Table 5. Overtime and Re-Crew Savings per Minute

Line Segment	Trains Per Year	Miles	$ OT&R Per Train Mile	% of $ OT&R from Slow Orders	Added Min./Track Mile from Slow Orders	$ Savings OT&R per Minute
Main						
N	5250	50	5.00	30	4.0	87,500
S	1000	40	5.00	30	4.0	15,000
Branch						
N	350	20	5.00	30	4.0	2,625
S	150	5	5.00	30	3.6	313

acceleration. On the other hand, increased speeds normally result in greater fuel consumption. This happens when slow orders applicable to long segments are removed. In the analysis, any changes in fuel consumption are assumed to negate each other and generate no savings.

(4) Accident Avoidance

As indicated in the discussion of decision making, senior railroad executives consider track-related accidents an important factor in project evaluation. The Association of American Railroads, moreover, has taken the position that the economic incentives of accident avoidance and assets preservation are sufficient for proper T/M [28]. The evaluation of accident costs (and frequently, causes) though, is largely subjective. In this case study, the savings that result from accident avoidance represent the difference between the expected costs of accidents before and after T/M program investment. Principal direct costs include damage to track, right of way, equipment and structures, and wreck clearance. Studies have indicated that total accident costs (direct and indirect) are about two to three times the direct costs [4,5,29].

The breakdown of number of accidents per year by line segment is (see Table 1) as follows: five each for main lines and two and one for branch lines N and S, respectively. It is assumed that the number of accidents will stay the same for the minimum short-term program $L_{(Min-ST)}$ but will become zero after full rehabilitation $L_{(Rehab-LT)}$. The minimum level long-term program $L_{(Min-LT)}$ for main line N will reduce the number of accidents to three for the first three years and to two thereafter. This trend reflects the higher density on main N and the installation of only one-third of the new rail required for full rehabilitation $L_{(Rehab-LT)}$. In contrast, for main line S, program level $L_{(Min-LT)}$ eliminates accidents. Main line S is a lower density line, and level $L_{(Min-LT)}$ provided for half of the new rail required in program $L_{(Rehab-LT)}$. Likewise, program level $L_{(Min-LT)}$ is assumed to eliminate accidents on both branch lines. Finally, the estimated cost per accident is the sum of the average system cost per accident ($16,000) and the average system cost for wreck clearance ($5,000). These figures were derived from 1977 FRA accident data for a representative railroad.

Financial Analysis

Program summaries itemize costs, cash flows, internal rate of return on incremental investment (IRR), and net present values (NPV) for alternatives $L_{(Min-LT)}$ (minimum maintenance--long-term) and $L_{(Rehab-LT)}$ (rehabilitation--long-term) (see Tables 6-9). Programs were treated as one-time investment decisions. The six-year cycle represented the elapsed time before the choice of new incremental maintenance confronts the decision maker. Furthermore, the railroad was assumed to be in a capital rationing situation. If both levels $L_{(Min-LT)}$ and $L_{(Rehab-LT)}$ met a minumum cutoff rate (for example, 15 percent), the alternative with the highest IRR represented the most efficient use of capital. If neither alternative met the cutoff, then minimum T/M $L_{(Min-ST)}$ or, possibly, abandonment $L_{(No)}$ was appropriate.

Finally, all cash flows illustrated here were assumed to be in constant dollars of year zero. Inflation can be treated in two ways. First, the cash flows can be increased at the compounded expected inflation rate. The proper discount rate, then, is the true minimum desired return on capital plus the inflation rate. With perfect forecasts of inflation, this method gives precise estimates of hard cash figures for planning and control. Unfortunately, the uncertainty surrounding the expected inflation rate makes perfect forecasts of inflation rate rather difficult to achieve.

The second method (used here) is to ignore inflation as a factor in evaluating a capital project. The discount rate is the minimum desired rate of return on capital (usually determined by the price earnings ratio and financial leverage plans).

Main Lines. Although both program levels for main line N meet the 15 percent cutoff, the full rehabilitation program $L_{(Rehab-LT)}$ is optimal. Even if $L_{(Rehab-LT)}$ cash flows are overestimated by 27 percent, the IRR still meets the required 15 percent return. Furthermore, if either T/M or accident savings are eliminated, $L_{(Rehab-LT)}$ remains optimal because operations have a disproportionate influence on total savings.

By contrast, neither alternative $L_{(Min-LT)}$ (IRR = .122) nor alternative $L_{(Rehab-LT)}$(IRR = .081) for main line S attains the 15 percent level (see Table 7). Altogether, however, a 10 percent increase in total saving flows of $L_{(Min-LT)}$ would mean the program clears the 15 percent IRR hurdle. For full rehabilitation

Table 6. Main Line (N) T/M Program Summary

COST-BENEFIT	$L_{(Min-LT)}$						$L_{(Rehab-LT)}$					
<u>Costs</u>												
Initial	$1,311,000*						$1,311,000*					
Avoidable	56,000						176,000					
Total	1,367,000						1,487,000					
Incremental	987,000						2,228,000					
Total	2,354,000						3,715,000					
<u>Savings</u>	Year						Year					
(yr)	1	2	3	4	5	6	1	2	3	4	5	6
(min)	(0.0)	(3.6)	(3.6)	(0.0)	(0.0)	(0.0)	(0.0)	(4.5)	(4.5)	(4.5)	(4.0)	(4.0)
<u>T/M</u>												
Avoidance	-0-	56,000	56,000	56,000	56,000	56,000	-0-	176,000	176,000	176,000	176,000	176,000
CWR	3,800	3,800	3,800	3,800	3,800	3,800	13,300	13,300	13,300	13,300	13,300	13,300
Operations												
Equipment	-0-	275,940	275,940	-0-	-0-	-0-	-0-	344,925	344,925	344,925	306,600	306,600
Labor	-0-	315,000	315,000	-0-	-0-	-0-	-0-	393,752	393,752	393,752	350,000	350,000
Fuel	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Accidents	42,000	42,000	42,000	21,000	21,000	21,000	105,000	105,000	105,000	105,000	105,000	84,000
Total	45,800	692,740	692,740	80,800	80,800	80,800	118,300	1,032,977	1,032,977	1,032,977	950,900	929,900
IRR	.214						.256					
NPV @ 15%	$153,426						$800,542					
@ 25%	$-71,570						$ 35,096					

*Initial cost for level 1.

Table 7. Main Line (S) T/M Program Summary

COST-BENEFIT	(Min-LT)						(Rehab-LT)					
Costs												
Initial			$ 503,000**						$ 503,000**			
Avoidable			126,000						246,000			
Total			629,000						749,000			
Incremental			1,678,500						2,628,000			
Total			2,307,500						3,377,000			
Savings (yr) (min)	1 (0)	2 (3.6)	3 (3.6)	4 (3.6)	5 (3.6)	6 (3.6)	1 (0)	2 (4.5)	3 (4.5)	4 (4.5)	5 (4.5)	6 (4.5)
T/M												
Avoidance	-0-	126,000	126,000	126,000	126,000	126,000	-0-	246,000	246,000	246,000	246,000	246,000
CWR	5,100	5,100	5,100	5,100	5,100	5,100	*10,800	10,800	10,800	10,800	10,800	10,800
Operations												
Equipment	-0-	42,048	42,048	42,048	42,048	42,048	-0-	52,560	52,560	52,560	52,560	52,560
Labor	-0-	216,000	216,000	216,000	216,000	216,000	-0-	270,000	270,000	270,000	270,000	270,000
Fuel	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Accidents	105,000	105,000	105,000	105,000	105,000	105,000	105,000	105,000	105,000	105,000	105,000	105,000
Total	110,100	494,148	494,148	494,148	494,148	494,148	115,800	684,360	684,360	684,360	684,360	684,360
IRR				.122						.081		
NPV @ 15%			$-142,360						$ -532,541			
@ 25%			$-527,298						$-1,063,011			

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*5 miles relay and assume .5 savings

**Initial cost for level 1.

Table 8. Branch (N) T/M Program Summary

COST-BENEFIT	L(Min-LT)						L(Rehab-LT)					
Costs												
Initial	$150,000*						$150,000*					
Avoidable	96,000						144,000					
Total	246,000						294,000					
Incremental	402,000						507,000					
Total	648,000						801,000					
Savings (yr)	1	2	3	4	5	6	1	2	3	4	5	6
(min)	(0)	(3.6)	(3.6)	(3.6)	(3.6)	(0)	(0)	(4.0)	(4.0)	(4.0)	(4.0)	(4.0)
T/M												
Avoidance	-0-	96,000	96,000	96,000	96,000	96,000	-0-	144,000	144,000	144,000	144,000	144,000
CWR	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000	3,000
Operations												
Equipment	-0-	4,234	4,234	4,234	4,234	-0-	-0-	4,704	4,704	4,704	4,704	4,704
Labor	-0-	9,450	9,450	9,450	9,450	-0-	-0-	10,500	10,500	10,500	10,500	10,500
Fuel	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-	-0-
Accidents	42,000	42,000	42,000	42,000	42,000	42,000	42,000	42,000	42,000	42,000	42,000	42,000
Total	45,000	154,684	154,684	154,684	154,684	141,000	45,000	204,204	204,204	204,204	204,204	204,204
IRR	.214						.226					
NPV @ 15%	$82,105						$127,368					
@ 25%	$ -36,796						$ -31,671					

*Initial cost for level 1.

Table 9. Branch (S) T/M Program Summary

COST-BENEFIT	$L_{(Min-LT)} = L_{(Rehab-LT)}$					
<u>Costs</u>						
Initial	$ 436,500*					
Avoidable	24,000					
Total	460,500					
Incremental	201,000					
Total	661,500					
<u>Savings</u> (yr)	1	2	3	4	5	6
(min)	(0)	(3.6)	(3.6)	(3.6)	(3.6)	(3.6)
<u>T/M</u>						
Avoidable	-0-	24,000	24,000	24,000	24,000	24,000
CWR	3,000	3,000	3,000	3,000	3,000	3,000
Operations						
Equipment	-0-	410	410	410	410	410
Labor	-0-	1,125	1,125	1,215	1,125	1,125
Fuel	-0-	-0-	-0-	-0-	-0-	-0-
Accidents	21,000	21,000	21,000	21,000	21,000	21,000
Total	24,000	49,535	49,535	49,535	49,535	49,535
IRR				.087		
NPV @ 15%			$ -35,740			
@ 25%			$ -75,229			

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*Initial cost for level 1.

$L_{(Rehab-LT)}$, cash flows would have to increase 26 percent. The choice between minimum maintenance short-term $L_{(Min-ST)}$ and long-term $L_{(Min-LT)}$, therefore, is somewhat sensitive only to underestimation of level $_{(Min-LT)}$ cash flows, of which operation-related savings are most important. Thus, to the extent that ordinary T/M expenses increase as a result of continuing track deterioration or accident costs (understated because accidents are generally more costly on higher speed main lines), $L_{(Min-LT)}$ will approach or exceed the cutoff.

Branch Lines. The IRR and NPV figures for branch Line N (see Table 8) show full rehabilitation $L_{(Rehab-LT)}$ to be optimal. This time, however, the program decision is quite sensitive to cash flow estimates. Level$_{(Min-LT)}$ cash flows would only have to change by 4 percent to have an IRR equivalent to level $_{(Rehab-LT)}$.

As shown in Table 9, program levels $L_{(Min-LT)}$ and $L_{(Rehab-LT)}$ are equivalent for branch line S. The IRR on incremental investment required for full rehabilitation is slightly more than half of the required 15 percent return. Given IRR as the sole decision criterion, cash flows would have to increase 22 percent for the additional investment required for rehabilitation to cross the 15 percent threshold.

Relative Importance of Factors. Table 10 summarizes the results of each financial analysis, the relative importance of T/M operation and accident savings, and the sensitivity of program level selection decisions to changes in savings flows. Several fundamental relationships emerge from the summarized results. Speed-related benefits (labor and equipment savings) have the greatest impact on the IRR results for high density line segments. For example, for main lines, speed-related savings comprise from about one-half to two-thirds of the total dollar benefits, while corresponding savings for branch lines represent less than one tenth of the total; the reason is that equipment and labor savings are a function of the reduction in time and the volume of traffic. Thus, while speed-related savings still have the greatest impact on the investment decision for main line S, the traffic density is insufficient to generate the total savings necessary to justify investment (given the 15% IRR cutoff) in $L_{(Min-LT)}$ or $L_{(Rehab-LT)}$.

Conversely, on low density lines, T/M or accident cost avoidance has the greatest influence on internal rates of return. For the north branch line, T/M is the most important single factor. The choice between program levels, moreover, is very sensitive to estimated T/M savings flows. By contrast,

Table 10. Financial Analysis Summary

			Cash Flows			Sensitivity		
			Relative Importance			% Change to Modify Decision		
Line Segments and Program Levels	IRR	T/M	Operations	Accidents	T/M	Operations	Accidents	Total
Main								
North								
$L_{(Min-LT)}$	.214	.16	.73	.11	64	13	82	10^a
$L_{(Rehab-LT)}$	.256	.19	.69	.13	*	39	*	27^b
South								
$L_{(Min-LT)}$	.122	.25	.49	.26	37	19	36	10^c
$L_{(Rehab-LT)}$	.081	.36	.45	.19	71	57	134	26^c
Branch								
North								
$L_{(Min-LT)}$	.214	.60	.07	.33	06	48	10	04^a
$L_{(Rehab-LT)}$	.226	.68	.07	.25	30	*	81	21^b
South								
$L_{(Min-LT)} = L_{(Rehab-LT)}$	.087	.49	.03	.48	44	799	45	22^c

*Could be eliminated and still make 15 percent cutoff.

[a] Average percent change in cash flows to meet $L_{(Rehab-LT)}$ internal rate of return.

[b] Average percent decrease in cash flows to meet 15 percent cutoff.

[c] Average percent change in cash flows to meet 15 percent cutoff.

accident cost avoidance is nearly equivalent to T/M savings in its influence on IRR for the south branch line. Furthermore, unlike the branch N program selection decision, the decision to select minimum short-term maintenance $L_{(\text{Min-ST})}$, or possibly abandonment $L_{(\text{No})}$, is not very sensitive to changes in any of the factors. To the extent that average accident costs overstate accident savings (because accidents at lower train speeds generally incur less damage and because subsequent delays in service, lost customers, per diem charges, etc., are more significant for high density lines), program selection for branch lines is more clearly defined.

Other Considerations

Thus far, the decision criteria have included only NPV and, in particular, IRR. Other considerations, of course, enter into the decision process.

Service. An implicit assumption in the financial analysis has been that program investment levels do not affect total traffic or revenues. Yet, speed, frequency, unit carrying capacity (i.e., carload and trainload sizes), and reliability are critical determinants of a rail freight carrier's competitive strength and profitability. The carrier's ability to retain and attract traffic and generate revenues is dependent upon the achievement (vis-à-vis competing carriers) of (1) competitive origin-to-destination transit times for individual shipments, (2) efficient carload and trainload size limits, (3) a favorable level of transit time consistency, and (4) a low freight loss and damage ratio [30]. The attainment of such attributes of rail freight service requires a track structure sufficient to sustain required train speeds and axle loadings and to conduct road and yard movements within acceptable limits of delay and of shock to lading.

As the track condition model demonstrates, increased tonnage on a line segment means less T/M cost avoidance, faster speed deterioration over time, and, ultimately, a downward bias on savings flows included in the financial analysis. Nevertheless, the net payoff is likely to be greater. A similar chain of events occurs when 100-ton cars and unit train movements are included in the analysis. While such equipment and operations may improve service and utilization and, therefore, total revenues, the net payoff is less certain in this instance because track consumption and, especially, structural defects may increase substantially [2,6,8,9].

Service quality thus presents itself as a determinant of the allocation of funds to track maintenance. Particular segments of trackage should be maintained at levels that maximize the net value (profit) of the principal types of transportation service produced through use of those segments. Main lines dedicated to the long-distance movement of highly time-sensitive (and truck-competitive) merchandise traffic require maintenance standards commensurate with the operation of relatively high speed freight trains. Likewise, lines dominated by unit trains of 100-ton cars require maintenance outlays sufficient to offset the higher rates of physical depreciation that such heavy carrying units impose upon rail, ties, ballast, and subgrade. Yard trackage also requires adequate attention if cars are to be moved through terminals without excessive track-related delays. Other examples could also be cited [31,32], but, fundamentally, they all involve the quest for a balance or trade-off between (1) the revenues which relate to particular service quality and capacity levels, and (2) the costs of providing such quality and capacity levels, of which maintenance is an important element.

Safety. Besides the economic costs of accidents, track safety regulations, at least to some extent, affect the decision process. If, as suggested in this case study, speed-related savings for high density line segments range from 50 to 67 percent of total savings and, as already noted, speed (length and consistency of transit time) is a key determinant of service and, ultimately, of freight revenues, then speed restrictions should provide a very effective incentive for railroads to meet corresponding track safety standards. On low density lines, however, the case analysis indicated that speed-related savings and service were not key factors in the investment decision. Instead, avoidable (accident and track maintenance) costs were dominant. Safety standards for the lowest track classification, therefore, will probably serve as a floor. Track maintenance spending will be set at the minimum levels required to meet the standards or prevent cessation of operations. Higher levels of investment will be made only when (1) the avoidable costs are sufficient to justify the decision; or (2) the actual or potential revenue generating capacity of low density line segments (individually or in the aggregate), when viewed as part of the entire system, justifies the investment.

Furthermore, track safety standards applicable to low density line segments may be counterproductive. At issue is the potential misallocation of resources [12,13,28,33,34]. FRA regulations sometimes require immediate repair of track and related defects on, for example, 5 to 10 mph line segments (where hazardous materials are involved). Such repairs may not affect track safety nor reduce the number of accidents; however, such a requirement disrupts and dilutes maintenance programs on high density line segments where the frequency and severity of accidents are significantly greater.

Budget Process. Budget allocations for track maintenance expenditures obviously must compete against other uses of corporate funds, e.g., investment in, and maintenance of, rolling stock and motive power, and payments of interest and dividends. The practice--made possible by use of so-called replacement or betterment accounting--of deferring track maintenance during periods of depressed earnings either to minimize reported net loss or to prevent reported net income from falling below a certain level, is well known. Indeed, there is evidence that some carriers have sacrificed maintenance essential to the long-term integrity of their track for the purpose of maintaining earnings per share and dividends within a short-term time frame. Finally, compounding the problem is the inability or unwillingness of many railroads to estimate savings from good track or to relate good track to profit [13,35-39].

3. METHODOLOGY

As already indicated in Section 1, two primary objectives of this research project were (1) to develop a model to explain T/M expenditure behavior and (2) to develop a data base derived from publicly available sources that would be adequate to test the model. The decision-making process and case study described in the previous section were employed to develop a structural model of T/M expenditures. This model, in turn, provided the basis for identifying a list of variables that could be presumed to affect T/M. These variables were then associated with alternative, available empirical measures. Various ratios and transformations of variables were developed so that the model could be formulated in real or normalized measures. All of these procedures are discussed below. The structural model is discussed first. Then the data collection is described; the sources, nature, and limitations of the data and the editing procedures are discussed in detail. A comprehensive outline of the data base and corresponding documentation are included in the Appendix. Finally, the analytical methodology is reviewed. This review begins by emphasizing the potential logical and statistical problems in this type of data analysis. An explanation of a statistical methodology for managing these problems is then provided, and a discussion of the relevant tests of hypotheses is also presented.

FACTORS AFFECTING MAINTENANCE OF WAY

Decisions by railroad companies to provide normalized maintenance and to upgrade or rebuild track depend on network characteristics, operations, resources, and expected return on investment. From the discussion in Section 2, and from an intuitive standpoint, one can see that these factors are, to a large extent, interdependent. Financial and physical resources both permit and limit expenditures. Maintenance equipment, manpower, operating revenues, borrowing capability, and information systems affect the level of spending and, ultimately, network conditions. Similarly, operating conditions (train speed and length, car capacity, and tonnage), as well as the financial and physical resources available, both affect and are limited by network conditions. Operations and resources, in turn, are affected by the volume and mix of freight traffic, the scope of passenger service, the strategic service goals, the track safety regulation, and the number and cost of derailments.

Thus, general economic conditions, government policies, and technological innovations are the broad categories that affect maintenance-of-way spending decisions. Figure 8 provides an overall view of some of the basic interrelationships. Dashed rectangles on the right hand side of this figure highlight primary factors, while other less direct, but key factors are shown on the left hand side.

Structural Model of Track Maintenance

The structural model shown in Figure 9 was derived from the interviews, the case study, and the literature discussed in Section 2. As illustrated in Figure 9, variables representing T/M behavior included both physical and financial measures. Network characteristics were broken down into system and route geometry categories. Variables associated with operations were divided into three groups: traffic (density and gross ton miles), service (train speed, equipment, and passenger operations), and safety (accidents and presence or absence of safety standards). The variables that represented the carriers' resources were gross operating revenue, return on investment, and dividend payout.

To test this model, the variables shown in Figure 9 (or their surrogates) had to be associated with measures developed from available empirical data. For several variables, however, it was not possible to develop the desired measurements from publicly available data. The results of this process are shown in Table 11 where the specific model variables used in this study and their working definitions are identified. The nature and rationale for specific variable measurements are discussed below.

Dependent Variables. This study included four measures of track maintenance. The physical measures (ties installed and miles of rails laid in replacement) were divided by the total number of ties and the total system track miles, respectively, to create tie (TIES) and rail (RAIL) replacement ratios. Replacement measures provide some insight into the maintenance philosophy of a railroad.

Besides the physical measures of T/M, two financial measures were included in the study. The first, nominal T/M dollar expenditures per track mile (TMEXP), was used to address the following research question: Which variables explain how current operating revenues available to a railroad are allocated to track maintenance?

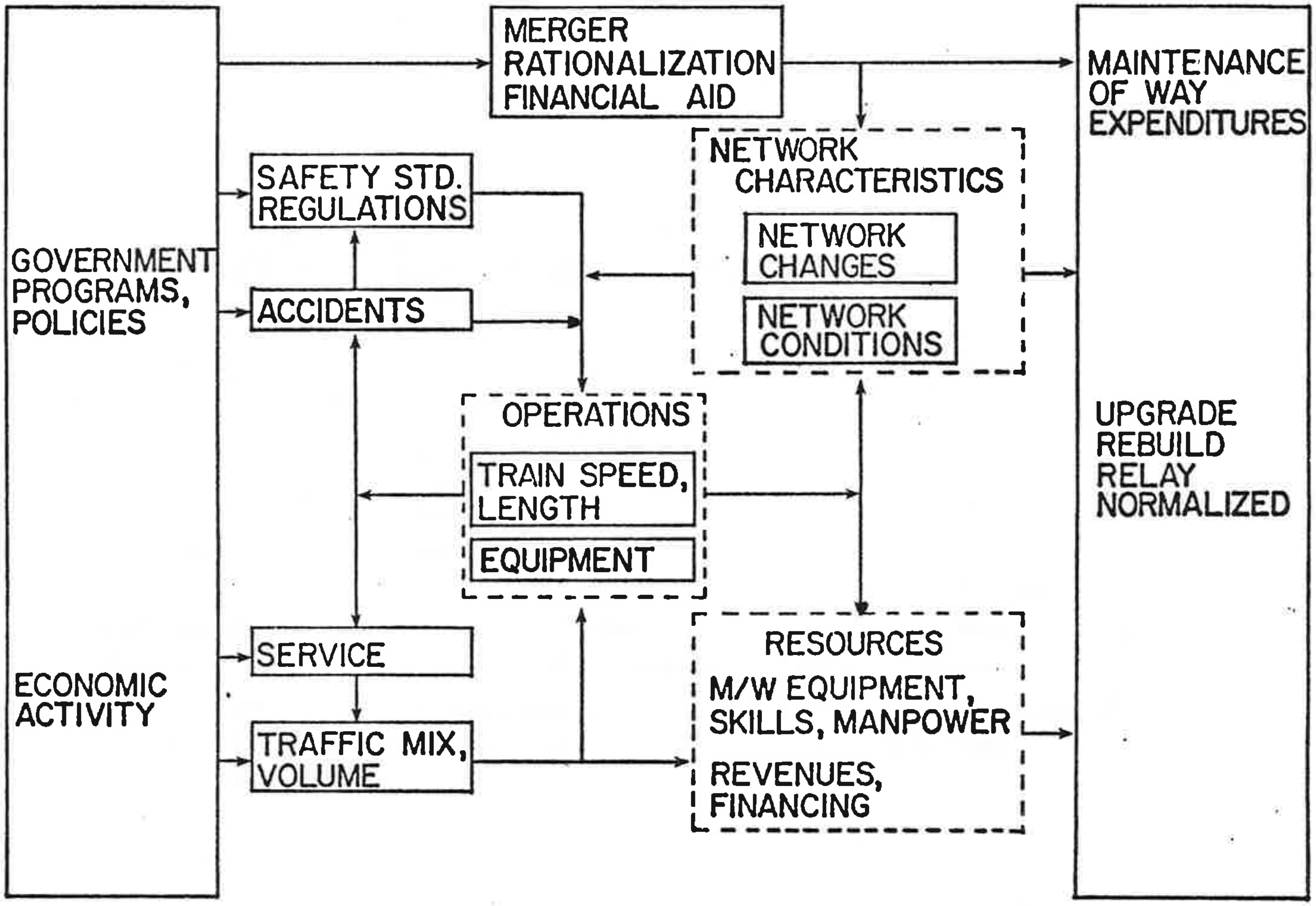

Figure 8. Factors Affecting Maintenance of Way

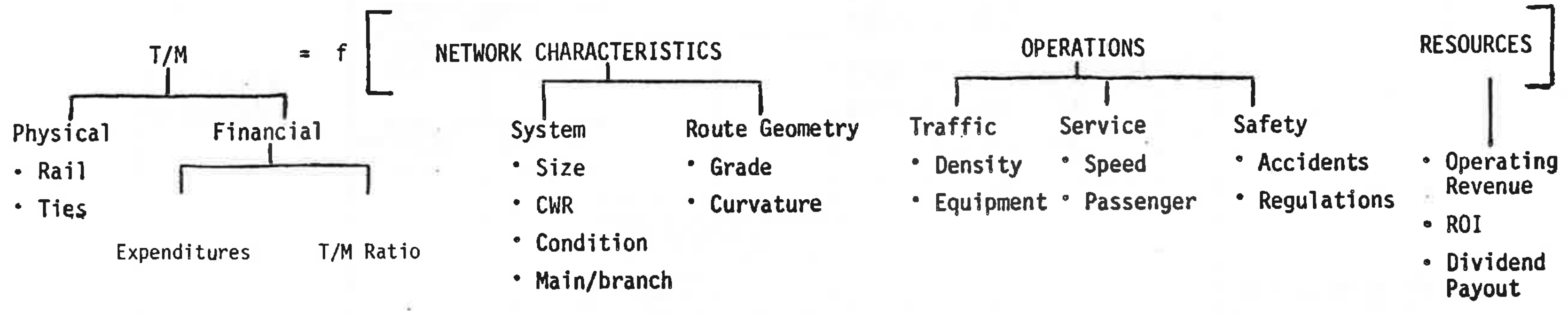

Figure 9. Structural Model of Track Maintenance (T/M)

Table 11. Model Variables and Working Definitions

Variable Name	Description	Measure (For railroad $_i$ for year $_t$)*
<u>Dependent</u>		
TMEXP	Track maintenance expenditures per track mile	Sum of nominal capital outlays and nominal maintenance expenses ÷ total system track miles (÷ 1000)
TMRATIO	Track maintenance ratio	Track maintenance expenditures ÷ gross operating revenues (x 100)
TIES	Tie replacement ratio	Ties installed ÷ total ties in place (x 100)
RAIL	Rail replacement ratio	Miles of rail installed ÷ total system track miles (x 10)
<u>Independent</u>		
CWRAIL	Proportion of continuous welded rail	Miles of CWR ÷ total system track miles (x 100)
SIZE	Track miles	Total system track miles (÷ 1000)
DENSITY	Traffic density	Million gross ton miles ÷ total system track miles
WEIGHT	Average carload weight	Average system tons per train ÷ average cars per train (÷ 1000)
LENGTH	Average train length	Average system car miles ÷ average train miles (÷ 10)
ΔSPEED	Change in average train speed	First difference in average system train miles ÷ system train hours

Table 11. Model Variables and Working Definitions (Continued)

Variable Name	Description	Measure (For railroad $_i$ for year $_t$)*
ACC_{t-1}	Track-related accidents per million gross ton mile	Total system track-related accidents ÷ million gross ton miles × 1000 lagged 1 year
SI1	Severity-frequency accident index - main/branch lines	Median dollar value of track-related accidents on line (main or branch) track × total system accidents on given track ÷ million gross ton miles**
SI2	Severity-frequency accident index--yard, siding, or way switching track	Median dollar value of track-related accidents on yard, siding, or way switching track × total system accidents on given track ÷ million gross ton miles**
DUMMY	Dummy variable for introduction of FRA track safety standards	0, if years are 1962-1971; 1, if years are 1972-1977
REV	Gross operating revenues per track mile	Nominal gross operating revenues ÷ total system track miles (÷ 1000)
ROI	Return on investment	Return on investment calculated using ICC methodology (× 100)
DIV	Dividend payout ratio	Dividends paid ÷ ordinary income
PIR	Price index ratio	AAR price index without fuel component ÷ AAR price index with fuel component
Grouping***		
PAX	Passenger service operations	
REGION	Proxy variable for climatic conditions	
SIZE	Size of system in track miles	

Table 11. Model Variables and Working Definitions (Continued)

Variable Name	Description	Measure (For railroad $_i$ for year $_t$)*
ROI	Financial strength	
DENSITY	Traffic volume	
SPEED	System train speed	

*$i = 1,\ldots,31$ and $t = 1,\ldots,16$

**$t = 6,\ldots,16$

***Specific categories and railroad groupings are shown in Table 12.

Since the physical size of Class I railroads varies considerably, and T/M expenditures are a function of size, the T/M measure was adjusted by dividing it by total system track miles in order to eliminate size as a confounding influence.

Another important research question was: Does a railroad devote a decreasing, constant, or increasing proportion of its available resources to track maintenance in response to key variables? To answer this question, the ratio of T/M expenditures to gross operating revenues (TMRATIO) was used. This track maintenance ratio addressed the research question and allowed the research team to avoid the problem of having to use possibly inadequate price level data to deflate nominal figures, for price was cancelled in the numerator and denominator.

Explanatory Variables

(1) Network Characteristics

(a) System

The physical size of railroad systems, measured in terms of gross track miles, was used in three different ways. Initially, as already noted, when T/M expenditures were of interest, total system track miles (SIZE) was used to adjust or normalize the T/M measure. Similarly, SIZE was used to adjust total operating revenues (REV), for revenues are also a function of network size. In the second instance, when T/M expenditures per gross track mile was not the dependent variable of interest, SIZE was included as an independent variable to control for possible economies of scale in track maintenance operations. The third approach created three groups of railroads arranged by size (see Table 12) in order to evaluate further the effects of size.

The condition of the track clearly affects the level of resources required for normalized track maintenance. If a large percentage of track components approaches the end of a life cycle, a greater level of resources must be devoted to maintenance and replacement. This often happens in instances where a major track upgrading or replacement program was completed 30 to 40 years ago. In addition, when maintenance has been clearly deferred, a greater-than-normal level of resources is required to maintain the track in a "status quo" condition. Unfortunately, the level of data aggregation

Table 12. Characteristics of Class I Railroads[a]

RAILROAD	CHARACTERISTIC					
	SPEED	SIZE	ROI	DENSITY	PASSENGER OPERATIONS	REGION
ATSF	H	L	H	H	Yes	S
BLE	L	S	H	H	No	N
BM	L	M	L	L	Yes	N
BN	M	L	M	M	Yes	N
BO	L	M	H	M	Yes	N
CNW	L	L	M	L	Yes	N
CO	L	M	H	M	Yes	N
DH	L	S	L	M	Yes	N
DMIR	L	S	H	L	No	N
DRGW	M	M	H	M	Yes	N
DTIR	L	S	H	L	No	N
EJE	L	S	H	L	No	N
FEC	M	S	M	L	No	S
GTW	M	M	L	L	Yes	N
ICG	L	L	M	L	Yes	Omit*
KCS	L	M	H	M	No	S
LN	L	L	H	H	Yes	S
MILW	M	L	L	L	Yes	N
MKT	L	M	L	L	No	S
MP	M	L	H	M	Yes	S
NW	L	L	H	H	Yes	N
PLE	L	S	H	M	Yes	N
RI	L	M	L	L	Yes	Omit*
SCL	L	L	H	M	Yes	S
SLSF	M	M	H	M	No	S
SOO	M	M	H	L	No	N
SOU	M	L	H	H	Yes	S
SPT	M	L	M	H	Yes	Omit*
UP	H	L	H	H	Yes	N
WM	L	S	H	L	No	N
WP	H	M	M	H	No	N

[a] Key for grouping railroads:

Speed (average train speed): L = low = less than 20
M = medium = 20 to 27
H = high = greater than 27

Size (track miles): S = small = less than 1,500
M = medium = 1,500 to 10,000
L = large = greater than 10,000

ROI (return on investment): L = low = less than 0
M = medium = 0 to .035
H = high = greater than .035

Density (gross ton miles ÷ track miles): L = low = less than 5
M = medium = 5 to 7
H = high = greater than 7

Region (proxy for climatic conditions): N = North
S = South

*Indicates that roads are too heterogeneous.

(measures for entire network systems) precluded any attempt to develop track condition indexes in this study.

(b) Route Geometry

The heterogeneous nature of network systems made network measures (quantitative or qualitative) of grade or curvature too vague for analysis. An attempt was made, though, to address the effects of climate on T/M activity. Railroads were grouped into northern and southern regions (REGION) (see Table 12), except for carriers with a north-south route structure, or carriers that were not clearly classifiable, which were excluded. The assumption was that railroads in the southern group would spend less on track maintenance than the northern group of railroads because work seasons in the South are longer, and weather is less severe. Cold weather, with freeze-thaw cycles, increases subgrade-related maintenance. The shorter work seasons associated with cold weather regions, moreover, decrease gang efficiency.

(2) Operations

The structural model included variables representing three facets of operations: traffic, service, and safety.

(a) Traffic

As demonstrated in Section 2, traffic density (DENSITY), normally measured by the railroad industry as million gross ton miles per mile, affects track maintenance decisions. Senior rail executives normally identified high density line segments as strategic routes, and, as demonstrated in the case study, speed-related savings were most significant for these routes. Higher density line segments, therefore, are normally maintained at (higher) levels commensurate with strategic speed and service objectives. Thus, DENSITY should have a positive effect on T/M measures. The effect, however, may be undetectable because the level of aggregation is rather gross; the model was unable to distinguish between high or low density line segments. Instead, only a broad measure of density for the overall network system was available. Also, much of the expected effect may be lost because, at the given level of aggregation, traffic density might be no more than a proxy variable for operating revenues. To address this potential problem, railroads were defined as low, medium, or high density systems (see Table 12) and analyzed by group.

Market forces and traffic conditions have led most firms in the railroad industry to use bigger cars and longer, heavier freight trains. This pattern has meant increasing consumption of track and structures. As pointed out in the track condition model discussion, heavy cars usually are harder on track and structures than light cars moving at the same speed. In addition, a train of identical heavy cars may shorten track component life by establishing harmonic action in the track. In an attempt to capture the effects of this pattern, two proxy variables were included in the model: (1) average system carload weight (WEIGHT) and (2) average system train length (LENGTH).

(b) Service

In the service category, variables representing train speed and passenger operations were developed. The first difference in average system train speed (ΔSPEED) provided the only quantitative measure of speed in the T/M model. The problem with using average speed (rather than the change in speed) was that it varied greatly among railroads. Since the data were not of particularly high quality, moreover, average system train speed might be more representative of track condition than speed. On the other hand, ΔSPEED normalized the T/M - speed relationship because it established a measure that was independent from the absolute level of speed (e.g., a reduction from 40 mph to 30 mph was equivalent to a change from 25 to 15 mph). Furthermore, from a policy perspective, it was desirable to examine the influence of changes in train speed (as a result of slow orders) on track maintenance expenditures. As suggested in the case study, though, a reduction in speed from 40 to 30 mph is likely to have less of an impact on T/M spending than a change from 25 to 15 mph. Consequently, average system train speed (SPEED) was used to place carriers in the three groups (low, medium, and high speed) shown in Table 12. The ΔSPEED variable was then evaluated for each group.

In addition, carriers were classified by the presence or absence of passenger operations (PAX). Each group was analyzed in order to isolate the effects of PAX on the T/M spending decision.

(c) Safety

In the safety area, the model included several measures of track-related accidents and a dummy variable representing the introduction of FRA safety standards. Only the total number of track-related accidents for the entire network system was available for the 16-year study period. Since the FRA threshold (in dollars) for reporting accidents changed during the time frame of the study, only accidents that had deflated dollar values greater than the larger of the two threshold values were counted. Further, the annual number of accidents $(ACC)_{t-1}$ was lagged one year, the assumption being that the number of accidents in the previous year affects budget decisions in the subsequent year. In addition, this variable $(ACC)_{t-1}$ (as well as all other accident variables) was normalized by dividing it by gross ton miles in order to relate the number of accidents to the exposure or potential for an accident. The more traffic or cars that a railroad handles, the more there is exposure to or likelihood of an accident. Similarly, the greater the distance each car is moved, the greater the potential is for an accident.

The total number (or the total cost) of network system accidents per year, alone, however, may produce misleading results since the total number of accidents fails to indicate serious safety problems when few, but severe, accidents occur. Similarly, total cost may be misleading because a few expensive accidents may be atypical and, therefore, not representative of any serious safety problem. Thus, following the procedure of Shulman and Taylor, frequency - severity accident indexes $(SI1)_{t-1}$ and $(SI2)_{t-1}$ were created for line (main or branch) and yard (including siding or way switching) track-related accidents [5]. Changes in reporting methods of FRA accident reports in 1973 made it impossible to develop separate safety index measures for main and branch line accidents.

The effect of federal track safety regulations may be reflected in increased levels of expenditure for track maintenance. If railroads were maintaining lines to levels below those required by the federal regulations, the FRA standards would require higher expenditures, unless train speeds were reduced. Additionally, the often cited "loss of maintenance efficiency" resulting from rigid enforcement of the regulations would raise track maintenance expenses, although physical measures (rail and ties) would probably remain unaffected.

In an attempt to identify the impact of FRA track safety standards on the T/M decision, a dummy variable (DUMMY), which indicated the presence or absence of the standards, was included in the analysis. Unfortunately, comparable railroads not subject to FRA track standards were not available to use as controls. Thus, this approach and its results must be viewed with caution, for rival hypotheses are available. For example, given that tie installation since the early 1950s and in the 1960s was less than normalized, as Dyer has noted, and given a 30-year maintenance cycle, mounting tie replacement requirements would place considerable pressure on management to increase expenditures, regardless of FRA safety standards [40].

(3) Resources

The model included three variables to reflect the financial dimension of the T/M spending decision. The clearest message promulgated by the railroad industry (in testimony before the FRA, during interviews, and in trade literature) has been that operating revenues (REV) have the greatest single influence on the size of the maintenance-of-way budget; the implication, of course, is that if sufficient revenues were available, track-related accidents would largely disappear. The fixed nature of track and structures combined with the difficulty in recovering investment costs should bankruptcy occur, as well as the betterment accounting system, make external sources of financing for track-related programs difficult to obtain and place much greater reliance for such expenditures on internally generated operating revenues. The practice of deferring maintenance programs in lean years and implementing them in good years, moreover, is probably widespread. Thus, when traffic and revenues decline, not only are fewer funds available, but also a smaller proportion of those funds may be allocated to maintenance programs.

The variable measuring rate of return on investment (ROI) provided an indication of the carrier's ability to generate funds. In addition, ROI was used as a qualitative (grouping) variable (see Table 12) to assess the impact of key variables on financially weak or strong carriers. A confounding influence, however, is dividend policy; the amount of net income paid out in dividends (DIVIDEND) limits revenues available for track maintenance expenditures.

Finally, the ratio of the AAR price index without the fuel component to the total index (PIR) was included for control purposes. This ratio reflected the additional budget needs of the operating department vis à vis the maintenance function as fuel prices increased.

Accident and Speed Models

In order to identify and evaluate statistically significant changes in the incidence of track-related accidents, or the average system train speed since the introduction of FRA track safety standards, accident and speed models were specified and tested with the same data base. In specifying the accident model, only the variables in the original data set that were determined to be essential, both a priori and from a regulatory and control point of view, were included. These variables represented the presence or absence of track safety standards (DUMMY), axle loads (WEIGHT), track condition/speed (SPEED), and resources, i.e., lagged variables representing the carrier's ability to undertake a commitment to track maintenance. Similarly, for the speed model, only variables deemed essential were analyzed. Besides DUMMY and lagged resource variables, only LENGTH was included in this model.

DATA COLLECTION

Track maintenance and related data for all the Class I railroads in 1978 essentially were developed from two secondary sources: the ICC's Annual R-1 Report and the FRA's Annual Safety Statistics. FRA accident data, however, were available only in summary form prior to 1966; consequently, more detailed accident data were collected only for the 1966-1977 period. Although variable transformations or redundancy reduced the total number of variables for analyses to nineteen, a complete raw data file containing the component parts of variable transformations, as well as the redundant variables, was created as part of this project. A detailed description of this file is found in the Appendix.

Aggregation

With the exception of the Clinchfield, the Long Island, and Conrail, the analysis was conducted with data for all Class I railroads in existence in 1978. During this period, several bankruptcies, mergers, and acquisitions took place. In order to achieve comparable year-by-year statistics, the data for assimilated railroads were aggregated with data for "parent" railroads (see Table 13). In one case, although the name of the surviving entity was the Norfolk Southern, the actual continuing firm was the Carolina and Northwestern, and from 1965 until the merger, the Carolina and Northwestern was a

Table 13. Class I Railroads and Assimilated Companies

- Atchison, Topeka and Santa Fe
- Boston & Maine Corp.
- Baltimore & Ohio
- Bessemer & Lake Erie
- Burlington Northern
  - Chicago, Burlington & Quincy
  - Great Northern
  - Northern Pacific
  - Spokane, Portland & Seattle
- Chicago & North Western Transportation Co.
  - Chicago Great Western
- Chesapeake & Ohio
- Colorado & Southern
- Chicago Milwaukee, St. Paul & Pacific
- Central R. R. of New Jersey*
  - Central R. R. of Pennsylvania
- Conrail Corp.*
- Chicago, Rock Island & Pacific
  - Chicago, Rock Island & Gulf
- Clinchfield*
- Delaware & Hudson
- Denver & Rio Grande Western
- Duluth, Missabe & Iron Range
- Detroit, Toledo & Ironton
- Elgin, Joliet & Eastern
- Erie Lackawanna*
- Florida East Coast
- Fort Worth & Denver
- Grand Trunk Western
- Illinois Central Gulf
- Gulf Mobile & Ohio
- Kansas City Southern
  - Louisiana & Arkansas
- Louisville & Nashville
  - Monon (Chicago, Indianapolis & Louisville)
- Long Island*
- Lehigh Valley*
- Missouri-Kansas-Texas
- Missouri Pacific
  - Chicago & Eastern Illinois
  - Texas & Pacific
- Norfolk & Western
  - New York, Chicago & St. Louis
  - Pittsburgh & West Virginia
  - Wabash
- Pittsburgh & Lake Erie

*Not included in statistical analyses.

Table 13. Class I Railroads and Assimilated Companies (Continued)

- Penn Central Transportation Co.
    - New York Central
    - New York Connecting Railroad
    - Pennsylvania
    - New York, New Haven & Hartford
- Reading*
- Seaboard Coastline
    - Atlantic Coastline
    - Seaboard Air Line
    - Piedmont & Northern
- St. Louis-San Francisco
- Soo Line R. R. Co.
    - Duluth, South Shore & Atlantic
    - Minneapolis, St. Paul & Sault Ste. Marie
- Southern
    - Alabama Great Southern
    - Cincinnati, New Orleans & Texas Pacific
    - Georgia Southern & Florida
    - New Orleans & Northeastern
    - Norfolk Southern
    - Central of Georgia
- Southern Pacific
    - Texas & New Orleans
    - Pacific Electric
    - St. Louis-Southwestern
- Union Pacific
- Western Maryland
- Western Pacific

* Not included in statistical analyses.

Class II railroad. For the purpose of consistency in aggregation, R-2 reports for the Carolina and Northwestern were obtained from the ICC and included in the study.

Three carriers -- the Consolidated Rail Corporation, the Clinchfield, and the Long Island -- were excluded from the study because of atypical conditions. Conrail's massive federally financed track maintenance program involved the elimination of enormous amounts of deferred maintenance in the properties of the bankrupt carriers that were taken over when Conrail was formed. Hence, Conrail had a maintenance program in a scale and time frame completely different from that of other carriers. Conrail, moreover, was developed from selected portions of the bankrupt carriers; thus, aggregation of the bankrupt carriers' data would not have been meaningful. The Clinchfield was excluded because of its unique ownership and funding status within the Family Lines System. Finally, the Long Island was excluded because it is primarily a suburban passenger carrier (relatively high train frequencies and relatively low axle loadings) with track maintenance conditions quite distinct from those of freight-oriented Class I carriers.

ANALYTICAL TECHNIQUES

In the current type of empirical study, the data analysis has the potential for certain statistical as well as logical problems. On the statistical side, a common data base suitable for model estimation is available only for 16 annual observations and for 31 Class I railroads.

If a time-series analysis is desired, the number of degrees of freedom for measuring model error are likely to be too small for much trust in the reliability of the model. If a cross-sectional analysis is desired, the number of degrees of freedom--especially after the railroads are grouped according to some single characteristic for homogeneity--are not likely to be large enough to permit even a numerical solution.

This study is tractable only by augmenting the sample size with panel data, i.e., by pooling time-series and cross-sectional data. This procedure perfectly fits the research objective of explaining maintenance-of-way expenditures by certain groups of railroads over time; however, it may cause statistical difficulties of considerable magnitude. It is not unexpected to find time-series relations subject to the problem of autocorrelation and cross-section relations subject to the problem of heteroscedasticity. While the existence of either problem destroys the usefulness of the statistical model for making inferences, these problems are easy to diagnose and to correct when they exist singly in either a time-series or a cross-sectional relationship. However, when panel data are employed, the problems may exist simultaneously with the cross section being heteroscedastic and the time series being autocorrelated. In this situation, diagnosis and remedial action is not simple; unless a generalized estimation approach is employed which guarantees the absence of both problems, the estimated model is not useful for statistical inference.

Logical errors in analysis may be committed when cross sections of data are used in testing a statistical model. As Swamy points out, there are two types of difficulties which arise with the use of cross-sectional data [41]. The first difficulty is that it is unlikely that interindividual differences can be explained by a simple regression equation with a few independent variables. While individual cross-sectional units may respond to exogenous influences over time, differences among units within a time period, when the exogenous or "market" forces are constant, become much more difficult to explain. The other difficulty is that, in cross-sectional models, the implicit assumption is that all individual units are subject to identical behavioral patterns in all regards. Unless this unlikely assumption is true (and this study will treat this assumption as a statistically testable proposition), a macro equation, obtained by aggregating a micro equation over micro units, will have biased coefficient estimates.

Statistical Methodology

All of the difficulties mentioned above, statistical and logical, can be managed and eliminated by employing a random coefficient regression (RCR) model developed by Swamy [41]. The difficulties are managed by allowing the coefficient vector of a regression model to be a random variable to account for interindividual heterogeneity (if, in fact, the heterogeneity assumption is warranted). Thus, the RCR model allows corresponding coefficients to be different among the various individual cross-sectional units. The RCR model then focuses on estimating the mean and variance of the vector of regression coefficients. It should also be noted that Swamy's procedure provides Aitken generalized least squares estimators - the estimator for the mean vector is consistent and asymptotically efficient while the estimator of the variance-covariance matrix of the coefficient vector is unbiased and consistent [41]. The Aitken procedure guarantees the absence of both autocorrelation and heteroscedasticity in the estimated relationships. The resulting statistical properties, particularly with the large sample size in this study, allow all relevant statistical inference procedures to be employed.

TESTS OF HYPOTHESES

The RCR program provides a test statistic to test the null hypothesis:

$$H_0: \quad \beta_1 = \beta_2 = \dots = \beta_N = \beta,$$

where β_i is a $(\Lambda x1)$ vector of fixed coefficients and where Λ is the number of independent variables in the regression equation. If H_0 is not rejected, it can be concluded that all of the individual (cross-sectional)units are homogenous with respect to the coefficient vectors β_i. The panel data can then be pooled without bias in estimation. Even with fixed coefficient estimation, the Aitken generalized least squares procedure is employed, and the resulting estimations are free of autocorrelation and heteroscedasticity.

The test statistic has the asymptotic distribution of χ^2 with $\Lambda(N-1)$ degrees of freedom, where N is the number of railroads in the equation. If χ^2 is small, a fixed coefficient model is used; if χ^2 is large, the RCR model must be employed.

Other tests of hypotheses will be conducted on the coefficients of the independent variables specified in Section 2 above. The RCR program provides t-statistics for each independent variable used to perform single coefficient t-tests of statistical significance on each variable. The final equation or equations are selected on the criteria of good statistical fit and highest significant t-statistics from among required groupings of variables.

4. STATISTICAL ANALYSES

This section contains the statistical study of the track maintenance, accident, and speed models presented in Section 3 and has three parts. The first part provides an overview of the statistical study and a summary of key findings. The second part contains a detailed discussion of the track maintenance models. Finally, the third part includes the analyses of accident and speed models.

OVERVIEW OF STATISTICAL STUDY AND KEY FINDINGS

The statistical analyses focused on three areas: track maintenance spending, track-related accidents, and system train speeds. In general, the task was to evaluate statistical models developed from the theoretical framework formulated in Sections 1-3. To a considerable extent, the accuracy, aggregation, and availability of data from public sources restricted this task. Given publicly available data, the smallest unit of observation is the Class I railroad, while the unit of time is one year. Variable measurements, therefore, represent annual systemwide averages. This level of aggregation means that the study results provide only a general profile of track maintenance, accident, or train speed behavior in response to the multiplicity of overlapping influences on such behavior.

The analytical technique used to develop final statistical models and test hypotheses was random coefficients regression (RCR). The nature of the study (time series and cross-sectional) made RCR essential from a statistical, theoretical, and logical point of view.

Track Maintenance Expenditure Models

Although statistical analyses were conducted in three related areas, the primary objective was to explain track maintenance behavior. Both financial and physical measures were used to represent track maintenance activity. For expenditure models, the research questions were:

- Which variables best explain how current operating revenues available to a railroad are allocated to track maintenance?
- Does a railroad devote a decreasing, constant, or increasing proportion of its available resources to track maintenance in response to key variables?

To answer these questions, regression models with track maintenance expenditures per track mile (TMEXP) and track maintenance expenditures as a proportion of total annual operating revenues (TMRATIO) were estimated. Both for a priori reasons and for purposes of regulation and control, variables representing speed (the change in average system train speed or Δ SPEED), accidents (the number of accidents per million gross ton miles, lagged one year $(ACC)_{t-1}$, and the frequency-severity accident indexes $(SI1)_{t-1}$ and $(SI2)_{t-1}$), and the introduction of FRA safety standards (DUMMY) were entered into models on an obligatory basis. Because measurements for accident indexes were available only for an eleven-year (1967-1977) period, models were developed for two time frames: (1) 1962-1977, where $(ACC)_{t-1}$ was used and (2) 1967-1977, where the indexes $(SI1)_{t-1}$ and $(SI2)_{t-1}$ were included.

In addition, analyses of track maintenance expenditure models were made for two different levels. Initially, industry models were developed and evaluated. Subsequently, final industry models were tested on six subgroups.

Key Findings

The results indicate that available operating revenues heavily influence industry track maintenance expenditures. Yet, operating revenue per track mile (REV) is highly collinear with other a priori variables of interest. Thus, the track maintenance ratio model (TMRATIO), which permits REV to be removed as an explanatory variable but keeps REV in the model equation and avoids the use of possibly deficient deflator data, was conceptually superior.

Safety-Related Variables. In TMRATIO models, safety-related variables are statistically significant predictors. In particular, *the years since FRA standards were instituted are associated with nearly a 1 percent increase in the proportion of revenues allocated to industry track maintenance expenditures*. Also, track maintenance expenditures show a significant positive response to unit increases in track-related accident rates. The link between safety standards and track maintenance expenditures, however, must be viewed with caution. The statistically significant upward shift in average track maintenance spending after 1972 may be the result of factors such as major renewal programs which, in turn, may have been the result of growing revenues or of anticipated growth--in coal or grain traffic for example--or of strategic goals that require upgrading service quality.

Furthermore, the analyses of railroad groups indicate that safety-related variables exhibit differential effects on various groups. Track maintenance decisions of railroad companies that operate trains at higher speeds appear to be more sensitive to accident rates and the introduction of FRA safety standards than similar decisions of companies that have slower average system train speeds. As one might intuitively expect, railroads with very low operating speeds seem not to be affected by FRA standards in their track maintenance allocations perhaps because the speeds are already so low that the standards do not serve as a disincentive to low track maintenance allocations, or perhaps because the carrier lacks the resources to undertake the major upgrading which would be required.

Large railroads appear to be more sensitive in their maintenance decisions to accident rates, perhaps because they possess the resources to undertake major rehabilitation. Profitable railroads appear to be more sensitive to accident rates and to the establishment of the FRA standards (contrary to indications given during interviews), while high density network systems seem more sensitive to accident rates than low density network systems.

For regional groups, the track maintenance expenditures of southern railroads appear more responsive than the expenditures of northern carriers to accident rates. Finally, for the passenger group, all models show accident variables with statistically significant coefficients that are larger for the passenger than for the nonpassenger groups. Not surprisingly, TMEXP and TMRATIO for railroads with passenger operations are more responsive to $(ACC)_{t-1}$ than carriers without such operations.

Train Speed and Car Weight. Overall, the change in average annual system train speed (Δ SPEED) was not a significant factor in the study of track maintenance spending. In regression equations for all railroads, Δ SPEED was not a statistically significant predictor of TMEXP or TMRATIO. In the analyses of subgroups, only TMEXP was responsive to Δ SPEED in medium size, low ROI, or low density railroad groups. For these groups, a reduction in average annual system train speed has a significant positive effect on the prediction of nominal track maintenance expenditures per track mile.

On the industry level, although average system carload weight (WEIGHT) has a significant direct effect on nominal track maintenance expenditures per track mile (TMEXP), it is not a significant predictor of real resources devoted to track maintenance (TMRATIO). For speed groups, although significant relationships are found in the low speed group, WEIGHT has a significant influence on the prediction of both track maintenance expenditure measures only in the medium speed group. Unlike speed groups, network-size groups show no significant relationships between WEIGHT and TMRATIO; when TMEXP is the dependent variable, statistically significant relationships occur only for the medium and the large network levels. For ROI groups, WEIGHT does have a significant effect on both track maintenance measures, but only at the low ROI level. The results for density groups are mixed; contrary results for medium and high groups as opposed to low density groups make interpretation difficult. The results are clear, however, for regional operations. Track maintenance expenditures of the northern group appear more sensitive to changes in average system carload weight. Finally, for passenger operation versus nonpassenger operation groupings, no patterns are apparent with respect to WEIGHT and track maintenance measures.

Tie and Rail Replacement Models

The second approach taken for the analysis of track maintenance activity was to estimate tie and rail replacement models. Besides the variables found statistically significant in the industry level study of track maintenance expenditures, a price index ratio (PIR) and the proportion of continuous welded rail (CWRAIL) were tested. Other operating variables such as DENSITY, SIZE, and LENGTH were not evaluated because they measure much of the same theoretical influences as WEIGHT.

Other than REV, no variable is significant in any regression equation for all railroads, and REV is significant only in the TIES model. In equations for carriers, other variables are significant, but changes in signs or in significance make interpretation difficult.

Accident and Speed Models

In developing final accident and speed models, variables considered essential (both a priori and from the point of view of regulation and control) as well as nonobligatory variables were tested. For accident models, the obligatory predictors were DUMMY, WEIGHT, and alternatively, $(\text{TMRATIO})_{t-1}$, $(\text{TMEXP})_{t-1}$, or $(\text{REV})_{t-1}$; others tested were ROI, $(\text{TIE})_{t-1}$, $(\text{RAIL})_{t-1}$, LENGTH, and DENSITY. Regardless of the combination of variables, accident models did not give useful results, primarily because a meaningful measure of track condition could not be included in the models tested, and because the level of aggregation tended to blur the effects of the variables that were included.

Except for the substitution of LENGTH for WEIGHT, the same set of obligatory variables was specified for models of average system train speed. Nonobligatory variables, however, included only $(\text{TIES})_{t-1}$, $(\text{RAIL})_{t-1}$, DENSITY, and SIZE. The regression results for all railroads show that a significant reduction in average system train speed occurred after the introduction of FRA track safety standards. LENGTH, $(\text{REV})_{t-1}$, and the nonobligatory variables were not statistically significant. The results for lagged track maintenance measures are unclear and must be used cautiously. Although there are several possible explanations for the negative signs of the significant $(\text{TMRATIO})_{t-1}$ and $(\text{TMEXP})_{t-1}$ coefficients, the results were contrary to initial theoretical expectations. Finally, no other variables proved statistically significant in regression models for all railroads.

ANALYSIS OF TRACK MAINTENANCE

In this part of Section 3, track maintenance models are developed and discussed. The initial focus is on financial measures (TMEXP and TMRATIO) of track maintenance. In order to analyze financial measures, industry models were developed and evaluated first. These models were then tested on the six subgroups of railroads. The ensuing discussion covers models that use physical measures as dependent variables. Although a similar approach was taken for the analysis of physical measures of track maintenance, the investigation was largely unproductive and the discussion of it is limited.

Track Maintenance Expenditure Models

In developing regression results for track maintenance expenditure models, the two research questions asked were: Which variables best explain how operating revenues available to a railroad are allocated to track maintenance? Does a railroad devote a decreasing, constant, or increasing proportion of its available resources to track maintenance in response to key variables? To answer these questions, regression models were estimated where track maintenance expenditures per track mile (TMEXP) and track maintenance expenditures as a proportion of total annual operating revenues (TMRATIO) were the dependent variables.

In developing explanatory equations, variables representing speed, accidents, and the introduction of FRA track standards were entered into the models on an obligatory basis, both a priori and for purposes of regulation and control. Specifically, these variables were: the change in average system train speed (Δ SPEED); the number of accidents per million gross ton miles lagged one year $(ACC)_{t-1}$; the severity-frequency accident indexes for line (main or branch) and yard (including siding or way switching) segments lagged one year $(SI1)_{t-1}$ and $(SI2)_{t-1}$, respectively; and the dummy variable for the introduction of FRA safety standards (DUMMY). Subsequently, other independent variables, alone and in combinations, were evaluated in the presence of the obligatory variables. As later discussion will demonstrate, however, the results did not yield any compelling reason for keeping $(SI1)_{t-1}$ in the final models.

Regression Results for All Railroads

(1) 1962-1977 and $(ACC)_{t-1}$ as the Measure of Accidents

The random coefficients regression equations for the final industry models are shown in Tables 14 and 15. Considering TMEXP models for the 16-year (1962-1977) period first (see Models 1 and 2, Table 14), it can be seen that when the annual operating revenue variable (REV) is added to Δ SPEED, $(ACC)_{t-1}$, and DUMMY, as well as average carload weight (WEIGHT) (which was the only other nonobligatory predictor found significant in other models), the results are those that appear in Model 1. (See Table 11 for variable definitions.) Only the coefficient of the REV variable is statistically significant.* Likewise, when other independent variables are included in the model with REV and the obligatory variables, only REV is statistically significant.

Plots of values among the independent variables, however, indicate high collinearity of REV with other independent variables. While the importance of REV in explaining TMEXP is recognized, the collinearity indicates that REV is capturing the independent effects of other variables and is dominating the other coefficients and standard errors.

As shown in Model 2, when REV is removed and other independent variables are evaluated, only WEIGHT is statistically significant in the presence of the obligatory variables. Nevertheless, every coefficient in Model 2, except for Δ SPEED, is statistically significant at the .01 level and has the expected sign. Furthermore, when DENSITY, DIVIDEND, and ROI are added, none is statistically significant. When the price index ratio (PIR) is added to the equation, its coefficient is highly significant, but has the wrong, i.e., negative sign. Since there is no a priori support for a

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*All t-tests for regression coefficients are one-tailed tests since there are a priori expectations of signs of coefficients.

Table 14. Random Coefficients Regression for All Railroads-Track Maintenance Expenditure Models 1962-1977

		INDEPENDENT VARIABLES[(a)]						
Dependent Variable	Model	Constant	Δ SPEED	$(ACC)_{t-1}$	DUMMY	WEIGHT	REV	χ^2-Statistic for Test of Homogeneity[(b)]
TMEXP	1	-0.4548 (0.0192)*	-0.0550 (0.1097)	0.1212 (0.1719)	-0.0746 (0.2537)	- 1.5501 (1.6066)	0.1268 (0.0272)*	2294 [180 d.f.]*
	2	-5.8206 (2.1128)*	-0.1537 (0.1599)	1.1018 (0.2271)*	1.5765 (0.3312)*	13.3332 (3.3055)*		2336 [150 d.f.]*
TMRATIO	3	5.7211 (2.3810)*	-0.1294 (0.1781)	1.0494 (0.1781)*	0.7909 (0.2577)*	3.9737 (4.1469)		1668 [150 d.f.]*

(a) Numbers in parentheses are standard errors.

(b) Numbers in brackets are degrees of freedom for statistical tests.

* Indicates significance at the .01 level.

Table 15. Random Coefficients Regression for All Railroads-Track Maintenance Expenditure Models 1967-1977

		INDEPENDENT VARIABLES[a]						
Dependent Variable	Model	Constant	Δ SPEED	$(SI1)_{t-1}$[c]	$(SI2)_{t-1}$[c]	DUMMY	WEIGHT	χ^2-Statistic for Test of Homogeneity[b]
TMEXP	1	-5.9413 (4.5332)	-0.1024 (0.1591)	0.0266 (0.0841)	0.5166 (0.1978)*	0.9091 (0.2787)*	15.0550 (8.0672)**	2361 [180 d.f.]*
	2	-4.9327 (3.1838)	-0.1051 (0.1283)		0.5505 (0.2005)*	1.0626 (0.2807)*	13.1792 (4.9276)*	2420 [150 d.f.]*
TMRATIO	3	9.8019 (2.8958)*	-0.0694 (0.1640)	0.0533 (0.0758)	0.4165 (0.2314)**	0.4482 (0.6945)	- 1.1396 (3.7726)	1738 [180 d.f.]*
	4	8.7334 (0.7282)*	-0.0242 (0.1422)		0.5549 (0.1976)*	0.6320 (0.3386)**	0.6061 (0.3859)	1869 [150 d.f.]*

(a) Numbers in parentheses are standard errors.
(b) Numbers in brackets are degrees of freedom for statistical tests.
(c) Data available from 1967.
* Indicates significance at the .01 level.
** Indicates significance at the .05 level.

negative coefficient, the result is judged to be a spurious relationship, and PIR was eliminated from the regression.

Thus, Models 1 and 2 provide some evidence on which factors determine levels of TMEXP. It appears that track maintenance expenditures per track mile are positively related to current revenues, the number of accidents in the previous period, average carload weight, and the introduction of FRA track safety standards.

However, a second research question, as noted above in the section on delineation of the track maintenance model, was also of interest. A determination was to be made whether railroads devote a decreasing, constant, or increasing proportion of their available resources to track maintenance in response to key variables. Hence, the analytical focus in this case shifts to Model 3 (Table 14) and to the ratio of track maintenance expenditures to operating revenues (TMRATIO). Furthermore, when TMRATIO is employed as a dependent variable (see Model 3), the model determines the railroad and industry action toward road rehabilitation, since TMRATIO represents commitment of real resources. Moreover, because track maintenance is essentially funded from operating revenues, TMRATIO represents the share of available financial resources the company is willing to commit to the maintenance function vis-à-vis other departments.

The random coefficients regression results indicate that the industry as a whole does have a real resource position on maintenance of way that is responsive to equation variables. Although WEIGHT is not a significant predictor, the signs of variables correspond to those in Models 1 and 2, and both DUMMY and $(ACC)_{t-1}$ are statistically significant at the .01 level.

(2) Alternative Accident Measures for 1967-1977

In Table 14, the track-safety variable was measured by $(ACC)_{t-1}$, the total number of accidents in the previous year. However, this measure has a major weakness because it fails to capture the impact of the severity of accidents. To remedy this weakness, ACC was replaced by two measures: SI1 and SI2. Since the data necessary to calculate SI1 and SI2 were available only for the period 1967-1977, regressions with the dependent variables TMEXP and TMRATIO were run for that period; the results are presented in Table 16.

Table 16 shows that when $(\mathrm{SI1})_{-1}$ and $(\mathrm{SI2})_{-1}$ are both in the equation (Model 1), the coefficients of DUMMY and WEIGHT are significant, while the coefficient of Δ SPEED is not. This pattern is the same as when $(\mathrm{ACC})_{-1}$ was employed as an explanatory variable. However, the coefficient of $(\mathrm{SI2})_{-1}$ is significant, and the coefficient of $(\mathrm{SI1})_{-1}$ is not. The unimportance of $(\mathrm{SI1})_{-1}$ as a variable seems further to be borne out by the small magnitude of the coefficient estimate. Since there did not seem to be any compelling reason to keep $(\mathrm{SI1})_{-1}$ in the equation as a maintained hypothesis, $(\mathrm{SI1})_{-1}$ was eliminated. The preferred equation is shown as Model 2 in Table 16.

The eleven-year industry models (3 and 4 in Table 15) with the alternative accident measure essentially corroborate the results of the corresponding industry models (2 and 3 in Table 14) for the 1962-1977 period. Accident variables have a significant influence on the prediction of nominal (TMEXP) and real (TMRATIO) track maintenance expenditures. Moreover, after the introduction of FRA track safety standards, there was a statistically significant increase in the industry's track maintenance expenditures (as defined in this study). An exception, however, is WEIGHT. Although the average system car weight has a positive effect on the prediction of nominal track maintenance expenditures, it is not a significant predictor of real resources (as measured by TMRATIO) devoted to track maintenance.* Finally, in no industry model was Δ SPEED a significant variable.

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*It should be emphasized here that although consistent results for 16- and 11-year models enhance confidence in the findings, it does not necessarily follow that inconsistent results diminish the findings. Differences may result not only from replacing $(\mathrm{ACC})_{t-1}$ with $(\mathrm{SI2})_{t-1}$, but also from changing the sample from 16 to 11 years.

Table 16. Random Coefficients Regression for Track Maintenance Expenditure Models Estimated by Speed Groups

Group	Dependent Variable	Time Frame (Yrs)	INDEPENDENT VARIABLES[(a)]						χ^2-Statistic[(b)] for Test of Homogeneity
			Constant	Δ SPEED	$(ACC)_{t-1}$	$(SI2)_{t-1}$	DUMMY	WEIGHT	
High Speed	TMEXP	16	- 7.7959 (8.5118)	-0.3270 (0.2993)	3.4912 (2.5379)		2.1873 (0.5904)*	16.8247 (11.5734)	58.31 [10 d.f.]*
		11	-19.6775 (17.0866)	0.0803 (0.3069)		1.3181 (0.4868)*	0.7416 (0.5554)	35.5387 (23.8179)	61.14 [10 d.f.]*
	TMRATIO	16	10.8381 (3.1074)*	-0.4980 (0.6167)	6.5567 (2.6637)*		1.3133 (0.7643)**	- 3.5375 (3.7138)	19.73 [10 d.f.]*
		11	7.8086 (5.1467)	-0.2337 (0.5695)		1.2051 (0.9782)	0.4307 (0.5868)	3.9274 (5.8450)	25.85 [10 d.f.]*
Medium Speed	TMEXP	16	- 8.7769 (2.2337)*	0.2518 (0.1884)	1.8326 (0.7862)**		1.8126 (0.5907)*	18.3345 (3.1560)*	606.33 [45 d.f.]*
		11	- 5.1605 (6.1784)	0.0309 (0.1353)		0.8735 (0.3540)*	0.8405 (0.3695)**	12.9918 (9.7643)	684.54 [45 d.f.]*
	TMRATIO	16	0.3797 (4.3442)	0.3495 (0.3079)	1.3923 (0.7345)**		1.2742 (0.5407)*	15.8344 (9.3361)**	366.83 [45 d.f.]*
		11	7.2789 (2.3512)*	-0.0163 (0.1977)		1.0223 (0.3638)	0.3237 (0.9419)	5.6445 (3.0449)**	503.78 [[45 d.f.]*
Low Speed	TMEXP	16	- 5.8139 (3.3080)**	0.0673 (0.2490)	0.8621 (0.2088)*		1.3157 (0.4717)*	13.4195 (5.3519)*	1113.84 [85 d.f.]*
		11	- 3.9513 (3.5499)	0.0851 (0.2549)		0.3082 (0.1680)**	1.0644 (0.4373)*	11.5194 (5.6167)**	928.77 [85 d.f.]*
	TMRATIO	16	7.5011 (3.2002)*	0.0094 (0.2557)	0.7169 (0.3490)**		0.5638 (0.3687)	- 0.3379 (4.6677)	1047.29 [85 d.f.]*
		11	8.6790 (2.0580)*	-0.0654 (0.2492)		0.1710 (0.1946)	0.6311 (0.4737)	- 0.9285 (1.4704)	1076.20 [85 d.f.]*

(a) Numbers in parentheses are standard errors.
(b) Numbers in brackets are degrees of freedom for statistical tests.

* Indicates significance at the .01 level.
** Indicates significance at the .05 level.

Regression Results for Railroad Groups. Different levels of six characteristics defined the groups into which railroads were classified for analysis (see Table 12). The selected characteristics represented various network, operating, or financial factors likely to affect track maintenance expenditures of railroad groups in different ways. The purpose was to present a descriptive comparison of such differential effects, as well as to investigate the results of industry models applied to particular subsets of railroads. The comparisons are descriptive rather than statistical because, in random coefficients estimation, the problem is that the total sum of squares will not necessarily partition into an error sum of squares and a model sum of squares. This result thus precludes, for example, any analysis based upon general analysis of covariance.

In addition, although the primary focus is on the TMRATIO model (Model 3, Table 14), the equivalent TMEXP model (Model 2, Table 14) was included in the analyses of subgroups in order to provide additional information and possible corroborative evidence. Tables were developed to show simultaneously the results of all models (16- and 11-year models for both TMEXP and TMRATIO) for each level of the grouping variable. Although somewhat cumbersome, the arrangement of tables allows one, by concentrating on a particular level (e.g., high speed) and variable column (e.g., WEIGHT), to identify easily any differences in model results. Finally, before proceeding to the results, it should be noted that although carriers were placed into "like" groups with respect to the blocking characteristic, χ^2 tests of homogeneity indicated diverse behavior even within groups to be the rule rather than the exception.

(1) Average System Train Speed

Focusing on Δ SPEED in Table 16, it is seen that, as in the aggregate industry models, Δ SPEED is an insignificant predictor. By contrast, accident measures are significant in eight of the twelve models. With one exception (i.e., as a predictor of TMEXP in the high speed group), coefficients of $(ACC)_{t-1}$ are significant predictors.

The size of these coefficients increases as the level of speed goes from low to high. This suggests that track maintenance expenditures become more sensitive to the number of accidents per million gross ton miles in the previous year as the group level of average system train speed increases.

Eleven-year models with $(SI2)_{t-1}$ as the measure of accidents confirm the significant influence of accidents in predicting TMEXP, but not in predicting TMRATIO. For the 11-year TMRATIO models, however, the signs and the relative magnitudes of $(SI2)_{t-1}$ coefficients are consistent with the findings for $(ACC)_{t-1}$.

A similar pattern of results occurs for DUMMY in the 16-year time frame. All but one of the coefficients of DUMMY is significant, and the same hierarchy appears. The results of the 11-year models, though, are mixed. Medium and high speed groups show DUMMY to have significant relationships with TMEXP, but the hierarchy of coefficients is reversed. Furthermore, DUMMY is not a significant predictor of TMRATIO in the 11-year models. Although significant relationships are found in the low speed group, the medium speed group is the only group in which WEIGHT has a significant influence on the prediction of both track maintenance expenditure measures. Thus, it appears that WEIGHT is statistically important only in the medium speed group.

(2) Network Size

While the response of both track maintenance expenditure variables to $(ACC)_{t-1}$, $(SI2)_{t-1}$, and DUMMY varies among size groups, only TMEXP has a statistically significant response to Δ SPEED and WEIGHT. As shown in Table 17, a consistent pattern of results occurs for accident measures for the large railroad networks. Both $(ACC)_{t-1}$ and $(SI2)_{t-1}$ are significant predictors of TMEXP and TMRATIO. On the other hand, DUMMY exerts its greatest influence in the medium size group. Although the coefficients of DUMMY in the 16-year TMEXP models are greater in the large group than in the medium and small group, only the medium group shows DUMMY to have an effect on TMRATIO.

Table 17. Random Coefficients Regression for Track Maintenance Expenditure Models Estimated by Size Groups

Group	Dependent Variable	Time Frame (Yrs)	INDEPENDENT VARIABLES[(a)] Constant	Δ SPEED	$(ACC)_{t-1}$	$(SI2)_{t-1}$	DUMMY	WEIGHT	χ^2-Statistic[(b)] for Test of Homogeneity
Large Size	TMEXP	16	- 7.1651 (3.9702)	-0.1838 (0.2115)	2.5612 (0.5320)*		1.0913 (0.4495)*	14.6057 (6.3784)*	1299.45 [55 d.f.]*
		11	- 5.8873 (5.5902)	-0.0057 (0.1825)		0.8531 (0.2799)*	0.6805 (0.3251)**	14.3327 (8.5526)**	1077.69 [55 d.f.]*
	TMRATIO	16	7.0977 (3.7743)	-0.1780 (0.3084)	2.4007 (0.6779)*		0.6366 (0.4460)	1.7008 (5.9979)	436.47 [55 d.f.]*
		11	10.6586 (4.8946)**	-0.0759 (0.2666)		0.7800 (0.2989)*	0.2516 (0.3330)	1.8449 (7.4784)	661.24 [55 d.f.]*
Medium Size	TMEXP	16	- 7.8892 (3.3721)**	-0.3746 (0.2217)**	0.4454 (0.2531)**		1.5956 (0.3567)*	17.1948 (5.4728)*	403.31 [50 d.f.]*
		11	- 8.4275 (3.1634)**	-0.5530 (0.1449)*		0.1974 (0.2203)	1.0519 (0.3425)*	18.4891 (4.9943)*	735.85 [50 d.f.]*
	TMRATIO	16	3.2342 (3.9938)	-0.1301 (0.3773)	0.7149 (0.4461)		1.1309 (0.5356)**	8.0317 (5.3819)	579.50 [50 d.f.]*
		11	8.2537 (0.9892)*	-0.3198 (0.2727)		0.0986 (0.1628)	1.2197 (0.4174)*	0.5486 (0.4958)	474.16 [50 d.f.]*
Small Size	TMEXP	16	0.8795 (3.4679)	-0.0126 (0.3821)	0.7961 (0.6231)		3.1039 (1.3060)*	3.1018 (4.0724)	244.91 [35 d.f.]*
		11	- 2.1779 (9.0147)	0.2049 (0.4043)		0.1240 (0.5548)	1.9343 (0.8429)**	9.4746 (14.2505)	177.55 [35 d.f.]*
	TMARTIO	16	5.7034 (1.2707)*	0.1244 (0.3258)	1.1918 (1.1048)		0.7650 (0.4628)	3.8358 (6.9509)	255.15 [35 d.f.]*
		11	9.0606 (1.9054)*	0.1656 (0.3772)		0.3495 (0.4412)	-0.2222 (1.2204)	0.7418 (0.9109)	248.02 [35 d.f.]*

(a) Numbers in parentheses are standard errors.
(b) Numbers in brackets are degrees of freedom for statistical tests.

* Indicates significance at the .01 level.
** Indicates significance at the .05 level.

Δ SPEED and WEIGHT are significant predictors of TMEXP only for medium or large groups. The coefficients of Δ SPEED have negative signs, an indication that a net reduction in average system train speed has a positive influence on the prediction of TMEXP. In contrast, the signs for WEIGHT are all positive, but coefficients are greater in the large group.

(3) Return on Investment

As shown in Table 18, accident variables are significant in all models for medium and high ROI levels. Coefficients of $(ACC)_{t-1}$ and $(SI2)_{t-1}$ in regressions of the middle level group, however, are roughly twice as large as corresponding coefficients found in the high ROI level. Thus, it appears that track maintenance expenditure decisions of less prosperous, though not poor, railroads (middle level) are relatively more sensitive to accidents than similar decisions of relatively prosperous or poor carriers (high and low ROI levels, respectively).

The third safety-related variable, DUMMY, is a consistently significant predictor only for the high ROI group. Apparently, more profitable carriers have had a significant increase in track maintenance expenditures after the introduction of FRA track safety standards. Although the low ROI group does show a significant positive relationship between the introduction of the standards and dollars spent per track mile in each time frame, real resource (TMRATIO) models do not show DUMMY to be significant.

Altogether, with the exception of DUMMY's significance in the high ROI group models, these results are basically consistent with the framework developed in Section 2. Regardless of the financial condition of the railroad visited, senior officials consistently indicated in interviews that, while accidents are often important in the decision process, FRA track safety standards had relatively little influence on track maintenance spending decisions. Similarly, the case study presented above demonstrated how accident costs might affect the investment decision, especially for low density branch lines, and also highlighted the economic incentives for accepting the slow orders, temporary or permanent (via downgrading the track classification), that the FRA might impose on the branch lines

Table 18. Random Coefficients Regression for Track Maintenance Expenditure Models Estimated by ROI Groups

Group	Dependent Variable	Time Frame (Yrs)	INDEPENDENT VARIABLES[a]						X^2-Statistic[b] for Test of Homogeneity
			Constant	Δ SPEED	$(ACC)_{t-1}$	$(SI2)_{t-1}$	DUMMY	WEIGHT	
High ROI	TMEXP	16	- 7.6208 (3.1939)*	-0.0656 (0.2010)	0.7235 (0.2000)*		1.6582 (0.4715)*	16.6345 (5.0316)*	859.96 [90 d.f.]*
		11	- 7.9058 (3.9507)	0.0480 (0.1539)		0.5747 (0.2274)*	1.1290 (0.4310)*	18.0715 (5.9518)*	922.00 [90 d.f.]*
	TMRATIO	16	6.3096 (3.2430)	-0.0521 (0.2272)	1.3271 (0.5445)*		0.9096 (0.3719)*	2.0891 (4.9681)	1266.71 [90 d.f.]*
		11	9.8925 (3.6672)*	0.0438 (0.1805)		0.5139 (0.2517)**	0.5315 (0.3126)**	- 1.3538 (5.1874)	1317.13 [90 d.f.]*
Medium ROI	TMEXP	16	- 1.3396 (4.3359)	0.1241 (0.2047)	2.5164 (1.0589)*		1.1163 (1.0059)	7.5123 (7.0342)	690.56 [25 d.f.]*
		11	- 1.6334 (7.8136)	0.1576 (0.2037)		1.3397 (0.5518)**	0.7946 (0.3714)**	8.2030 (11.6685)	383.36 [25 d.f.]*
	TMRATIO	16	3.5099 (4.5326)	-0.5435 (0.4819)	2.2756 (1.1838)**		0.7059 (0.3699)**	11.4775 (11.7177)	226.745 [25 d.f.]*
		11	8.2013 (2.7327)*	0.2695 (0.3553)		1.6576 (0.5494)**	0.3591 (1.3477)	5.0098 (2.5248)**	295.70 [25 d.f.]*
Low ROI	TMEXP	16	- 8.4345 (2.0550)*	-0.5511 (0.2941)**	0.4484 (0.4193)		1.5805 (0.3835)*	17.4056 (3.7520)*	151.325 [25 d.f.]*
		11	- 5.5908 (2.3843)	-0.5258 (0.3027)**		0.1894 (0.1973)	1.3453 (0.4018)*	12.4285 (4.2162)*	127.67 [25 d.f.]*
	TMRATIO	16	- 3.4393 (6.4397)	-0.1698 (0.5130)	0.6877 (0.6888)		1.3202 (1.4470)	18.9022 (9.9897)**	60.59 [25 d.f.]*
		11	4.0084 (5.7142)	-0.3048 (0.3169)		0.2298 (0.1217)**	0.6973 (0.5982)	6.8034 (9.8380)	36.75 [25 d.f.]*

(a) Numbers in parentheses are standard errors.
(b) Numbers in brackets are degrees of freedom for statistical tests.

* Indicates significance at the .01 level.
** Indicates significance at the .05 level.

where speed-related savings are not sufficient to justify normalized maintenance. The significance of the exception, of course, is tentative, for the high ROI group's increase in track maintenance expenditures after the introduction of safety standards may simply reflect rising levels of traffic and revenue during the same period or, possibly, independent renewal programs for track laid just after World War II.

In three of the four models for the low ROI group, WEIGHT is a significant predictor of either TMEXP or TMRATIO. In the high ROI group, WEIGHT is significant in the TMEXP models for the 16-year period only; in this group, TMRATIO is unresponsive to changes in average system carload weight.

(4) Traffic Density

As shown in Table 19, safety-related variables affect density groups differently. $(ACC)_{t-1}$ or $(SI2)_{t-1}$ coefficients all exhibit expected signs and are significant in ten of twelve models. Although accident variables are consistently significant predictors of track maintenance expenditures for all density groups, expenditure measures essentially are successively more responsive to changes in $(ACC)_{t-1}$ and $(SI2)_{t-1}$ for medium and high density railroads.

Like accident variables, DUMMY affects density groups differently. The results, especially for TMRATIO models in the 16-year time frame, are basically the same as the findings for accident variables in either time frame. The significant coefficients of DUMMY indicate that DUMMY has successively greater influence on the prediction of track maintenance variables as density levels progress from low to high. Apparently, many medium and high density railroads have spent more nominal dollars for, and devoted a greater share of operating revenues to, track maintenance since 1972.

Unlike the results for safety-related variables, the results for Δ SPEED and WEIGHT are mixed. Δ SPEED is a significant predictor of TMEXP in the low density group, but the signs change in other models; in addition, Δ SPEED is not significant in any of the TMRATIO models. Likewise, little corroboratory evidence is shown in the results for WEIGHT.

Table 19. Random Coefficients Regression for Track Maintenance Expenditure Models Estimated by Density Groups

			INDEPENDENT VARIABLES[a]						
Group	Dependent Variable	Time Frame (Yrs)	Constant	Δ SPEED	$(ACC)_{t-1}$	$(SI2)_{t-1}$	DUMMY	WEIGHT	χ^2-Statistic[b] for Test of Homogeneity
High Density	TMEXP	16	- 8.3370 (4.2222)*	-0.1111 (0.3587)	2.8897 (1.0245)*		2.5280 (0.9115)*	16.6267 (5.4554)*	180.54 [35 d.f.]*
		11	-10.8200 (7.2169)	0.2426 (0.3537)		0.9809 (0.3346)*	1.2489 (0.7678)	21.6217 (10.0175)**	166.80 [35 d.f.]*
	TMRATIO	16	7.3734 (3.0330)**	-0.2856 (0.4015)	3.2198 (1.0986)*		1.2863 (0.6206)**	0.6617 (4.5068)	191.19 [35 d.f.]*
		11	9.0368 (5.1606)	-0.1027 (0.2452)		0.9442 (0.3905)*	0.5671 (0.3978)	0.4322 (7.6056)	399.24 [35 d.f.]*
Medium Density	TMEXP	16	- 9.2796 (5.5073)**	0.1678 (0.1798)	1.2691 (0.4400)*		1.0035 (0.5488)**	18.7657 (9.0372)**	269.76 [45 d.f.]*
		11	-10.6510 (5.5257)	0.0919 (0.1566)		0.4988 (0.1954)*	0.7612 (0.5537)	22.5725 (8.7929)*	289.81 [45 d.f.]*
	TMRATIO	16	16.3122 (5.5501)*	-0.0755 (0.2102)	0.9964 (0.8013)		1.8192 (0.5502)*	-11.6618 (9.8328)	499.08 [45 d.f.]*
		11	2.9133 (6.2247)	0.3590 (0.2498)		0.7985 (0.2144)*	1.0594 (0.5077)**	11.0992 (9.1538)	566.56 [45 d.f.]*
Low Density	TMEXP	16	0.7705 (0.4695)	-0.2748 (0.1445)**	0.7102 (0.3939)**		1.6834 (0.9115)**	1.7448 (1.1860)	794.36 [60 d.f.]*
		11	1.2424 (3.6323)	-0.3744 (0.1266)*		0.7530 (0.3562)**	1.2592 (0.2607)*	2.4275 (5.7155)	465.07 [60 d.f.]*
	TMRATIO	16	5.3279 (1.2396)*	0.1840 (0.3368)	0.9965 (0.7535)		0.9533 (0.4019)*	4.9141 (4.4604)	809.44 [60 d.f.]*
		11	7.6238 (1.0352)*	-0.2507 (0.2342)		0.6847 (0.2552)*	-0.2064 (0.7362)	2.7780 (0.8636)*	685.42 [60 d.f.]*

(a) Numbers in parentheses are standard errors.
(b) Numbers in brackets are degrees of freedom for statistical tests.

* Indicates significance at the .01 level.
** Indicates significance at the .05 level.

(5) Regional Operations

The track maintenance expenditures of southern railroads appear more responsive than the expenditures of northern carriers to accident variables (see Table 20). All four models for the southern group show $(ACC)_{t-1}$ and $(SI2)_{t-1}$ as statistically significant variables that have larger coefficients in the southern group than in the northern group. The results for DUMMY, however, are mixed. While the southern group appears more responsive to DUMMY in the 16-year models, 11-year models suggest the opposite. Like the 11-year model results for DUMMY, the coefficients of WEIGHT also indicate that track maintenance expenditures of the northern group are more sensitive to changes in WEIGHT. Δ SPEED, however, is uniformly insignificant.

(6) Passenger Operations

Not surprisingly, TMEXP and TMRATIO for railroads with passenger operations are more responsive to $(ACC)_{t-1}$ or $(SI2)_{t-1}$ than carriers without such operations. For the passenger group, all models show accident variables with statistically significant coefficients that are larger for the passenger than for the nonpassenger groups (see Table 21). Although the results for DUMMY also exhibit a relatively high degree of consistency, it is the nonpassenger group, rather than the passenger group, that appears to have undertaken increased track maintenance spending after the introduction of FRA track standards. The results for WEIGHT, however, are mixed, and no patterns are apparent.

Tie and Rail Replacement Models

An attempt was made to estimate both tie replacement (TIES) and rail replacement (RAIL) models. Both TIES and RAIL were regressed against DUMMY, Δ SPEED, $(ACC)_{-1}$, and WEIGHT. Since the right-hand side of the final track maintenance expenditure equations has no financial variables, the explanatory variables in expenditure models should apply equally to physical models. In addition, the analysis included the price index ratio (PIR) and the proportion of CWR in the network system (CWRAIL), because these predictors had a strong likelihood of being

Table 20. Random Coefficients Regression for Track Maintenance Expenditure Models Estimated by Region Groupings

Group	Dependent Variable	Time Frame (Yrs)	INDEPENDENT VARIABLES$^{(a)}$ Constant	Δ SPEED	$(ACC)_{t-1}$	$(SI2)_{t-1}$	DUMMY	WEIGHT	χ^2-Statistic$^{(b)}$ for Test of Homogeneity
Northern	TMEXP	16	- 7.8693 (2.7353)*	-0.0119 (0.2404)	0.9446 (0.2432)*		1.6045 (0.4282)*	16.8008 (4.1864)*	1293.09 [90 d.f.]*
		11	- 8.1837 (2.7092)*	0.0528 (0.2395)		0.3754 (0.1767)**	1.2239 (0.4082)*	18.4793 (4.1207)*	1593.08 [90 d.f.]*
	TMRATIO	16	1.4497 (2.6781)	-0.0647 (0.2434)	0.4709 (0.3848)		0.7574 (0.3429)**	10.2687 (3.9965)*	1164.01 [90 d.f.]*
		11	7.9303 (1.2533)*	-0.0253 (0.2415)		0.3461 (0.1627)**	0.9901 (0.2946)*	0.2147 (0.1847)	1029.19 [90 d.f.]*
Southern	TMEXP	16	- 2.4922 (4.1844)	0.0443 (0.2864)	1.8755 (0.4745)*		2.1806 (0.6764)*	7.3779 (6.7323)	253.72 [40 d.f.]*
		11	- 0.8760 (8.6316)	0.1853 (0.1857)		0.8494 (0.4147)**	0.9368 (0.4010)*	5.9161 (12.8476)	228.12 [40 d.f.]*
	TMRATIO	16	7.5905 (4.7969)	-0.0707 (0.3146)	2.0729 (0.9458)**		1.1939 (0.6638)**	3.8580 (10.8333)	168.74 [40 d.f.]*
		11	10.5811 (1.4735)*	0.0780 (0.2857)		0.9859 (0.4190)*	0.0948 (1.0476)	1.5374 (0.7536)**	322.21 [40 d.f.]

(a) Numbers in parentheses are standard errors.
(b) Numbers in brackets are degrees of freedom for statistical tests.

* Indicates significance at the .01 level.
** Indicates significance at the .05 level.

Table 21. Random Coefficients Regression for Track Maintenance Expenditure Models Estimated by Passenger Service Groups

Group	Dependent Variable	Time Frame (Yrs)	INDEPENDENT VARIABLES[a]						χ^2-Statistic[b] for Test of Homogeneity
			Constant	Δ SPEED	$(ACC)_{t-1}$	$(SI2)_{t-1}$	DUMMY	WEIGHT	
Passenger Service	TMEXP	16	- 8.1806 (2.9264)*	-0.0451 (0.2073)	1.37078 (0.3268)*		1.1202 (0.3357)*	16.8333 (4.7797)*	1826.93 [95 d.f.]*
		11	- 8.3510 (3.7493)**	0.0629 (0.1333)		0.6574 (0.2079)*	0.7944 (0.3059)*	18.4883 (5.7874)*	1845.05 [95 d.f.]*
	TMRATIO	16	3.4622 (3.4410)	-0.2057 (0.2302)	1.2194 (0.5482)**		0.7599 (0.3498)**	7.5809 (5.3593)	896.96 [95 d.f.]*
		11	6.4806 (2.8645)**	-0.0131 (0.1944)		0.5982 (0.2327)*	0.8513 (0.2717)*	3.9138 (3.7079)	1069.12 [95 d.f.]*
No Passenger Service	TMEXP	16	0.1147 (2.7540)	0.1055 (0.3329)	0.9417 (0.4489)**		2.6138 (0.9833)**	3.9789 (1.1027)*	477.70 [50 d.f.]*
		11	- 0.7106 (5.6331)	0.2895 (0.3304)		0.4259 (.4758)	1.6164 (0.6573)**	5.8868 (8.4302)	558.27 [50 d.f.]*
	TMRATIO	16	6.0717 (1.9029)*	-0.2824 (0.3123)	1.1809 (0.8055)		1.0429 (0.4075)*	4.4870 (5.8452)	633.49 [50 d.f.]*
		11	9.0087 (1.2824)*	0.0401 (0.2921)		0.2352 (0.3449)	0.1111 (0.8742)	1.4117 (0.6624)**	662.58 [50 d.f.]*

(a) Numbers in parentheses are standard errors.
(b) Numbers in brackets are degrees of freedom for statistical tests.

* Indicates significance at the .01 level.
** Indicates significance at the .05 level.

significant. Other operating variables such as DENSITY, SIZE, and LENGTH were not included in the physical models because, in track maintenance expenditure models, they were highly collinear with WEIGHT; in fact, these variables measure much of the same theoretical influences on physical maintenance-of-way activity. WEIGHT, moreover, is the theoretically superior and thus the preferred measure. Finally, as in the expenditure models, REV was evaluated in the presence of the priori variables.

Unfortunately, in the priori models no coefficient is statistically significant. Likewise, when the variables PIR and CWRAIL are added to these models, both singly and in combination, no coefficients are significant. When REV is added to the equation, however, it is significant, but only in the TIES model. As before, no other predictors are statistically significant. Thus, TIES is responsive only to changes in REV; i.e., industry tie replacement rates are directly related to the level of industry revenue per track mile. Caution must be exercised when interpreting these results because multicollinearity was apparent in the individual time series regressions. While significant coefficients for REV were all positive, considerable shifts in sign or in significance occurred for other variables in the individual equations.

The problem, of course, is that rail and tie replacement rates are only two of several physical measures of track maintenance. Miles of surfacing, cubic yards of ballast placed, and miles of ditching, are other physical measures that could be used to represent track maintenance efforts. RAIL and TIES were, however, the two variables for which data were publicly available. Given the number of activities for which track maintenance dollars can be spent, it is not surprising that the physical models included in this study were disappointing.

ACCIDENTS AND TRAIN SPEED

Accident Models

In specifying an accident model, three variables are considered essential to the model, both a priori and from the point of view of regulation and control. The variables are DUMMY, WEIGHT, and lagged variables representing the carrier's ability to undertake a commitment to maintenance of way. (The lagged variables were represented alternatively by $(\text{TMRATIO})_{t-1}$, $(\text{TMEXP})_{t-1}$, or $(\text{REV})_{t-1}$.) Besides the obligatory variables, nonobligatory predictors included in the models tested, either alone or in combinations, are ROI, $(\text{TIE})_{t-1}$, $(\text{RAIL})_{t-1}$, LENGTH, and DENSITY.

In general, the accident models did not perform well statistically. The results of estimating these models are given in Table 22. Using the total number of accidents per year (ACC) as the dependent variable, only weight is significant in explaining ACC, and then, only when $(\text{TMRATIO})_{t-1}$ is included in the equation. When $(\text{TMEXP})_{t-1}$ and $(\text{REV})_{t-1}$ are included in the model, no coefficients are statistically significant. Thus, the relationship between accidents and track maintenance expenditures appears to lie in one direction, for while $(\text{ACC})_{t-1}$ is significant in explaining both TMEXP and TMRATIO, neither $(\text{TMEXP})_{t-1}$ nor $(\text{TMRATIO})_{t-1}$ is statistically important in the prediction of ACC.

When nonobligatory variables are added to the equation, above or in combination, no coefficient of any variable is statistically significant in regression models for all railroads. Furthermore, the results of the regression equations for individual carriers showed frequent changes in the sign, significance, and size of variable coefficients as different railroads and different models for the same railroad were examined. Variable transformations and interaction terms did not make a difference. Fluctuations in coefficient attributes, moreover, were apparent among weak (low ROI) and strong (high ROI) railroads.

Two related reasons help to explain the poor performance of the accident models. First, what should be the most important explanatory variable, track condition, is not included in the model because the data gathered from public sources and the level of aggregation precluded its use. Second, the level of aggregation, which provides only average network system measurements, tends to blur the effects of independent variables in the accident models. To provide meaningful results for assessing current track safety regulations or developing new safety policies, accident models should be situation specific, that is, they

Table 22. Aggregate Random Coefficients Regression Results for Determining Total Number of Accidents (ACC) and Speed, All Railroads, 1962-1977$^{(a)}$

	INDEPENDENT VARIABLES							
Dependent Variable	Constant	Dummy	Length	Weight	TMRATIO$_{t-1}$	TMEXP$_{t-1}$	(REV)$_{t-1}$	X^2
ACC	- 2.1685 (1.2409)**	0.2609 (0.1892)		3.4601 (1.8840)**	0.1086 (0.0745)			3565.88 [120 d.f.]*
ACC	- 0.9833 (1.1895)	0.1203 (0.1285)		1.9911 (1.8279)		0.2923 (0.1807)		4134.25 [120 d.f.]*
ACC	- 0.4519 (0.6502)	0.0226 (0.3354)		0.1487 (0.6065)			0.0430 (0.0315)	4389.87 [120 d.f.]*
SPEED	23.6241 (2.0398)*	-1.2274 (0.3071)*	0.0565 (0.2897)		-0.2795 (0.1659)**			26027.40 [120 d.f.]*
SPEED	22.0754 (2.4864)*	-0.6126 (0.2794)*	0.1594 (0.3580)			-0.5076 (0.2130)*		25229.00 [120 d.f.]*
SPEED	22.9082 (2.6158)*	-0.5970 (0.2875)*	0.1209 (0.3703)				-0.0416 (0.0538)	32650.40 [120 d.f.]*

(a) Numbers in parentheses are standard errors.

* Indicates significance at the .01 level.

** Indicates significance at the .05 level.

should focus on specific line segments and include measurements of explanatory/policy variables directly related to the given segments.

Speed Models

In speed models, the variables specified as essential to the model from the a priori and the regulatory and control perspective included DUMMY, LENGTH, and track maintenance expenditure measures lagged one year. Final models were developed also by evaluating other independent variables (DENSITY, $(\mathrm{TIES})_{t-1}$, $(\mathrm{RAIL})_{t-1}$, and SIZE) in the presence of the obligatory predictors. The results of estimating final models are shown in Table 22. Although LENGTH and $(\mathrm{REV})_{t-1}$ do not have a significant influence on the prediction of SPEED, other variables do, e.g., DUMMY, $(\mathrm{TMRATIO})_{t-1}$, and $(\mathrm{TMEXP})_{t-1}$. The results for DUMMY clearly indicate that a significant reduction in average industry train speed occurred after the introduction of FRA track safety standards. The results for track maintenance expenditure measures, however, are not as clear and must be viewed with caution. The statistically significant coefficients of both $(\mathrm{TMRATIO})_{t-1}$ and $(\mathrm{TMEXP})_{t-1}$ have signs that are contrary to initial theoretical expectations. When railroads, in a given year, devote a greater share of their operating revenues per track mile to track maintenance and spend more nominal dollars per track mile, one would expect these actions to have a positive effect on average system train speeds in the following year. A possible explanation of the actual results is that the introduction of the safety standards has meant a reduction in average system train speeds, which has led, in turn, to increased track maintenance expenditures (for example, to restore service levels at least over strategic routes), but these expenditures have been insufficient to stem a significant amount of track deterioration. Furthermore, while track safety standards might have led some railroads to spend more on track maintenance in order to maintain desired train speeds, other roads not so sensitive to speed-related savings might have responded by allowing operating speeds for many nonstrategic line segments to decrease, while maintaining or increasing track maintenance programs for strategic routes.

5. SUMMARY

This section contains a discussion of the limitations and possible uses of the track maintenance models developed in this research. In the first part, the nature of the data which were used to develop the models is discussed. Particular attention is given to the limitations of the data and the effect of these limitations on the models. Next, potential uses of the track maintenance models which have been developed are discussed. Finally, a summary of the findings of the models is presented. Included in this summary is a suggestion for additional research which would be required before the effects of modifications in the track safety standards can be examined.

LIMITATIONS OF THE DATA

Application of the models of (1) track maintenance expenditures, (2) track maintenance ratio, (3) accidents, and (4) physical components of the track structure, which are used to study the impact of changes in the nature of federal safety regulations, must be examined with respect to the limitations of the models. The limitations stem from two sources: (1) the nature of the data utilized to develop the models and (2) the time frame associated with the data.

Sources

As was previously discussed, the development of the track maintenance models was limited to publicly available data. Data of sufficient detail for purposes of this study and reasonably consistent throughout the time period and between carriers were available from only two sources: the annual reports of Class I railroads to the Interstate Commerce Commission (ICC Form R-1) and the accident reports filed by the carriers with the Federal Railroad Administration (FRA), formerly filed with the ICC. Both sources of data have some degree of uncertainty associated with the quality of their data.

Annual Reports of Railroads of Class I to the Interstate Commerce Commission. Although the R-1 reports are based on a uniform system of accounts, thereby providing some degree of reporting consistency between the various railroads, reporting and recording errors were occasionally found. For example, in several cases, where separate columns were provided for debits and credits to a specific account, negative numbers were entered in the credit locations, or positive numbers in the debit location, or both. In other cases, numbers which were expected to add up differed significantly from the reported totals.

Other problems for users of time series data stem from changes in the Uniform System of Accounts. These changes are of two basic types: (1) revisions in the classification or categories for expense, revenue, asset, and liability elements and (2) changes in the methods for determining values held in balance sheet accounts. Sizable differences in the magnitude of certain variables may occur as a result of these and other changes and thus impede the comparability of data over periods of time that straddle such changes. For example, in 1963, the Interstate Commerce Commission required Class I railroads to adjust the book cost of their properties to a value determined by the Commission. This change in the value of rail assets caused a discontinuity in the time series relationships, e.g., for rate of return on net invested assets. The stated asset values of some roads were increased by the adjustment, while those of others were decreased.

The degree of aggregation of much of the R-1 data also introduces a significant limitation. The postulated effect of several of the factors, such as train speed and car weight, are based on specific values; values obtained from the R-1 reports are system average values. On large systems, with heterogenous characteristics with respect to traffic density and train speed, the system average values will differ from those on a specific line. Thus, the use of system average values will underestimate maintenance requirements on some lines and overestimate them on others. If the effects of some parameters are nonlinear, the overestimates and underestimates will not balance.

Accident Data. The accident data utilized in the study were taken from the accident reports that railroads filed with the Interstate Commerce Commission and, later, the Federal Railroad Administration. Reports prior to 1965 contain only information on the total number of accidents by cause. After 1965, however, copies of the individual accident reports were available.

As with the R-1 reports, recording errors, reporting errors, and changes in the reporting criteria affect the quality of the accident data. Since the reporting threshold is based on the dollar value of the damages, both the number of accidents reported and the value of the damage reported are subject to inflationary effects. Moreover, the reported cost of the accident reflects only damage to equipment and facilities. Other costs, which management should consider in assessing the trade-offs between maintenance levels and accidents (such as train delays and lost traffic), are not included.

The accident cause, as listed in the report, may also lead to some bias in the analysis. During the interview phase of the study, several officials were asked to comment on their perception of the reliability of the reported causes. Responses ranged from "often questionable" to "highly accurate." The degree of confidence varied with the procedure that was established to determine cause when no clear-cut evidence was available. It was suggested during interviews, for example, that often the cause is determined by the highest ranking official on the scene, who is likely to favor his own department if the cause is not obvious. On railroads where great confidence was expressed in the accuracy of the reported cause, interdepartmental committees were often established to determine the cause of an accident in unclear cases. Given the lack of confidence in the reported cause, the damage due to track-related accidents as reported may not accurately indicate actual track-related damage.

Variables Selected

In reviewing the limitations of the model that has been developed, it is helpful to review the model development phase and the selection of variables that were used in the statistical analysis.

The variables which were used in the development of statistical analysis are presented in Table 11. By comparing these variables to those postulated in the structural model of the track maintenance function (Figure 9), the proxy nature of many of these variables is evident.

The primary transformation between the postulated independent variables and the variables which were derived from publicly available data is the system wide vis-à-vis line-specific nature of the variables. Car weight is a good example of how system average values may diminish the explanatory value of a parameter. A recent study indicated that rail wear with 125-ton cars is 5 times that experienced with 100-ton cars [17]. Thus rail wear is a function of the weight of individual cars in addition to the total tonnage moving over the line. Average car weight does not reflect sufficiently the actual spectrum of car weights operating on an individual line.

In several other cases, variables which were postulated in the structural model were either not quantifiable or not available in the data base. Where possible, proxy variables were used to approximate the effect of the theoretical variable. Track condition is a good example of this type of approximation. Track condition is difficult to quantify, and what values do exist are not included in publicly available sources. The model utilizes the change in system average train speed to capture the trends in track condition, i.e., as track condition deteriorates, the imposition of additional slow orders reduces average train speed. Average train speed may, however, be affected by other factors such as longer trains, or attempts to reduce fuel consumption. Furthermore, for one railroad, average train speed was reduced during periods of increased maintenance spending, apparently due to train delays occasioned by the maintenance operations.

Limitations Imposed by the Time Frame

The results of an analysis of time series data may also be affected by the duration of the time series selected. The fairly long in-service lives of track components such as rail and ties require that time frames be selected which are sufficiently long to capture the life cycles of these components. However, time series which are of sufficient duration to encompass component life cycles may also include other factors which affect the maintenance function. Recent events which have affected the allocation of maintenance resources include changes in car size and weight, development of improved maintenance techniques, and changes in managerial philospy.

The time frames which have been utilized in the analysis represent a compromise among the requirements of track component life. These time frames minimize external influences and consider the availability of sufficient data. However, changes in managerial commitment to the preservation of the railroad infrastructure have affected the results of several of the regression models. Other changes, such as the increasing use of long high cars, unit trains and six axle locomotives, as well as improved rail metallurgy and increased mechanization of maintenance operations, are embodied in these time series.

USE OF THE MODEL

Nonetheless, the Track Maintenance Models developed in this study are useful in analyzing the behavior and sensitivity of the industry as a whole, as well as the railroad groups, to changes in the various network, operation, or resource factors. The significance of the key explanatory variables specified in the model provides insight into the relative importance of each factor to the track maintenance budgeting process. The equations permit quantitative estimates of track maintenance expenditures both in terms of nominal dollars and as a proportion of revenues. Changes in the magnitude of parameters such as car weight and accidents can thus be examined in light of their impact on track maintenance expenditures.

The focus of these models has been primarily on the track maintenance allocations process, which is only part of the overall relationship between track maintenance expenditures, track conditions, track-related accidents, and FRA safety standards. The use of publicly available data precluded the development of an objective measure of track quality, without which it is impossible to say anything about how FRA safety standards might be strengthened, altered or improved, or to explain the impact of any revisions on the resources allocated to track maintenance.

FINDINGS

In spite of the limitations imposed by the use of publicly available data, this research has produced several interesting insights into the effects of the federal track safety standards. The standards were intended to reduce track-related accidents by imposing speed restrictions in accordance with track conditions. If the reduced speeds were imposed on high-density lines, the increased operating costs associated with decreased car and locomotive utilization would provide the economic justification to increase maintenance expenditures. If, on the other hand, the increased operating costs were not sufficient to stimulate increased maintenance activity, the lower train speeds would enhance safety.

Maintenance Expenditures

The results suggest that the imposition of the standards has had the predicted impacts on both maintenance spending and on train speeds. In the years since the standards were imposed, there has been a statistically significant increase in the proportion of railway revenues which have been devoted to track maintenance. As might be expected, those railroads which operate trains at higher speeds appear to be more sensitive to the introduction of the safety standards than those which operate with lower system speeds. In contrast, the group of carriers which have very low system speeds were not affected by the standards, possibly because the speeds at which they operate were already lower than those which might be imposed by the federal standards. Profitable railroads were also found to be more sensitive to the standards, perhaps because they possess the resources to undertake rehabilitation efforts.

Train Speeds

It appears that average train speeds have also been influenced by the imposition of the standards. The models indicate that the standards have had a statistically significant negative influence on the prediction of average train speeds. However, this result must be considered in light of other influences, such as fuel conservation efforts, which may also have had negative influences on operating speeds.

Accidents

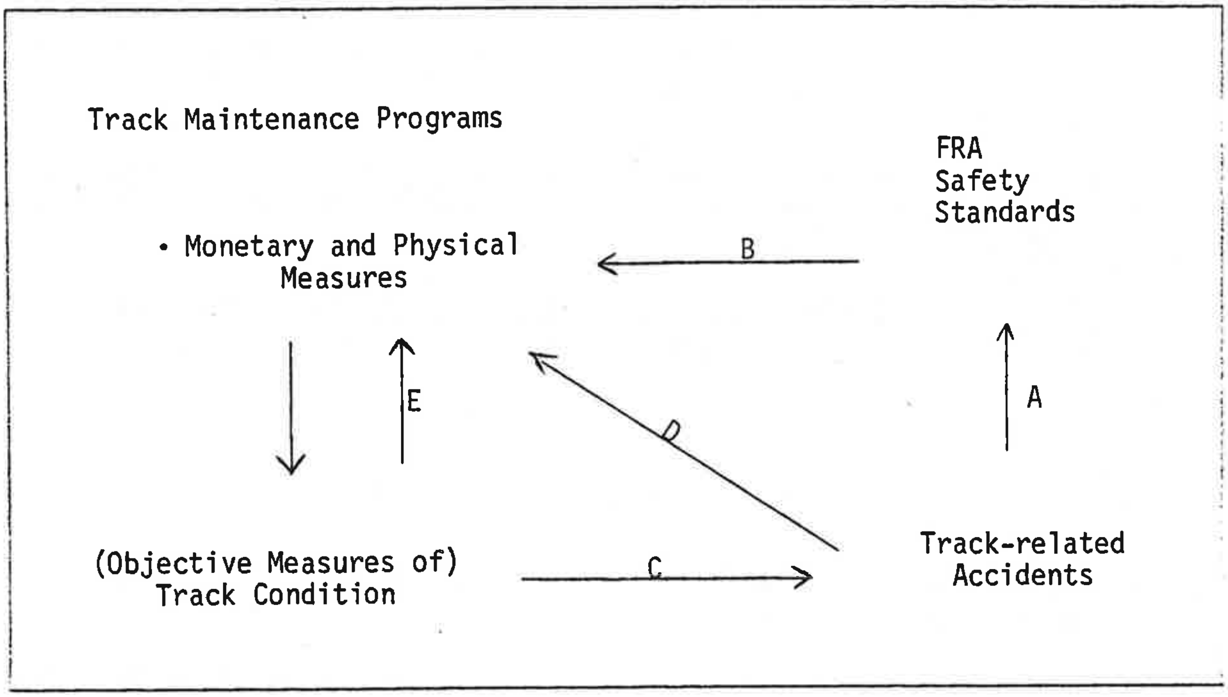
The major area in which the standards have not had the intended effect is in the reduction of the number of track-related accidents. In spite of the imposition of the standards, the accident rate has not decreased; rather, it has increased. It is possible, of course, that the imposition of the standards prevented a much larger increase in the accident rate, but it is not possible to investigate this hypothesis.

The industry, however, is sensitive to accident rates in the maintenance budgeting process. Carriers which are profitable operate at higher average speeds; carriers which represent high density lines are more sensitive to the accident rate than are slow, unprofitable, or low density carriers.

ADDITIONAL RESEARCH

While these findings have illuminated some of the effects of the FRA safety standards, they do not say anything about how the standards might be altered or improved to increase their effectiveness. This cannot be accomplished without an objective measure of track condition which has been statistically related either to the occurrence of track-related accidents or to the level of maintenance expenditures. Figure 10 illustrates the relationship between maintenance activities, track condition, accident rates, and safety standards. The research detailed in this report investigated the relationships labeled "A" and "B."

The next logical phase of research is noted as "C" and "D" in Figure 10. The collection of specific, disaggregate track condition data on specific railroad line segments, as well as the corresponding accident data, will permit a statistical analysis of the relationship between the two data sets. Alternative means of representing track condition should be explored, including the possible formulation of a weighted Track Quality and Use Index. The development of such an index would provide a meaningful basis on which to predict accident probability. Moreover, the index can provide the means to assess what maintenance expenditures would provide the greatest reductions in accident probability.



Note: A-B = research performed using aggregate data

C-E = proposed research using disaggregate, line-specific data

Figure 10. Relationships Among Maintenance, Track Condition, and Safety

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APPENDIX A

DATA BASE DOCUMENTATION

Maintenance of Way Expenditure - Master File

FIELD NO.	COLUMNS	FORMAT	DESCRIPTION	SOURCE
1	1-4	A4	Four letter railroad abbreviation code	
2	5-6	I2	Year	
3	7-18	I12	Gross operating revenues (deflated 1967)*	Line 1, Schedule 300-R-1 report
4	19-30	I12	Total of all expense accounts relating to maintenance of track and structure (deflated 1967).	Lines 1-28, Line 49, Schedule 320, R-1 report
5	31-42	I12	Net change in capital accounts. Related to Track and Structure (deflated 1967)	Lines 9-13 (1962, 1963), lines 8-12 (1964-1977), column i, Schedule 211, R-1 report
6	43-44	I2	Dummy variable reflecting the existence of Amtrak passenger operations (1 = yes, 0 = no)	Quantitative judgement
7	45-50	F6.3	Return on investment (old ICC methodology)	Line 22, Schedule 300, divided by sum of lines 1, 13, and 41, Schedule 200, R-1 report
8	51-55	F5.1	Estimate of Average train speed calculated by dividing total train miles by total train hours	Line 6, col. a + b divided by line 30, col. a + b, Schedule 531, R-1 report
9	56-61	I6	Total system track miles	Dyer tape, Rl, field #6
10	62-68	I7	Gross ton miles	Dyer tape, Rl, field #11

*All deflated monetary variables adjusted by the AAR regional price index

Maintenance of Way Expenditure - Master File (cont.)

FIELD NO.	COLUMNS	FORMAT	DESCRIPTION	SOURCE
11	69-77	I9	Total cross ties in place	Dyer tape, R1, field #8
12	78-86	I9	Total cross ties installed	Dyer tape, R2, fields 2, 5, 8, 11
13	87-94	I8	Total track miles of rail installed	Dyer tape, R3, derived by following formula. Quantity (tons) ÷ weight class = $\frac{\text{yard tons}}{\text{Lb}}$; $\times \frac{\text{2000 Lb}}{\text{ton}} \times \frac{\text{3 ft}}{\text{1 yard}}$ $\times \frac{\text{1 mile}}{\text{5280 ft}} \div \frac{\text{2 Rails}}{\text{Track}}$ = Track miles of Rail
14	95-104	F10.2	CWR rail installed	First difference of field #17 this report ***
15	105-116	I12	Total train miles	Line 6, Schedule 531, R-1 report
16	117-128	I12	Total car miles	Line 26, Schedule 531, R-1 report
17	129-138	F10.2	CWR rail in place	Dyer tape, R3, field #8
18	139-143	F5.1	Estimate of average train length car miles/train miles	Fields 15 and 16 this report
19	144-151	I8	Estimate of average train weight gross ton miles/train miles	Fields 10 and 15 this report
20	152-155	I4	# of accidents in speed Category 1	Safety Tapes**
21	156-165	I10	Total damage in Cat. 1 (deflated 1967)	" "

**See Appendix I for explanation of the Accident Variables.

***Where differences were found between the miles of CWR installed as reported on line 29 Schedule 515 of the R-1 and the first difference of field #17 the miles of CWR laid as reported is contained in this field.

Maintenance of Way Expenditure - Master File (cont.)

FIELD NO.	COLUMNS	FORMAT	DESCRIPTION	SOURCE
22	166-168	I3	Total # of hazardous material accidents in Cat. 1	Safety Tapes**
23	169-172	I4	# of accidents in Speed Cat. 2	" "
24	173-182	I10	Total damage in Cat. 2 (deflated 1967)	" "
25	183-185	I3	Total # of hazarodous accidents Cat. 2	" "
26	186-189	I4	# of accidents in speed Cat. 3	" "
27	190-199	I10	Total damage in Cat. 3 (deflated 1967)	" "
28	200-202	I3	Total # of hazardous accidents Cat. 3	" "
29	203-206	I4	# of accidents in speed Cat. 4	" "
30	207-216	I10	Total damage in Cat. 4 (deflated 1967)	" "
31	217-219	I3	Total # of hazardous accidents Cat. 4	" "
32	220-224	I5	Total accidents	" "
33	225-230	F6.3	Proportion of track miles in CWR	Fields 9 and 17 this report
34	231-236	F6.3	Ratio of $\frac{\text{(Capital Exp. + Maint. Exp.)}}{\text{Revenue}}$	Fields 3, 4, and 5 this report
35	237-245	F9.6	Ratio of $\frac{\text{Gross Ton Mile}}{\text{Gross Track Miles}}$	Fields 9 and 10 this report

Maintenance of Way Expenditure - Master File (cont.)

FIELD NO.	COLUMNS	FORMAT	DESCRIPTION	SOURCE
36	246-257	I12	Revenue in nominal dollars	Line 1, Schedule 300, R-1 report
37	258-269	I12	Maintenance Exp. in nominal dollars	See field no. 4
38	270-281	I12	Capital Exp. in nominal dollars	See field no. 5
39	282-291	I10	Nominal dollars Field #21 this report	
40	292-301	I10	" " " #24 "	
41	302-311	I10	" " " #27 "	
42	312-321	I10	" " " #30 "	
43	322-331	I10	Median value of accident damage on "main" track. Nominal dollars	Safety Tapes**
44	332-341	I10	Median value of accident damage on "main" Deflated dollars	" "
45	342-351	I10	Median value of accident damage on "branch" track. Nominal dollars	" "
46	352-361	I10	Median value of accident damage on "branch" Deflated dollars	" "
47	362-371	I10	Total accidents on "main" track	" "
48	372-381	I10	Total accidents on "branch"track	" "
49	382-391	F10.6	Accident index 1. (field # 43 * field #47)/field #10.	This report

Maintenance of Way Expenditure - Master File (cont.)

FIELD NO.	COLUMNS	FORMAT	DESCRIPTION	SOURCE
50	392-401	F10.6	Accident index 2. (field #44 * field # 47)/field #10	This report
51	402-411	F10.6	Accident index 3. (field #45 * field # 48)/field #10	This report
52	412-421	F10.6	Accident index 4. (field #46 * field #48)/field #10	This report
53	422-431	F10.3	Divident payout ratio	Line 11, Schedule 305, divided by Line 55, Schedule 300 R1-report.
54	432-438	F7.1	Price index w/o fuel	AAR price index
55	439-445	F7.1	Price index w fuel	" " "
56	446-451	F6.3	Ratio of main line/total track mile 1976	"Consad" Tape

Safety Tape Variables

The Safety variables Fields 20-32 were derived in the following manner: total damage (TOT-DMG - old files; sum of EQUIPDAMAGE and TRACKDAMAGE on new file) was read off of each individual report which met the following criteria:

1. It was an original report.
2. The cause code (CAUSE on old files CAUSE 1 on new files) was related to track failure.
3. The damage of the incident was above the threshold. (The threshold was calculated using deflated values of the FRA's threshold).

The incident was classified according to speed (TRN - SPD on old file, SPEED on new file) and whether or not hazardous materials were involved (EXPZP on old, HAZMAT on new). Within each speed category (0 - 20 MPH = 1; 20 - 40 MPH = 2; 40 - 60 MPH = 3; over 60 MPH = 4) the total damage value, the number of accidents, and the number of accidents involving hazardous materials were calculated.

The index variables fields 43 - 46, were calculated using the same total damage and criteria above. However, each incident was classified according to the type of track on which the incident occurred (DEFECT on olds files, TYPTRACK on new files). The median values of accidents for the categories "Main" (codes 1, 6, 7) or "Branch" (codes 2, 3, 8) were calculated. The index was calculated by (median value * number of accidents in that category ÷ Gross Ton Miles.

APPENDIX B
REPORT OF NEW TECHNOLOGY

This report contains a statistical analysis of historical railroad maintenance-of-way spending. As such no new technologies have been explored in this study.

55 copies

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