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TRACK AND BRIDGE MAINTENANCE RESEARCH REQUIREMENTS

MARCH 1980
FINAL REPORT

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
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16. Abstract

This report includes the design of seven research plans in the area of track and bridge maintenance. The railroad industry was surveyed to ascertain the maintenance problems of their greatest concern which lend themselves to resolution by research. The problems uncovered in the survey were ranked based upon the opinion of the industry and the following seven of the top ranked problem categories were selected for the development of research plans:

I Bridge Inspection, Rating and Evaluation of Remaining Life
II Subgrade Stabilization and Improvement
III Timber Cross Tie Rehabilitation and Disposal
IV Special Trackwork Maintenance
V Bolted Joints
VI Ballast Fouling From External Sources
VII Switch Point Wear Limits

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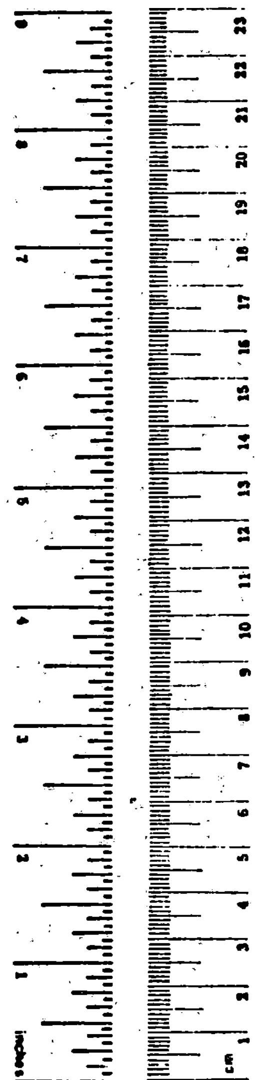
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

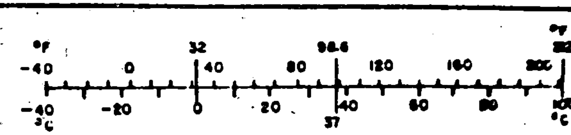
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
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)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*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

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
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			
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)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
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)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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INTRODUCTION

BACKGROUND

The Track Research Program, sponsored by the Federal Railroad Administration and administered by the Office of Rail Safety Research, subordinate to the Office of Research and Development, is divided into two parts. These two divisions are referred to as the Track Accident Reduction Research program and the Improved Track Performance Research program. The objectives of these two programs are to reduce the frequency of track-caused train derailments and to develop service-oriented track system performance criteria, specifications and maintenance approaches that will be maximally cost beneficial. The effort of this project will contribute to the latter of these objectives.

The national railroad network has existed for many years and witnessed substantial evolution of train operating capabilities along with constantly increasing track, bridge and tunnel load-acceptance requirements. Following the Second World War, track maintenance procedures, which had been largely manual up to that time, entered an era of automation. In the United States, the thrust of these developments was toward mechanized replacement of the manual track maintenance operation.

With the recent advent of large Federal investment in the upgrading of the national network, consideration of the manner in which these funds will be applied becomes important. It is not certain, for example, that reliance on track maintenance techniques conceptually determined in the United States in the 1950's is the most effective methodology. It is equally uncertain as to which of the major track, bridge and tunnel maintenance problems are susceptible to improvement by research, federally sponsored or otherwise. At the same time, there are few sources maintaining that there is no room for further improvement within the matrix of contemporary domestic practice.

OBJECTIVE

The effort of this project is to determine the nature of track, bridge and tunnel maintenance problems that lend themselves to resolution through research and their rank-ordered importance in terms of near and long-term payoff, should the solution be applied.

The end product of this project is to develop research plans for discrete problems identified from the survey of the railroad industry and rank-ordered by importance.

TECHNICAL REVIEW PANEL

A Technical Review Panel was appointed to review the work of the Consultant and advise the Federal Railroad Administration. The panel consisted of:

- R. M. Brown, Chief Engineer, Union Pacific R.R.
- W. W. Simpson, Vice President-Engineering, with C. E. Webb, Assistant Vice President, Engineering & Research, as alternate, Southern Ry. Company
- G. H. Way, Jr., Assistant Vice President, Association of American Railroads
- C. E. Godfrey, Manager of Trackwork Products, Abex Corporation
- W. R. Hamilton, Director, Research and Development, Portec, Inc., Railway Products Division
- R. E. Kleist, Assistance Evaluation Division, Federal Railroad Administration
- J. A. Richard, Manager, Components and Facilities Program, Federal Railroad Administration
- Philip Olekszyk, Chief, Analysis and Evaluation Division, Federal Railroad Administration
- R. A. Smith, Transportation Systems Center

The panel was convened several times during the course of the work on this project to hear presentations by the Consultant and offer comments.

TECHNICAL APPROACH

GENERAL

The methodology employed in this project consisted of the following tasks:

- o Information Gathering
- o Ranking
- o Literature Search
- o Design of Research Plans

INFORMATION GATHERING

Objective

The output of this task was the identification of maintenance problems emerging from personal discussions with the participating organizations and their ranking of these problems in the order they believed to be of most concern.

Participating Organizations

A list of the participating organizations appears in Table 1 which includes 23 Class 1 railroads, 3 trade magazines, 5 material suppliers and 4 equipment manufacturers.

In nearly all cases the Consultant talked with the chief engineer of the participating railroad. He met with the editors of the magazines and people from the material and equipment industries who were knowledgeable in the railroad field. In all cases the Consultant was made to feel welcome and the participating organizations expressed great interest in the project and hoped that useful research would come out of it.

Methodology

The Information Gathering task started with introductory letters written by the Federal Railroad Administration. The letters to the railroads were sent under a covering letter by the Association of American Railroads and those to the suppliers and manufacturers by the Railway Progress Institute. The Federal Railroad Administration wrote directly to the magazines.

TABLE 1: PARTICIPATING ORGANIZATIONS

Railroads

The Atchison, Topeka & Santa Fe Ry. Company
Boston & Maine Corp.
Burlington Northern
Chessie System
Chicago and North Western Transportation Co.
Chicago, Milwaukee, St. Paul & Pacific R.R. Co.
Chicago, Rock Island & Pacific R.R. Co.
Consolidated Rail Corporation
Delaware & Hudson Ry. Co.
The Denver & Rio Grande Western R.R. Co.
Florida East Coast Ry. Co.
Grand Trunk Western R.R. Co.
The Kansas City Southern Ry. Co.
Louisville & Nashville R.R. Co.
Missouri Pacific R.R. Co.
Norfolk & Western Ry. Co.
St. Louis - San Francisco Ry. Co.
Seaboard Coast Line R.R. Co.
Soo Line R.R. Co.
Southern Pacific Transportation Co.
Southern Ry. Company
Union Pacific R.R.
Western Pacific R.R. Co.

Magazines

Railway Track and Structures
Progressive Railroading
Modern Railroads

Material Suppliers

Abex Corporation, Railroad Products Group
American Iron and Steel Institute, Technical Committee on Railroad Materials
Koppers Company, Inc.
Portec, Inc., Railway Products Division
Weir Kilby Division, L. B. Foster Co.

Equipment Manufacturers

Canron RailGroup
Portec, Inc., RMC Division
Racine Railroad Products, Inc.
Speno Rail Services, Inc.

A list of typical problems was attached to the FRA letter sent to each participating organization in order to assist them in focusing their thoughts prior to the meeting with the Consultant. The major areas of these problems were:

I. TRACK

1. Rail
2. Special Trackwork
3. Joint Bars
4. Fasteners - Timber Tie
5. Fasteners - Concrete Tie
6. Anchors
7. Ties - Timber
8. Ties - Concrete
9. Ballast
10. Subgrade
11. Track System

II. BRIDGE

12. Bridge Structure Maintenance

III. TUNNEL

13. Tunnel Maintenance

A complete list of the problems, including those uncovered in the interviews, appears in Appendix A.

Telephone calls were made by the Consultant to all participating organizations to set up appointments for the meetings and, in this conversation, the project was further described.

The Consultant's discussion teams, for the most part, consisted of two persons with a total of ten different persons involved. The number of persons was kept to a minimum to provide consistency in the discussions with the participating organizations. There was interchange in the team members in order that experience from a greater variety of discussions could be brought to the subsequent interviews.

The information gathered varied somewhat in format because the discussion was not formally structured nor was a formal questionnaire used. The Consultant's team attempted to have the participating organization talk freely about his problems without prompting or asking leading questions. Frequently the Typical Problem Profile was used as an agenda. Some of the organizations ranked the problems in order of their concern but when they did not the team members did so by considering the length of time devoted to the subject, when the subject was brought up in the meeting and by using judgment. Most of the ranking was within the individual categories and not many organizations could make an overall ranking in the short time devoted to the meeting, consequently again the team members had to use judgment to accomplish this.

The length of the visits varied from 45 minutes to 8 hours with an average length of time of about three hours. The participating organizations realized that the Consultant was prepared to leave after 45 minutes, so the longer meeting time was an indication of their interest.

RANKING

Objective

The output of this task was the final ranking of potential research projects from which selections could be made for the design of research plans.

Methodology

A similar survey of track rehabilitation problems was conducted by the Mitre Corporation and started prior to this project, however, the work on the two projects overlapped in time. The two surveys addressed different segments of the railroad community. Both surveys showed a number of similar problems which ranked high in the concern of the railroad industry.

The results of the survey conducted by Mitre and those of the survey from this project were correlated.

Appendix A lists 95 track problems, 18 bridge problems and 9 tunnel problems. Mitre's survey uncovered 66 track problems.

The 122 problems shown in Appendix A were ranked according to industry opinion as determined by the survey for this project. The resulting ranking of the top 49 problems is shown in Appendix B, Table B-1.

Similar track problems of this survey and Mitre's survey were combined and the bridge and tunnel problems were added to produce a compiled list as shown in Appendix B, Table B-2. The "scores" shown are measures of industry opinion and are normalized, i.e., the raw scores for this project were multiplied by a factor so that the total of the scores for this survey and the total for the Mitre survey are the same. The problems were then grouped by combining similar items that could be addressed by a specific research plan and new scores were assigned resulting in a new rank ordering based upon industry opinion as determined by the survey conducted by this project's Consultant. This ranking is shown in Appendix B, Table B-3.

Since Mitre's work preceded that of this project, they had already developed research plans that addressed many of the problems uncovered in this survey, as shown in Appendix B, Table B-4. These duplicate problems were eliminated and a new list was formed and then ranked based upon the opinion of the organizations surveyed by the Consultant for this project. This list of the 31 top-ranking problems, shown in Appendix B, Table B-5 was presented to the Technical Review Panel from which each panel member was asked to select nine that he considered most important. The selection by the panel is shown in Appendix B, Table B-6.

The Federal Railroad Administration, after taking under advisement the guidance of the panel members, selected the following research plans for development:

I. Bridge Inspection, Rating and Evaluation of Remaining Life

II. Subgrade Stabilization and Improvement

III. Timber Cross Tie Rehabilitation and Disposal

IV. Special Trackwork Maintenance

V. Bolted Joints

VI. Ballast Fouling from External Sources

VII. Switch Point Wear Limits

LITERATURE SEARCH

Objective

The objective of the literature search was to ascertain past and on-going research relevant to track, bridge and tunnel maintenance in order to avoid recommending duplicate efforts when developing the research plans and to provide a bibliography for appending to the research plans.

Methodology

The principal source used for searching literature was the Railroad Research Information Service which provides abstracts of titles of articles and research reports.

An initial compilation of information was started as soon as the survey interviews identified the more important maintenance problems.

After the selection of the problem categories for which research plans were to be developed a more narrowly focused search was made on the broad subjects of railroad bridges, ballast and subgrade, timber ties, special trackwork and bolted joints. The abstracts, and in some cases, the complete articles, were used in the preparation of the research plans.

DESIGN OF RESEARCH PLANS

Objective

The objective of this task was to design research plans for the seven selected problem categories, which would then enable the Federal Railroad Administration to plan research programs and the funding thereof, and to provide an outline of the research plans.

Methodology

Each research plan addressed the following items:

A. Objective
B. Background
C. Appropriate Technical Effort
D. Period of Performance
E. Technical Effort
F. Nature of End Product
G. Analysis of Savings and Benefits
H. Strategy for Implementation
I. Involving Concerned Elements of Client Sectors

The analysis of savings and benefits contemplated starting to accrue the savings and benefits at the end of the research program as directed by the Federal Railroad Administration. For some research plans full savings can be realized the first year, while for other plans, wherein substantial capital improvements are phased in over a number of years, full benefits will not be realized until such improvements are made throughout the system. Present values were based on 10% rate of interest.

Following the Appendix of this report are the research plans.

The Consultant for this project met with representatives of the Federal Railroad Administration and the Mitre Corporation, because of their experience in this area, and assigned "other impact" and risk factors to the seven research plans.

TYPICAL PROBLEM PROFILE

I - TRACK

1. RAIL

   A. Flaw Detection
   B. Excessive Wear Under Heavy Load
   C. Premature Failure
   D. Bolt Hole Failure
   E. Longitudinal Rail Stress Measurement
   F. Field Welds
   G. Improve Rail Metallurgy
   H. Longer Lengths of Rolled Rail
   I. Rail Lubrication
   J. Heat Treating Rail in Track
   K. Rail Corrugation
   L. Optimum Size/Weight for Heavy Loads
   M. Wear on Curves
   N. Cropping and Welding Rail in Track
   * O. FRA Standards

2. SPECIAL TRACKWORK

   A. Excessive Switch Point Wear
   B. Acceptable Limits of Switch Point Wear and Condition are Unknown
   C. Field Repair Methods
   D. Frog Failures
   * E. Standardization of Parts
   F. Welding all Joints in Turnout
   G. Snow and Ice in Switch Points
   * H. Test of Field Welds

3. JOINT BARS

   A. Excessive Breakage (Standard Bar)
   B. Insulation Deterioration (Insulated)
   * C. Excessive Wear (Both Types)
   D. Bolt Tension

4. FASTENERS - TIMBER TIE

   A. Inability to Hold Gage on Curves
   B. Premature Loss of Holding Power
   C. Inability to Prevent Rail Rollover on Curves
   D. Effects of Various Plate Cants
   E. Resistance to Lateral Displacement
   F. Rail Fastener other than Spike
   G. Information on Pandrol Clip
   H. Pre-Plating of Ties
   I. Improved Rail/Tie-Plate Fasteners

5. FASTENERS - CONCRETE TIE

* A. Premature Pullout or Failure
* B. Insufficient Pad Durability
  C. Optimal Damping
  D. Rail Restraint Problems

6. ANCHORS

  A. Insufficient Holding Power
  B. Optimal Installation Patterns
  C. Anchoring Requirements on Open-Deck Bridges
  D. Damage from Derailments
  E. Required Holding-Power Unknown
* F. Reclamation Process

7. TIES - TIMBER

  A. Disposal Costs/Methods
  B. Premature Splitting
  C. Excessive Mechanical Wear
  D. Future Availability/Cost
  E. Installation Problems
  F. Optimum Tie Size, Length and Spacing
* G. Repair of Ties in Track
  H. Information on Cedrite Ties
  I. Quality of Wood
  J. Treatment and Conditioning of Ties

8. TIES - CONCRETE

* A. Premature Cracking-Rail Seat
* B. Premature Cracking-Center
  C. Excessive Handling Cost
* D. Installation Problems
  E. Spacing
  F. Spot Replacement

9. BALLAST

  A. Excessive Pumping
  B. Excessive Fouling
  C. Insufficient Knowledge of Compaction
  D. Layer Thickness
  E. Gradation
* F. Shoulder Width
  G. Revise/Improve AREA Ballast Specification
  H. Quantification of Ballast Performance
  I. Comprehensive Study of Ballast

10. SUBGRADE

A. Excessive Pumping
B. Premature Slipout, Slides
C. Soil Stabilization Techniques
D. Subgrade Evaluation Technique
E. Drainage
F. Comprehensive Study of Subgrade

11. TRACK SYSTEM

A. Track Strength Assessment
B. Track Buckling
C. Track Quality Measuring System
D. Implementation of FAST Test Results
E. Determination of Track Segment Condition to Accept Changes in Train Service
F. Standards for Maintenance Technique/Work Equipment Performance Evaluation
G. Grade Crossing
* H. Vegetation Control
I. Track Availability
J. Track Modulus Determination
K. Standardization of Parts
L. Fouling Ballast by Blowing Sand and Dirt
M. Reduce Number of M/W Machines
N. Need Better Track M/W Equipment
O. Need Standardized Roadway Equipment
P. Need Better Sand Fences
Q. Out-of-Face or Spot Renewal M/W Method
R. Improve/Speed-up FAST Output

II - BRIDGE

12. BRIDGE STRUCTURE MAINTENANCE

A. Technique for Evaluating Remaining Life
B. Adequacy of Current Rating Procedures
C. Repair/Maintenance Technique Problems
D. Deficiencies in Contemporary Inspection Methods/Tools
E. Loose Loads
F. Deck Waterproofing
G. Fatigue Crack Detection in Steel
H. Eye-Bar Wear
I. Expansion Bearings
J. Expansion Joints
K. Concrete Spalling
L. Information on PSC Spans
M. Better Bridge Pier Protection
N. Fireproofing Decks

12. BRIDGE STRUCTURE MAINTENANCE (Cont'd.)

O. Protection of Concrete Surfacing
P. Effective Preservation of Existing Wood Decks
Q. Behavior of CWR
R. Protective Coating of Steel

III - TUNNEL

13. TUNNEL MAINTENANCE

A. Inspection Method/Tool Problems
* B. Work Environment Hazards
C. Techniques for Undertaking Specific Repairs
* D. Application of Research/Procedures Developed by U.S. Bureau of Mines
E. Drainage
F. Spalling of Rock or Concrete Lining
* G. Ventilation
H. Track Maintenance
I. Fire Retardant for Timber Tunnels

*Typical problem that did not receive sufficient emphasis during the interviews to warrant scoring.

TABLE B-1: RANKING OF PROBLEMS BASED ON INDUSTRY OPINION

Rank		Category		Problem
1	1.	Rail	G.	Improve rail metallurgy
2	12.	Bridge Structure Maintenance	A.	Technique for evaluating remaining life
3	10.	Subgrade	C.	Soil stabilization techniques
4	7.	Ties-Timber	A.	Disposal costs/methods
5	1.	Rail	E.	Longitudinal rail stress measurement
6	1.	Rail	B.	Excessive wear under heavy load
7	11.	Track System	C.	Track quality measuring system
8	4.	Fasteners-Timber Tie	A.	Inability to hold gage on curves
9	1.	Rail	A.	Flaw detection
10	10.	Subgrade	E.	Drainage
11	11.	Track System	B.	Track buckling
12	12.	Bridge Structure Maintenance	C.	Repair/maintenance technique problems
13	12.	Bridge Structure Maintenance	F.	Deck waterproofing
14	1.	Rail	L.	Rail corrugation
15	2.	Special Trackwork	A.	Excessive switch point wear
16	4.	Fasteners-Timber Tie	E.	Resistance to lateral displacement
17	12.	Bridge Structure Maintenance	G.	Fatigue crack detection in steel
18	4.	Fasteners-Timber Tie	C.	Inability to prevent rail rollover on curves
19	9.	Ballast	C.	Insufficient knowledge of compaction
20	3.	Joint Bars	B.	Insulation deterioration (insulated)
21	13.	Tunnel Maintenance	E.	Drainage
22	2.	Special Trackwork	D.	Frog failures
23	10.	Subgrade	A.	Excessive pumping
24	9.	Ballast	D.	Layer thickness
25	7.	Ties-Timber	C.	Excessive mechanical wear
26	9.	Ballast	B.	Excessive fouling
27	2.	Special Trackwork	B.	Acceptable limits of switch point wear and condition are unknown
28	7.	Ties-Timber	D.	Future availability/cost
29	11.	Track System	M.	Fouling ballast by blowing sand and dirt
30	12.	Bridge Structure Maintenance	B.	Adequacy of current rating procedures

Rank	Category		Problem	
31	11.	Track System	F.	Standards for maintenance technique/work equipment performance evaluation
32	1.	Rail	F.	Field Welds
33	1.	Rail	N.	Wear on curves
34	10.	Subgrade	D.	Subgrade evaluation technique
35	11.	Track System	I.	Track availability
36	11.	Track System	K.	Track modulus determination
37	9.	Ballast	A.	Excessive pumping
38	1.	Rail	O.	Cropping and welding rail in track
39	4.	Fasteners-Timber Tie	D.	Effects of various plate cants
40	5.	Fasteners-Concrete Tie	D.	Rail restraint problems
41	6.	Anchors	B.	Optimal installation patterns
42	11.	Track System	E.	Determination of track segment condition to accept changes in train service
43	1.	Rail	H.	Longer lengths of rolled rail
44	1.	Rail	C.	Premature failure
45	11.	Track System	A.	Track strength assessment
46	4.	Fasteners-Timber Tie	B.	Premature loss of holding power
47	9.	Ballast	E.	Gradation
48	9.	Ballast	I.	Quantification of ballast performance
49	11.	Track System	L.	Standardization of parts

TABLE B-2: RANKING OF PROBLEMS BASED ON INDUSTRY OPINION AFTER COMBINING PBQ&D'S PROBLEMS WITH MITRE'S

RANK PBQ&D	RANK MITRE	PROBLEM	SCORE PBQ&D	SCORE MITRE
1	7	Inadequate performance of spikes/plates as fasteners	366.9	151.5
2	2	Excessive rail wear	290.4	200.7
3		Inadequate technique for evaluating remaining bridge life	244.6	0
4	3	Insufficient cost/performance information on ballast	221.7	197.5
5	21	Inadequate wood tie renewal/disposal methods	214.0	69.8
6	13	Excessive rail plastic flow defects	191.1	97.3
7	23	Inability to determine rail stresses in the field	168.2	62.0
8	12	Unknown cost/performance of subgrade improvement methods	168.2	108.8
9	15	Inadequate methods for subgrade improvement	168.2	83.9
10	9	Premature rail failure	142.9	146.3
11		Inadequate track geometry measuring methods	137.6	0
12	25	Inadequate field rail flaw detection	129.9	60.5
13	1	Inadequate track structure cost/performance data	107.0	1039.0
14	4	Excessive longitudinal rail stress	99.4	189.4
15	17	Excessive ballast/subgrade interactions (pumping)	99.4	81.0
16		Inadequate bridge repair/maintenance techniques	91.7	0
17		Inadequate method of waterproofing bridge decks	91.7	0
18	11	Inadequate field welding techniques	84.1	118.3
19	32	Excessive switch wear	84.1	39.1
20	6	Inadequate maintenance of way methods	84.1	161.1
21	19	Excessive wood tie degradation	84.1	77.8
22	24	Unknown anchor effectiveness/performance	76.4	60.9
23		Inadequate method of detecting fatigue cracks in steel bridges	76.4	0
24	62	Inadequate bolted insulated joint performance	68.8	7.1
25		Inadequate methods of tunnel drainage	68.8	0

Note: Where a score of 0 is shown, the survey by that Consultant did not uncover that problem.

RANK			SCORE	
PBQ&D	MITRE	PROBLEM	PBQ&D	MITRE
26		Excessive frog wear and failure rate	61.1	0
27	26	Unknown future cost/availability of wood ties	53.5	55.4
28		Unknown limits of switch point wear and condition	53.5	0
29		Inadequate bridge rating procedures	53.5	0
30		Deficiencies in bridge inspection methods/tools	53.5	0
31	37	Excessive ballast fouling	49.7	33.0
32	34	Inadequate subgrade assessment techniques	45.9	36.5
33		Insufficient track availability for maintenance	45.9	0
34	14	Inadequate concrete tie fastener design	45.9	89.9
35	18	Track system R&D results not properly disseminated	38.2	79.8
36		Insufficient cost/performance data-optimum rail length	30.6	0
37		Non-standardization of track components	30.6	0
38	16	Excessive ballast degradation	26.8	81.6
39		Excessive eye-bar wear in bridges	22.9	0
40		Inadequate bridge expansion bearing performance	22.9	0
41		Inadequate performance of bridge expansion joints	22.9	0
42		Excessive concrete spalling on bridges	22.9	0
43	20	Bolt/bolt hole problems	22.9	75.5
44	43	Inadequate joint maintenance methods	22.9	24.6
45		Inadequate joint performance at turnouts	22.9	0
46	33	Insufficient cost/performance data -- innovative wood tie fasteners	22.9	37.4
47		Inadequate timber tie installation methods	22.9	0
48	22	High concrete tie initial/installation costs	22.9	67.6
49	36	Inadequate concrete tie cost/performance data	22.9	34.7
50	42	Inadequate mow methods at crossings	22.9	24.7
51		Inadequate tunnel inspection methods/tools	22.9	0
52	8	Insufficient cost/performance data -- proper rail selection	15.3	146.9
53		Inadequate rail lubrication methods	15.3	0
54	52	Premature joint bar breakage	15.3	15.1
55	10	Insufficient information about subgrade performance	15.3	122.1

RANK PBQ&D	RANK MITRE	PROBLEM	SCORE PBQ&D	SCORE MITRE
56	38	Inadequate slope stabilization methods	15.3	29.6
57	27	Insufficient cost/performance data -- optimum wood tie utilization	15.3	54.1
58	35	Inadequate wood tie cost/performance data	15.3	35.9
59		Inadequate protection from blowing soil	15.3	0
60		Inadequate methods of preserving wood decks on bridges	15.3	0
61		Insufficient knowledge of CWR behavior on bridges	15.3	0
62		Inadequate techniques for specific tunnel repairs	15.3	0
63		Inadequate bridge pier protection methods	7.6	0
64		Inadequate methods of protection of bridge concrete surfaces	7.6	0
65		Inadequate methods for fireproofing bridge decks	7.6	0
66		Inadequate fire protection for timber tunnels	7.6	0
67	31	Insufficient info -- cost/perf of innovative wood-base ties	7.6	44.2
68		Snow and ice in switch points	7.6	0
69		Excessive track damage from anchors due to derailments	7.6	0
70		Damage to bridges from loose loads	7.6	0
71		Insufficient information about PSC bridge spans	7.6	0
72		Insufficient cost/performance date on bridge steel protective coating	7.6	0
73		Excessive spalling of tunnel rock or concrete lining	7.6	0
74		Inadequate tunnel track maintenance methods	7.6	0
75	28	Insufficient knowledge about cost/perf of special trackwork	2.3	53.8
76	40	Inadequate stock rail maintenance methods	2.3	26.0
77	46	Inadequate mow methods at switches	2.3	19.5
78	61	Inadequate methods for maintaining track geom at spec trackwork	2.3	8.6
	5	Inadequate concrete tie performance	0	172.3
	29	Inadequate frog maintenance methods	0	53.2

RANK PBQ&D	RANK MITRE	PROBLEM	SCORE PBQ&D	SCORE MITRE
	30	Track geometry problems	0	46.5
	39	Insufficient information on the causes of railway accidents	0	27.5
	41	Inadequate ballast maintenance/rehabilitation methods	0	25.3
	44	Cost/benefits associated with tie plate area unknown	0	23.0
	45	Subgrade heaving	0	21.9
	47	Inadequate methods for evaluating in-situ track	0	17.9
	48	Unknown cost/performance of concrete tie fasteners	0	17.4
	49	Inadequate bonded joint maintenance	0	17.3
	50	Inadequate field weld inspection techniques	0	16.6
	51	Track system R&D goals not clear -- gov/public/RR conflicts	0	15.6
	53	Unknown effects of track design/irreg's on rail vehicles	0	14.3
	54	High cost of insulated joint installation methods	0	13.4
	55	Inadequate cost/perf data -- optimum joint bar for conditions	0	13.2
	56	Inadequate anchor installation methods	0	12.7
	57	Line speed/yard capability not compatible	0	12.6
	58	Inadequate field joint bar flaw detection	0	11.1
	59	Excessive joint bar wear	0	10.6
	60	Inadequate vegetation control methods	0	9.5
	63	Inadequate bonded joint performance	0	5.7
	64	Too much curved track (line modification needed)	0	3.8
	65	Insufficient information about non-conventional structures	0	3.2
	66	Unrealistic government track standards regulatory action	0	2.1
		Totals	4714.8	4715.2

TABLE B-3: RANKING BASED ON INDUSTRY OPINION AFTER COMBINING PBQ&D'S PROBLEMS WITH MITRE'S AND THEN GROUPING SIMILAR PROBLEMS

RANK PBQ&D	RANK MITRE	PROBLEM	SCORE PBQ&D	SCORE MITRE
1	2	Excessive rail wear Excessive rail plastic flow defects Premature rail failure Insufficient cost/performance data--proper rail selection	639.7	591.2
2	3	Unknown cost/performance of subgrade improvement methods Inadequate methods for subgrade improvement Inadequate subgrade assessment techniques Insufficient information about subgrade performance Inadequate slope stabilization methods Subgrade heaving	412.9	402.8
3	7	Inadequate performance of spikes/plates as fasteners Insufficient cost/performance data--innovative wood tie fasteners Cost/benefits associated with tie plate area unknown	389.8	211.9
4		Inadequate technique for evaluating remaining bridge life Inadequate bridge rating procedures Deficiencies in bridge inspection methods/tools	351.6	0
5		Inadequate bridge repair/maintenance techniques Inadequate method of waterproofing bridge decks Excessive eye-bar wear in bridges Inadequate bridge expansion bearing performance Inadequate performance of bridge expansion joints Excessive concrete spalling on bridges Inadequate methods of preserving wood decks on bridges	320.7	0

NOTE: Where a score of 0 is shown, the survey by that consultant did not uncover that problem.

RANK PBQ&D	RANK MITRE	PROBLEM	SCORE PBQ&D	SCORE MITRE
5 (cont'd)		Inadequate bridge pier protection methods Inadequate methods of protection of bridge concrete surfaces Inadequate methods for fireproofing bridge decks Insufficient cost/performance data on bridge steel protective coating		
6	6	Inability to determine rail stresses in the field Excessive longitudinal rail stress Insufficient knowledge of CWR behavior on bridges	282.9	251.4
7	5	Insufficient cost/performance information on ballast Excessive ballast degradation Inadequate ballast maintenance/rehabilitation methods	248.5	304.4
8	17	Inadequate wood tie renewal/disposal methods	214.0	69.8
9		Inadequate track geometry measuring methods	137.6	0
10	19	Inadequate field rail flaw detection	129.9	60.5
11	8	Excessive wood tie degradation Insufficient cost/performance data-optimum wood tie utilization Inadequate wood tie cost/performance data	114.7	167.8
12	1	Inadequate track structure cost/performance data	107.0	1039.0
13	13	Excessive ballast/subgrade interactions (pumping)	99.4	81.0
14	4	Inadequate concrete tie fastener design High concrete tie initial/installation costs Inadequate concrete tie cost/performance data Inadequate concrete tie performance Unknown cost/performance of concrete tie fasteners	91.7	381.9
15	12	Excessive switch wear Inadequate stock rail maintenance methods Inadequate MOW methods at switches	88.7	84.6

RANK			SCORE	
PBQ&D	MITRE	PROBLEM	PBQ&D	MITRE
16	10	Inadequate field welding techniques Inadequate field weld inspection techniques	84.1	134.9
17	9	Inadequate maintenance of way methods	84.1	161.1
18	16	Unknown anchor effectiveness/performance Inadequate anchor installation methods	76.4	73.6
19		Inadequate method of detecting fatigue cracks in steel bridges	76.4	0
20	27	Inadequate bolted insulated joint performance High cost of insulated joint installation methods	68.8	20.5
21		Inadequate methods of tunnel drainage	68.8	0
22	24	Excessive ballast fouling Inadequate protection from blowing soil	65.0	33.0
23	21	Excessive frog wear and failure rate Inadequate frog maintenance methods	61.1	53.2
24	11	Inadequate joint maintenance methods Inadequate joint performance at turnouts Premature joint bar breakage Inadequate bonded joint maintenance Inadequate cost performance data--optimum joint bar for conditions Excessive joint bar wear Inadequate bonded joint performance	61.1	86.5
25	20	Unknown future cost/availability of wood ties	53.5	55.4
26		Unknown limits of switch point wear and condition	53.5	0
27		Insufficient track availability for maintenance	45.9	0
28	14	Track system R & D results not properly disseminated	38.2	79.8

RANK PBQ&D	RANK MITRE	PROBLEM	SCORE PBQ&D	SCORE MITRE
29		Insufficient cost/performance data-optimum rail length	30.6	0
30		Non-standardization of track components	30.6	0
31	15	Bolt/bolt hole problems	22.9	75.5
32		Inadequate timber tie installation methods	22.9	0
33	26	Inadequate MOW methods at crossings	22.9	24.7
34		Inadequate tunnel inspection methods/tools	22.9	0
35	38	Inadequate rail lubrication methods	15.3	0
36		Inadequate techniques for specific tunnel repairs	15.3	0
37		Inadequate fire protection for timber tunnels	7.6	0
38	23	Insufficient info--cost/performance of innovative wood-base ties	7.6	44.2
39		Snow and ice in switch points	7.6	0
40		Excessive track damage from anchors due to derailments	7.6	0
41		Damage to bridges from loose loads	7.6	0
42		Insufficient information about PSC bridge spans	7.6	0
43		Excessive spalling of tunnel rock or concrete lining	7.6	0
44		Inadequate tunnel track maintenance methods	7.6	0
45	18	Insufficient knowledge about cost/performance of special trackwork Inadequate methods for maintaining track geometry at spec trackwork	4.6	62.4
	22	Track geometry problems	0	46.5

RANK			SCORE	
PBQ&D	MITRE	PROBLEM	PBQ&D	MITRE
	25	Insufficient information on the causes of railway accidents	0	27.5
	28	Inadequate methods for evaluating in-situ track	0	17.9
	29	Track system R & D goals not clear--Gov/public/RR conflicts	0	15.6
	30	Unknown effects of track design/irreg's on rail vehicles	0	14.3
	31	Line speed/yard capability not compatible	0	12.6
	32	Inadequate field joint bar flaw detection	0	11.1
	33	Inadequate vegetation control methods	0	9.5
	34	Too much curved track (line modification needed)	0	3.8
	35	Insufficient information about non-conventional structures	0	3.2
	36	Unrealistic Government track standards regulatory actions	0	2.1
		Totals	4714.8	4715.2

TABLE B-4: PROBLEMS INDICATED BY * HAVE BEEN RECOMMENDED BY MITRE FOR RESEARCH

RANK			SCORE	
PBQ&D	MITRE	PROBLEM	PBQ&D	MITRE
1	2	*Excessive rail wear *Excessive rail plastic flow defects *Premature rail failure *Insufficient cost/performance data--proper rail selection	639.7	591.2
2	3	*Unknown cost/performance of subgrade improvement methods Inadequate methods for subgrade improvement *Inadequate subgrade assessment techniques *Insufficient information about subgrade performance Inadequate slope stabilization methods Subgrade heaving	412.9	402.8
3	7	*Inadequate performance of spikes/plates as fasteners *Insufficient cost/performance data--innovative wood tie fasteners *Cost/benefits associated with tie plate area unknown	389.8	211.9
4		Inadequate technique for evaluating remaining bridge life Inadequate bridge rating procedures Deficiencies in bridge inspection methods/tools	351.6	0
5		Inadequate bridge repair/maintenance techniques Inadequate method of waterproofing bridge decks Excessive eye-bar wear in bridges Inadequate bridge expansion bearing performance Inadequate performance of bridge expansion joints Excessive concrete spalling on bridges Inadequate methods of preserving wood decks on bridges	320.7	0

NOTE: Where a score of 0 is shown, the survey by that consultant did not uncover that problem.

RANK PBQ&D	RANK MITRE	PROBLEM	SCORE PBQ&D	SCORE MITRE
5 (cont'd)		Inadequate bridge pier protection methods		
		Inadequate methods of protection of bridge concrete surfaces		
		Inadequate methods for fireproofing bridge decks		
		Insufficient cost/performance data on bridge steel protective coating		
6	6	*Inability to determine rail stresses in the field	282.9	251.4
		*Excessive longitudinal rail stress		
		Insufficient knowledge of CWR behavior on bridges		
7	5	*Insufficient cost/performance information on ballast	248.5	304.4
		*Excessive ballast degradation		
		*Inadequate ballast maintenance/rehabilitation methods		
8	17	Inadequate wood tie renewal/disposal methods	214.0	69.8
9		Inadequate track geometry measuring methods	137.6	0
10	19	Inadequate field rail flaw detection	129.9	60.5
11	8	*Excessive wood tie degradation	114.7	167.8
		*Insufficient cost/performance data-optimum wood tie utilization		
		*Inadequate wood tie cost/performance data		
12	1	*Inadequate track structure cost/performance data	107.0	1039.0
13	13	Excessive ballast/subgrade interactions (pumping)	99.4	81.0
14	4	*Inadequate concrete tie fastener design	91.7	381.9
		High concrete tie initial/installation costs		
		*Inadequate concrete tie cost/performance data		
		*Inadequate concrete tie performance		
		*Unknown cost/performance of concrete tie fasteners		
15	12	Excessive switch wear	88.7	84.6
		Inadequate stock rail maintenance methods		
		Inadequate MOW methods at switches		

RANK			SCORE	
PBQ&D	MITRE	PROBLEM	PBQ&D	MITRE
16	10	*Inadequate field welding techniques Inadequate field weld inspection techniques	84.1	134.9
17	9	Inadequate maintenance of way methods	84.1	161.1
18	16	*Unknown anchor effectiveness/performance Inadequate anchor installation methods	76.4	73.6
19		Inadequate method of detecting fatigue cracks in steel bridges	76.4	0
20	27	Inadequate bolted insulated joint performance High cost of insulated joint installation methods	68.8	20.5
21		Inadequate methods of tunnel drainage	68.8	0
22	24	Excessive ballast fouling Inadequate protection from blowing soil	65.0	33.0
23	21	Excessive frog wear and failure rate Inadequate frog maintenance methods	61.1	53.2
24	11	Inadequate joint maintenance methods Inadequate joint performance at turnouts Premature joint bar breakage Inadequate bonded joint maintenance *Inadequate cost performance data--optimum joint bar for conditions Excessive joint bar wear Inadequate bonded joint performance	61.1	86.5
25	20	*Unknown future cost/availability of wood ties	53.5	55.4
26		Unknown limits of switch point wear and condition	53.5	0
27		Insufficient track availability for maintenance	45.9	0
28	14	Track system R & D results not properly disseminated	38.2	79.8

RANK		PROBLEM	SCORE	
PBQ&D	MITRE		PBQ&D	MITRE
29		Insufficient cost/performance data-optimum rail length	30.6	0
30		Non-standardization of track components	30.6	0
31	15	*Bolt/bolt hole problems	22.9	75.5
32		Inadequate timber tie installation methods	22.9	0
33	26	Inadequate MOW methods at crossings	22.9	24.7
34		Inadequate tunnel inspection methods/tools	22.9	0
35		Inadequate rail lubrication methods	15.3	0
36		Inadequate techniques for specific tunnel repairs	15.3	0
37		Inadequate fire protection for timber tunnels	7.6	0
38	23	*Insufficient info--cost/performance of innovative wood-base ties	7.6	44.2
39		Snow and ice in switch points	7.6	0
40		Excessive track damage from anchors due to derailments	7.6	0
41		Damage to bridges from loose loads	7.6	0
42		Insufficient information about PSC bridge spans	7.6	0
43		Excessive spalling of tunnel rock or concrete lining	7.6	0
44		Inadequate tunnel track maintenance methods	7.6	0
45	18	Insufficient knowledge about cost/performance of special trackwork Inadequate methods for maintaining track geometry at spec trackwork	4.6	62.4
	22	Track geometry problems	0	46.5

RANK PBQ&D	RANK MITRE	PROBLEM	SCORE PBQ&D	SCORE MITRE
	25	Insufficient information on the causes of railway accidents	0	27.5
	28	Inadequate methods for evaluating in-situ track	0	17.9
	29	Track system R & D goals not clear--Gov/public/RR conflicts	0	15.6
	30	Unknown effects of track design/irreg's on rail vehicles	0	14.3
	31	Line speed/yard capability not compatible	0	12.6
	32	Inadequate field joint bar flaw detection	0	11.1
	33	Inadequate vegetation control methods	0	9.5
	34	Too much curved track (line modification needed)	0	3.8
	35	Insufficient information about non-conventional structures	0	3.2
	36	Unrealistic Government track standards regulatory actions	0	2.1
		Totals	4714.8	4715.2

TABLE B-5: RANKING BASED ON INDUSTRY OPINION AFTER GROUPING SIMILAR PROBLEMS AND ELIMINATING PROBLEMS RECOMMENDED FOR RESEARCH BY MITRE

RANK PBQ&D	PROBLEM	SCORE PBQ&D
1	Inadequate technique for evaluating remaining bridge life	351.6
	Inadequate bridge rating procedures	
	Deficiencies in bridge inspection methods/tools	
2	Inadequate methods for subgrade improvement	282.9
	Inadequate slope stabilization methods	
	Subgrade heaving	
	Excessive ballast/subgrade interactions (pumping)	
3	Inadequate wood tie renewal/disposal methods	214.0
4	Excessive switch wear	152.1
	Inadequate stock rail maintenance methods	
	Inadequate MOW methods at switches	
	Excessive frog wear and failure rate	
	Inadequate frog maintenance methods	
	Inadequate methods for maintaining track geom at spec trackwork	
5	Inadequate track geometry measuring methods	137.6
6	Inadequate maintenance of way methods	137.5
	Inadequate timber tie installation methods	
	Inadequate MOW methods at crossings	
	Snow and ice in switch points	
7	Inadequate field rail flaw detection	129.9

RANK PBQ&D	PROBLEM	SCORE PBQ&D
8	Inadequate bolted insulated joint performance	129.9
	Inadequate joint maintenance methods	
	Inadequate joint performance at turnouts	
	Premature joint bar breakage	
9	Inadequate method of waterproofing bridge decks	128.4
10	Excessive eye-bar wear in bridges	96.2
	Inadequate bridge expansion bearing performance	
	Inadequate performance of bridge expansion joints	
11	Inadequate method of detecting fatigue cracks in steel bridges	76.4
12	Inadequate methods of tunnel drainage	68.8
13	Excessive ballast fouling	65.0
	Inadequate protection from blowing soil	
14	Unknown limits of switch point wear and condition	55.8
	Insufficient knowledge about cost/perf of special trackwork	
15	Excessive concrete spalling on bridges	53.4
	Inadequate bridge pier protection methods	
	Inadequate methods of protection of bridge concrete surfaces	
16	Insufficient track availability for maintenance	45.9
17	Track system R & D results not properly disseminated	38.2
18	Inadequate methods of preserving wood decks on bridges	32.1
	Inadequate methods for fireproofing bridge decks	
19	Insufficient cost/performance data-optimum rail length	30.6
20	Non-standardization of track components	30.6

RANK PBQ&D	PROBLEM	SCORE PBQ&D
21	High concrete tie initial/installation costs	22.9
22	Inadequate tunnel inspection methods/tools	22.9
23	Inadequate techniques for specific tunnel repairs Excessive spalling of tunnel rock or concrete lining	22.9
24	Inadequate rail lubrication methods	15.3
25	Insufficient knowledge of CWR behavior or bridges	15.3
26	Insufficient cost/performance data on bridge steel protective coating	10.6
27	Inadequate fire protection for timber tunnels	7.6
28	Excessive track damage from anchors due to derailments	7.6
29	Damage to bridges from loose loads	7.6
30	Insufficient information about PSC bridge spans	7.6
31	Inadequate tunnel track maintenance methods	7.6

TABLE B-6: SELECTION AND RANKING OF PROBLEM CATEGORIES BY TECHNICAL REVIEW PANEL

	Problem Category	Ranking
1.	Bridge Life, Rating	9
2.	Subgrade	5
3.	Tie Disposal	1
4.	Switches and Frogs	3
5.	Geometry Measuring	10
6.	MOW Methods	7
7.	Flaw Detection	4
8.	Rail Joints	2
9.	Waterproofing Bridge Decks	13
10.	Bridge Eye-Bar, Bearings, Joints	15
11.	Fatigue Cracks - Bridges	11
12.	Tunnel Drainage	16
13.	Ballast Fouling	6
14.	Limits of Switchpoint Wear	8
15.	Bridge Concrete	25
16.	Track Availability	12
17.	Dissemination of R & D	17
18.	Wood Decks on Bridges	26
19.	Optimum Rail Length	18
20.	Non-Standardization	19
21.	High Concrete Tie Costs	20
22.	Tunnel Inspection Methods	27
23.	Tunnel Repair Techniques	21
24.	Rail Lubrication	22
25.	CWR on Bridges	14
26.	Bridge Steel Coatings	-
27.	Tunnel Fire Protection	28
28.	Track Damage from Anchors	-
29.	Loose Loads	-
30.	PSC Bridge Spans	23
31.	Tunnel Track Maintenance	24

I BRIDGE INSPECTION, RATING AND EVALUATION OF REMAINING LIFE

OBJECTIVE

This research is to develop improved techniques and tools for determining present bridge conditions and improved rating procedures in order to evaluate more adequately bridge safety in handling present loads, ability to handle increased loads in many instances, and remaining bridge life.

BACKGROUND

Many railroad bridges now in use date back to the last century. That they are still able to carry today's heavier loads at increased speeds is a tribute to the conservativeness of their design and the quality of materials and workmanship used in their construction. However, many of these old bridges, and others built more recently, have been victims of decades of deferred maintenance as has the balance of the railroad infrastructure. Therefore, there is growing concern regarding the ability of bridges to carry increasing loads at higher speeds and often loads on bridges and/or speeds are restricted, sometimes unnecessarily. Thus, the need exists for more adequate information on bridge condition and better techniques for rating bridges in order to make better operating decisions. This pertains also to decisions concerning remaining life and whether to continue a bridge in service, rebuild it, or replace it.

Although there has not been a catastrophic failure of a railroad bridge in the last couple of decades that compares to the failure of the "Silver Bridge" across the Ohio River, the potential for such failures exists. Railroads are better able to control loads on their bridges than are highways, by imposing weight and speed restrictions, but again the objective is not to err so much on the side of safety as to unduly restrict operations.

Railroads are constantly seeking to increase tonnages on their lines, such as for unit coal trains, and bridges are often the controlling or limiting factor. Thus, the need exists for evaluating the ability to carry greater loads.

Salt is not used on railroads for de-icing purposes as it is on highway bridges. Thus, after the discontinuance of brine refrigerator cars a decade or so ago, salt is not the problem for railroad bridges that it is for highway bridges.

However, deferred maintenance has created other problems for railroad bridges. Many railroad bridges have not been painted for decades. For main exposed structural members, this is not usually a problem, but the lack of minimum maintenance, even cleaning, has allowed accumulation of dirt, debris and moisture that causes insidious deterioration in connections, pockets, etc.

Cooper E loadings and corresponding bridge ratings, developed for steam locomotive-drawn trains, are widely used today for rating bridges for diesel locomotive-drawn trains. The AAR and some railroads have developed computer programs for rating selected types and spans of truss and girder bridges in conformance with the AREA specifications.

To enable railroad management to make more intelligent decisions concerning the future of bridges, it is desirable to evaluate their useful remaining life. The decision may affect more than the bridge itself, as in the case of a key bridge it may extend to a rail line itself.

APPROPRIATE TECHNICAL EFFORT

This research is divided into three major sections:

1. Bridge Inspection
2. Bridge Rating
3. Evaluation of Remaining Life of Bridges.

1. Bridge Inspection

This section of the research involves developing techniques for:

1.1 Inspection for rating and evaluation of remaining life.

1.2 Routine inspection.

This research will not include detection of fatigue cracks. This will be studied under other research efforts.

1.1 Inspection for rating and evaluation of remaining life

General

The research for inspection shall be developed based on the following efforts:

- Study and research current inspection procedures of representative railroads.

- o Research, collect and study current maintenance and inspection manuals or papers.

- o Identify, locate and study any work still in the development or research stage.

- o Obtain records of bridge inspections from representative railroads.

Procedure

The research shall develop techniques or tools to:

- o Inspect inaccessible parts of steel, concrete and timber bridges.

- o Evaluate and determine the remaining effective section of corroded, worn and deteriorated steel members.

- o Evaluate physical properties of the remaining materials of steel bridges.

- o Evaluate physical properties and interior condition of timber and concrete members.

Tools

In addition to standard inspection tools, the research shall investigate the use of:

- o Special scaffolds or snoopers.

- o Mirror and magnifying glass.

- o Power wire brush.

- o Calipers.

- o Power drill and bits.

Instruments

Some instruments, although the list is not all inclusive, to be investigated, tested and evaluated for use in inspecting steel, concrete and timber structures are:

- o Ultrasonic thickness gage.

- o Strain gages.

- o Infrared scanners for subsurface flaws.

- o Pulse Velocity Instrumentation to locate interior cracks and determine wall thicknesses.
- o Nuclear Moisture Detecting Devices for slab type bridges to be used to locate damage to waterproofing membrane.
- o Pachometer or R-meter, to locate and measure concrete cover over a given reinforcing bar or to determine the size of bars for a given cover.
- o Copper/Copper Sulphate Half Cell tests to determine level of corrosion activity in the reinforcing bars or structural steel encased in concrete.
- o Other instruments which the researchers will identify as useful for this task.

Tests

The research shall include certain tests with evaluations to determine, among other things, the effect of age and loading on bridge construction materials.

- o Cores, to test strength and determine physical properties.
- o Coupons, to test for metallurgical analysis, weldability and strength.

1.2 Routine inspection

This research task involves inspection procedures to update known inspection methods as established by the results of the above inspection procedure of Section 1.1 and to provide a method of inspection which the railroads can accomplish using their own maintenance personnel. It shall also include recommendations for:

- o Comparison with previous reports and updating them where necessary.
- o Closer inspection and monitoring of the critical areas identified in the previous reports.
- o Establishing the frequency of this inspection in order to fully ascertain the condition of the bridges at any given time.
- o Methods of providing easy access to, and comparison of, different cyclical/periodical reports.

2. Bridge Rating

The research for bridge rating shall study and develop improved methods of rating various types of bridges to determine their ability to carry contemporary loads.

This research shall address the following items and their influence on rating bridges:

- o Study and research current rating methods of representative railroads.

- o List and obtain all papers and literature on available methods of rating steel, concrete and timber bridges.

- o Investigate and identify ongoing research on the subject and obtain early information where possible to assess its effect on this research program.

- o Investigate and establish by field tests, the correlation between Cooper loadings and actual train loadings on different members and/or types of bridges.

- o Analyze and establish loading systems which compare favorably with actual stresses obtained by field test measurements conducted with actual loads.

- o Compare and evaluate distribution factors and other design assumptions with actual test results.

- o Investigate and evaluate methods of analysis, other than AREA, for rating of bridges, such as "Load Factor Design". Realistic load factors for different dead load force effects should be investigated.

- o Investigate and compare the effect of speed on impact and loading factors on different bridge components.

- o Investigate the effect of vibration and natural frequency of the trains used by various railroads on different types of bridges.

- o Investigate and determine how to incorporate the redundancy factor into rating calculations of different types of bridges.

- o Develop guidelines for new computer programs which will incorporate findings of this research project with capabilities to handle:

- different types of bridges,
- different types of bridge materials, and
- different types of bridge loading systems.

This research shall as a minimum investigate the following types of bridges:

- o Iron and Steel
  - Truss
  - Girder (both open and closed deck)
  - Stringer
- o Concrete
  - Flat slab
  - Arch
- o Timber
  - Trestle

3. Evaluating Remaining Life of Bridges

This research shall study and develop a method of estimating the remaining life of the various types of bridges. This section is divided into two parts:

3.1 Remaining Static (Service) Life

3.2 Remaining Fatigue Life

3.1 Remaining Static (Service) Life

The work shall develop a method to determine the remaining static life of bridges. This method shall address but shall not be limited to the following items:

- o Perform routine cyclical/periodical inspection and compare with the findings of previous inspection reports.
- o Evaluate the rate of deterioration of different materials at a given location.
- o Evaluate the effect of environment and live load on various components of bridges.
- o Identify areas where routine and simple maintenance can extend the life of bridges.
- o Evaluate the effect of vandalism.
- o Evaluate deterioration caused by accidents and lack of timely repair.

3.2 Remaining Fatigue Life

The research shall develop a method of estimating the remaining fatigue life of bridges. The method shall consider but shall not be limited to the following items:

- o Identify and obtain all applicable publications and papers.

- o Identify and obtain information about ongoing research.

- o Develop stress cycle criteria using past and projected probable load spectrums for representative railroads.

  Past load spectrums shall be established by obtaining historical loading data from reliable sources such as:

  - car types for major commodities
  - input from railroads
  - input from railroad users
  - input from railroad car manufacturers
  - others.

- o Investigate and evaluate methods of establishing fatigue strength of materials of highly stressed members.

- o Conduct strain gage measurements of certain bridge members to assist with the analytical determination of the stress resultants and to verify applicability of using traffic projections to evaluate stress cycles.

- o Conduct coupon tests as necessary on materials taken from varying stress regions of bridges and compare results to help establish guidelines.

- o Develop approaches such as fracture mechanics or otherwise to predict fatigue life of members.

In the course of this investigation, other methods for evaluating the remaining life of bridges may be revealed. If considered practical, these should be developed and tested.

TECHNICAL DISCIPLINES AND FACILITIES REQUIRED

The types of personnel with a description of their qualifications required for the Bridge Inspection, Rating and Evaluation of Remaining Life Research Plan are as follows:

Manager
To direct the entire project and coordinate the efforts of all parts. In addition to having managerial abilities, he should be experienced in bridge design, inspection and rating.

Librarian
Experienced technical research librarian.

Bridge Engineer
Structural engineer familiar with design, rating and inspection of bridges, preferably some with experience in railroad bridges.

Bridge Inspector
Experienced in inspection of bridges, preferably one or more experienced in railroad bridges.

Bridge Analytic Specialist
Structural analyst familiar with bridge design and rating.

Technician
Familiar with structural testing of steel, wood and concrete

Other assistance and facilities required are:

Participating Railroads

Cooperation from railroads with representative types of bridges to determine present inspection and rating procedures and to test and evaluate new instruments and techniques.

Participating Manufacturers

Instrument manufacturers to identify and possibly develop new test instruments, steel and other material manufacturers.

AREA Committee 15

Assistance of this committee in reviewing and applying existing specifications and possibly revising specifications as a result of this research.

AAR Research Laboratory

Assistance in testing and analyzing specimens removed from bridges and conducting tests on bridges.

PERIOD OF PERFORMANCE

All parts of the research program as described above can progress simultaneously and should take about three years to complete. During the first year material and information gathering identifying railroads and defining types of studies and tests will be done. In the second year, field preparation, testing and analytical analysis will be performed. Finally, during the final year methods and tools in a simplified format will be developed and field tested.

TECHNICAL EFFORT

The estimated manpower effort is shown in Figure 1. Table 1 shows the estimated major direct expenses:

TABLE 1: ESTIMATED MAJOR DIRECT EXPENSES

Cost of site preparation, scaffolding and instrumentation of field tests (5 assumed)	$ 750,000
Lab tests	100,000
Purchase of instruments	100,000
Computer costs	100,000
	$1,050,000
Estimated labor costs from Figure 1 including overhead and profit	3,000,000
Grand Total	$4,050,000

The above cost does not include the cost of maintenance of railroad traffic and railroad equipment to be used for testing, or any costs for the use of railroad facilities.

NATURE OF END PRODUCT

It is anticipated that the end product of the improved bridge inspection portion of this research project will provide more accurate results of inspections with a decrease in the cost and time for performing them. Potential future maintenance problems conceivably could be discovered early enough so that less costly repairs could be made.

The research connected with rating and evaluating the remaining life of bridges will result in a more accurate determination of the capacity and remaining life of bridges by using the latest structural engineering technology and theory.

FIGURE I: SCHEDULE

	Task	R&D Cost ($1,000)	Years (1, 2, 3)
1.	Review Present Practice and Determine State-of-Art	300	(2 Engrs.)
2.	Literature Search	70	(Librarian)
3.	Plan Research Program	100	(2 Engrs.)
4.	Research, Identify and/or Develop Instruments & Techniques	580	(2 Engrs.)
5.	Develop Methodologies	600	(2 Engrs., Analyst
6.	Lab Test Instruments & Methodologies	400	(2 Engrs., Analyst, Tech.)
7.	Field Test Instruments & Methodologies	1,000	(4 Engrs., 2 Analysts, Tech.)
8.	Summarize Results	300	(2 Engrs., Analyst)
9.	Finalize Methods and Tools	300	(2 Engrs. (Analyst)
10.	Field Test Final Methods and Tools	300	(2 Engrs., Analyst, Tech.)
11.	Conclusion and Reports	100	(2 Engrs.)
	Total	$4,050	

( ) Indicates number and discipline of people assigned to task

ANALYSIS OF SAVINGS AND BENEFITS

The benefits of the bridge inspection portion of this research project are, to a large extent, intangible since the results are improved methods providing a more accurate description of the condition of bridges. The condition of inaccessible members of a steel bridge such as the pin connection of an eye-bar truss as well as the eye of an interior member can be determined. A more accurate method of determining the soundness of timber members, rather than hammering to locate hollows and then the laborious drilling to confirm or deny this condition, can be an output to this research.

Two cost savings can be effected. One is a decrease in the manpower to inspect bridges and the other is to surface maintenance problems early when repairs would be less costly as opposed to making major repairs later.

Assume there are 175,000 bridges which must be inspected at least once annually and that routine inspections system-wide can be performed by three two-man teams to inspect 10,000 bridges annually. Additionally, division inspectors look at certain bridges more frequently. Using an average annual salary of $25,000 with a markup of 1.45, the annual cost of inspecting 10,000 bridges with six systems inspectors and two from the divisions is $290,000. The present cost of inspecting 175,000 bridges is $5,000,000. Improved inspection techniques should save 10% or $500,000 annually.

Present annual maintenance costs of bridges and trestles is $79,000,000.[16] If 10% could be saved by performing repairs before the deterioration or distress reached an advanced stage by discovering the need for repair through improved inspection procedures, $8,000,000 could be saved annually.

The benefits of improved procedures and techniques for rating and evaluating the remaining life of bridges are also, to a great extent, intangible. The present rating procedures do not consider the effect of fatigue to any degree. It is now recognized that repeated cycles of loads shorten the life of a bridge or reduce its capacity. There is always the possibility that a new rating procedure may indicate a bridge capacity less than that determined under the present rating rules. This is probably unlikely because the damaging loads come from 100 car - 100-ton unit trains which have not been in service for more than a decade or so. Previously mixed-consist trains were the rule with rarely more than a few heavy loads per train with the exception of the steam locomotive.

Assuming the new procedures forthcoming from this research will indicate an increased capacity and longer life than the present procedures do, the benefits can be expected to be increased operating speed (lower operating costs) and/or increased loads permitted (higher revenues).

Annual operating revenues of the Class 1 railroads are $20 billion.[17] Assuming the annual operating revenues can be increased by 0.02% due to the combination of increased operating speeds and increased load carrying capacity, the benefit will be $4,000,000 of increased revenues per year. This is an average of $100,000 per Class 1 railroad which is conceivable.

Another benefit to be gained, if the remaining life of bridges based upon the new procedure can be extended, is the deferral of replacement costs.

SUMMARY OF SAVINGS AND BENEFITS

1.	Cost of R & D	$4,050.00
2.	Time of R & D	3 years
3.	Accidents Prevented in 5 Years	0
4.	Annual Net Savings	$12.5 million
5.	Savings - First 5 Years	$62.5 million
6.	Present Value of Savings - First 25 Years	$113 million
7.	Benefit/Cost Ratio	28

STRATEGY FOR IMPLEMENTATION

Upon completion of this research project, its results should be sent to all railroads and related industry. The trade magazines should receive it and be asked to include articles on it in their publications.

Soon after the publicizing of the research results seminars should be held in several places in the country to which the railroads and other interested parties would be invited. The material for the seminars should be well prepared using the latest visual aids. Prepared audiovisual materials could be loaned to maintenance-of-way clubs and interested engineering societies.

INVOLVING CONCERNED ELEMENTS OF CLIENT SECTORS

Voluntary work on the research could be asked of the AAR, AREA, the railroads and related industry. Where significant cost is involved, such as may be encountered in testing in the track under actual loads, compensation to the railroads may be required.

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II SUBGRADE STABILIZATION AND IMPROVEMENT

OBJECTIVE

This research is to develop subgrade condition survey methods for direct evaluation of structural adequacy of subgrades and other subgrade related problems and means of prediction of future service life of subgrades with respect to environmental and traffic conditions. This research will develop economical and practical methods to salvage, strengthen and stabilize deficient subgrades with respect to various subgrade materials to prevent settlement, slipouts, slides, heaving and subgrade pumping.

BACKGROUND

Much of the railway roadbeds in use today were built in the last century. Many subgrades were built of local materials without benefit of compaction, admixture, moisture control and even before the development of proper design procedure that takes into account the interrelationship between subgrade support, rail loading and load distribution through ties and ballast. In addition, many miles of track were built on embankment fills on wetlands, swamps and soft foundation soils without use of modern soil mechanics knowledge. Consequently some of the track built in the early days still contains a variety of problems related to the subgrade in terms of soft spots, sinks, unstable and settling embankment fills, unstable cut slopes, poor drainage and stretches of weak subgrade that require excessive maintenance.

In many cases railroad maintenance funds were spent mostly on track structure deferring maintenance of the subgrade that resulted in further deterioration of weak subgrades. In other cases routine maintenance was provided without a definitive goal for development of a permanent stabilization method.

Moreover, some areas, where weak subgrades became stable over many years of use, are no longer adequate as a result of today's higher wheel loads and higher speeds.

The combination of the above factors has resulted in today's subgrade problems. "Roadway Maintenance" accounted for about 5% ($146 million) of the 1976 expenditure for maintenance of way and structures.[1] It is estimated that 10% of this amount was subgrade related. Much of the surfacing in Account 220, "Track Laying and Surfacing" (TL&S) can be attributed to poor subgrade. It is conservatively estimated that about 15%

of the three quarters of a billion dollars spent in 1976 on TL&S, or $112.5 million, can be attributed to poor subgrade. A total of 160 accidents causing approximately $6.4 million damage was attributed to roadbed defects in 1976[2] and it is estimated that 20% of this amount was due to poor subgrade.

Although subgrade support problems and design have been studied quite extensively in highway and airport pavements, little attention has been paid by railroads to comprehensive planning and investigation of subgrade problems and development of rational methods for subgrade design and rehabilitation using today's soil mechanics knowledge.

The major components of subgrade-related problems are as follows:

1. Inadequate structural support from the weak subgrades

2. Unstable and/or settling embankment fills and unstable cut slopes

3. Subgrade heaving

4. Pumping of subgrade materials into the ballast

5. Inadequate subgrade drainage

The subgrade problems are widely variable due to variation of subgrade materials, their density, compaction condition, moisture contents, frost action and other environmental conditions.

Inadequate subgrade support is generally found in areas of fine-grained subgrade soils, soft silts, clays, and soils with high organic content, poor density and excessive moisture. Continuing sources of trouble are also encountered in swelling and expansive clays and sensitive silts and clays. Where an embankment is founded on soft and compressible soil as when a fill was built across old lake deposits or swamps, gradual settling of the fill continues causing subgrade settlement. However, excessive settlement in many cases results in foundation failure of the embankment slope. Other problems of slope instability are the result of continuing wear and erosion of unprotected soil slopes.

Many weak subgrades, particularly in cohesive silts and clays, are successfully treated by using lime injection techniques. However, some failures are experienced in lime-treated subgrades which indicate that one single stabilization technique cannot solve all subgrade problems. Various ground improvement techniques for embankment stabilization can be found in soil mechanics and highway research publications.

During cold weather many subgrades of fine-grained frost-susceptible soils are damaged by frost heaving requiring excessive maintenance during winter and spring. Formation of ice lenses in railroad beds tends to swell road beds and distort track line. Furthermore, cycles of freeze and thaw provide excessive free water in the soil resulting in lowering the strength of the subgrade.

Maintenance of proper drainage and replacing fine-grained soils with free-draining soils are adequate to minimize frost problems. Some use of chemical additives to reduce frost susceptibility are also found in railroad maintenance programs. Where the track structure is founded on weak and compressible fine-grained subgrade soil, vertical motion of the track structure under load brings the subgrade soil to the surface through the ballast by "pumping" action. In the presence of excessive moisture the subgrade becomes softened and the traffic loads force the ballast into the subgrade.

The problem of pumping can be successfully treated by using proper drainage with some filter barrier between the subgrade and the ballast. Various filter fabrics are in use today for this purpose. However, these fabrics are not always the most durable material and can be damaged, especially if the ballast is laid directly over the fabric.

Inadequate subgrade and surface drainage is the single most important cause for all the subgrade problems described above. If positive drainage can be provided to keep the subgrade relatively dry, much of the subgrade-related problems will be solved. Excessive moisture weakens the subgrade, aggravates pumping action, helps form ice lenses and reduces shear strength of cohesive soils resulting in reduced subgrade support. Regular maintenance of side ditches in most of the areas and provision of subgrade drainage in specific areas help alleviate excessive moisture problems.

APPROPRIATE TECHNICAL EFFORT

This research on subgrade can be divided into five major parts:

1. Subgrade condition survey methods

2. Stabilizing existing subgrades

3. Subgrade heaving

4. Preventing pumping of subgrade materials into the ballast

5. Inadequate surface and subgrade drainage

1. Subgrade Condition Survey Methods

This part can be subdivided as:

1.1 Determination of subgrade soil characteristics

1.2 Determination of structural adequacy or support capability of various subgrade materials.

A method must be developed to evaluate subgrade conditions in potential problem areas. Identification of the problem, e.g., soft subgrade, unstable fill, etc., should be made with respect to the subgrade soil material, subsoil foundation material and other environmental conditions, e.g., high groundwater table, etc. This part of the problem can generally be handled with the available tools and techniques of geotechnical engineering in terms of field exploration and laboratory classification and testing of the subgrade and subsoils.

- Test borings and in situ borehole testing
- Test pits and in situ testing
- Obtaining undisturbed samples for laboratory testing
- Groundwater observation wells
- Laboratory testing for soil classification, determination of strength, moisture content and grain size distribution
- Laboratory compaction tests
- Laboratory testing of subgrade materials by simulating repetitive rail loads to evaluate soil modulus and permanent strain.
- In-place testing for load deflection characteristic of the subgrade

The last two items need some further research. Repetitive load laboratory testing has been performed on various subgrade materials; however, more research is needed for more types of subgrade materials under a wider variety of environmental conditions.

Although indirect measurement of subgrade soil strength can be evaluated from conventional geotechnical exploration, a direct and simple non-destructive testing method must be developed for determination of load deflection characteristics of the in-place subgrade soil. Various methods have been developed and used for highway and airport pavements which can be modified for use in the railroad industry.

One economical, non-destructive testing method has been developed recently by Yang Stevens Fabian Engineers PC. of New York City under a contract from the Federal Aviation Administration. It is called "Frequency Sweep" and utilizes a "thumper" to introduce a vibratory load to the pavement and then measure the load deflection. The readings in turn are fed into a computer which produces pavement profile, estimated life, and repair options for the airport pavements. This method can be modified for use in the railroad industry with development of various computer programs to evaluate subgrade conditions.

2. Stabilizing Existing Subgrades

Should the subgrade condition survey methods indicate need for improvement or stabilization of the existing subgrade, the following options should be evaluated.

2.1. Treat the subgrade soil to improve its properties

2.2. Remove the poor material and replace it with good material

2.3. Redesign the track structure for the poor subgrade condition

A wide variety of ground improvement and soil stabilization techniques are available for different types of soils that can be used to solve overall embankment problems. Among these:

- Providing stabilization berms near the toe of the slope or flattening the slopes with appropriate slope protection

- Providing retaining wall to contain embankment fill

- Reinforcing the weak soil by driving compaction piles, sand or stone columns

- Horizontal reinforcement of the soil with metal strips or membranes

- Pressure injection of lime or grouting with cement and chemical grouts

- o Admixture stabilization with cement, lime and other chemical addition

- o Densification by mechanical compaction

- o Lowering the groundwater or control of seepage to reduce the moisture content

Removing unsuitable materials that cannot be stabilized by any practical means usually requires replacement with suitable materials. An economic and effective technique should be developed for excavation and replacement without creating too much disturbance to traffic operation.

If the weak subgrade is generally dry and has no other adverse environmental and stability problem, criteria should be provided for redesign of the track structure in terms of ballast and subballast depth, so that no further degradation of the subgrade would be expected from the rail loading only. One area of needed research is to evaluate the effectiveness of various ground improvement techniques with respect to repetitive and vibratory railroad loadings.

3. Subgrade Heaving

Some positive design guidelines should be made to eliminate or at least to minimize subgrade heaving and freeze-thaw softening of subgrades. The guidelines are needed in the following areas:

- o Required depth of free-draining non-frost-susceptible soils

- o Adequate drainage criteria to eliminate capillary water, seepage water and surface water

- o Chemical additives or other injection techniques for reducing frost susceptibility of various subgrade soils.

The most positive method of minimizing subgrade heaving is to provide free-draining non-frost-susceptible materials down to the frost-penetration depth. Since this method is very expensive and sometimes not practical, an alternative method must be developed to minimize frost heave. Some research has been done regarding treatment of the track and subgrade structure with chemical additives. Further research is necessary to evaluate the influence of freeze-thaw cycles and repetitive loads on such techniques taking into account a wide variety of subgrade soils.

4. Pumping of Subgrade Materials into the Ballast

Guidelines should be developed under this research program for the use of filter fabrics and other filter gradation of subballast, etc., for protection of various fine-grained subgrade soils, and methods of providing effective drainage and moisture control, etc., taking into account the influence of repetitive loading. Some specification should be provided for use of filter fabrics, e.g., thickness and type of cover material over the fabrics and under the ballast, strength and durability characteristics of various types of fabrics, etc.

5. Inadequate Surface and Subgrade Drainage

Since appropriate drainage is by far the best effective means to eliminate or at least alleviate almost all of the subgrade problems discussed, a great emphasis must be provided for research of this particular item.

The work can be subdivided into:

5.1. Maintaining and restoring existing drainage

5.2. Installation of new drainage facilities

The following items should be addressed for maintaining and restoring existing drainage:

- o Improved tools/techniques for cleaning ditches
- o Improved tools/techniques for maintaining culverts and pipes
- o Improved method for preventing ponding
- o Improved tools, materials and methods for controlling vegetation

In areas where existing drainage cannot be improved to the required quality, new drainage facilities may have to be installed. Recommendation or guidelines should be provided in this research for the following items:

- o Types of new subgrade drainage, perforated pipes, types, sizes, filter requirement, installation technique, etc.
- o Use of filter fabrics or other free-draining filter material at the subgrade level
- o Other moisture control techniques in terms of moisture barrier, impervious membranes, lime or asphalt treatment of subgrade, etc.

- o Use of advanced dewatering techniques in wetland or other high-water areas.

All the above technical effort will include investigation of existing conditions, literature search, analytical studies, field exploration and laboratory testing and field test sections if needed.

TECHNICAL DISCIPLINES AND FACILITIES REQUIRED

The types of personnel with a description of their qualifications required for the subgrade evaluation and stabilization program are as follows:

Manager

To direct the entire project and coordinate the efforts of the various parts. This person should, in addition to his leadership capability, be experienced in research and practical work in the field of geotechnical engineering.

Librarian

Required to research the publications and reports of the past. One person should perform this task for the entire problem as the subjects are interrelated. This person must be an experienced research librarian.

Geotechnical Engineer

Experienced in the field of ground improvement techniques, field instrumentation, and railroad or highway design and drainage work.

Hydrologist/Water Resources Engineer

Experienced in the field of highway and railroad drainage projects.

Civil Engineer

A railroad civil engineer with track and subgrade maintenance experience.

Other assistance and facilities required are:

Technician

Experienced in soils testing, both laboratory and field

Participating Railroads

Assistance from at least two or three railroads in different parts of the country in the performance of "in-place" subgrade testing, and field test sections if required.

Participating Manufacturers

The help of material manufacturers and suppliers to the railroad industry to make the materials available for research.

Association of American Railroads

Assistance of the AAR in securing acceptance by the railroad industry of the research results as well as providing advice during research.

PERIOD OF PERFORMANCE

It is estimated that this research plan can be conducted in approximately 4 years. The periods of performance for the various tasks are shown in Figure 1.

TECHNICAL EFFORT

It is estimated that this research plan can be conducted for $4.5 million. The estimated cost of each element of the plan is shown in Table 1.

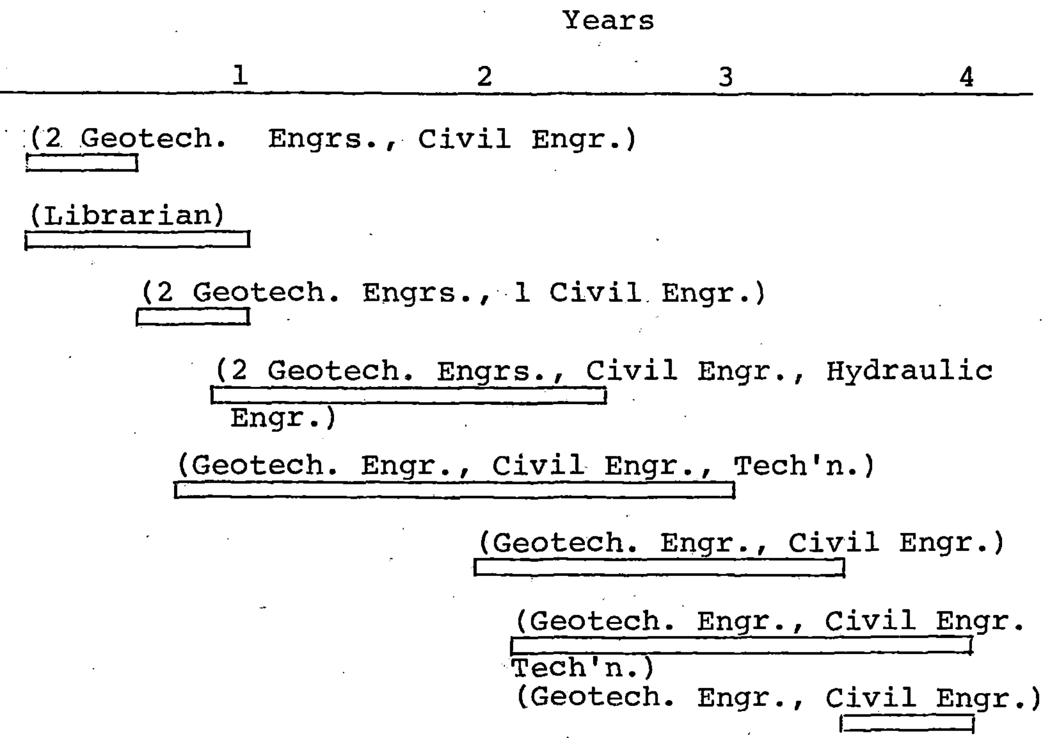
NATURE OF END PRODUCT

This research will provide improved evaluation and analysis techniques to determine subgrade conditions and to alert railroad forces of potential problems before they result in settlement, slides or slipouts, improved methods for maintaining and improving drainage and stabilizing problem soils, more efficient methods for removing totally unsuitable soils and replacing them with stabilized ones, and improved means to eliminate interaction between subgrade and ballast (pumping).

FIGURE 1:

	Task	R&D Cost ($1,000)
1.	Determine State-of-Art	200
2.	Literature Search	70
3.	Plan Research Program	130
4.	Field Exploration	1,000
5.	Laboratory Testing	500
6.	Analytical Studies	1,000
7.	Field Testing	1,500
8.	Results & Reports	100
	Total	$4,500

SCHEDULE



( ) Indicates number and discipline of people assigned to task

TABLE 1: TECHNICAL EFFORT

		Manpower	Testing Laboratory	Testing Field
1.	Subgrade condition survey methods			
	1.1 Subgrade soils evaluation	$ 300,000	$ 100,000	$ 100,000
	1.2 Subgrade support evaluation. Development of new techniques	400,000	200,000	400,000
2.	Stabilization of existing subgrades			
	2.1 Available techniques	200,000	100,000	200,000
	2.2 Development of new techniques	300,000	300,000	400,000
3.	Subgrade heaving	50,000	50,000	150,000
4.	Pumping of subgrade materials into the ballast	50,000	50,000	150,000
5.	Inadequate surface and subgrade drainage			
	5.1 Maintenance and restoring of existing drainage	100,000	100,000	200,000
	5.2 Installing new drainage	200,000	100,000	300,000
	Total	$ 1,600,000	$1,000,000	$1,900,000
	GRAND TOTAL	$ 4,500,000		

ANALYSIS OF SAVINGS AND BENEFITS

The potential annual savings for each of the tasks of this research project are summarized in Table 2 below.

TABLE 2: ANNUAL NET SAVINGS

Task		Potential Annual Savings ($ Million)
1.	Subgrade Condition Survey Methods	$ 6.4
2.	Stabilizing Existing Subgrades	3.4
3.	Subgrade Heaving	1.2
4.	Pumping of Subgrade Materials into the Ballast	5.5
5.	Inadequate Surface and Subgrade Drainage	9.8
		$ 26.3

An analysis of the derivation of these estimated savings and benefits for this research plan is given below.

From the "Background" section of this report, it has been estimated that 10% of the "Roadway Maintenance" cost for 1976 ($146.0 million), or $14.6 million, represents the amount related to subgrade maintenance. It is conservatively estimated that 15% of the $750 million spent in 1976 on Track Laying and Surfacing, or $112.5 million, can be attributed to poor subgrade. Additionally, 20% of the accident damage costs related to roadbed defects, or $1.3 million, can be attributed to poor subgrade. The sum of these three amounts, or $128.4 million, represents the total estimated cost in 1976 for subgrade-related problems and maintenance.

Table 3 gives a breakdown by research task item of the estimated portions of these costs that were attributable to each subgrade problem category.

The following assumptions were made in order to estimate the potential annual net savings for this research plan.

1. Assume that an overall 5% reduction in the total annual subgrade-related costs, or $6.4 million (.05 x $128.4 million) will result from the effort to evaluate subgrade condition survey methods, as described in task 1. $ 6.4 million

2.	Assume 25% reduction in annual soils stabilization costs ($14.2 million, Table 3)	$ 3.4 million
3.	Assume 20% reduction in subgrade heaving costs ($6.5 million, Table 3)	$ 1.2 million
4.	Assume 15% reduction in subgrade pumping costs ($38.7 million, Table 3)	$ 5.5 million
5.	Assume 15% reduction in surface and drainage costs ($69.0 million, Table 3)	$ 9.8 million
	Total annual net savings	$26.3 million

Assume that 20% of the worst subgrade is improved each of the first five years as a result of this research and thereafter the annual savings of $26.3 million is realized.

SUMMARY OF SAVINGS AND BENEFITS

1.	Cost of R & D	$ 4,500,000
2.	Time of R & D	4 years
3.	Accidents Prevented in 5 Years	96
4.	Ultimate Annual Net Savings	$26.3 million
5.	Savings - First 5 Years	$45 million
6.	Present Value of Savings - First 25 Years	$178 million
7.	Benefit/Cost Ratio	40

TABLE 3: BREAKDOWN OF ACCIDENT, MAINTENANCE-OF-WAY AND TRACK LAYING AND SURFACING COSTS, BY RESEARCH TASK

Task	Accidents		M.O.W.		TL&S		Total
	% of Cost	$ Million	% of Cost	$ Million	% of Cost	$ Million	
1. Survey Methods	-	-	-	-	-	-	-
2. Stabilization	5	.1	20	2.9	10	11.2	14.2
3. Subgrade Heaving	15	.2	5	.7	5	5.6	6.5
4. Subgrade Pumping	40	.5	30	4.4	30	33.8	38.7
5. Surface & Subgrade Drainage	40	.5	45	6.6	55	61.9	69.0
Total	100	1.3	100	14.6	100	112.5	128.4

STRATEGY FOR IMPLEMENTATION

Field evaluations will be conducted on several railroads. These railroads will be anxious to adopt successful results as subgrade problems are among their most basic problems. Information on results will be published in reports and at conferences. A workshop(s) will be conducted to demonstrate techniques for stabilizing subgrades in a location(s) where a problem area has been stabilized some time before so the railroad industry can see the results.

INVOLVING CONCERNED ELEMENTS OF CLIENT SECTORS

Several railroads will be visited and their engineers interviewed to further assess subgrade problems. Manufacturers of evaluation devices, stabilizing materials, drainage materials, machinery, etc. will be surveyed to see what materials they have and their cooperation will be sought in developing new products that the research plan may prove to be helpful for improving subgrades. As pointed out above, field evaluations will be held on several railroads and engineers from these railroads will be involved in conducting tests and evaluating the results.

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III TIMBER CROSS TIE REHABILITATION AND DISPOSAL

OBJECTIVES

This research is to develop acceptable methods for the rehabilitation of timber cross ties in place or at a plant site and for disposing of ties that are no longer serviceable.

BACKGROUND

During the last two years, the railroads in the United States have installed 25 million ties annually in the track. The annual tie installation for the past ten years is shown in Table 1. The rate of installation is tied to business conditions and varies from year to year.

TABLE 1: TIMBER CROSS TIES RENEWED ANNUALLY BY U.S. RAILROADS

Year	Total New Timber Cross Ties	Renewals Per Mile	Average Life All Roads
1968	16,649,116	56	
1969	16,997,355	57	
1970	17,804,000	60	
1971	21,228,356	72	43
1972	20,540,402	70	43
1973	17,830,145	61	49
1974	18,790,665	61	47
1975	18,740,625	65	47
1976	24,703,487	86	35
1977	25,266,286	91	33

From AREA Bulletins

The General Accounting Office has projected the annual needs of the railroads to be 40 million ties annually over the next 10 years.[(1)] Committee 3, Ties and Wood Preservation, AREA forecast a need for 30 million ties annually for the years 1980 through 1983. The figure of 30 million new ties annually will be used hereafter in this report.

Ties are removed from the track for six general causes as shown in Table 2 and the percentage removed annually by cause is also shown.

TABLE 2: CAUSES OF TIMBER CROSS TIE DETERIORATION [1]

CAUSE	PERCENT REMOVED ANNUALLY
Decay and Wood Deterioration (Crushing)	43-44
Plate Cutting	18-20
Splitting	16-18
Spike Killing	14-16
Broken Ties	2-3
Other (Mechanical Damage such as Derailments and Rail Anchor Damage)	2-4

Railroads have followed the philosophy of using the tie to its fullest life by leaving it in the track as long as possible. To date, the cost of removal, repair, and replacement of the tie has been too high to be economical. With the cost of ties increasing, as well as that of labor, the rehabilitation of ties must be reviewed and further efforts put forth to improve the means and methods.

Those defects which particularly lend themselves to field repair are plate cutting, where cutting is not too severe, splitting and spike killing. (This research will not consider solutions to spike killing because it is being investigated under another research project.) A tie rehabilitation plant could handle all defects, however tie decay would be repaired only on those ties with limited decay.

If it is assumed that half of the ties removed because of plate cutting and splitting are renewable and that their life could be extended from 5 to 15 years the number of new ties required annually could be decreased from 30 million to 25 million.

Ties are removed from and replaced in the track by the following general methods:

- o Small crews using hand tools or with small tie removal equipment.

- o Program maintenance crews removing and replacing at least 300-400 ties per mile. These crews are equipped with tie removal and replacement machines. The crews work on a cycle basis returning to the same track every 4, 5 or 6 years.

- o Out-of-face removals in connection with complete track overhaul and may be done by a large track machine.

- o Track crews making track repairs after derailments who may or may not have tie renewal machines.

In removals by machines, the ties are either removed in 3 pieces or one piece depending upon the type of machine employed. Approximately 28% of ties removed are taken out of the track in one piece. The other 72% are removed in three pieces. [3] The 3-piece removal is preferred by many railroads as it is claimed that the machine which saws or shears the ties in 3 pieces simultaneously causes less disturbance to the track both horizontally and vertically. Both one-piece removal and three-piece removal require surfacing and lining behind or following the tie renewal work.

Ties are disposed of by the following means:

Reused in other tracks, if suitably sound.

Left to deteriorate along the right-of-way.

Burned along the right-of-way.

Hauled to a disposal area.

Buried along the right-of-way.

Sold or given away.

Chipped and chips spread along the right-of-way.

Used as fuel.

The disposal on any railroad is a combination of the above means, depending upon local conditions, need to remove ties to eliminate hazards or vandalisim, and environmental considerations. Some states, federal agencies, and environmental agencies do not permit either burning or disposal of ties along the right-of-way.

Those one-piece ties which are reusable, and the standards vary from road to road, may be reused in secondary tracks.

Many ties are either sold or given away. The market for full length ties is excellent while that for the "shorts" or 3-piece is very limited. The sale of ties presents some problems to the railroads because of the liability to the railroad if persons are permitted to enter the railroad's property to pick up the ties. Also, there is an accounting problem in connection with sale of ties.

In large cities and terminal areas ties are loaded in cars and hauled to disposal areas. This can be quite costly, but is done because of both potential hazard when left along tracks and possible vandalism.

Ties can be chipped by a machine which operates on the track and spread along the railroad right-of-way.

The use of ties for fuel is limited and no commercial use is known at this time.

APPROPRIATE TECHNICAL EFFORT

TASKS

This research on the subject of timber cross ties is divided into two major parts:

1. Rehabilitation

2. Disposal

Rehabilitation, in turn, is further subdivided as follows:

1.1 Cause due to tie plate cutting

1.2 Cause due to splitting

1.3 Rehabilitation of entire tie

1. Rehabilitation

This part of the research concerns the rehabilitation of timber cross ties by one or several possible means, either in the track or in a plant, to extend the life resulting in the full economical use of the tie.

Over the years, the tie has been studied extensively, especially the possibilities of extending its life. One of the most recent reports is the "Refurbishment of Railroad Crossties".[1] The report "U.S. - U.S.S.R. Track and Rail Metallurgy - Information Exchange" [2] describes the USSR's plant for refurbishment of ties.

A number of tests have been made and reported on in various AREA Bulletins. Several railroads have done some experimental work on coating the surface of ties and some materials are under test today.

1.1 Tie Plate Cutting

This research will determine the limit of tie plate cutting beyond which point the tie will no longer function as a support for the loads imposed on the rail. This is to be a theoretical analysis.

Establish the practical limit of the plate cutting into the tie considering the limitations of tie dapping machines refacing ties in the field and the difficulty of removing ties from the track when plate cut. This is to be done in the field, by observation, investigation, and interviews.

Field Repairs

The research shall include a search of publications and reports to determine what has been done in the past including what the AAR Laboratory and manufacturers have done in the development and testing of tie pads. Obtain samples of tie pads which are on the market today and determine whether or not the AAR Laboratory has tested these materials. If not, have the tests performed. Investigate some of the modern materials, (fiber glass, etc.) as to their use as a tie pad and develop the most promising ones and test in the laboratory and field.

Determine whether or not there are protective coatings on the market which could economically function as a tie protective material. If so, develop and test in the laboratory and field.

Develop a fibrous pad with sealer in the pad which, when placed under a tie plate, will release the sealer under load thus sealing the surface of the tie. This shall be tested in the laboratory and field.

In the course of this work, other materials or methods may be revealed. If considered practical, these should be developed and tested.

In-Plant Repairs

This work shall be similar to that for Tie Plate Cutting repairs made in the field except that the entire tie shall be removed from the track and shipped to a plant where the repair work will be performed.

Use of creosote shall also be considered for the repair of the tie after the plate area is adzed, cleaned and the holes filled. Several ties shall then be installed in track for long term observation under traffic.

Another alternative shall be the preparation of a fibrous pad with suitable resins and/or other materials to bond the fibers and then shall be applied to a tie which has been cleaned, adzed and dried to accept the pad. This shall be tested in the laboratory with the standard AAR tie plate abrasion test. If this meets the laboratory test, place several ties in the track for further testing.

A fibrous sealer pad which was developed in the previous section shall be applied to a plant-prepared tie, that is dry, adzed and cleaned. Test this application in the AAR tie plate abrasion machine. If satisfactory, place several ties in track for further testing.

Investigate use of coatings to be applied to a tie which has been prepared by air drying, adzing and cleaning. These coatings are to be those on the market which appear to provide a sealed water-resistant surface on a tie.

In the course of this investigation, other materials or methods may be revealed. If considered practical, these should be developed and tested.

1.2 Splitting

Determine limits of extent of splitting beyond which point it is uneconomical to rehabilitate the tie. This is to be done by field observation and measurements. Samples, full size, of ties should be obtained for examination and possible tests.

Field Repairs

The research shall include a search of publications and reports to determine what has been done in the past including what the AAR Laboratory has done. Also an investigation shall be made as to the practice of several major railroads.

A review shall be made of the present materials available. Investigate their suitability to either field application or in-plant use. The material must be easily applied by track labor and be economical in its costs. Materials shall be tested in the laboratory for their ability to adhere to surface of ties, penetration, environmental effect, and health and safety aspects.

A railroad shall be selected which, on a compensatory basis, will participate in a long-term test. The test site must be in an area of freezing and thawing cycles. Apply coatings to selected areas with adjacent tracks as control sections.

Observe the track periodically for a period of years in conjunction with Committee 3, Ties and Wood Preservation and report on condition of ties annually. The formal portion of the test to end 3 years after application, however, the test will continue and be monitored by both the railroad and Committee 3 for a number of years.

In-Plant Repairs

The research shall investigate the use of dowels in second hand ties to determine if they will accept dowels and to what extent dowels adequately repair the tie. Also there shall be consideration given to the banding of ties and the use of "S" irons to repair and hold a split tie together.

A surface application of a coated fiber glass material will be considered for extending the tie life.

This work may lead to other methods of holding together a split tie and they shall be considered.

Tests shall be conducted on all methods which prove to be practical, in track under traffic.

1.3 Rehabilitation of Entire Tie

This research combines the rehabilitation of a tie with both tie plate cutting and splitting defects in one operation as well as where there is limited decay. The results of the research from the two previous sections shall be applied with further research of reworking or restrengthening the entire tie, cutting out and filling small areas of decay and creosoting the entire tie.

The research shall consider preparing a "used" tie specification to be used as a guide in the selection of whole ties removed from the track which are to be rehabilitated. This specification will be empirical at this point, however, as methods and related costs are developed, and experience is had with the rehabilitation of ties, the specification shall be revised. Inspection of work sites on several railroads shall be made to observe and record the condition of the ties removed and those judged suitable for rehabilitation.

A method shall be developed to determine the amount of decay within a tie to supplement the visual method now employed in order to determine the condition of the tie and therefore its suitability for rehabilitation. A number of ties which are judged to be decayed by visual method shall be obtained and used in testing the developed method or equipment.

A more complex plant will be required to rehabilitate the entire tie than needed to rehabilitate a tie due to just plate cutting or just splitting. Therefore, this research shall determine the market for rehabilitated ties by a survey of the railroads in the States using the two reports "Refurbishment of Railroad Crossties" and "U.S. - U.S.S.R., Track and Rail Metallurgy Information Exchange" as guides.

Determination shall be made as whether or not there are railroads or a group of railroads interested in establishing a plant for rehabilitating ties. The latter group should have a common connection where a plant could be built and operated. The support of a plant may take the form of a long term guarantee or sharing the cost of a construction and operation. Perhaps a contractor would be willing to construct a plant if he were guaranteed sufficient work.

This research shall determine the number of ties suitable and available for rehabilitation over the next ten, fifteen and twenty years, and from which railroads.

2.1 Disposal
One-Piece vs. Three-Piece Removal

Ties are removed from the track in either one piece or three pieces, except for those that disintegrate upon removal. Full-length ties can be more readily sold or disposed of while there is but very limited demand for short or 3-piece ties.

This research shall study the effect on the track and the economics of the two methods of tie removal in various conditions of ballast and tie (i.e. plate-cut, soft ties, split, etc.). Different manufacturers' tie removal machines have different effects on the track. Determine this effect or extent of disturbance and its significance. Severely plate-cut ties present a difficult problem since the rail must be raised out of the tie to clear the tie when the tie is pushed or pulled out. What should be done? Determinte the costs of the two methods.

Determine whether there is any additional amount of track surfacing and lining required in one-piece removal vs. three pieces and the relative costs.

This investigation will require field observation and measurement before the tie removals, during and after completion of the work including surfacing and lining. The use of a track measurement car may be required.

2.2 Reconstituted Tie

This research shall review efforts to reconstitute ties and investigate the work done on the Cedrite tie which is now under testing at the FAST test track at Pueblo, Colorado. The "Glue Lam" tie as proposed by the U.S. Forest Products Laboratory in Madison, Wisconsin, shall also be investigated. Assist the AAR Special Committee on ties to obtain a number of these ties for testing in the laboratory and at the FAST test site. The number of ties to be tested shall be determined after reviewing the results of prior tests.

The research shall investigate further the reuse of discarded ties as a source for manufacture of a reconstituted tie. Other processes which may lead to the reuse of discarded ties shall be considered.

2.3 Uses for Discarded Ties

The research shall make a market analysis for the possible sale of both one-piece and three-piece ties in the United States. Included in this work will be a determination of the number of marketable ties available for sale. The analysis shall include a pricing report.

The use of ties for landscaping shall be investigated. The possible uses shall be listed and other possibilities developed. The preparation of a booklet describing the uses, with sketches, especially the proper design of retaining walls would aid in marketing.

The use of ties for fuel is the subject of a report entitled "Recycling of Old Crossties for Industrial Fuel". [8] This shall be reviewed and brought up to date. There has been considerable interest in the use of ties for fuel in Minnesota. This should be followed up and tests made.

2.4 Ties with No Further Use

The research shall investigate the disposal of ties which have no further use or have physical limitations which prevent disposal by other more useful means. Consider leaving the tie in one or three pieces along the right-of-way; grinding the ties into chips and spreading along the right-of-way; and burying the tie along the right-of-way or in central disposal areas. These methods of disposal must consider the environmental effects of the leaching of the creosote into the ground and the fire hazard of leaving ties or chips along the right-of-way.

Consideration shall be given to applying a non-polluting chemical to hasten the decay.

Other disposal methods which may come to light during the research shall be studied.

TECHNICAL DISCIPLINES AND FACILITIES REQUIRED

The types of personnel with a description of their qualifications required for the Timber Cross Tie Rehabilitation and Disposal research program are as follows:

Manager

To direct the entire project and coordinate the efforts of the various parts. This person should, in addition to his leadership ability, be experienced in research and the field of wood technology.

Librarian

Required to research the publications and reports of the past. One person should perform this task for the entire problem as the subjects are interrelated. This person must be an experienced research librarian.

Forest Products Specialist

Experienced in the field of wood technology.

Engineer

A railroad civil engineer with track maintenance experience.

Laboratory Technician

Familiar with the testing of wood and wood products.

Market Economist

Experienced in the field of market analysis, preferable for railroad products.

Industrial Engineer

Experienced in costs and estimating costs of plant construction, processes and operation.

Power Plant Fuel Engineer

An engineer with power plant experience and with knowledge of fuel and boiler firing.

Landscape Architect

Experienced in the development of outside areas and uses of timber for practical and aesthetic needs.

Forest Service Specialist

A specialist in prevention and control of brush and forest fires.

Agronomist

A person with the experience to evaluate the effects of decaying creosoted ties and chips on the soil.

Environmental Specialist

Experienced in the effects on the environment by the various disposal methods.

Other assistance and facilities required are:

Participating Railroads

Assistance from at least three railroads in different parts of the country in the performance of "in track" testing.

Participating Manufacturers

The help of material manufacturers and suppliers to the railroad industry to make the materials available.

AREA Committee 3

Assistance of this committee in securing acceptance by the railroad industry of the research results as well as providing advice during the research.

AAR

Assistance by the special AAR committee on ties by providing advice during the research and obtaining the cooperation of the railroads.

PERIOD OF PERFORMANCE

All parts of the rehabilitation research program and the research program for disposal of ties can be progressed simultaneously and should take three years at which time there should be an indication of success. The greatest effort will take place in the first year during which time new products or methods will be developed. The second and third years will be devoted to laboratory and field testing. Final results may not be known until up to 15 years and the work in the intervening years will consist principally of periodic observations.

TECHNICAL EFFORT

The estimated technical effort to conduct the research on Timber Cross Tie Rehabilitation and Disposal is shown in Table 3 and Figure 1.

TABLE 3: TECHNICAL EFFORT

	Manpower	Testing Laboratory	Field
1. Rehabilitation			
1.1 Tie Plate Cutting			
In Field	$214,000	$6,000	$4,500
In Plant	173,000	6,000	4,500
1.2 Splitting			
In Field	206,000	3,000	3,000
In Plant	156,000	3,000	3,000
1.3 Rehabilitation of Entire Tie	352,000	30,000	18,000
2. Disposal			
2.1 One-Piece vs. Three-Piece Removal	61,000	--	12,000
2.2 Reconstituted Ties	483,000	25,000	14,000
2.3 Uses for Discarded Ties	128,000	5,000	--
2.4 Ties with no Further Use	169,000	15,000	6,000
Total	$1,942,000	$93,000	$65,000
Grand Total		$2,100,000	

NATURE OF END PRODUCT

It is anticipated that the end product of the timber cross tie rehabilitation portion of this research project will increase the life of a tie by five to fifteen years and that the method will be economically justifiable.

The research for tie disposal should produce a method of disposing of ties at less than present cost or at least provide an environmentally acceptable method at a cost no greater than that which the railroads are now paying.

ANALYSIS OF SAVINGS AND BENEFITS

The potential annual savings for each of the parts of this research project are shown in Table 4.

TABLE 4: POTENTIAL ANNUAL SAVINGS

1. Rehabilitation (See Table 5)		
	1.1 Tie Plate Cutting	
	In Field	$12,700,000
	In Plant	1,000,000
	1.2 Splitting	
	In Field	6,800,000
	In Plant	1,900,000
	1.3 Rehabilitation of Entire Tie	600,000
TOTAL		$23,000,000
2. Disposal (See Table 6)		
	One-Piece vs Three-Piece Removal	$ 1,000,000
	Reconstituted Ties	
	Use for Discarded Ties	23,000,000
	Ties with no Further Use	3,000,000

If each of the parts of the rehabilitation research is successful it is conceivable that $23,000,000 could be saved annually. This figure represents 8.2 percent of the 30,000,000 new ties required annually.

The savings from successful research on disposal cannot be similarly added because the same tie was considered for more than one research project.

Likewise, the savings from all parts of the rehabilitation research cannot be added to those from the disposal research because a rehabilitated tie is not available for disposal and vice versa.

A conservative estimate of annual savings from this entire research project would be $23,000,000.

TABLE 5: REHABILITATION POTENTIAL ANNUAL SAVINGS

Based on saving the purchase of the indicated number of ties at $16 from the annual total of 30 million new or rehabilitated ties.

		No. Rehab. by Ind. Method (1,000)	Cost to Rehab. ($)	Annual Savings ($ Million)
1.1	Tie Plate Cutting. 19% removed for this cause of which 25% are repairable.			
	Field Rehabilitation			
	Rail Relay ($2.50 Mat'l + $1.50 Labor)	220	4.00	2.6
	Tie Program ($2.50 Mat'l + $3 Labor)	960	5.50	10.1
	Plant Rehabilitation	220	11.40 (1)*	1.0
1.2	Splitting. 17% removed for this cause of which 16% are repairable.			
	Field Rehabilitation	600	4.69 (1)*	6.8
	Plant Rehabilitation	240	8.25 (1)*	1.9
1.3	Entire Tie			
	Capacity of one plant (1)	210	13.00 (1)*	0.6
			Total	$23.0 million

*Escalated to 1979 cost.

TABLE 6: DISPOSAL POSSIBLE ANNUAL SAVINGS

Based on: disposing of 30 million ties annually; sale where possible at $1 per tie; and loading out cost for removing from ROW at $0.90 per tie.

	No. Ties (1,000)	Cost Per Tie ($)	Possible Saving ($ Million)
2.1 One-Piece vs. Three-Piece Removal. Assume research increases number of ties removed in one piece.	1,000	(1)	1.0
2.2 Reconstituted Ties. No disposal savings quantifiable			
2.3 Uses for Discarded Ties. Potential for landscaping, fuel, etc. (assume 7 million ties too decayed for any use)	23,000	(1)	24
2.4 Ties with No Further Use. Disposed of along ROW as follows:			
Remain along ROW	1,500	0	1.4
Burn	1,500	0.15	1.1
Chip	1,500	1.20	(0.4)
Bury	1,500	0.32	0.9
		Net Subtotal	3.0

SUMMARY OF SAVINGS AND BENEFITS

1.	Cost of R&D	$2,100,000
2.	Time of R&D	3 years
3.	Accidents Prevented in 5 Years	0
4.	Annual Net Savings	$23 million
5.	Annual Savings - First 5 Years	$115 million
6.	Present Value of Annual Savings - First 25 Years	$208 million
7.	Benefit/Cost Ratio	99

FIGURE 1: SCHEDULE

	Task	R&D Cost ($1,000)	Years 1 2 3
1.	Determine State-of-Art	70	(Engr., For. Prod. Spec.)
2.	Literature Search	40	(Libr.)
3.	Plan Research Program	60	(Engr., For. Prod. Spec.)
4.	Identify Potential Products and Processes	200	(Engr., For. Prod. Spec., Ind. Engr., Landscape Architect, Agron. Environ., Econ.)
5.	Lab Test Potential Products and Processes	200	(Engr., For. Prod. Spec., Tech'n, Fuel Engr.)
6.	FAST Tests	550	(Engr., For. Prod. Spec.)
7.	Railroad Tests	800	(Engr., For. Prod. Spec., Ind. Engr., Landscape Arch., Agron, Environ, For. Svc. Spec.)
8	Evaluate and Recommend	180	(Engr., For. Prod. Spec. Econ., Ind. Engr.)
	Total	$2,100	

( ) Indicates number and discipline of people assigned to task

STRATEGY FOR IMPLEMENTATION

Upon completion of this research project, its results should be sent to all railroads and related industry. The trade magazines should receive it and be asked to include articles on it in their publications.

Soon after the publicizing of the research results seminars should be held in several places in the country to which the railroads and other interested parties would be invited. The material for the seminars should be well prepared using the latest visual aids. Prepared audiovisual materials could be loaned to maintenance-of-way clubs and interested engineering societies.

INVOLVING CONCERNED ELEMENTS OF CLIENT SECTORS

Voluntary work on the research could be asked of the AAR, AREA, power industry associations, the railroads and related industry. Where significant cost is involved, such as may be encountered in testing in the track under actual loads, compensation to the railroads may be required.

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IV SPECIAL TRACKWORK MAINTENANCE

OBJECTIVES

The objective of this research is to analyze the various problems encountered in the maintenance of special trackwork, and to develop improved maintenance methods. The items to be addressed relating to special trackwork in this research include switches, frogs, railroad grade crossings (type, design and metallurgy) and methods for maintaining track geometry for each item.

BACKGROUND

In 1976, 842 train accidents were attributed to special trackwork on Class I and Class II railroads, constituting about twenty percent of the total of 4260 accidents related to track, roadbed and structures.(1)

Damages to track and equipment amounted to $7,218,000, or 8.4 percent of the total cost of all accidents in this category. This figure does not include accident clean-up costs, damages to lading, or intangible costs related to train delays, inability to meet schedules and loss of business to competing modes.

It is estimated that for the approximately 215,000 miles(2) (See Table 1) of main track (1977), there are .82 turnouts per mile of main track and 2.65 turnouts per mile of other tracks, yielding a total of 441,300 turnouts (215,000 x .82 and 100,000 x 2.65) to be maintained. Total turnout length is estimated at 13,707 miles in all tracks, representing 4.4 percent of the total track miles. Thus, an estimated 4.4 percent of the total track length was the cause of 8.4 percent of the total damage costs to track and equipment. Applying these same percentages to damages to lading and other items mentioned above, it is evident that special trackwork accounts for at least $15 million(3) annually in railway operating expenses related to train accidents.

In addition to these costs are the annual maintenance costs for special trackwork. A study has recently been published by AREA Committee #22 to develop a system for computing relative maintenance workload values on various track sections. It is entitled "Developing the Maintenance Workload and Force Requirements Using a Modified Equated Mileage Parameter Taking into Account the Various Variables".(4) This study updates and refines a former

AREA study on comparative track values. The factors selected in the new study that have a significant effect on the values of track equivalents are as follows:

1. Category of track
2. Speed, freight and passenger
3. Tonnage - annual gross ton miles
4. Curvature
5. Rail weight and whether jointed or CWR
6. Heavy axle loads
7. Type and depth of ballast
8. Concrete ties
9. Track condition
10. Gradients
11. Track modulus
12. Winter conditions

An estimate of the total equated track miles for all U.S. Class I and Class II railroads has been computed, based on the parameters discussed in the aforementioned AREA study and is shown in Table 1.

TABLE 1: ESTIMATED EQUATED TRACK MILES U. S. CLASS I & II RAILROADS

1.	First main track, miles	200,000	@	1.00	=	200,000
2.	Other main track, miles	15,000	@	.80	=	12,000
3.	Other trackage, miles	100,000	@	.41	=	41,000
4.	Main track switch, each	176,300	@	.07	=	12,341
5.	Side track switch, each	265,000	@	.05	=	13,250
6.	Railway crossings, each (5)	2,500	@	.10	=	250
7.	Paved street or highway crossing (5)	219,000	@	.05	=	10,950
8.	Unpaved highway crossing (5)	142,000	@	.02	=	2,840
		Total E.T.M.				292,631

Certain revisions to the values published in the AREA study were required in the above computation. Data were not available on total miles of second, third and fourth main line tracks. A value of 0.80 was used to compute "other main track miles", based on the assumption that there are more second (double tracks) than third and fourth tracks. An average value of 0.41 was used for "other trackage miles" which includes passing tracks, branch line tracks and yard and switch tracks. The number of main line turnouts and side track turnouts were estimated by using a weighted average of .82 turnouts per mile of main track and 2.65 turnouts per mile of other track, based on figures obtained from a large eastern and a large western railway.

The above table indicates that a total of 25,841 (sum of lines 4, 5 and 6) equated track miles represents special trackwork consisting of turnouts and railway crossings, or 8.8 percent of the total equated mileage.

The total MOW costs which are related to trackwork, based on ICC accounting figures for 1976,[2] are given in Table 2.

TABLE 2: MOW COSTS RELATED TO TRACKWORK

ICC Acct. No.	Item	Cost ($Million)
201	Superintendence	263
202	Roadway Maintenance	146
212	Ties	280
214	Rails	185
216	Other track material	186
218	Ballast	64
220	Track Laying and Surfacing	760
266	Property Depreciation	164
269	Roadway Machines	139
271	Small Tools and Supplies	86
249	Signals & Interlockers	161
		$2,434

It may then be considered that 8.8 percent of the total MOW cost, or approximately $214 million represented the cost of maintaining special trackwork in 1976. This 8.8 percent of the total maintenance of way cost applies to special trackwork comprising only about 4.4 percent of the total track mileage. This dollar figure is far greater than the previously estimated $15 million cost of train accidents attributed to special trackwork. Thus, the largest potential for reducing railway costs for special trackwork seems to be centered around the development of new research designed to minimize special trackwork maintenance costs.

APPROPRIATE TECHNICAL EFFORT

A carefully planned research effort will be required to improve the present special trackwork design standards and maintenance practices. The most effective approach in developing a research plan would be as follows:

1. Review the history and development of past research
2. Review FAST technical data relating to improved designs for special trackwork, particularly research related to the movement of 100 ton cars.
3. Isolate and analyze the specific problem areas related to special trackwork maintenance, by individual component.
4. Investigate and make recommendations for improvement of present inspection procedures.

Considerable service testing will be required for improved trackwork components and revised maintenance techniques in this research program.

Performance tests should be conducted at the FAST track facility, and on several Class I railroads.

Subgrade and ballast support for track is more important in special trackwork than in regular running track. However, this support is being addressed in another project. For purposes of this research plan, adequate subgrade and ballast support will be assumed.

TASKS

1.0 Excessive switch point wear

1.1 Investigate the use of harder and more wear-resistant materials (alloy, heat-treated or a combination of both, and other materials).

Evaluate the effectiveness of using interchangeable manganese steel tips and manganese inserts on switch points.

1.2 Study the optimum geometry of switch points. Compare AREA designs with other designs, including the Samson point, the German point, and the Japanese point.

1.3 Investigate the recontouring of worn switch points and build-up by electric welding, including types of electrodes, amperage of current, and use of alloyed replaceable tips. Consider present usage of this technique in yard tracks, main line tracks, etc. Investigate the practicality of developing and using gages or templates for assessing the degree of switch point wear and, for welded points, the contour to which the worn point should be restored.

2.0 Stock Rail Maintenance Methods

2.1 Investigate the usage on various railroads of harder and more wear-resistant materials for stock rails, including heat-treated, alloy rails, and other materials. Obtain data on procurement costs, maintenance and replacement costs, and service life for several types of stock rails, and evaluate their relative economies.

2.2 Study the geometry of the stock rail relative to the switch point, and ascertain the optimum cost-effective combination. Examine current practices relative to the use of switch point protectors. Analyze the effectiveness of undercutting the lower portion of the head on the gage side of stock rails. Examine the practice of bending the stock rail on the turnout side to protect the ends of switch points.

2.3 Examine the usage of special tie plates, tie plate fastenings, and adjustable rail braces on the field side of the stock rail. Conduct comparative tests at the FAST facility to determine the most cost-effective design of these components, and to identify those designs which most effectively resist high lateral loads.

3.0 MOW methods at switches

3.1 Investigate the versatility and effectiveness of automated equipment that is currently available for maintaining special trackwork. Examine present inspection procedures (visual, manual, automated) to assess their relative merits and limitations. Specify the optimal ballast height in tie cribs that will allow for moderate snowfall accumulations without disturbing switching operations. Conduct a study of switch heater usage, including a comparative economic and engineering analysis of the various types of switch heaters that are currently available.

3.2 Identify and analyze switch lubrication and cleaning methods, including the usage of spray-on graphite lubricators. Determine the effectiveness of periodic build-up by electric welding of worn switch points and switch point heels. Assess the relative merits of lubrication and welding techniques for minimizing wear rates of switch components.

3.3 Review the utilization and effectiveness of all tools and gages that are employed for switch maintenance and adjustment. Identify design criteria for development of new or improved tools, gages and other instruments.

3.4 Analyze methods for tightening lock washers, Huck bolts, high strength bolts and other switch components. Relate the effects of train vibration and thermal expansion and contraction to the need for periodic tightening and adjustment of these components.

3.5 Investigate the advantages and disadvantages of welded joints versus bolted joints for maintaining switch alignment, eliminating low joints and reducing rail end batter. Conduct a study to determine whether heel blocks should be used together with high strength bolts and spring washers at a switch heel.

4.0 Excessive Frog Wear and Failure Rate

The objective of this research will be to determine the most suitable type of turnout frog for a given operating condition, and to determine the best methods of maintaining frogs.

4.1 Examine the effectiveness of using explosive hardening and press hardening techniques for prolonging the service life of frog points and wing contact areas. Determine the feasibility of developing durable, weldable cast inserts for decreasing frog point wear rates.

4.2 Examine methods to eliminate fatigue cracks in the flangeways of rail-bound manganese turnout frogs, particularly at railway grade crossings.

4.3 Investigate the cost effectiveness of butt welding main line rails together with frog wing rails, and closure rails with frog wing rails.[6]

5.0 Guard Rails

A research effort should be initiated to determine the optimum geometric shape or taper of guard rail flares. The lateral forces exerted by wheelsets on the flares should be measured using electric strain gage techniques. These measurements would then be used to arrive at a rate or slope of the flare which would accommodate high lateral loads imposed by 100-ton cars moving at 70 mph.

6.0 Frog Maintenance Methods

An analysis of the most cost-effective methods for frog repair should be made, and will depend on the amount of wear, the type of frog, and the general condition of the frog.

6.1 Conduct a study to determine those frog wear conditions that can be satisfactorily repaired in the field; consider the effects of traffic density conditions. Investigate the advantages of field versus shop repair and hardening methods. Examine the use of wire feed electrodes for increasing frog wear life. Include as items of study the replacement of broken rails on rail bound manganese wing rails, the plastic flow on spring rail frog points, the condition of spring rail frog points, the condition of spring rail hold-downs, the fishing surface wear in filler block areas, the welding required on bolted rail frogs to build up end batter, and the wear rates of frog bolts. Study the effects of elevating the wing rail contact areas to accommodate all types of wheel contours (new, hollowed, severely worn). Examine the usage of elastic stop nuts and their effectiveness in maintaining bolt tension.

6.2 Investigate the need for designing more efficient frog repair tools for field and shop situations.

6.3 Determine the most cost effective procedure for building up an inventory of spare frog parts, including an investigation of new and second-hand parts.

Throughout the foregoing design research, the possibility will be kept in mind of an entirely different concept in turnout design. This would involve an "inventive" breakthrough which is recognized to be a remote possibility, but one which should not be overlooked or given no consideration.

7.0 Inadequate Methods for Maintaining Track Geometry at Special Trackwork

The most common causes of poor track geometry at special trackwork are wide gage at switch points and frog points, poor cross level at the heels of switch points and frog points, and misalinement due to running or creepage of the adjoining rail or to lateral forces from poor cross level.

7.1 Investigate methods for designing improved fasteners to replace cut spikes for fastening special trackwork to ties. Devise techniques for improving and strengthening tie plates, long insulated plates, and rail braces. Measure the lateral forces exerted by 100-ton cars passing over special trackwork at high speed.

7.2 Examine the optimum size and spacing of ties, with regard to cost and performance characteristics. Consider the relative effectiveness of reducing or minimizing the present intensity of tie bearing pressure on the ballast. Study the selection and availability of various hardwood ties. Examine creosote treatment practices, including depth of penetration, possible carcinogenic effects, and alternative preservatives. Examine AREA documents to determine if recommendations are given for optimum tie size, length, spacing, species selection, treatment and curing, as related to special trackwork.

7.3 Study the present usage of gages for special trackwork measurements, and develop new ones if these are found to be inadequate. Review the extent to which automated equipment is used to make comprehensive repairs or adjustments. Specify additional tools that would reduce special trackwork maintenance costs.

TECHNICAL DISCIPLINES REQUIRED

The types of personnel, with a description of their qualifications, required for the Special Trackwork Maintenance research program are as follows:

Manager

To direct the entire project and coordinate the efforts of the various parts.

Research Librarian

Required to research past publications and reports. Should be familiar with technical and trade publications.

Lab Technician

Familiar with materials testing.

Market Economist

Experienced in the field of market analysis, preferably for railroad products.

Environmentalist

Experienced in the effects on the environment of the various research solutions.

Civil Engineer

A railroad civil engineer with experience in test planning, track construction and maintenance-of-way practices.

Metallurgist

A professional researcher experienced in the design, testing and research analysis of metal products.

Maintenance-of-Way Engineer

A railroad civil engineer with track maintenance experience.

Mechanical or Industrial Engineer

Familiar with metallurgical test procedures, research planning, track component design, preparation of technical reports, maintenance-of-way machinery.

PERIOD OF PERFORMANCE

It is estimated that one year will be required to conduct the literature search and to become acquainted with special trackwork plans and maintenance procedures on 6 or 8 railways having minimal derailments in this category. Two years will be required to make tests in the field of lateral forces exerted on critical components of special trackwork by 100-ton cars, locomotives, etc. at a range of speeds, and to prepare reports of results. Two years will be required to test some special trackwork designs, at least one year of which would be concurrent with the preceding series of tests. Thus, it is estimated that a period of four years will be required to produce results that can be used by the industry. It is proposed that service tests of special component designs be conducted on a few heavy traffic railroads. Observations and service evaluation would continue on these until definite results are obtained, which will require an additional two or three years.

TECHNICAL EFFORT

The timing schedule and estimated cost for each phase of the work is shown in Figure 1.

It is estimated that $3.4 million will be required to execute this research plan, including preparation of reports, recommendations and results of railroad service and FAST tests under traffic. The number and discipline assigned to each task is shown in Figure 1.

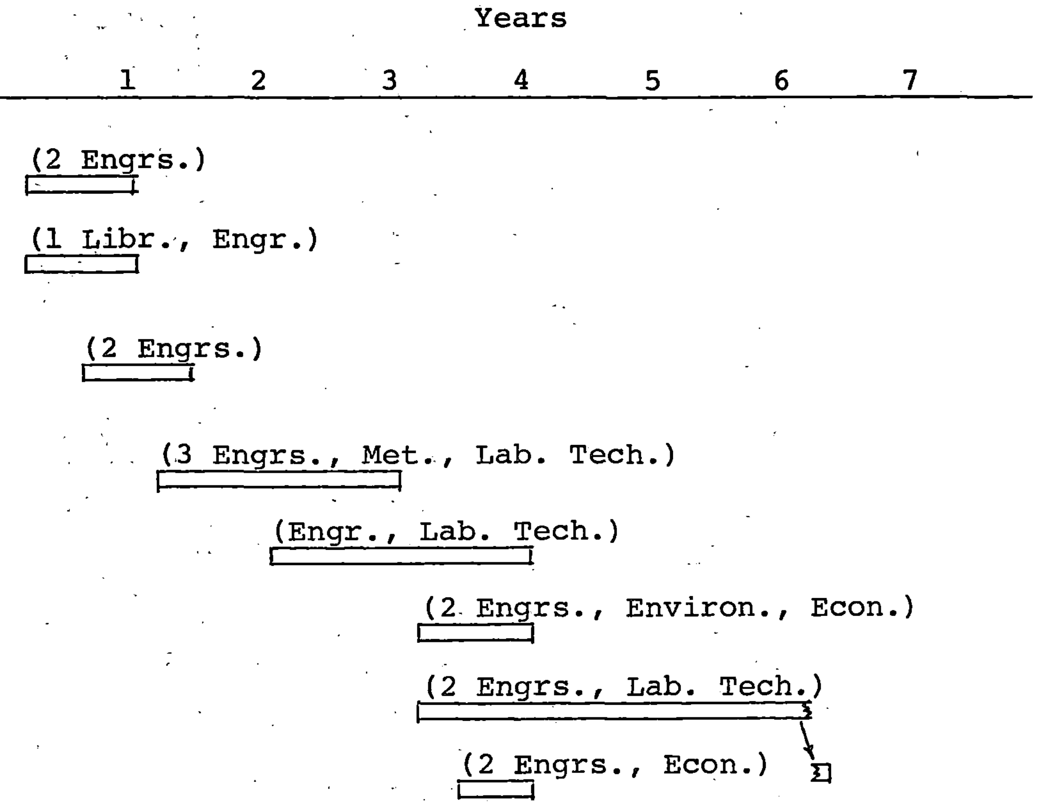
NATURE OF END PRODUCT

Improved, more reliable trackwork requiring less maintenance will result from this research plan. Better ways of maintaining special trackwork will be developed. Improved gages and tools will be developed. If the recommendations resulting from this research plan are adopted by railways, the number of derailments attributed to special trackwork will be decreased.

FIGURE

	Task	R&D Cost ($1,000)
1.	Review Design and Maintenance Practices	200
2.	Literature Search	170
3.	Plan Research Program and Tests	200
4.	Conduct Research Program and Tests	450
5.	FAST Tests	950
6.	Evaluate Results	200
7.	RR Service Tests	850
8.	Prepare Report of Test Results	135
9.	Contingencies	245
	Total	$3,400

1: SCHEDULE



( ) Indicates number and discipline of people assigned to task

ANALYSIS OF SAVINGS AND BENEFITS

The potential annual savings for each part of this research are summarized in Table 3 below:

TABLE 3: POTENTIAL ANNUAL SAVINGS

		$ Million
1.0	Excessive Switch Point Wear	7.5
2.0	Stock Rail Maintenance Methods	1.7
3.0	MOW at Switches	3.2
4.0	Excessive Frog Wear and Failure Rate	5.5
5.0	Guard Rails	0.6
6.0	Frog Maintenance Methods	2.1
7.0	Track Geometry Maintenance	5.4
	Total	26.0

If each of the parts of the research is successful, it is conceivable that $25 million could be saved annually.

An analysis of the derivation of these estimated annual net savings for this research plan is given below.

Assume annual costs of $15 million in accidents and $214 in maintenance of way expenses for special trackwork, as derived in the "Background" section of this report. An estimate has been made of the breakdown of these costs by switch components, corresponding to research tasks 1.0 - 7.0, and is summarized in Table 4.

Improved maintenance procedures, accounting for half of the savings from this research, can be adopted upon completion of this research project, but savings from improved designs of switch points, frogs, etc. will increase over a number of years as these products are phased in. For the purpose of estimating savings, it is assumed that 10% of special trackwork is replaced annually with components of improved design and that after 10 years a total of $25 million in annual savings will be realized.

A conservatively estimated annual net savings that might be achieved through the implementation of these research plans is presented in Table 5, and itemized according to research tasks. A total savings of $26.0 million has been computed.

SUMMARY OF SAVINGS AND BENEFITS

1.	Cost of R & D	$3,400,000
2.	Time of R & D	6 years
3.	Accidents Prevented in 5 Years	137
4.	Ultimate Annual Net Savings	25
5.	Annual Savings - First 5 Years	$81 million
6.	Present Value of Annual Savings - First 25 Years	$186 million
7.	Benefit/Cost Ratio	55

TABLE 4: BREAKDOWN OF ESTIMATED ACCIDENT AND M.O.W. COSTS FOR SPECIAL TRACKWORK

Task		% of Accident Costs	Amount ($ Million)	% of M.O.W. Costs	Amount ($ Million)	Total ($ Million)
1.0	Excessive Switch Point Wear	50	7.5	20	42.8	50.3
2.0	Stock Rail Maintenance Methods	15	2.2	15	32.1	34.3
3.0	M.O.W. Methods at Switches	-	-	10	21.4	21.4
4.0	Excessive Frog Wear and Failure Rate	30	4.5	15	32.1	36.6
5.0	Guard Rails	5	0.8	5	10.7	11.5
6.0	Frog Maintenance Methods	-	-	10	21.4	21.4
7.0	Track Geometry Maintenance	-	-	25	53.5	53.5
	Totals	100%	$15.0*	100%	$214.0*	$229.0

*Based on figures derived in "Background" of this plan.

TABLE 5: ESTIMATED ANNAUL NET SAVINGS FOR EACH RESEARCH TASK

Task		Annual Costs (Table 4) ($ Million)	% Savings from Research Plan	Total Savings ($ Million)
1.0	Excessive Switch Point Wear	50.3	15	7.5
2.0	Stock Rail Maintenance Methods	34.3	5	1.7
3.0	M.O.W. Methods at Switches	21.4	15	3.2
4.0	Excessive Frog Wear and Failure Rate	36.6	15	5.5
5.0	Guard Rails	11.5	5	.6
6.0	Frog Maintenance Methods	21.4	10	2.1
7.0	Track Geometry Maintenance	53.5	10	5.4
		229.0		26.0

Strategy for Implementation

Manufacturers of special trackwork will be involved in many phases of this Research Plan, particularly in producing improved special trackwork for evaluation and testing. Those involved and others will be informed of improved special trackwork that evolves from this Research Plan so they can incorporate such improvements in their products. Likewise, manufacturers of gauges and tools will be involved in and informed of improvements in these products that will result in better maintenance of special trackwork.

Research will be conducted on some railroads and testing will also be conducted on some railroads and at FAST. Thus many railroads will be able to observe results first-hand on their own properties and will adopt successful ones. Results of this Research Plan will be published and through this means and observations at FAST the results will be made available to the industry.

Involving Concerned Elements of Client Sector

Conditions on operating railroads will be studied during the early phases of this Research Plan to direct the focus of the Plan. Manufacturers of special trackwork will also be consulted.

Manufacturers will be involved in producing improved products and railroads will be involved in evaluating these improved products and improved tools and techniques for maintaining special trackwork.

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V BOLTED JOINTS

OBJECTIVES

This research is to develop improved designs and maintenance methods to upgrade performance of bolted joints and to prevent premature joint bar breakage. The research will address inadequate insulated joint performance, inadequate non-insulated joint performance, premature joint bar breakage and inadequate joint maintenance methods.

BACKGROUND

Although the majority of new rail is now installed as continuously welded rail (CWR), this practice has been followed for only the last decade or so and about 85% of the track mileage is still fastened together with bolted joints.[1] Bolted joints are used in most turnouts for convenience of field installation and replacement of worn components. Bolted joints are mandatory for insulated joints. Therefore, bolted joints are a fact of life for railroads and their design and maintenance are of paramount concern. Bolted joints represent a discontinuity in the rail and even the strongest designs are less strong and stiff than the rail itself. This reduced strength and stiffness of bolted joints, especially with poor ballast and subgrade support, combine with high center-of-gravity cars and truck centers that coincide with the 39-ft length of rail to cause the present-day phenomenon of "rock and roll". Heavy, 100-ton cars accentuate joint problems.

Bolted joints have always caused problems, hence the accelerating trend to CWR. Bolts become loose and even fall out; joint bars break; bars and the rail wear, especially when the joint gets loose; and defects in the rail occur at a much greater frequency within the joint bar area than they do outside this area.[1] Rail end batter is a unique problem with bolted joints.[2]

Insulated joints have always been a particular problem. They are necessary at the ends of signal circuits and cannot be replaced by welds. The insulating materials used in these joints are subject to accelerated wear and in some heavily travelled areas must be replaced every few months.[2] When insulated joints get loose and dirt gets in the components wear accelerates. The practice of bonding insulated joints with epoxy adhesives, although considerably more costly originally, shows promise for greatly increasing the life of insulated joints. (2)(9)

Support from ballast and subgrade is recognized to be important for joint performance, but this subject is being studied in other projects.

Of the $186 million in "Other Track Material" maintenance expense in 1976, [3] it is estimated that 50%, or $93 million, is attributed to bolted joints. Of the $760 million of "Track Laying and Surfacing" expense [3], an estimated 16%, or $120 million, is attributed to bolted joints.

One hundred accidents in 1976 [4] were directly attributed to joint bar and bolt problems. An additional 152 accidents were attributed to rail problems within the joint bar area. Some of the latter problems would be solved by bolt-hole crack prevention and restraint research to be done by others, but it is estimated that about one third or 50 of these accidents were caused by factors that are within the scope of this research plan. "Cross Level of Track Irregular at Joints" caused 505 accidents in 1976. [4] It is estimated that 400 of these accidents could be prevented by improved joint performance. The resulting 550 accidents caused an approximate damage to track, structures and equipment of $16.1 million. [4] The total losses due to these accidents is estimated to be about $34 million. [5]

Thus, approximately a quarter of a billion dollars can be attributed annually to bolted joint maintenance and accident costs. Additional costs due to delays to traffic during maintenance and clearing of accidents and loss of customers are also substantial, but are difficult to quantify. Furthermore, joint defects, such as low and irregular joints, induce excessive wear in rolling stock.

APPROPRIATE TECHNICAL EFFORT

Research on this subject is divided into two major parts:

1. Design

2. Maintenance

1. Design

Research the bolted joint problem to obtain true performance/cost data under present conditions for various types of bolted joints. These will include insulated and non-insulated joints, both of the glued and non-glued types.

Compare this performance/cost data with similar data for field welding by the thermite and mobile flash-butt weld processes and for picking up the jointed rail, transporting it to a welding plant, cropping and welding it in the plant, transporting it back to the site and relaying it.

Investigate improved designs and materials for bolted joints. Explore approaches to achieving stronger and stiffer joint bars both by geometric changes to increase the sectional properties of the bars and material changes to increase their strength and stiffness.

Investigate improved fasteners. Explore stronger bolts that will permit tighter joints and reduce the incidence of bolt breakage. Investigate improved lock washers and special fasteners such as Huck fasteners that prevent the fasteners from coming loose.

Investigate improved adhesives for glued joints that are stronger, quicker-curing preferably without the need for heat application, that are more tolerant of field conditions such as dirt, and that are less temperature-sensitive.

Explore improved insulating materials that are more resistant to wear and atmospheric and track conditions.

Analyze the economics of the higher-performing components that will probably cost more than presently used components but that should reduce failures and maintenance costs.

Perform laboratory tests on materials and designs that show the most promise for improving the performance of bolted joints. Manufacturers' data on improved materials and designs will be reviewed. Additional laboratory tests by manufacturers may be encouraged and funded if necessary. Monitor such tests carefully.

Conduct tests at the AAR Laboratory. These will include rolling load tests and other tests usually conducted to evaluate bolted joints.

Install joint bars and associated components that show the most promise from laboratory tests in the FAST track. Monitor performance in this high-intensity service closely and compare with the performance of standard components.

Make test installations of promising improved products on operating railroads in heavy tonnage locations where more conventional bolted joints have had problems. Follow these installations closely.

Evaluate the results of all tests. Assess the economics of the probably more costly but longer lasting components that require less maintenance. Develop recommendations for improved bolted joint designs.

Leave test installations in place at FAST and on railroads for continuing evaluation under long-term service.

2. Maintenance

Investigate present maintenance practices relating to bolted joints on a number of representative railroads. This will include frequency, method and cost of inspection and maintenance. Develop accurate performance/cost data for various present maintenance strategies. This investigation can be conducted concurrently with the research on present design in 1, above.

Investigate improved methods and tools for inspecting and maintaining bolted joints. Explore the possibility of a device that can test joints for tightness and integrity while travelling over the rails at a reasonable speed. Investigate improved, faster machines for tightening bolts to prescribed torques. Where the need for a particular non-existant tool is identified, manufacturers of similar tools will be encouraged to develop it. In some instances, where it is deemed to be in the industry's interest, funding for such development may be provided.

Test new inspection/maintenance tools at the FAST track and on representative railroads.

Establish programs to introduce the new inspection/maintenance tools and techniques on representative railroads or sections of railroads. Keep accurate performance/cost data and compare with present practice so that the economics of the improved tools/methods can be assessed.

Make an analysis of the effectiveness of the improved inspection/maintenance tools and techniques so that recommendations for the conditions under which they should be adopted by the industry can be made. Develop specific guidelines for bolted joint inspection/maintenance for various classes and conditions of track and various operating conditions including weight of cars, speed and density of traffic.

TECHNICAL DISCIPLINES AND FACILITIES REQUIRED

The types of personnel with a description of their qualifications required for this research plan are as follows:

Manager

To direct the entire project. In addition to managerial abilities, this individual should be familiar with bolted joints and should be able to work with railroads.

Librarian

An experienced research librarian to determine what has been published on this subject.

Track Engineer

An engineer familiar with trackwork, especially joints, construction and maintenance.

Metallurgist

Familiar with trackwork materials, heat-treating and alloys.

Chemist

Familiar with insulating and bonding materials.

Laboratory Technician

Familiar with laboratory testing of bolted joints and insulating and bonding materials.

Technician, Field

Familiar with instrumentation and testing in a railroad environment.

Economist

To make economic analyses of improved joints and maintenance practices.

Other assistance and facilities required are:

Railroads

Assistance from several railroads in researching present joint performance and problems. Cooperation in testing improved joints in their track.

AAR Laboratory

Test proposed improved designs on rolling load tester and other equipment.

FAST Test Loop

Testing of proposed improved joints in this accelerated test facility.

Manufacturers

Cooperation from manufacturers to identify, develop and manufacture improved joint products.

AREA Committees 4, 5 and 16

Cooperation from these committees during study of joint problem, testing and introduction of improved designs and practices.

PERIOD OF PERFORMANCE

It is estimated that this research plan can be executed in about three years. The estimated time for accomplishing the various tasks is shown on Figure 1.

TECHNICAL EFFORT

This research plan is estimated to cost about $2.2 million. The number and disciplines of the people assigned to each task and the cost of this manpower and associated construction, testing and manufacturing are shown on Figure 1.

NATURE OF END PRODUCT

This research will produce adequate information to judge which of the following is the best course of action: Maintain present jointed rail, field-weld or plant-weld existing jointed rail. It will produce improved designs of bolted joints - both insulated and non-insulated - including a field-assembled bonded joint that is as strong and durable as a shop-assembled unit. It will also develop improved joint maintenance tools/methods.

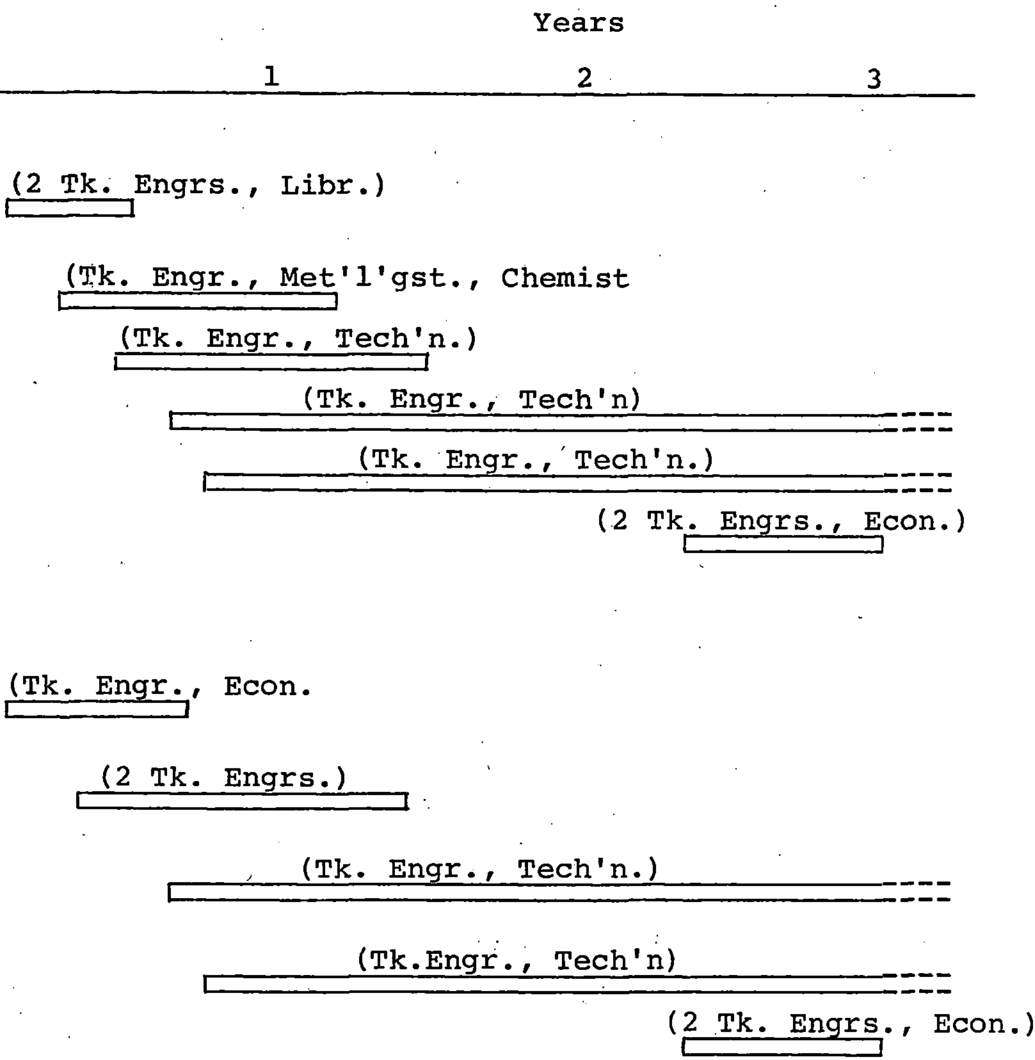
ANALYSIS OF SAVINGS AND BENEFITS

Even if research efforts of this plan produce non-insulated joints that are markedly superior to present joints, it is anticipated that such improved joints will not be installed in sufficient quantities to substantially affect the present population of some 70 million bolted joints for some years. A wholesale changeout of existing bolted joints to improved designs could hardly be expected. New rail is predominately installed as CWR as pointed out before. Thus, the principal market for improved non-insulated bolted joints

FIGURE 1:

Task	R&D Cost ($1,000)
1. Improve Design	
a. Research the Problem	100
b. Investigate Improved Designs/Materials	200
c. Lab Tests	150
d. FAST Tests	300
e. Railroad Tests	300
f. Evaluate and Recommend	150
2. Improve Maintenance	
a. Obtain Performance/Cost Data with Present Maintenance Practice	100
b. Investigate Improved Maintenance Tools/Methods	200
c. Test Improved Maintenance Tools/Methods at FAST	300
d. Test Improv. Maintenance Tools/ Methods on Railroads	300
e. Evaluate and Recommend	100
Total	$2,200

SCHEDULE



( ) Indicates number and discipline of people assigned to task

would be for joining strings of CWR in the field (where non-field welded) and for replacing broken and excessively worn joint bars. It is estimated that such improved joints would be installed at a rate of one million per year, that they would cost 20% more than existing joints, but that they would reduce maintenance costs and joint-related accidents by 75%. It is assumed that such improved non-insulated joints would be developed during the first year of this project and that one million would be installed during the second year and each year thereafter.

Insulated joints have proportionately more promise for savings benefits because they are more costly and because present designs must be repaired or replaced frequently. This is true despite the fact that they are much fewer in number than non-insulated joints. It is estimated that there are about 1-1/4 million insulated joints on American roads (approximately 50,000 highway crossings with active warning devices (7) and eight insulated joints per crossing; 114,500 miles of signalled track (8) with an average of six insulated joints per mile to account for turnouts, railway crossings, etc.; plus an estimated 160,000 insulated joints in yards, interlockings, etc.). It is further estimated that each of these insulated joints is replaced or at least has its insulation renewed an average of every five years. Assuming the research plan develops a system for field assembling a bonded insulated joint for $120 (6) that is as sound and durable as a shop-assembled joint that costs $210 (6) to produce and field weld into the track, a saving of $90 per joint can be realized. Thus, an annual saving of $22.5 million by field assembling joints instead of shop assembling would result. Furthermore, maintenance of the bonded joints is estimated to be $10 less annually than for the non-bonded joints they replace. For purposes of estimating savings it is assumed that a successful field-assembled bonded joint is developed and that during the first year of implementation of this program one-fifth of the insulated joints, or 250,000, are replaced with this new joint and each of the succeeding four years until all insulated joints are essentially changed over to the improved design. Thereafter, the improved joints that are estimated to last an average of ten years compared to the present average of five years for non-bonded insulated joints will reduce annual maintenance expense.

Savings estimated to result from successful execution of this research plan and implementation of the findings are as follows:

Non-Insulated Joints	
Maintenance	
Other Track Material	$93 million/yr.
Track Laying and Surfacing	$120
	$213 Million ÷ 70 million joints = $3/joint/year

Reduce by 75% = $2.25/joint/year

Estimate present joint costs	$40	
Estimate improved joint costs	$48	(20% more)
	$ 8	increase

Accidents

$34 million ÷ 70 million = $0.49/joint

Reduce by 75%=$0.36/joint

Maintenance and Accidnet Savings

First five years -	($5 million)
Present Value First 25 years -	$122 million

Insulated Joints

Installation and Maintenance Savings

First five years -	$130 million
Present Value First 25 years -	$206 million

Summary of Savings and Benefits

1.	Cost of R & D	$2,200,000
2.	Time of R & D	3 years
3.	Accidents Prevented in 5 Years	75
4.	Savings - First 5 Years	$125 million
5.	Present Value of Savings - First 25 Years	$328 million
6.	Benefit/Cost Ratio	149

STRATEGY FOR IMPLEMENTATION

Many railroads will be involved during the investigative, testing and evaluation phases of this Research Plan. They will be eager to adopt improvements that will help overcome the vexing problems that they have with bolted joints. Reports of the results of this research plan will be published and conferences will be held to disseminate the results. A workshop(s) will be held to demonstrate the performance of improved joints and better ways of maintaining joints.

INVOLVING CONCERNED ELEMENTS OF CLIENT SECTORS

Railroads will be involved in most phases of the research plan as much of the investigation, testing and evaluation will be done on working railroads. Manufacturers of joint materials will be involved in developing, testing and manufacturing new designs and materials.

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VI BALLAST FOULING FROM EXTERNAL SOURCES

OBJECTIVE

An objective of this project is to identify and investigate the external sources of ballast fouling and to develop methods for preventing or controlling those fouling problems from airborne and waterborne sources.

Another objective of this research is to investigate current methods and costs for cleaning fouled ballast, and to develop new or improved ballast cleaning methods.

BACKGROUND

A sufficient depth of clean, well-drained ballast under all ties is a vitally important element of sound railroad track that can be maintained at minimum cost. A clean ballast section is necessary to provide a firm bearing for the ties, to evenly distribute wheel loads over the subgrade, to provide drainage to the track structure, to inhibit the growth of vegetation, and to provide track stability in the longitudinal, lateral, and vertical planes. When fouling occurs, fines fill the voids in ballast, destroying the drainage capability and providing a soil for the growth of vegetation. Moisture pockets often form in the ballast voids, contributing to frost heaving, physical and chemical deterioration of some types of ballast, and eventually to the general deterioration of ties, rails and fastenings. Moisture-laden fouled ballast loses its ability to evenly distribute the loads. Permanent deformation may occur as the ballast is forced into the subgrade.

Ballast fouling from external sources magnifies the problems created by other fouling mechanisms such as sand and mud pumping, upward percolation of subgrade, and abrasion of ballast pieces during the passage of trains. Wet, dirty ballast contributes heavily to the loss of line, surface, and superelevation. Track geometry must periodically be restored through spotting, smoothing, surfacing and reballasting operations.

Fouled ballast must either be cleaned periodically with expensive ballast-cleaning equipment, plowed from under the track, cleaned and replaced, or the track must be raised on new ballast while retaining the old ballast as sub-ballast. Because of the obvious costs involved in maintaining ballast in prime condition, these procedures are often neglected.

A list of cost factors related to the elimination of the ballast fouling problem is given below:

1. Ballast cleaning
2. Cost of ballast materials
3. Road bed stabilization
4. Spotting, smoothing, surfacing & reballasting (track geometry maintenance)
5. Labor and machine costs incidental to foregoing
6. Foreshortened life of ties, rails, fastenings

An attempt has been made to estimate the cost of ballast fouling from external sources, based on data obtained from FRA accident statistics for Class I and II railroads for the calendar year 1976, and from railway operating expense data compiled by the AAR for Class I railroads in 1976.(1)

Selected railway maintenance-of-way expense items that may include costs for eliminating the ballast fouling problem are listed as follows:(2)

TABLE 1: MOW EXPENSES RELATED TO BALLAST

I.C.C. Account No.	Item (Main Line, Side, Yard Tracks)	Total Cost for 1976 (Passenger & Frt) Class I Railroads ($ Million)
202	Roadway Maintenance	$146
216	Other Track Material	186
218	Ballast	64
220	Track Laying & Surfacing	759
221	Fences, Snowsheds, Signs	8
272	Removing Snow, Ice, Sand	32
		$1,195
	Rounded Off	$1,200

Assume 10% of these costs are related directly to ballast fouling from external sources or $120,000,000.

Train accidents (collisions and derailments) caused by roadbed defects or track geometry defects, for Class I and II railroads in 1976, were as follows:[3]

TABLE 2: ACCIDENTS RELATED TO BALLAST

FRA Cause Code	Cause	Total Accidents
101	Roadbed Settled or Soft	125
102	Washout/Rain/Slide/Flood Snow/Ice	42
114	Track Alinement Irregular	101
115	Track Alinement Irregular (Buckled)	100
116	Track Profile Improper	15
117	Superelevation Improper, Excessive, Insufficient	70
118	Superelevation Runoff Improper	6
119	Cross Level of Track Irregular (at Joints)	505
120	Cross Level of Track Irregular (Not at Joints)	288
		1252

Assume 4% or 50 of these accidents are related to ballast fouling from external sources.

The average cost per incident, including damages to track and equipment, clearing wrecks, loss and damage to freight, and injury compensation, is $40,000.[4]

Total Accident cost =	
50 x $40,000 =	$ 2,000,000
Add MOW costs from above	120,000,000
	$122,000,000

Assume 30% of this figure, or $37 million, represents the costs related to fouling from wind and waterborne materials, and 70% relates to fouling from excessive sanding or spilled lading.

APPROPRIATE TECHNICAL EFFORT

Tasks

The research on the subject of ballast fouling from external sources is divided into four major parts:

1. Fouling from airborne dust, dirt & sand
2. Fouling from waterborne soil and sediment
3. Fouling from excessive sanding and spilled lading
4. Ballast cleaning techniques

1.0 Airborne dust, dirt and sand

This part of the research concerns the development of improved or alternative approaches to prevent wind-blown particles from accumulating on the track structure and from spreading into and fouling the ballast section. A comprehensive literature search should be conducted for each of the following subject areas prior to the commencement of any research activity.

1.1 Plantings (trees, shrubs)

Investigate the degree of success or failure that has been achieved by various railroads, particularly in the southwest to control wind-blown sand and dust. Study the varieties of trees and shrubs which have been planted as shelter belts; examine the growth rates, costs, required annual maintenance, mortality rates, climatic & soil conditions, drainage characteristics and environmental impact for each variety. Determine the optimal pattern (spacing and width) required for trees and/or shrubs to minimize particle accumulations on the track structure. Calculate the quantities of wind-blown materials that will be diverted by various shelter belt designs. Establish guidelines for recommended plantings by geographic and climatic regions.

1.2 Fencing

Examine the present usage of fencing throughout the industry as a means of sand and dust control. Review A.R.E.A. specifications for their manufacture and installation. Study the relative merits of windward vs. leeward location; consider the effects of topography, metereological conditions, grades, embankments, and railroad alignments. Investigate various types of fencing materials (existing or new) including costs and required maintenance for each. Perform laboratory tests (wind tunnel) to examine velocity distributions, rates of deposition, particle sizes and gradations, dispersion of particles, etc. for several types of fencing. Compare theoretical with observed lab test results for each type of fencing.

1.3 Ditching or diking

Determine the effectiveness of constructing ditches and/or dikes by bulldozers in rows upwind of railroad tracks to catch blowing sand and dust. Assess the amount of maintenance and reconstruction required as deposits accumulate, depending on local conditions.

1.4 Spraying with petroleum

Examine the practice of spraying the windward side of sand dunes in desert regions with an appropriate petroleum or other product to stabilize shifting sands. Determine the requirements for re-spraying, including associated retreatment costs.

1.5 Conveying wind-blown material across track.

Investigate the possibilities for mechanically conveying deposited materials from the adjacent windward side of the railway track to the leeward side. Study the performance characteristics of various machines, including Jordan spreaders, ballast regulators, on-track ballast cleaners, etc. to determine if these machines could be equipped with elevating loaders to pick up sand & dirt from the windward ditches and convey it across the track to the leeward side.

1.6 Construction of covered shelters

Establish design parameters for the development of a relatively inexpensive, movable covered shelter, to be built over selected track sections as a protective barrier against shifting sands. Perform required field, lab, and materials testing for proposed designs. Examine the use of heavy gage corrugated metal plate sections and concrete foundations as one possible design solution.

2.0 Waterborne soil and sediment

This part of the research is devoted to developing methodologies for diverting or preventing sediment-laden water courses from encroaching upon the track structure and depositing soils, sand, etc. on the roadbed or ballast section.

2.1 Vegetative cover

Investigate methods of providing vegetative cover (grasses, shrubs, etc.) to stabilize exposed slopes and fields, particularly along cuts adjacent to the right of way. Examine growth rates, costs, climatic & soil conditions, drainage characteristics, topgraphy, and environmental impact for each type of grass, shrub, etc.

2.2 Improved drainage

Investigate methods for channeling water away from the track structure by constructing side ditches, subdrains, and dikes. Examine the effectiveness of providing vertical drainage through the ballast section and backfilling with free-draining sand. Study these construction techniques with regard to local subgrade and site conditions.

2.3 Cleaning culverts and bridge openings

Conduct a study to determine the relative rates of accumulation of sediments and other materials at culvert and bridge openings.

Estimate maintenance costs and re-cleaning cycles for various types of structures, according to climate, topography, geography, track geometry and cross section. Evaluate present manual and mechanized cleaning techniques.

3.0 Excessive sanding, spilled lading

It is recognized that these items contribute very significantly to the fouled ballast problem in certain areas. However the prevention of ballast fouling by these items is beyond the scope of this research plan.

4.0 Ballast cleaning methods

This section is devoted to a discussion of developing research plans to improve current ballast cleaning techniques.

4.1 Shoulder cleaning

Compare shoulder ballast cleaning practices employed by various railroads to determine the suitability and cost effectiveness of this practice for eliminating fouled shoulder ballast.

Examine shoulder cleaning operations on heavy tonnage lines, particularly on the low sides of curves. Study the effectiveness of shoulder cleaning performed in combination with track raises. Devise methods for improving the capabilities of ballast cleaning equipment under wet or muddy conditions.

4.2 Undercutting

Develop improved equipment designs and operating methods for accelerating the present rates of progress of track undercutting and for minimizing train delays. Devise techniques for minimizing wasted ballast, including possible improvements in screening methods. Consider methods of minimizing dust production during undercutting.

4.3 Sledding and plowing

Develop techniques for decreasing the amount of track occupancy time required for sledding and plowing equipment. Investigate the possibility of in-place rehabilitation of defective ties that are exposed by plowing operations. Consider methods to reduce the extent and duration of slow orders imposed after completion of sledding operations.

4.4 Surfacing Raise

Investigate methods of preventing fresh ballast layers from becoming contaminated by underlying fouled ballast materials. Study the maintenance cycles subsequent to track raising operations and consider methods for extending the period of time between raises. Devise methods for eliminating centerbound track and for minimizing deterioration of embankments and loss of ballast resulting from track raises.

TECHNICAL DISCIPLINES REQUIRED

The following is a listing of the types of qualified technical personnel who will perform the research activity for ballast fouling from external sources:

Manager

To direct the entire project and to coordinate the efforts of the various parts. This person should be familiar with railroad maintenance-of-way operations and with technical publications related to the various research tasks.

Research Librarian

Required to perform a comprehensive search for all research tasks. Should be experienced with technical and trade publications.

Botanist

Extensive knowledge of all types of plants, trees, vegetative cover, including climatic, topographic, meterological and environmental effects.

Maintenance-of-Way Engineer

A railroad civil engineer with track maintenance experience.

Industrial Engineer

Capable of analyzing the performance characteristics of railroad work equipment; must be able to make cost estimates for various machine operations.

Hydrologist

Experienced in the design and maintenance of drainage structures.

Soils/Geotechnical Engineer

Familiar with the fluid mechanics of windblown and waterborne soils, dune formation, erosion, etc.

Lab Technican

Familiar with materials testing and wind tunnel testing.

Market Economist

Experienced in the field of market analysis, preferably for railroad products.

Environmentalist

Experienced in the effects on the environment of the various research solutions.

Civil Engineer

A railroad civil engineer with experience in structural design, and earthwork & embankment construction techniques.

Other assistance and facilities required are:

Participating Railroads
Assistance from at least three railroads in different parts of the country in the performance of required testing.

Participating Manufacturers

The help of material manufacturers and suppliers to make the materials available.

AREA Committee 1 - Roadway and Ballast

Assistance of this committee in securing acceptance by the railroad industry of the research results as well as providing advice during the research.

AAR

Assistance by the special AAR committee on ballast by providing advice during the research and obtaining the cooperation of the railroads.

PERIOD OF PERFORMANCE

All parts of the research program can be progressed simultaneously and should take three years, at which time there should be an indication of success. The greatest effort will take place in the first and second years, during which time new products or methods will be developed. The third year will be devoted to laboratory and field testing. Final results may not be known until up to 15 years. The work in the intervening years will consist principally of periodic observations.

TECHNICAL EFFORT

The estimated technical effort to conduct the research on "Ballast Fouling From External Sources" is shown in Table 3.

NATURE OF END PRODUCT

It is anticipated that the end product of the "Ballast Fouling From External Sources" portion of the research project will be a reduction of surfacing requirements, an increase in rail and tie life, and a reduction in ballast requirements. Train accidents and maintenance-of-way costs related to ballast fouling will also be reduced. Other intangible benefits will include:

1. Extended work season
2. Reduced track possession for track maintenance
3. Strengthened track structure and reduced rolling resistance
4. Increased life of rail fastenings
5. Increased workability of track during periods of rainy weather

ANALYSIS OF SAVINGS AND BENEFITS

The potential annual savings for each of the tasks of this research project are summarized in Table 4.

TABLE 3 -

1.0 Airborne Dirt, Dust, Sand

- 1.1 Plantings
- 1.2 Fending
- 1.3 Ditching and Diking
- 1.4 Petroleum Spraying
- 1.5 Transport Sands Across Grade
- 1.6 Construct Covered Shelters

2.0 Waterborne Soil and Sediment

- 2.1 Vegetative Cover
- 2.2 Improved Drainage
- 2.3 Clear Culverts, Bridge Openings

4.0 Ballast Cleaning Methods

- 4.1 Shoulder Cleaning
- 4.2 Undercutting
- 4.3 Sledding and Plowing
- 4.4 Track Raise

TOTALS

GRAND TOTAL - $1,420,000

TECHNICAL EFFORT

Manpower	Lab	Field
100,000	-	-
90,000	15,000	15,000
80,000	-	10,000
40,000	10,000	15,000
40,000	-	15,000
90,000	20,000	25,000
100,000	-	-
85,000	-	20,000
50,000	-	-
140,000	-	15,000
150,000	10,000	15,000
90,000	-	15,000
150,000	-	15,000
$1,205,000	$55,000	$160,000

FIGURE 1: SCHEDULE

	Task	R&D Cost ($1,000)	Years (1, 2, 3)
1.	Determine State-of-Art	80	(Engrs.)
2.	Literature Search	50	(Libr.)
3.	Plan Research Program	50	(Engrs.)
4.	Identify Potential Designs, Products, etc.	300	(Bot., Engrs., Hydr., Environ., Econ.)
5.	Lab Tests	220	(Engrs., Lab. Tech'n.)
6.	Field Tests	480	(Engrs., Bot., Environ., Hydr.)
7.	Evaluate and Recommend	240	(Engrs., Econ.)
	Total	1,420	

( ) Indicates number and discipline of people assigned to task

TABLE 4: ANNUAL NET SAVINGS

Item	Potential Annual Savings
1.0 Airborne dust, dirt and sand 2.0 Waterborne soil and sediment	($1,000,000)
3.0 Excessive sanding, spilled lading (savings included in 4.0)	
4.0 Ballast cleaning methods	
4.1 Shoulder cleaning 4.2 Undercutting 4.3 Sledding and plowing	$5,650,000
4.4 Surfacing raise	$2,800,000
Total	$7,450,000

If each of the parts of the research is successful, it is conceivable that $7.45 million could be saved annually.

An analysis of the derivation of these estimated annual net savings for this research plan is given below.

1.& 2.	Assume 30% of annual costs of ballast fouling from external sources ($122 million form "background") equals annual costs related to airborne and waterborne materials, or $37 million	
	Assume implementation of research solutions results in 20% reduction in accident and M.O.W. costs, or $7.4 million. Annual savings = cost reduction ($7.4 million) minus annualized improvement costs ($8.4 million - Table 7) or	($1,000,000)
4.1-3	Assume 10% reduction in annual ballast cleaning costs ($56,500,000 - Table 5) due to research-related improvements	$5,650,000
4.4	Assume 1.8% elimination of track raises, (and 1.8% reduction in annual cost of raises, or $152,000,000 - Table 6), due to research-related improvements	$2,800,000
	Total annual net savings	$7,450,000

TABLE 5: ESTIMATED ANNUAL COST FOR BALLAST CLEANING OF 20,000* MILES OF CLASS I MAINLINE TRACKAGE, BASED ON 1976 COST DATA [5]

Item	% of Miles	Total Miles	Estimated Cost per Mile ($)	Total Cost ($)
Undercutting	25	5,000	5,600	28,000,000
Shoulder Cleaning	45	9,000	2,500	22,500,000
Sledding & Plowing	30	6,000	1,000	6,000,000
Total				$56,500,000

*Assume 6% of total mileage of 325,000 [7] cleaned annually.

TABLE 6: ESTIMATED ANNUAL COSTS FOR SURFACING RAISES FOR CLASS I RAILROADS, BASED ON AVAILABLE DATA FOR 1976

1.	Material cost of ballast in 1976	$64,332,000
2.	Assume $2.62 [6] average cost per cu. yd. for ballast (slag, granite, 50% ea.) at quarry site	
3.	Transportation cost (assume on-line haul) = total cu. yds. x average on-line haul cost/yd. = ($64,332,000 ÷ $2.62) x $2.20 [6]	$54,019,000
4.	Other costs - work train, per diem, switching, labor to unload = ($64,332,000 ÷ $2.62) x $1.39 [6]	$34,130,000
	Total	$152,481,000
	Rounded Off	$152,000,000

TABLE 7 - ESTIMATED COST TO IMPROVE 2,000* MILES OF CLASS I MAIN LINE TRACKAGE TO PREVENT FOULING FROM AIRBORNE AND WATERBORNE MATERIALS IN SEVERE PROBLEM AREAS

	Item	% of Miles	Total Miles	Estimated Cost per Mile	Total Cost
1.1	Planting trees, etc.**	10	200	100,000	20,000,000
1.2	Fencing**	25	500	13,000	6,500,000
1.3	Ditching, diking**	20	400	10,000	4,000,000
1.4	Spray with petroleum	2	40	10,000	400,000
1.5	Convey across track	2	40	5,000	200,000
1.6	Construct covered shelters**	1	20	80,000	1,600,000
2.1	Plant vegetative cover**	10	200	10,000	2,000,000
2.2	Improve drainage**	20	400	5,000	2,000,000
2.3	Clean culverts	10	200	1,500	300,000
	Totals	100	2,000		$37,000,000

* Assume 1% of 200,000 miles [7] of main line track is subject to severe problems from airborne and waterborne fouling.

** These items represent capital expenditures equal to $36.1 million or 98% of the total improvement costs. Costs listed for non-starred items represent annual maintenance expenses.

Annualized capital expense over 10 year period, @10%	$ 5,850,000
Estimated annual maintenance cost of above improvements	$ 2,500,000
Total annualized improvement costs	$ 8,400,000

SUMMARY OF SAVINGS AND BENEFITS

1.	Cost of R & D	\$1,420,000
2.	Time of R & D	3 years
3.	Accidents Prevented in 5 Years	141
4.	Ultimate Annual Net Savings	\$7.45 million
5.	Savings - First 5 Years	\$22.4 million
6.	Present Value of Savings - First 25 Years	\$107 million
7.	Benefit/Cost Ratio	76

STRATEGY FOR IMPLEMENTATION

Upon completion of this research project, the results should be sent to all railroads and related industries. The trade magazines should receive them and be invited to include articles on the research results in their publications.

Soon after the publication of the research results, seminars should be held in several locations throughout the United States; the railroads and other interested parties would be invited. The material for the seminars should be well-prepared using the latest visual aids. Prepared audiovisual materials could be loaned to maintenance-of-way clubs and interested engineering societies.

INVOLVING CONCERNED ELEMENTS OF CLIENT SECTORS

Voluntary work on the research could be asked of the AAR, AREA, the railroads and related industries. Where significant cost is involved, compensation to the contributing organizations may be required.

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VII SWITCH POINT WEAR LIMITS

OBJECTIVES

The objective of this research is to develop improved methods for assessing switch point wear and condition, including the design of gauges for determining the allowable limits of switch point wear. Another objective is to obtain more knowledge regarding the cost/performance of special trackwork, to facilitate the decision-making process pertaining to their design and maintenance.

BACKGROUND

The permissible limits of switch point wear, chipping, and spalling are presently determined by track personnel in a very subjective manner. Manuals, gauges, guidelines, and/or procedures are not available to assist the track inspector in determining the need for repair or replacement of switch points and related track components. Maintenance practices seem to vary widely throughout the railroad industry. Track inspection over a single railroad line has often revealed wide variations from point to point as to the limits of wear. These differences may frequently be attributed to a lack of experienced track personnel who are assigned to inspect switches.

The pressure which should be exerted by a switch point against a stock rail in the closed position to permit the safe passage of trains is not exactly known. Strain gauge measurements on the switch stand connecting rod have been made by the AAR Engineering Division Research Staff for the Canadian National Railroads, but were never published. These results indicated that there is an appreciable change in the force applied by the connecting rod when the wheels pass from the stock rail to the switch points, or from the point to the stock rail.

Sufficient information is not currently available on the degree of looseness of connections between the switch stand, connecting rods, and main and common rods and their connections to the switch points. The required degree of tightness of connections at power switches has not been adequately assessed.

Railroads have not been adequately informed of the cost and performance comparisons for special trackwork of "regular" components versus the improved metallurgy components. These include the heat-treated and alloy components for switch points, frogs, guard rails, etc. Other items include manganese inserts for switch points and frogs, Samson switch points, and hardened (press or explosive) manganese steel components. Detailed cost/benefit analyses have not been developed for these longer-life components.

APPROPRIATE TECHNICAL EFFORT

This research is divided into two general categories:

1. Switch Point Wear Limits
2. Cost/Performance Data for Special Trackwork

1. Switch point wear limits

1.1 Review of existing procedures for switch point inspection.

The first research effort would be to conduct a general literature search on the subject of switch point wear limits, including a review of both foreign and domestic railroad-related publications.

1.2 Statistics on accidents at switches.

A detailed study should be conducted to determine the number and causes of accidents (derailments plus collisions) that have occurred at special trackwork locations within the most recent five year period. This sutdy would reveal to what extent a defective, worn, or chipped switch point was the reason for an accident.

1.3 Frequency, procedure of inspection, maintenance techniques.

Direct contacts should be established with the appropriate staff members of several major railroads to determine the current procedures for the inspection of switch points (i.e. method and frequency of track patrol). Assess the methodology employed by various track personnel for identifying the need for repair, replacement, or build-up by welding of switch points. Examine the usage of any special gauges or tools for measuring switch point wear. Study the techniques employed by various railroads for switch point maintenance and adjustment.

1.4 Investigate and test new procedures and gauge designs.

Information should be developed on the actual contact and bearing of wheels in various states of wear (from new to condemnable limits) as the wheels pass over several types of switch points in various stages of wear. The outer rail of a curve on a main line turnout should be selected as the site for these tests, in order to monitor the movement of regular freight trains having a variety of worn wheel contour conditions. Two possible test designs are given below.

1.5 Motion picture techniques.

Set up a slow motion picture camera or closed circuit television camera, electrically operated and mechanically controlled, to record on film the point of contact of the wheel and the switch point during the passage of trains. It is believed that this technique would develop definitive information regarding switch point wear rates.

1.6 Collection pan device

Fasten a collection pan to the gauge side of several types of switch points to collect particles of metal that are ground from the point and the passing wheels. The pan should be magnetized to retain the metallic particles. Although it would not be possible to separate the metallic particles worn from the wheels from those that are worn from the switch points, the test would afford a comparison of the different amounts of wear for several types of points. Unit trains would provide the best assessment of wear data due to their uniformity in car type and length of trains.

1.7 Lateral switch point pressure on the stock rail

Develop a thin pressure-sensitive measuring device, to be located in the contact zone between the switch point and the stock rail in the closed position, to measure the lateral force exerted on the stock rail by the switch point. Measurements of lateral pressure should be made in the unloaded condition, i.e., in the absence of wheel loads. Variations in forces should be carefully documented for a variety of switch points and connecting rods. Lateral switch point pressure is particularly important when trains are approaching a switch in a facing movement, due to the possibility of a thin wheel flange becoming wedged between the point and the stock rail, resulting in wheel climb and possible derailment.

1.8 Optimum inspection frequency for various conditions

From these tests and related data it is believed that the optimum inspection frequency for different traffic densities and degrees of curvature can be judged. Also, information would be obtained on specific locations of maximum point wear, to aid in the development of gauges to measure the amount of wear at these locations. It is presumed that during these tests some pictures would be obtained of worn point and wheel wear conditions where wheel climb is impending or actually beginning to occur. For test purposes, the opposite switch point could be replaced by a guard rail to prevent the wheel from derailing in the event of wheel climb. The FAST test track would be an ideal location for these tests because the same train is operated on successive runs, and because there is a turnout on the outside of a curve.

1.9 Development of standard gauges

From the foregoing research, standard gauges would be developed to determine the permissible limits of wear of the switch points, both vertically and laterally, and at varying locations along the length of the point. A manual would then be prepared to qualify the inspectors in the proper use of these gauges. It is believed that the frequency of switch point inspection for various conditions (i.e. gross tonnage, speed, weather, class and type of track,etc.) could be determined.

2. Cost/performance data for special trackwork

Railroads have not been adequately informed of the useful life and performance characteristics that can be obtained from "improved" special trackwork components. This information would include life cycle and cost/benefit comparisons for heat-treated or alloy components for switches, frogs, or guard rails, as compared to the life of regular components. Other items include manganese inserts for switch points and frogs, Samson switch points, and hardened (press or explosive) manganese steel components.

2.1 Revenue service testing on railroads.

It is planned to conduct service tests on selected railroads and to make observations and measurements throughout the life of these "improved" components. These observations and measurements would necessarily include any welding repair during the serviceable life of the component. It would be necessary to obtain performance data relative to traffic density, tonnage, and time intervals between required adjustment, maintenance, or replacement.

2.2 Establish life cycle costs

From these service tests, a few of which may be conducted on the FAST track, it will be possible to establish life cycle costs for various designs of special trackwork versus regular components. The goal is to determine from these service tests the optimum designs, materials, and inspection and maintenance procedures for various traffic conditions and environments.

TECHNICAL DISCIPLINES REQUIRED

The types of personnel, with a description of their qualifications, that are required for the Switch Point Wear Limits research program are as follows:

Manager

To direct the entire project and coordinate the efforts of the various parts.

Research Librarian

Required to research past publications and reports. Should be familiar with technical and trade publications.

Lab Technician

Familiar with metals testing.

Market Economist

Experienced in the field of market analysis, preferably for railroad-related products.

Environmentalist

Experienced in the effects on the environment of the various research solutions.

Civil Engineer

A railroad civil engineer with experience in test planning, track construction and maintenance-of-way practices.

Metallurgist

A professional researcher experienced in the design, testing and research analysis of metal products.

Maintenance-of-Way Engineer

A railroad civil engineer with track maintenance experience.

Mechanical Engineer

Familiar with test design and procedures, track component design, preparation of technical reports.

PERIOD OF PERFORMANCE

It is estimated that the research programs in Task 1 can be completed in two years, and those in Task 2 in about five years. This latter time frame is contingent upon the availability of either the FAST track or a heavy traffic density railroad for in-service testing.

TECHNICAL EFFORT

The timing schedule and estimated cost for each phase of the work is shown in Figure 1.

It is estimated that $1.4 million will be required to execute this research plan, including preparation of reports, recommendations and results of railroad service and FAST tests. The number and discipline assigned to each task is shown in Figure 1.

NATURE OF END PRODUCT

The improved gauges and inspection procedures that will be developed will permit the railroads to more readily determine the safe operating limits over switches. More information of the cost and performance of special trackwork will be available to permit railroads to more accurately develop maintenance and purchasing strategies for special trackwork.

ANALYSIS OF SAVINGS AND BENEFITS

The establishment of definitive limits on switch point wear and condition will reduce the accidents caused by special trackwork by an estimated 20%. The 842 accidents attributed to special trackwork in 1976 [5] caused an approximate total damage of $15 million. [7] Thus, an annual savings of approximately $3 million should result from accident reductions as a result of this research.

The development of limits, gauges and methods for determining safe switch wear and condition will facilitate maintenance by making switch inspection simpler and more reliable. It is estimated that this will reduce the annual cost of special trackwork maintenance of $214 million [8] by 1% or $2 million.

It is assumed that sufficient knowledge of cost/performance of special trackwork will verify that presently generally available improved components (at 40% higher cost but with less maintenance and longer life) will be more cost effective than regular components.

FIGURE 1 - SCHEDULE

Task	R&D Cost ($1,000)	Staffing (Years 1–5)
1. Switch Point Wear Limits		
a. Review of Literature & Statistics	70	(Engr., Libr.)
b. Review Existing Practices	40	(Engr.)
c. Prepare Field Test Program	60	(2 Engrs.)
d. Conduct Field Test Program	400	(Engr., Met'lgst., 2 Techn.)
e. Set Standards for Gages	40	(Engr.)
f. Set Standards for Inspection Frequency	40	(Engr.)
Subtotal	650	
2. Cost/Performance - Special Trackwork		
a. Plan Test Program	50	(2 Engrs.)
b. Install Test Components	500	(2 Engrs., Techn.)
c. Make Periodic Observations	100	(Engr.)
d. Establish Life Cycle Costs	50	(Engr., Econ.)
e. Make Cost/Benefit Analysis	50	(Engr., Econ.)
Subtotal	750	
Grand Total	1,400	

( ) Indicates average number and discipline of people assigned to task

For the approximately 440,000 turnouts in the country, it is assumed that 66,000 switch points of improved material and design at $770 each are installed annually in the early years of implementation of this program instead of 66,000 regular points at $550 each, that improved ones reduce maintenance by 50% and last twice as long (20 years average vs. 10) as regular points. The number of improved switch points that would have to be installed annually would decrease as the longer life of these points becomes effective so that ultimately only half as many improved points would have to be installed as would be the case if regular points were used.

It is assumed that one-tenth of the frogs, or 44,000, would be replaced annually by frogs of improved design, at a cost of $2100 each instead of a like number of regular frogs at $1500 each during the early years of implementation of this program, that the improved frogs would reduce maintenance by 75% and would last twice as long as regular frogs. The number of improved frogs that would have to be installed annually would also decrease as their longer life becomes effective.

In a similar manner, other improved components of special trackwork, such as stock rails, guard rails, etc., would cost more initially, but would save in the long run.

The estimated savings for the various facets of this research discussed above are shown in Table 1.

TABLE 1: ESTIMATED SAVINGS

Components	Savings $ Million 5-Year	Savings $ Million 25-Year Present Value
Gauges and methods to provide sufficient knowledge of switch point wear and condition	24	35
Improved switch points	(24)	115
Improved frogs	(59)	135
Other improved special trackwork, (stock rails, guard rails, etc.)	(20)	15
Totals	(79)	300

SUMMARY OF SAVINGS AND BENEFITS:

1.	Cost of R & D	$1,400,000
2.	Time of R & D	5 years
3.	Accidents Prevented in 5 Years	572
4.	Savings - First 5 Years	($79 million)
5.	Present Value of Savings - First 25 Years	$300 million
6.	Benefit/Cost Ratio	214

STRATEGY FOR IMPLEMENTATION

Many railroads will be involved in the information-gathering and testing phases of this research plan. They will observe the results and will be anxious to apply those that are promising to help solve their problems with switches and other special trackwork. Tests and results will be observed at FAST. Reports will be issued on the results of this research plan. A workshop(s) will be conducted to demonstrate new gauges and procedures for inspecting switches and the performance of improved designs and materials for special trackwork.

INVOLVING CONCERNED ELEMENTS OF CLIENT SECTORS

Many railroads will be involved in several phases of the research plan. Manufacturers of gauges will be involved in reviewing existing gauges and developing and manufacturing new ones. Special trackwork manufacturers will be involved in developing cost and performance data for existing and improved designs.

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