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TRACK REHABILITATION RESEARCH AND DEVELOPMENT

A Basis for Program Planning

MARCH 1980

FINAL REPORT

Prepared for

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16. Abstract

The Federal Railroad Administration has established a Track Rehabilitation Research and Development program to better meet its obligations under the Railroad Revitalization and Regulatory Reform Act of 1976. In support of that effort, this report identifies and rank-orders track system problems, suggests a number of subprograms aimed at solving the more important problems, and evaluates and rank-orders the subprograms. This report contains detail of the subprograms as identified in part in a previously published summary report "Track Rehabilitation and Maintenance Research Requirements", FRA/OR&D-80/09. These recommended candidate subprograms will be considered by the Federal Railroad Administration, Office of Research and Development as part of the process of establishing track research projects. The selected projects may support a variety of research requirements, in addition to those detailed herein, and therefore may not be implemented precisely as described. Also, the sequence of progression of the projects may not exactly match the recommended rankings due to other considerations which could not be reflected in this report.

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1.0 INTRODUCTION AND SUMMARY

In recent years, the economic health of many of the nation's railroads has declined substantially. Average rates of return on net investment, for example equalled only 1.2 percent in 1975 contrasted with 3.7 percent in 1965.(1) This low rate, coupled with other factors (such as increased competition) has restricted the industry's ability to generate or attract investment capital. Consequently, the railroads have had to reduce expenditures. Deferring maintenance and fixed-plant improvements have been two approaches used to reduce operating expenses. Estimates of industry-wide deferred maintenance expenditures have ranged between $6 billion and $7 billion in 1975.(2)

Logically, the practice of deferring maintenance should have a negative impact on the safety of existing track structure. In fact, train accident statistics do provide one index of track deterioration. For example, derailments have increased an average of 42 percent between 1966 and 1975.(3) Similarly, the number of train accidents in which defects in way or structures were cited as primary contributing factors more than doubled during the same period.(4) A recent Association of American Railroads (AAR) study(5) provides additional evidence. The results of this study suggest that there may be a positive relation between track-related train accidents and deferred maintenance.

Recognizing the importance of high quality track to the safety and financial viability of the overall railroad industry, both Congress and the Federal Railroad Administration (FRA) have taken action. In 1976, Congress passed the Railroad Revitalization and Regulatory Reform Act (4R Act) which, among other things, provides capital to the railroads for rehabilitation and maintenance of facilities including track structures. FRA, on the other hand, has incorporated an

Improved Track Structures Research program into its overall research and development (R&D) activity. The program's objective is a safer and more cost-effective track system.

1.1 Study Objective and Scope

As with many major R&D efforts, the resources of the Improved Track Structures Program are not sufficient to address all problems associated with track systems. Furthermore, solutions to some problems are more important than solutions to others, and the cost in R&D dollars will be more for some solutions and less for others. This leads to an important question. How should the limited resources of this program be allocated to the problems?

In a broad sense, the purpose of this study is to help FRA answer that question. More specifically, the study seeks to identify alternative R&D areas or thrusts aimed at improving the track system, and to rank-order those alternatives according to some measure, or set of measures, which reflects both government and industry concerns.

There are, however, some constraints. In accord with the 4R Act, the Improved Track Structures Research Program is in fact pursuing its goals along two avenues: one deals primarily with track rehabilitation oriented R&D, while the other deals primarily with track maintenance oriented R&D. This study focuses on the former, with full recognition that the line dividing the two is not always clear. Another study, conducted by Parsons, Brinckerhoff, Quade & Douglas, Incorporated, focuses on the latter. Furthermore, this study was to base its findings on information obtained from the literature, from representatives of government and the research community, and from railroads owned by the federal government or engaged in extensive rehabilitation efforts with federal financial aid. The other study, on the other hand, was to base its findings on the results obtained from the literature, from other railroads, and from the track system supply industry. Results of both studies will be used by FRA staff to develop what will hopefully be the best Improved Track Structures Research Program with the funds available.

1.2 Report Objective

This report describes the track rehabilitation R&D study approach and presents its findings. Since the approach was somewhat novel, at least in its application to suggesting track system R&D priorities, it is described in considerable detail. Section 2 summarizes the approach while the Appendices present the details. Section 3 presents the more important track system problems uncovered in the study, while Section 4 presents solution approaches to some of those problems. Each solution approach is in fact an alternative area of endeavor for the Improved Track Structures Research Program. The alternatives are rank-ordered in Section 5 and the sensitivity of the rank-ordering to the more uncertain parameters is analyzed in Section 6. Some conclusions and recommendations are offered in Section 7.

1.3 Summary

The first step taken to achieve the study objectives was to identify as many track system problems as possible, and to differentiate the important from the less important ones. More than 50 representatives of government, the research community, Conrail, AMTRAK and the Alaska Railroad were interviewed to accomplish this.

The foremost concern or problem regarding the track system can be described in general terms as one of insufficient understanding of how traffic, the environment, and rehabilitation and maintenance methods affect the track structure and the individual components within the structure. The problem has many ramifications. Track system engineers are uncertain about the effects of alternative components on life-cycle costs; maintenance personnel are uncertain about the effects of maintenance practices on costs; rates for commodities that move with heavy axle loads cannot be properly determined because the track degradation caused by such loads is not known with sufficient certainty; and government officials are unable to evaluate track rehabilitation loan applications properly.

The second most important problem concerns rails. Interviewees felt that wear, plastic flow, and failure rates are all excessive under heavy load. Next in order of importance are problems associated with excessive longitudinal rail stress (track buckling), inadequate performance of the conventional spike and plate fastening system, and inadequate field welding techniques. In all, 66 track related problems were identified and rank-ordered using interview results.

Solution approaches were then developed for the more important problems. The approaches, or subprograms as they are referred to in this study, were developed by the study staff, although in many cases the interviewees provided valuable advice. Thirteen such subprograms emerged with a primary impact on 17 of the top 30 problems, and a secondary impact on eight more of those problems. The subprograms, listed in Table 4-1, ranged in size from three to eight projects, from $0.3 to $5.7 million dollars, and from 2.2 to 7 years duration. At this point, the 13 subprograms were considered equally desirable.

Using the safety and cost-effectiveness objectives of the Improved Track Structures Research Program as a guide, and considering the urgent need for the railroad industry to make the most of its capital, a quantitatively oriented process was devised to evaluate and rank-order the subprograms. The process included six evaluation criteria (e.g., benefit-cost ratio, R&D time) reflecting the various objectives and needs of the government and industry, it considered the relative importance of each criterion, and it took into account the risk associated with each endeavor. Objective analyses were used to determine values for measures corresponding to five criteria, and 20 evaluators from government, the research community, the railroads, and the railroad supply industry convened for a day to subjectively determine the remaining evaluation parameters.*

Results of the evaluation and ranking process and of a subsequent sensitivity analysis suggest that the 13 subprograms fall into three groups of relative desirability. The high rank group includes the following subprograms:

- In-Place Repair of Spike-Killed Ties
- Track System Handbook
- In-Place Rail Welding

The medium rank group consists of:

- On-Site Electric Flash-Butt Welding
- Improved Lateral Track Stability
- Bolt Hole Crack Prevention
- In-Place Rail Hardening
- Improved Thermite Welding

The low rank group consists of:

- Improved Wood-Based Tie
- In-Place Bolt Hole Crack Restraint
- Improved Rail Metallurgy
- Improved Wood-Tie Fastening System
- Improved Concrete Tie & Fastener Selection & Utilization.

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*Evaluators are listed in Appendix F, pp. F-11 and 12.

To assure meaningful results, a Technical Review Panel was established by FRA to review and comment on the study as it progressed. The panel, composed of railroad, railroad supply industry, and government representatives met five times. Panel members are listed in Section 2.

2.0 STUDY APPROACH

In describing how this study was conducted, it will be convenient to use three terms which frequently mean different things to different people. To avoid misunderstanding, the terms are defined here. The terms are project, subprogram and program.

A project is defined as a unit of work, typically subdivided into tasks, performed under a single contract or order, contained within a single subprogram, and having an explicitly stated cost, a stated duration, and an objective. A subprogram is defined as a series of projects, or a single project, which delineates a specific approach toward solving a specific problem and is directed toward a quantifiable objective which can be either a product or a finding of value to the government or to the railroad industry. In Section 1, the term "solution approach" and the phrase "alternative R&D areas or thrusts" were used to describe what will hereafter be referred to as a subprogram. A program (e.g., the Improved Track Structures Research Program) is composed of one or more subprograms.

In a very general sense, the approach followed in this study was to seek out information relevant to a track rehabilitation R&D program from a number of sources and to combine that information into a meaningful set of candidate R&D subprograms and to rank-order that set. The approach is described in more detail below and in the introductions to Sections 3, 4, 5 and 6 and in Appendix F.

To assure meaningful results, interim reports were presented several times throughout the study to the FRA project engineer, and to a Technical Review Panel (TRP) established by FRA for review and comment. TRP members are listed below:

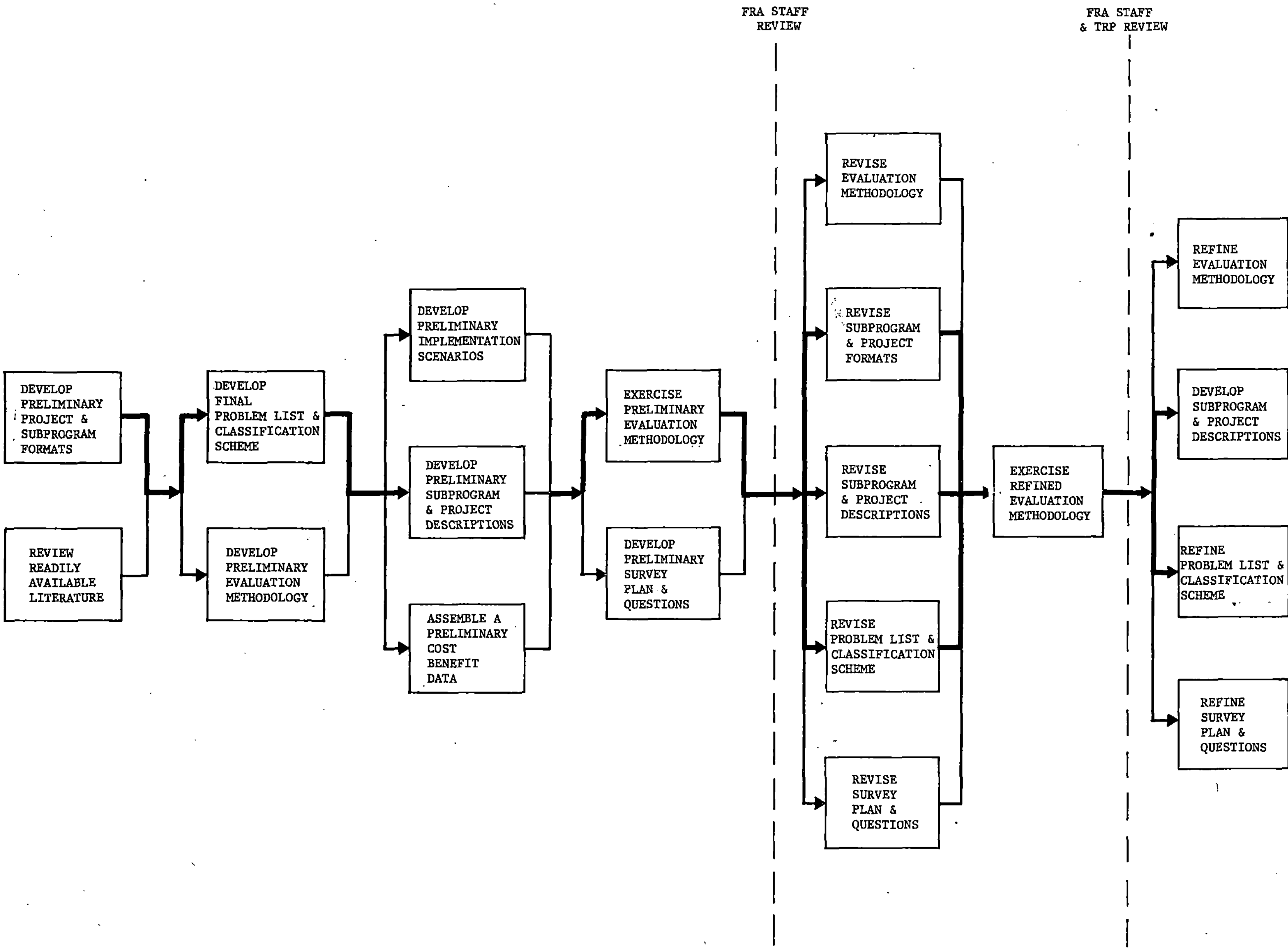
- G. H. Way--Association of American Railroads
- R. M. Brown--Union Pacific Railroad
- W. S. Simpson--Southern Railway Company
- C. E. Godfrey--Abex Corporation
- W. R. Hamilton--Portec, Incorporated
- R. E. Kleist--FRA Office of Federal Assistance
- J. A. Richard--FRA Northeast Corridor Project
- P. Olekszyk--FRA Office of Research and Development
- R. A. Smith--U.S. DOT, Transportation Systems Center

The presentations divided the study into parts or phases which are convenient for describing the study approach in more detail. Figure 2-1 illustrates the approach.

In Phase I, the project staff drew upon its knowledge and upon the readily available literature, to develop a preliminary:

1. Format for describing R&D subprograms in a standard manner.
2. Sample set of track system problems which might be amenable to R&D solution and a scheme for classifying related problems.
3. Method, criteria, and measures for evaluating subprograms.
4. Sample set of subprograms, projects and implementation scenarios for a sample set of problems.
5. Set of cost and benefit data.

With these in hand, an attempt was made to evaluate each subprogram by computing values for all objectively determined evaluation measures (e.g., cost, monetary benefit, lives saved, injuries prevented, etc.), by polling the MITRE staff on subjective measures, and finally by combining the results according to the evaluation methodology. The rationale for this approach was to gauge all aspects of the problem of producing a rank-ordered list of subprograms as soon as possible so that study resources could be appropriately allocated throughout subsequent phases of the study.


FRA STAFF REVIEW
FRA STAFF & TRP REVIEW
DEVELOP PRELIMINARY PROJECT & SUBPROGRAM FORMATS
REVIEW READILY AVAILABLE LITERATURE
DEVELOP FINAL PROBLEM LIST & CLASSIFICATION SCHEME
DEVELOP PRELIMINARY EVALUATION METHODOLOGY
DEVELOP PRELIMINARY IMPLEMENTATION SCENARIOS
DEVELOP PRELIMINARY SUBPROGRAM & PROJECT DESCRIPTIONS
ASSEMBLE A PRELIMINARY COST BENEFIT DATA
EXERCISE PRELIMINARY EVALUATION METHODOLOGY
DEVELOP PRELIMINARY SURVEY PLAN & QUESTIONS
REVISE EVALUATION METHODOLOGY
REVISE SUBPROGRAM & PROJECT FORMATS
REVISE SUBPROGRAM & PROJECT DESCRIPTIONS
REVISE PROBLEM LIST & CLASSIFICATION SCHEME
REVISE SURVEY PLAN & QUESTIONS
EXERCISE REFINED EVALUATION METHODOLOGY
REFINE EVALUATION METHODOLOGY
DEVELOP SUBPROGRAM & PROJECT DESCRIPTIONS
REFINE PROBLEM LIST & CLASSIFICATION SCHEME
REFINE SURVEY PLAN & QUESTIONS

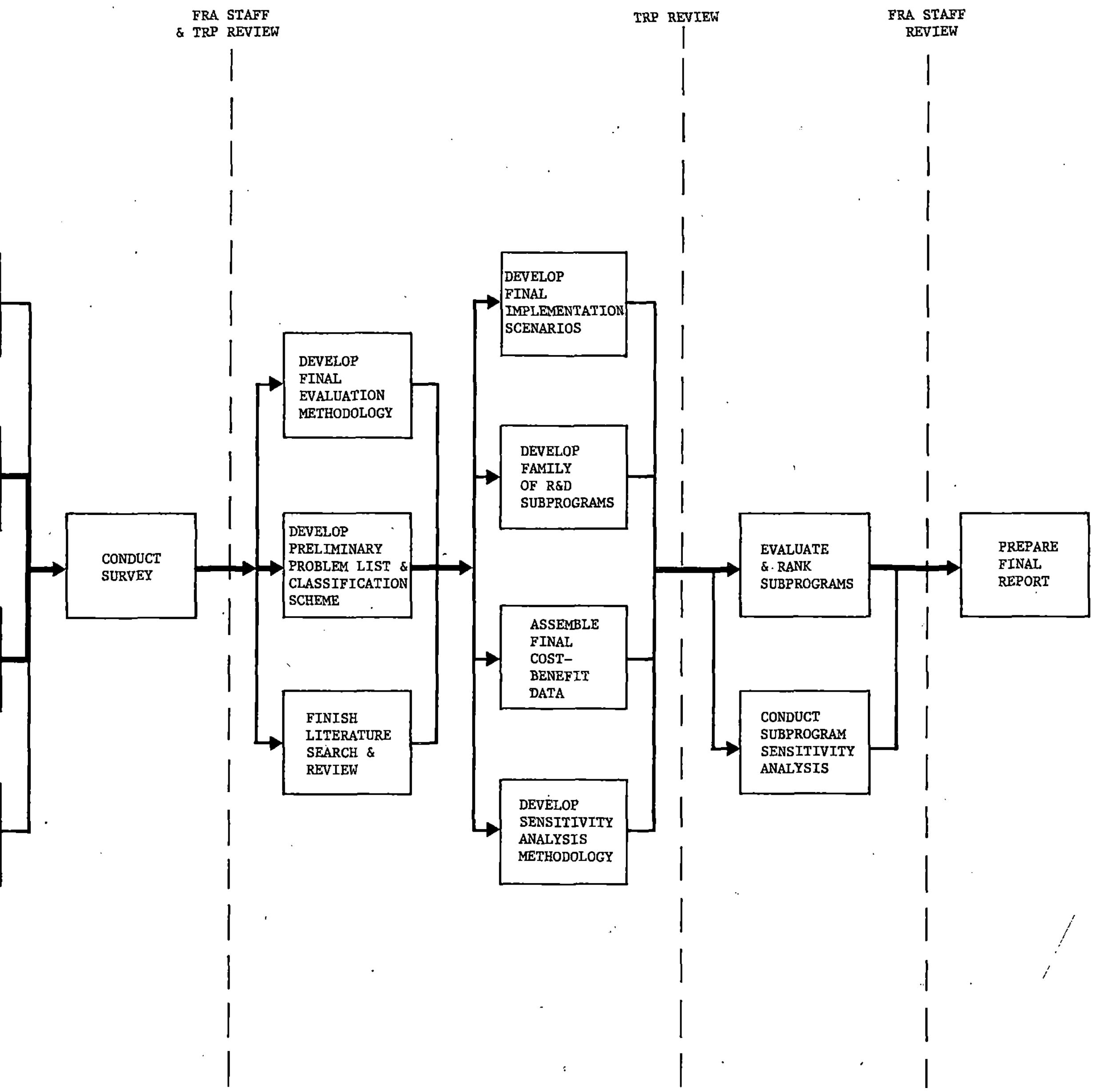


FIGURE 2-1
STUDY APPROACH

All the above, along with a preliminary set of information needs and a plan for obtaining the information through a series of interviews with government, research and railroad representatives were presented to the FRA Project Engineer for review and comment.

The results of Phase I were refined in Phase II. In particular, comments from the FRA review were incorporated into the draft R&D problem list, subprogram evaluation methodology, information needs and collection plan, standard project and subprogram description format, and the sample project and subprogram descriptions. The project and subprogram description formats were in near final form at this time. The remaining material was then informally discussed with representatives from other FRA offices and from the Transportation Systems Center (TSC). Based on these discussions, the entire set of material was again reviewed, and the evaluation methodology was exercised once more. Results were then presented to the FRA staff and the TRP for review, comment and FRA approval.

In Phase III, comments from the TRP were used to refine the evaluation methodology, problem list and classification scheme, and the survey plan and questions. Concurrent with these refinements work continued on developing subprogram and project descriptions for each significant problem area identified thus far. Significant problems were those with a high probability of being included in the final Track Rehabilitation R&D program. At this point, those problems were identified by the project staff, FRA and the TRP.

The information needs and the collection plan were in final form at this time. Information needs fell into three categories of importance. First and foremost, information was needed to help:

1. Identify the problems and needs which are associated with upgrading the track system and its components and which might be solved or satisfied through the R&D process.

2. Determine the relative importance of each problem.

Second, there was a need for information about:

1. The state-of-the-art, or state-of-knowledge, relative to each important problem.

2. Quantifiable objectives for each important problem.

3. Potential approaches toward solving each important problem.

Third, the need was for:

1. Data which would be useful in determining values for the set of qualitative and quantitative measures used to evaluate the potential solution approaches.

2. Information about the implementation potential of the resulting R&D solution.

3. Comments on the methodology proposed for evaluating and selecting subprograms for inclusion in the overall program.

This kind of a description along with supporting material was mailed to the interviewees such that they received it at least a week before being visited by a project staff member. Rather than a formal questionnaire, a directed interview approach was used. To reduce delays caused by note taking and to reduce mistakes or lost information, the interview was taped with interviewee permission.

Results of the survey were presented to the FRA staff and TRP for review along with an assessment of how the results might impact the evaluation methodology, problem list, proposed subprograms, and proposed projects as they existed at the time.

In Phase IV, all data, methods, lists and schemes were placed in final form. Interview results, and FRA and TRP comments were to be used to develop a final evaluation method, a final problem list and classification scheme, and to narrow the search for relevant literature. Together with the literature, the results were used to establish the current state-of-knowledge about each problem. Interview results were also used to develop the final set of candidate R&D subprograms, and to refine the cost-benefit data base. The subprograms, evaluation methodology, and significant assumptions and data to be used in the evaluation were then presented to TRP for review.

Phase V involved evaluation and ranking of the subprograms. Evaluation, as defined here, was the process of assigning numerical values to the set of measures adopted as a basis for ranking the subprograms. Six criteria and corresponding measures were adopted. Most of the evaluation was based on objective analyses done by the project staff. A considerable part, however, was based on the subjective judgement of a panel of 20 evaluators who convened for a full day expressly for this purpose.

Ranking was the process of combining the values associated with each subprogram into an overall value relative to all other subprograms. The process was formalized into a computer program which was used during the evaluation conference. At the conclusion of the conference the subprograms were rank-ordered, and the final ranking was presented to the TRP for review.

The final phase involved the preparation of this report.

Another way of looking at the study is in terms of the following basic tasks or steps that had to be accomplished:

- problem identification and ranking
- subprogram definition
- subprogram evaluation and ranking
- sensitivity analysis of ranked subprograms

The approach followed in each of these steps and the results are presented in the following sections.

3.0 PROBLEM IDENTIFICATION AND RANKING

3.1 Methodology

Initially, a preliminary list of track system problems was compiled based on information obtained from the MITRE staff, the literature, and from a survey conducted by the Association of American Railroads (AAR) several years earlier.(6) The problems were then classified by track system component and according to whether they concerned inadequate materials, inadequate methods, or insufficient information about existing materials or methods. The list and classification scheme were reviewed and refined by FRA and the TRP. Appendix A contains the resultant list.

Concurrently, a list of persons knowledgeable about track system problems was compiled by FRA. These individuals were contacted to determine their willingness to assist the study by granting an interview to the study staff. In all, 52 persons agreed to be interviewed. Eighteen represented three government organizations, 22 represented 15 R&D contractors, nine represented three railroads, and three represented the Association of American Railroads. Appendix B contains the names and affiliations of each interviewee. Of the 52, three were selected to serve as test cases for the interview procedure and supporting materials. Using the test interview results, a package of materials was developed and sent to each of the remaining interviewees about ten days before the scheduled interview date. The package contained the list of track system problems shown in Appendix A and a brief set of instructions for improving the productivity of the interview. In particular, each interviewee was asked to do the following:

- review the list of track system problems
- add any new problems to the list which were believed to be at least as important as those on the list
- identify the more important problems on the list
- rank-order the more important problems

Approximately half the interviewees followed the instructions and ranked the problems prior to the interview. In the cases where the problems had not been ranked, the first part of the interview was devoted to this task. With the ranking complete, each important problem was discussed briefly to determine why it was believed to be important and to make certain the interviewer understood exactly what problem the interviewee had in mind. The latter point was essential, since different interviewees used different problem statements to essentially describe the same problem. This concluded the problem identification and ranking portion of the interview. Other kinds of information needed in the study were then sought.

Of the 52 interviewees, 42 provided sufficient problem ranking information to allow their results to be combined with that of others into a composite ranking. The remainder felt unqualified to rank outside their area of expertise (e.g., ballast or subgrade), or unqualified to rank at all.

Before the interview results could be combined, however, two difficulties had to be overcome. The first, stemmed from the fact that different problem statements were used to describe essentially the same problem, while the second was due to the interviewees ranking different numbers of problems--the number ranged from a low of four to a high of 20. The latter point brought into question the validity of a straight-forward combination of individual rankings into a composite ranking.

The first difficulty was overcome by examining all the problem statements and classifying the equivalent ones into groups where each group was represented by a single, generic problem statement. In effect, many different but equivalent problem statements obtained in the interviews were restated using a single generic statement. In all, the 453 different problem statements obtained in the interviews yielded 66 different generic problems. Appendix C contains the generic problems as well as the problem statements each represents.

To overcome the second difficulty, two quite different methods of combining the results were devised which seemed to bracket the range of reasonable alternatives. If the two yielded comparable results, then one or the other, or a combination of both, would be selected.

In general, the methods differed in the amount of weight or influence each interviewee's ranking had on the final composite ranking. The first method assigned 100 points to each interviewee and then distributed those points in a uniformly decreasing amount across the rank-ordered problems. Thus, if an individual ranked only four problems, the highest ranking problem contributed 40 points to the composite rank, the second highest 30 points, the third highest 20 points and the last 10 points. If five problems were ranked, the highest ranking problem received 31.67 points while the lowest received 6.33 points. For each problem, the points were summed over all interviewees. The sums provided the basis for the composite ranking.

Under the second method, each interviewee was assigned ten points for each ranked problem. As in the first method, the total number of points was then distributed in a uniformly decreasing amount across the ranked problems. Thus, the interviewee who ranked only four problems received only 40 points while the one who ranked 20 problems received 200 points. The effect of the latter interviewee on the composite rank-ordering was considerably more than that of the former interviewee--in fact five times more.

Despite the differences, the results of the two methods were quite similar indicating the composite ranking to be relatively insensitive to reasonable alternatives for combining the interviewee rankings. Therefore, a combination of the two methods described above was selected. For each problem, the number of points was determined using each of the two procedures. The average number of points for the two methods was then computed and used as the basis for the composite ranking.

3.2 Results

In this section, the results of the problem identification and ranking process are presented. Table 3-1 illustrates the derived list of 66 generic problems and their relative priority based on the two different ranking methods. In addition, the composite scores resulting from combining both ranking approaches are also presented. The scores range from a high of 1,039 for "Inadequate Track Structure Cost/ Performance Data" to 2.1 for "Unrealistic Government Track Standards Regulatory Action." The similarity of problem priorities regardless of ranking method is clearly evident.

Track system problems were also rank-ordered according to interviewee class (Table 3-2). Interviewees were grouped into five job functional classes and the problem priorities recorded. The objective here was to determine if track problems were perceived differently by government, researchers, track inspectors and railroad staff.

Aside from obvious biases due to job function and responsibilities, problem priorities varied considerably across interviewee classes. For example, "Insufficient Cost/Performance Data--Proper Rail Selection" was ranked fifth by railroad operations staff and 27th by government administrative personnel.

TABLE 3-1

RANK-ORDERED TRACK SYSTEM PROBLEMS

PROBLEMS	RANKING METHODS (1) 10 POINTS PER PROBLEM RANK	(2) 100 POINTS PER INTERVIEWEE RANK	(3) 10 POINTS/PROBLEM + 100 POINTS/INTERVIEWED RANK	SCORE
1. INADEQUATE TRACK STRUCTURE COST/PERFORMANCE DATA	1	1	1	1039.0
2. EXCESSIVE RAIL WEAR	3	2	2	200.7
3. INSUFFICIENT COST/PERFORMANCE INFORMATION ON BALLAST	2	3	3	197.5
4. EXCESSIVE LONGITUDINAL RAIL STRESS	4	4	4	189.4
5. INADEQUATE CONCRETE TIE PERFORMANCE	5	5	5	172.3
6. INADEQUATE MAINTENANCE OF WAY METHODS	6	6	6	161.1
7. INADEQUATE PERFORMANCE OF SPIKES/PLATES AS FASTENERS	7	8	7	151.5
8. INSUFFICIENT COST/PERFORMANCE DATA -- PROPER RAIL SELECTION	9	7	8	146.9
9. PREMATURE RAIL FAILURE	8	9	9	146.3
10. INSUFFICIENT INFORMATION ABOUT SUBGRADE PERFORMANCE	11	10	10	122.1
11. INADEQUATE FIELD WELDING TECHNIQUES	10	11	11	118.3
12. UNKNOWN COST/PERFORMANCE OF SUBGRADE IMPROVEMENT METHODS	12	12	12	108.8
13. EXCESSIVE RAIL PLASTIC FLOW DEFECTS	14	13	13	97.3
14. INADEQUATE CONCRETE TIE FASTENER DESIGN	13	17	14	89.9
15. INADEQUATE METHODS FOR SUBGRADE IMPROVEMENT	17	15	15	83.9
16. EXCESSIVE BALLAST DEGRADATION	21	14	16	81.6
17. EXCESSIVE BALLAST/SUBGRADE INTERACTIONS (PUMPING)	19	16	17	81.0
18. TRACK SYSTEM R&D RESULTS NOT PROPERLY DISSEMINATED	15	18	18	79.8
19. EXCESSIVE WOOD TIE DEGRADATION	16	19	19	77.8
20. BOLT/BOLT HOLE PROBLEMS	18	20	20	75.5
21. INADEQUATE WOOD TIE RENEWAL METHODS	20	21	21	69.8
22. HIGH CONCRETE TIE INITIAL/INSTALLATION COSTS	22	22	22	67.6
23. INABILITY TO DETERMINE RAIL STRESSES IN THE FIELD	24	23	23	62.0
24. UNKNOWN ANCHOR EFFECTIVENESS/PERFORMANCE	23	24	24	60.9
25. INADEQUATE FIELD RAIL FLAW DETECTION	25	26	25	60.5
26. UNKNOWN FUTURE COST/AVAILABILITY OF WOOD TIES	27	27	26	55.4
27. INSUFFICIENT COST/PERFORMANCE DATA -- OPTIMUM WOOD TIE UTILIZATION	26	29	27	54.1
28. INSUFFICIENT KNOWLEDGE ABOUT COST/PERFORMANCE OF SPECIAL TRACKWORK	28	28	28	53.8
29. INADEQUATE FROG MAINTENANCE METHODS	30	25	29	53.2
30. TRACK GEOMETRY PROBLEMS	29	31	30	46.5
31. INSUFFICIENT INFO -- COST/PERFORMANCE OF INNOVATIVE WOOD-BASE TIES	31	30	31	44.2

TABLE 3-1 (Cont'd)

RANK-ORDERED TRACK SYSTEM PROBLEMS

PROBLEMS	RANKING METHODS (1) 10 POINTS PER PROBLEM RANK	(2) 100 POINTS PER INTERVIEWEE RANK	(3) 10 POINTS/PROBLEM + 100 POINTS/INTERVIEWED RANK	SCORE
32. EXCESSIVE SWITCH WEAR	32	33	31	44.2
33. INSUFFICIENT COST/PERFORMANCE DATA -- INNOVATIVE WOOD TIE FASTENERS	33	35	33	37.4
34. INADEQUATE SUBGRADE ASSESSMENT TECHNIQUES	35	32	34	36.5
35. INSUFFICIENT COST/PERFORMANCE DATA -- WOOD TIE SELECTION	34	36	35	35.9
36. INADEQUATE CONCRETE TIE COST/PERFORMANCE DATA	36	34	36	34.7
37. EXCESSIVE BALLAST FOULING	37	37	37	33.0
38. INADEQUATE SLOPE STABILIZATION METHODS	38	41	38	29.6
39. INSUFFICIENT INFORMATION ON THE CAUSES OF RAILWAY ACCIDENTS	41	38	39	27.5
40. INADEQUATE STOCK RAIL MAINTENANCE METHODS	40	42	40	26.0
41. INADEQUATE BALLAST MAINTENANCE/REHABILITATION METHODS	43	40	41	25.3
42. INADEQUATE MOW METHODS AT CROSSINGS	45	39	42	24.7
43. INADEQUATE JOINT MAINTENANCE METHODS	39	45	43	24.6
44. COST/BENEFITS ASSOCIATED WITH TIE PLATE AREA UNKNOWN	44	44	44	23.0
45. SUBGRADE HEAVING	42	46	45	21.9
46. INADEQUATE MOW METHODS AT SWITCHES	53	43	46	19.5
47. INADEQUATE METHODS FOR EVALUATING IN-SITU TRACK	47	47	47	17.9
48. UNKNOWN COST/PERFORMANCE OF CONCRETE TIE FASTENERS	50	49	48	17.4
49. INADEQUATE BONDED JOINT MAINTENANCE	46	50	49	17.3
50. INADEQUATE FIELD WELD INSPECTION TECHNIQUES	52	48	50	16.6
51. TRACK SYSTEM R&D GOALS NOT CLEAR -- GOV/PUBLIC/RR CONFLICTS	49	53	51	15.6
52. PREMATURE JOINT BAR BREAKAGE	51	52	52	15.1
53. UNKNOWN EFFECTS OF TRACK DESIGN/IRREGULARITIES ON RAIL VEHICLES	48	57	53	14.3
54. HIGH COST OF INSULATED JOINT INSTALLATION METHODS	58	51	54	13.4
55. INADEQUATE COST/PERF DATA -- OPTIMUM JOINT BAR FOR CONDITIONS	56	56	56	12.7
56. INADEQUATE ANCHOR INSTALLATION METHODS	55	56	56	12.7
57. LINE SPEED/YARD CAPABILITY NOT COMPATIBLE	57	55	57	12.6
58. INADEQUATE FIELD JOINT BAR FLAW DETECTION	54	59	58	11.1
59. EXCESSIVE JOINT BAR WEAR	59	58	59	10.6
60. INADEQUATE VEGETATION CONTROL METHODS	60	60	60	9.5
61. INADEQUATE METHODS FOR MAINTAINING TRACK GEOM AT SPEC TRACKWORK	61	62	61	8.6
62. INADEQUATE BOLTED INSULATED JOINT PERFORMANCE	62	61	62	7.1

TABLE 3-1 (Cont'd)

RANK-ORDERED TRACK SYSTEM PROBLEMS

PROBLEMS	RANKING METHODS (1) 10 POINTS PER PROBLEM	(2) 100 POINTS PER INTERVIEWEE	(3) 10 POINTS/PROBLEM + 100 POINTS/INTERVIEWED	
	RANK	RANK	RANK	SCORE
63. INADEQUATE BONDED JOINT PERFORMANCE	63	63	63	5.7
64. TOO MUCH CURVED TRACK (LINE MODIFICATION NEEDED)	64	64	64	3.8
65. INSUFFICIENT INFORMATION ABOUT NON-CONVENTIONAL STRUCTURES	65	65	65	3.2
66. UNREALISTIC GOVERNMENT TRACK STANDARDS REGULATORY ACTION	66	66	66	2.1

TABLE 3-2

RANK-ORDERED TRACK SYSTEM PROBLEMS -- BY INTERVIEWEE CLASS

PROBLEM		INTERVIEWEE CLASS				
NO.	DESCRIPTION	GOV'T. ADMINIS-TRATION	RESEARCH	GOV'T. ADMIN./ RESEARCH	RAILROAD	TRACK INSPECTOR
1.	INADEQUATE TRACK STRUCTURE COST/PERFORMANCE DATA	1	1	1	1	1
2.	EXCESSIVE RAIL WEAR	24	4	5	3	5
3.	INSUFFICIENT COST/PERFORMANCE INFORMATION ON BALLAST	2	8	19	2	21
4.	EXCESSIVE LONGITUDINAL RAIL STRESS	3	3	6	6	–
5.	INADEQUATE CONCRETE TIE PERFORMANCE	9	12	2	7	–
6.	INADEQUATE MAINTENANCE OF WAY METHODS	7	17	9	4	8
7.	INADEQUATE PERFORMANCE OF SPIKES/PLATES AS FASTENERS	6	9	12	13	3
8.	INSUFFICIENT COST/PERFORMANCE DATA -- PROPER RAIL SELECTION	27	10	15	5	7
9.	PREMATURE RAIL FAILURE	4	5	–	–	23
10.	INSUFFICIENT INFORMATION ABOUT SUBGRADE PERFORMANCE	–	2	17	20	9
11.	INADEQUATE FIELD WELDING TECHNIQUES	28	7	3	34	25
12.	UNKNOWN COST/PERFORMANCE OF SUBGRADE IMPROVEMENT METHODS	35	13	26	12	4
13.	EXCESSIVE RAIL PLASTIC FLOW DEFECTS	30	30	11	8	11
14.	INADEQUATE CONCRETE TIE FASTENER DESIGN	8	24	8	28	28
15.	INADEQUATE METHODS FOR SUBGRADE IMPROVEMENT	–	15	–	9	–
16.	EXCESSIVE BALLAST DEGRADATION	20	11	–	27	–
17.	EXCESSIVE BALLAST/SUBGRADE INTERACTIONS (PUMPING)	5	14	–	–	24
18.	TRACK SYSTEM R&D RESULTS NOT PROPERLY DISSEMINATED	18	6	29	–	–
19.	EXCESSIVE WOOD TIE DEGRADATION	–	21	7	22	–
20.	BOLT/BOLT HOLE PROBLEMS	14	18	10	–	–
21.	INADEQUATE WOOD TIE RENEWAL/DISPOSAL METHODS	12	32	21	10	–
22.	HIGH CONCRETE TIE INITIAL/INSTALLATION COSTS	–	23	–	14	–
23.	INABILITY TO DETERMINE RAIL STRESSES IN THE FIELD	–	16	–	26	–
24.	UNKNOWN ANCHOR EFFECTIVENESS/PERFORMANCE	34	37	13	21	22
25.	INADEQUATE FIELD RAIL FLAW DETECTION	19	20	–	–	6
26.	UNKNOWN FUTURE COST/AVAILABILITY OF WOOD TIES	33	25	20	23	30
27.	INSUFF COST/PERF DATA -- OPTIMUM WOOD TIE UTILIZATION	–	42	–	30	2
28.	INSUFFICIENT KNOWLEDGE ABOUT COST/PERF OF SPECIAL TRACKWORK	17	34	27	11	–
29.	INADEQUATE FROG MAINTENANCE METHODS	32	33	–	16	13
30.	TRACK GEOMETRY PROBLEMS	–	22	16	–	–

Two problems, however, were ranked relatively consistently across all interviewee classes. The first, "Inadequate Track Structure Cost/ Performance Data" was considered the highest priority problem by all groups. The second "Excessive Longitudinal Rail Stress" (problem number 4) was ranked third by administration and research personnel, and sixth by administrative/research and railroad operations staff.

Problem priorities were also examined from the point of view of the track components themselves and the nature of the problem (i.e., inadequate materials, design, method, information, etc.). Table 3-3 illustrates the findings. Considering the track structure, the top three problem components identified by those surveyed were:

- track system
- rail
- subballast/subgrade

For these and other components, most interviewees felt that "insufficient information about materials or methods" existed presently to solve track structure problems.

Resource constraints and the need for a manageable R&D program required that the highest ranking track rehabilitation problems be selected as a basis for developing subprograms. The top thirty problems were selected by the project team to serve as the source for a track rehabilitation R&D program.

TABLE 3-3

TRACK SYSTEM PROBLEMS
RANKED BY PHYSICAL COMPONENT AND BY PROBLEM NATURE

SYSTEM/COMPONENT	INSUFFICIENT INFORMATION ABOUT MATERIALS OR METHODS	INADEQUATE MATERIALS OR DESIGNS	INADEQUATE METHODS	TOTALS	RANK
TRACK SYSTEM	1097.2	189.4	179.0	1465.6	1
RAIL	146.9	444.3	257.4	848.6	2
WOOD TIES	189.6	77.8	69.8	337.2	5
CONCRETE TIES	34.7	240.0	0.0	274.7	6
WOOD TIE FASTENERS	60.4	151.5	0.0	211.9	8
BALLAST	197.5	114.6	25.3	337.4	4
SUBBALLAST/SUBGRADE	231.0	102.8	159.5	493.3	3
SPECIAL TRACKWORK	53.8	39.1	131.9	224.8	7
NON-CONVENTIONAL TRACK	3.2	0.0	0.0	3.2	13
ANCHORS	60.9	0.0	12.7	73.6	11
RAIL JOINTS	13.2	113.9	66.3	193.4	9
TRACK GEOMETRY	0.0	46.5	0.0	46.5	12
OTHER	97.5	0.0	0.0	97.5	10
TOTALS	2185.9	1519.9	901.9	4607.7	
RANK	1	2	3		

4.0 SUBPROGRAM DEFINITION

4.1 Methodology

Early in the study, the project team developed a standard format for describing subprograms. To illustrate its use, several hypothetical subprograms were defined and presented to FRA and the TRP for review. The format called for each subprogram to be described in terms of the following:

1. Title.
2. Problem Statement--including a brief discussion of the importance of the problem.
3. Quantitative Objective--including a cost component and a performance or effectiveness component.
4. State-of-the-Art Discussion.
5. R&D Projects--brief descriptions of projects required to advance from the state-of-the-art to the desired objective.
6. Implementation Factors--incentives and barriers to utilization of the R&D results if and when achieved.
7. Cost--for each project.
8. Schedule--for each project.
9. Rank.
10. Justification of the Rank--including a benefit summary and a summary of the evaluation measures.

In this, the subprogram definition step, only the first five elements were defined; the last five were defined in subsequent steps.

Given the format and the rank-ordered list of track system problems, the highest ranking track rehabilitation--rather than track maintenance--problem was selected and a corresponding subprogram was defined. The information required to describe the subprogram was obtained from four sources: the interviews described earlier, literature reviews, telephone conversations with the interviewees and other experts, and the experiences of the study team. Typically, a subprogram designed to solve one problem actually affected several problems due to the particular solution approach developed. For example, solving the problems of excessive rail wear through improved rail metallurgy also goes a long way toward solving the problems of premature rail failure and excessive rail corrugation.

After the highest ranking problem was addressed, the next highest ranking problem without a corresponding subprogram was selected and a subprogram was defined. This process was repeated until the study resources allocated to the subprogram definition task were depleted. In all, 13 subprograms were defined. They are listed in Table 4-1.

TABLE 4-1

TRACK REHABILITATION R&D SUBPROGRAMS

ID	TITLE
A	Track System Handbook
B	Improved Lateral Track Stability
C	Improved Rail Metallurgy
D	In-Place Rail Hardening
E	Improved Thermite Welding
F	On-Site Electric Flash-Butt Welding
G	In-Place Rail Welding
H	Bolt Hole Crack Prevention
I	In-Place Bolt Hole Crack Restraint
J	Improved Wood Tie Fastening System
K	Improved Wood-Based Tie
L	In-Place Repair of Spike-Killed Ties
M	Improved Concrete Tie and Fastener Selection and Utilization

Table 4-2 shows how the subprograms related to the 30 highest ranking track system problems as uncovered in this study. In all, 18 problems are attacked directly by the 13 subprograms, while an additional eight problems are attacked indirectly.

It can also be seen in Table 4-2 that some of the higher ranking problems are not attacked or are attacked only indirectly. In the case of Problems 5 and 14 dealing with concrete ties, the rationale for not defining a subprogram was that the complete story on currently available concrete ties and their associated fastening systems is simply not known. Some combinations appear to be performing well at the Facility for Accelerated Testing (FAST). Problem 6, "Inadequate Maintenance of Way Methods," was not attacked because it was clearly a maintenance rather than a rehabilitation problem. As such, it was beyond the scope of this study. Problems 15 and 16, dealing with inadequate subgrade improvement methods and excessive ballast degradation, were not attacked directly, simply because no reasonable solution approaches could be conceived or uncovered in the time available. The Track System Handbook--Subprogram A--is, however, expected to ameliorate these problems to some extent by providing better information about the performance of known subgrade improvement methods and about selecting the proper ballast. Problem 17, dealing with ballast pumping, was not attacked directly because a possible solution (i.e., the engineering fabric) is beginning to receive acceptance by the railroads, and because a better solution approach could not be conceived or uncovered. Beyond Problem 20, the study resources available for defining subprograms were exhausted.

It is worth noting that in 11 of the subprograms it was possible to establish quantitative objectives that a number of knowledgeable people believed to be appropriate. In the case of Subprogram A--Track System Handbook and Subprogram J--Improved Wood-Tie Fastening Systems, however, this was not possible. There simply was not enough available information. Since a quantitative objective was needed to

TABLE 4-2

PROBLEMS VERSUS SUBPROGRAMS

PROBLEM		SUBPROGRAM												
RANK	DESCRIPTION	A	B	C	D	E	F	G	H	I	J	K	L	M
1.	INADEQUATE TRACK STRUCTURE COST/PERFORMANCE DATA	●												
2.	EXCESSIVE RAIL WEAR	o		●	●									
3.	INSUFFICIENT COST/PERFORMANCE INFORMATION ON BALLAST	●												
4.	EXCESSIVE LONGITUDINAL RAIL STRESS	o	●											
5.	INADEQUATE CONCRETE TIE PERFORMANCE													o
6.	INADEQUATE MAINTENANCE OF WAY METHODS													
7.	INADEQUATE PERFORMANCE OF SPIKES/PLATES AS FASTENERS										●			
8.	INSUFFICIENT COST/PERFORMANCE DATA--PROPER RAIL SELECTION	●		o										
9.	PREMATURE RAIL FAILURE			●	●									
10.	INSUFFICIENT INFORMATION ABOUT SUBGRADE PERFORMANCE	●												
11.	INADEQUATE FIELD WELDING TECHNIQUES					●	●	●						
12.	UNKNOWN COST/PERFORMANCE OF SUBGRADE IMPROVEMENT METHODS	●												
13.	EXCESSIVE RAIL PLASTIC FLOW DEFECTS			●	●									
14.	INADEQUATE CONCRETE TIE FASTENER DESIGN													o
15.	INADEQUATE METHODS FOR SUBGRADE IMPROVEMENT	o												
16.	EXCESSIVE BALLAST DEGRADATION	o												
17.	EXCESSIVE BALLAST/SUBGRADE INTERACTIONS (PUMPING)	o												
18.	TRACK SYSTEM R&D RESULTS NOT PROPERLY DISSEMINATED	o	o	o	o	o	o	o	o	o	o	o	o	o
19.	EXCESSIVE WOOD TIE DEGRADATION	o									o	●	●	
20.	BOLT/BOLT HOLE PROBLEMS			o	o				●	●				
21.	INADEQUATE WOOD TIE RENEWAL/DISPOSAL METHODS	o										o	o	
22.	HIGH CONCRETE TIE INITIAL/INSTALLATION COSTS													
23.	INABILITY TO DETERMINE RAIL STRESSES IN THE FIELD		●											
24.	UNKNOWN ANCHOR EFFECTIVENESS/PERFORMANCE	●	o											
25.	INADEQUATE FIELD RAIL FLAW DETECTION													
26.	UNKNOWN FUTURE COST/AVAILABILITY OF WOOD TIES											●		
27.	INSUFFICIENT COST/PERFORMANCE DATA -- OPTIMUM WOOD TIE UTILIZATION	●												
28.	INSUFFICIENT KNOWLEDGE ABOUT COST/PERFORMANCE OF SPECIAL TRACKWORK													
29.	INADEQUATE FROG MAINTENANCE METHODS													
30.	TRACK GEOMETRY PROBLEMS	o												

Note: ● - primary relationship
o - secondary relationship

determine certain evaluation measures, it was decided to utilize the expertise of the subprogram evaluation panel by asking each of them to subjectively estimate key factors for quantifying the objective. The panel average was the value adopted.

At this point in the study, the 13 subprograms were considered to be of equal value or worth. The fact that some addressed higher ranking problems than others was no longer relevant since the subprogram ranking and evaluation process (Section 5.0) would distinguish between subprograms and help establish priorities.

4.2 Results

In this section each of the 13 subprograms is summarized. Brief information is presented relative to the problem to be solved, the R&D objective to be attained, the present level of understanding about each problem, the R&D projects required, and the estimated R&D costs and time to complete the subprogram. It is important to keep in mind that both R&D costs and schedules are estimates which must be periodically monitored and updated as more information on each R&D project becomes available.

Considerably more detailed subprogram descriptions are in Appendix D.

4.2.1 Subprogram A--Track System Handbook

Problem--Railroad engineering, track maintenance, and government personnel administering financial support programs recognize the need for cost-effective track structures. They do not, however, have the cost and performance information necessary to design such structures, to recognize when such structures are proposed, or to recommend proper maintenance or rehabilitation practices for existing structures.

<u>Objective</u>--A track system handbook will be developed which will help railroads determine optimal or near optimal track structures, as well as maintenance and rehabilitation practices, for various loading, environmental and subgrade conditions such that total annual track construction, rehabilitation and maintenance expenditures are reduced by 1.2 percent relative to their cost without the handbook.

<u>State-of-the-Art</u>--The literature contains numerous isolated information and mathematical relationships concerning the track system and its components. Some is old, some is new. Several researchers claim this information can be integrated into a track structure model capable of producing the information needed in the handbook. One claims to possess such a model. Others believe that considerably more work in the form of component degradation, and maintenance cost and effectiveness model development must be done.

<u>R&D Projects Required</u>--This subprogram is composed of 12 distinct R&D projects which are briefly described below.

1. Requirements Study-specifies the information potential users of the Handbook will need in order to use the Handbook and identifies information readily available.

2. Track System Handbook-Version I--satisfies all or a reasonable subset of initial requirements determined in Project 1 and is developed using existing models with minimal additional data collection efforts.

3. Results Dissemination and Evaluation-Version I--conduct a seminar for those who make or influence track system decisions in order to get the contents of the Handbook to users as quickly as possible.

4. Feasibility Conference-Version II--convene a workshop with track system modeling and research experts to determine the technical and commercial feasibility of developing a better version of the Handbook.

5. Macro-Level Model Design--design a track system model which, when properly calibrated and validated, will be capable of generating information required in the Handbook.

6. Component and Geometry Degradation Studies--includes six projects directed at developing mathematical models of track component (e.g., rail, tie, fastener...) and track geometry degradation as a function of service.

7. Component and Geometry Restoration and Cost Studies--includes three projects designed to predict the cost and operational restoration activities needed to improve the track system. The three projects address common maintenance operations, common rehabilitation operations and derailment repairs.

8. Test Planning--this project will develop a data collection plan for conducting FAST and in-service tests.

9. In-Service and FAST Tests--in this project the test plan developed in Project 8, will be implemented at various test sites.

10. Simplified Structural Model--a structural model of the track system is to be developed which, computationally, will be more economical to operate than existing models.

11. Track Systems Analysis and Handbook Preparation--the results of the previous projects will be assembled into a track system model which will be exercised to develop information for the Handbook. The Handbook will be used to assess track performance, maintenance operations and costs, and ultimately to evaluate specifications for new components.

12. Results Dissemination and Evaluation-Version II--dissemination and evaluation of this version of the handbook will be similar to Project 3.

Estimated R&D costs and schedule for developing the handbook are $5,684,000 and seven years, respectively.

4.2.2 Subprogram B--Improved Lateral Track Stability

Problem--Excessive longitudinal rail stress resulting from production, installation, track shift, wheel loads and temperature extremes can cause track to buckle or to pull apart. In 1976 there were 101 accidents attributed to buckling in which 44 people were injured. Presently, the railroad industry does not have simple or reliable means for determining when or where these problems will occur, nor are cost guidelines for track design available for preventing buckling problems.

Ojective--Develop information which will allow railroads to reduce accidents caused by track buckling or by rail pull apart by 90 percent, and reduce unnecessary track restraint and maintenace by 10 percent.

State-of-the Art--Several track buckling models have been developed, but not validated because buckling experiements for U.S. track conditions have not been performed.

There is currently no method for portable nondestructive measurement of in-situ rail longitudinal stress, although several approaches to the problem have been proposed.

R&D Projects Required--This subprogram is comprised of the following nine R&D projects:

1. Problem Definition Study-determine the costs and techniques currently in practice for the prevention of buckling/pull apart, and the conditions under which these failures occur.
2. Track Buckling Test Facility Design--establish requirements for a facility based upon data gathered in the Problem Definition Study.
3. Track Buckling Test Facility Construction.
4. Buckling Test Planning--establish test requirements based upon the determination of those track parameters which will most economically prevent buckling/pull apart.
5. Buckling Tests & Analysis--conduct tests, analyze results, calibrate and validate models, and write a report suitable for inclusion as a section in the Track System Handbook.

6. Stress Detector Feasibility Studies--conduct studies of innovative technologies for the in-situ measurement of rail stress.
7. Stress Detector Prototype Development and Laboratory Test--develop and test the two most promising concepts, selected on the basis of accuracy, portability, simplicity of usage, etc.
8. Stress Detector In-Service Test and Evaluation--evaluate prototype accuracy, usage, and costs. Report results in a manner suitable for inclusion in the Track System Handbook.
9. Results Dissemination--produce a summary report, seminar and trade literature articles.

Estimated R&D costs and schedule are $1,303,000 and four years, respectively.

4.2.3 Subprogram C--Improved Rail Metallurgy

Problem--Various forms of rail wear, degradation, and failure are estimated to have caused 1,000 accidents in 1976 costing the railroads and shippers $63,000,000 and to have necessitated the replacement of 250,000 rails (39 foot length) at a cost of another $61,000,000.

Objective--Develop a rail such that wear life is increased at least by a factor of 2, probability of failure is decreased at least by a factor of 0.2, and price is increased no more than 10 percent above that of standard carbon rail (using 1978 dollars as a basis).

State-of-the Art--There is little doubt that rail wear and failure properties can be improved substantially through metallurgy. The principal question is, can it be done at an affordable price to the railroads. The aims of researchers in other countries who have pursued improved rail metallurgy perhaps more vigorously than in the United States, suggest that an affordable price might be achievable.

R&D Projects Required--Eight R&D projects comprise this subprogram:

1. Rail Demand Study--estimate near and long term rail demand as a function of price, rail wear, and failure properties.
2. Laboratory and FAST Tests-test alternative rail metallurgies to determine wear and failure properties.
3. Rail Supply Study--estimate expected price based on existing domestic and alternative production methods.
4. Pilot Plant--construct pilot plant to demonstrate cost-effectiveness of unproven production methods, if such a method is selected in Project 3.
5. Test Planning--develop plan for in-service and FAST tests of most cost-effective metallurgies.
6. In-Service and FAST Test--produce, install and test samples of improved rail in operational service and compare with standard rail.
7. Analysis and Report--estimate cost and performance of track structures using improved rail and those using standard rail.
8. Dissemination of Results--prepare report on subprogram results and use as a basis for convening a research utilization seminar for suppliers and other rail industry representatives.

The estimated R&D costs and schedule for this subprogram are $1,440,000 and approximately six years.

4.2.4 Subprogram D--In-Place Rail Hardening

Problem--Rail wear and various forms of degradation and failure are estimated to have resulted in 1,000 accidents in 1976 costing the railroads $63,000,000, and to have necessitated the replacement of 250,000 rails at a cost of another $61,000,000.

Objective--Develop a method for hardening rails in-place such that the wear life is increased at least by a factor of 1.5 and the probability of failure is decreased at least by a factor of 0.4 relative to standard carbon rail. Cost must be less than $5 per rail (1978 costs).

State-of-the-Art--Results of a preliminary study indicate that it is theoretically feasible to flame harden or stress relieve rail in-place by towing an array of fuel gas torches along the track at constant speed. However, quality and consistency of flame hardened rails has not always been satisfactory, and the costs associated with the method are uncertain.

R&D Projects Required--This subprogram is composed of six R&D projects.

1. Heat Flow Analysis--predict the temperature at the rail and tie-plate interface and the tie and tie-plate interface when hardening rail in place.
2. Laboratory Test and Analysis--determine operating conditions and control that provide the best product in terms of consistency, wear, and failure properties. Estimate costs.
3. Prototype Equipment Specification--develop specification for in-place rail hardening equipment including vehicle subsystem, if required.
4. Prototype Equipment--design and construct prototype equipment specified in Project 3.
5. Field Tests and Analysis--conduct field tests, measure cost and performance, revise vehicle specifications and operating procedures as required.
6. Results Dissemination--produce summary report, seminar and trade journal articles to disseminate findings.

The estimated R&D costs and timetable for this subprogram are $1,570,000 and 4.5 years.

4.2.5 Subprogram E--Improved Thermite Welding

Problem--The growing use of CWR has made field welding an increasingly troublesome problem. While in-plant welds are reliable and reasonably cheap, field welds are not. Thermite field welds fail anywhere from 3 to 100 times as often an in-plant welds.

Objective--Improve thermite weld reliability to that of in-plant flash-butt welds at a cost differential of no more than $3.50 per weld (1978 costs).

State-of-the-Art--Thermite welding is a standard field welding technique used extensively in the U.S. Defective welds are common and appear to be due to inadequate training of field crews and lack of quality controls.

R&D Projects Required--This subprogram is composed of four projects:

1. Analysis of Current Procedures--identify and analyze cost-effective procedures and practices.
2. Improved Procedures--develop procedures and equipment (if needed) to improve cost effectiveness of thermite welds.
3. FAST and In-Service Demonstration--procedures and equipment developed in Project 2 will be demonstrated on FAST and cooperating railroads.
4. Results Dissemination--produce report documenting results of subprogram; conduct seminar and training sessions to demonstrate new procedures.

Estimated R&D costs and schedule are $500,000 and slightly over 4.5 years.

4.2.6 Subprogram F--On-Site Electric Flash-Butt Welding

Problem--Electric flash-butt welding techniques are usually used in-plant to produce CWR of about 1/4 mile lengths. These lengths must then be joined on-site usually by thermite welds or other joining techniques. The unreliability and high costs of field welds are problems in many railroads.

Objective--Develop a field welding technique as reliable as in-plant flash-butt welding. Costs per weld should approximate in-plant welds, or about $10 to $30 per weld (1978 costs). State-of-the-art flash welding, which produces inexpensive, reliable welds in a plant has recently been tried in the field with some success. The process does, however, require removal of spikes and anchors so the rails can be pulled together, and a relatively large amount of upset material is produced. Removal of the upset material is relatively expensive.

R&D Projects Required--Four R&D projects are recommended for this subprogram:

1. Test Planning--develop plan for monitoring existing on-site flash-butt welds.
2. Cost-Effectiveness Study--monitor performance of existing on-site flash-butt welds and compare with cost and performance of thermite and other in-plant welds.
3. Shear Evaluation Study--monitor the performance of an automatic shear developed in the Soviet Union and develop modifications, if required.
4. Results Dissemination--Publish report and conduct seminar on subprogram results.

The estimated R&D costs and schedule for this subprogram are $315,000 and approximately two years.

4.2.7 Subprogram G--In-Place Rail Welding

Problem--Jointed track, approximately 85 percent of all U.S. track, has much higher maintenance costs than CWR track. Maintenance costs could be substantially reduced if track could be welded in-place. Considering about 270 joints per mile of track, the cost of thermite welds would be prohibitive for in-situ conversion.

Objective--Test and evaluate methods to weld jointed rails while leaving them spiked and anchored. Cost of process should not exceed $50 per weld to be competitive with other welding techniques.

State-of-the-Art--Present in-field welding procedures all require spike and anchor removal. New techniques such as friction welding, electron-beam welding, and laser-beam welding may be attractive to the railroads if they can be developed to the point where they can be more properly evaluated.

R&D Projects Required--Seven projects are recommended for this subprogram:

1. Market Study--evaluate trends and costs of CWR installations to determine market for in-place rail welding.
2. Survey of Techniques--identify techniques for in-place welds that do not require rails to be drawn together and determine adaptability for field use.
3. Laboratory Test Plan--develop evaluation plan for techniques found most favorable for field use.
4. Laboratory Tests--conduct laboratory tests of welding technique identified in Project 3.
5. Track Test Plan--design demonstration of recommended welding technique (Project 4).
6. FAST and In-Service Tests--conduct field test at FAST to determine reliability. If acceptable, conduct further in-service tests with various railroads.
7. Results Dissemination--publish findings in final report and hold seminar to describe new technique.

The R&D schedule and estimated costs for this subprogram are $620,000 and about five years, respectively.

4.2.8 Subprogram H--Bolt Hole Crack Prevention

Problem--Bolt holes in rail joints are a problem because cracks develop at the holes because of stress concentrations at the holes, the discontinuous structure and the dynamic loading produced by the rail joints. In 1976 bolt hole cracks led to more than 100 train accidents and cost about $3 million in damage to track and equipment.

Objective--Develop a system for treating non-cracked bolt holes to eliminate future cracks.

State-of-the-Art--Bolt holes can be strengthened by various approaches including sleeve expansion, shot peening, and edge coining. Of these, sleeve expansion appears to be the most promising technique to prevent cracks.

R&D Projects Required--Three projects make up this subprogram which is directed at the treatment of serviceable bolt holes in place.

1. Test Plan--design demonstration of in-place bolt hole expansion to establish sleeve expansion capabilities and costs.
2. Demonstration--obtain in-track performance using FAST and other railroads to assess rail life with and without expanded bolt holes.
3. Results Dissemination--document demonstration results and conduct seminars for maintenance/rehabilitation personnel.

The schedule and estimated costs for these projects amount to nearly five years and $130,000.

4.2.9 Subprogram I--In-Place Bolt Hole Crack Restraint

Problem--Approximately 85 percent of total U.S. track is still jointed rail. Considering present and predicted CWR installation rates, jointed track will remain the predominant type in service within the foreseeable future. Nearly one bolt hole crack was detected for every 2 miles of track inspected in 1970.

If procedures could be developed to repair bolt-hole cracks in the field, rail life would be extended and rail replacement costs could be reduced.

Objective--Develop a system to repair bolt hole cracks to 1/2 inch in length at repair costs less than 25 percent of the rail replacement (in-field) costs.

State-of-the-Art--Bolt hole cracks can be repaired by the sleeve cold-expansion process. Various other techniques such as shot peening and edge coining have been suggested, but do not appear as promising as sleeve expansion. There is a need to conclusively demonstrate the effectiveness of sleeve expansion on cracked bolt holes.

R&D Projects Required--Five projects are recommended for this subprogram. Several may be combined and performed by a single contractor.

1. Test Planning--develop plans for both laboratory and in-service testing which can establish the performance of repaired bolt holes.
2. Laboratory Testing--conduct lab tests to determine the largest size bolt hole crack that can be repaired by sleeve expansion.
3. Demonstration--validate laboratory test results at FAST by repairing/installing cracked rail segments obtained from railroads.
4. Crack Detection Guidelines--specify detection requirements for inspection equipment.
5. Results Dissemination--demonstration project findings will be documented in report format, trade journal articles, and via industry-wide seminars.

Estimated R&D costs and timetables are $710,000 and approximately 4.5 years.

4.2.10 Subprogram J--Improved Wood Tie Fastening System

Problem--The performance of rail-tie fastening assemblies is a matter of considerable economic concern to the railroad industry. Until recently, the conventional wood tie fastening system (tie plate, base rail anchor, cut spike) performed well on U.S. tracks. Increasing wheel loads and higher tonnage, however, appear to be taxing the performance of this system. Many train accidents attributed to track geometry defect can be traced to the rail-tie interface. In 1976, nearly 500 accidents were conservatively estimated to be fastener-related.

Objective--Develop information about currently available improved systems for fastening rails to wood ties which will allow the industry to save $3.0 million even for improved fastening systems costing no more than 44 percent more than conventional systems (1978 dollars).

State-of-the-Art--The variety of fastener designs in current use and testing in the world is staggering. In addition to conventional system variations, improved performance systems are even more diverse. These include, for example, lock spikes, screw spikes, compression clips, elastic clip tie plates, and elastic clips.

Improved tie fastening systems have been used more extensively in other countries. In the U.S., a variety of such systems are being tested at FAST and other railroads. Performance and cost data are lacking thus restricting selection and installation recommendations for industry adoption.

R&D Projects Required--Seven projects are recommended which will provide information on improved fastening systems for wood ties thus allowing the railroad industry to select those designs which ensure satisfactory and economical performance for localized track-train conditions.

1. Fastener Economic Study--Conduct preliminary economic assessment of the use of improved wood tie fasteners for various track/train conditions.

2. Laboratory Test Planning--develop plan for testing improved fastener systems in laboratory.
3. Laboratory Testing and Analysis--conduct laboratory tests identified in Project 2.
4. Test Planning--develop plan for conducting FAST and in-service tests of most promising fastener systems determined in Project 3.
5. In-Service and FAST Tests--collect load, climatic, and degradation data specified in the test plan.
6. Analysis and Report--estimate benefits achievable by using the highest performing fastening system in a variety of track configurations.
7. Results Dissemination--prepare report documenting test results and analyses and conduct research utilization seminar.

The R&D schedule and cost estimates for this subprogram are six years and $1,665,000.

4.2.11 Subprogram K--Improved Wood-Based Tie

Problem--Based on figures provided by the railroads, it is estimated that Class I railroads inserted 25.6 million new ties in 1978. In 1979, these same railroads will probably install about 27 million crossties. Such volume accounts for a sizeable part of the total maintenance of way budget annually (about 17 percent in 1978).

Timber ties are the mainstay of the industry accounting for more than 99 percent of all ties in place during 1977. Nevertheless, timber ties deteriorate due to natural forces as well as increasing wheel loads. Tie crushing, splitting, plate cutting and spike-killing are examples of deterioration modes due to natural and man-made forces.

Sharp increases in the price of timber ties, supply uncertainties, heavier wheel loads, and alternative technologies suggest a detailed review of the role of timber ties in new track systems.

Objective--Increase the useful life of newly inserted wood (or wood-based) crossties by at least 33 percent relative to existing conventional hardwood ties at a price differential of not more than $1 per tie (1978 costs).

State-of-the-Art--Recent government and industry studies cast some doubt on the ability of timber tie producers to meet expected demand by railroads. Various technologies and procedures are in use today to extend tie life either by reducing decay rates or damage caused by increasingly heavier wheel loads. Bonded or laminated ties and others developed from wood chips are being tested under operational conditions at FAST and other railroads.

R&D Projects Required--Six R&D projects are recommended:

1. Timber Tie Supply Study--estimate the availability and price of timber ties through the year 2000.
2. Preliminary Analysis of Alternative Wood-Based Ties--select the most promising alternative wood-based ties currently being tested and conduct a preliminary cost/performance study.
3. Test Planning--develop test plan for in-service and FAST testing of viable wood-based tie alternatives.
4. In-Service and FAST Tests--conduct tests specified in Project 3 and obtain load, climatic and degradation data.
5. Analysis and Report--establish the best wood-based tie alternative to use under different track system and environmental conditions.
6. Results Dissemination--document the results of all projects and conduct research utilization seminar for suppliers and other railroad representatives.

Estimated R&D costs and timetable for the overall subprogram are $885,000 and about 5.5 years.

4.2.12 Subprogram L--In-Place Repair of Spike-Killed Ties

Problem--Despite the fact that timber ties have been improved sufficiently over the years to withstand competition from other materials and methods, timber ties deteriorate. In addition to normal decay, heavier wheel loads have accelerated tie deterioration due to crushing, plate cutting, splitting and spike-killing.

It has been estimated that about 15 percent of all ties removed each year are removed because of spike-kill. Accordingly, U.S. railroads spent about $80 million in 1978 to replace some 4.5 million spike-killed ties.

Objective--Verify, through experiements, that in-place application of available chemical filling materials can extend the life of spike-killed ties by 8 years at a cost of $0.30 per tie in (1978 costs).

State-of-the-Art--Repair of spike-killed ties presently involves driving a peg or dowl into the spike hole and re-spiking. Recently, various chemical filling agents have become available which are claimed to be able to restore and retain 80 percent of spike-tie bond at a cost per tie of $0.25. While operational tests on various railroads are in-progress, data are inadequate for industry-wide recommendation.

R&D Projects Required--Four projects are included in the subprogram:

1. Test Planning--design laboratory, FAST, and in-service tests to collect information on spike holding power under various traffic and environmental conditions.
2. Laboratory and FAST Tests--conduct laboratory and FAST tests to provide preliminary determination of chemical filler materials performance.
3. In-Service and FAST Tests and Analyses--based on Project 2 results, conduct expanded in-service tests of chemical filler materials.

4. Results Dissemination--summarize project results into final report and conduct various research utilization seminars to disseminate results to railroad maintenance and management staff.

The costs and timetable to complete this subprogram are: $410,000 and approximately 4.5 years.

4.2.13 Subprogram M--Improved Concrete Tie and Fastener Selection and Utilization

Problem--Less than one percent of all ties in-place in the U.S. are concrete ties. Most of these have performed reasonably well to date. Yet data do indicate that some areas of the concrete tie track system require further research. One problem area has been the rail fastener which has resulted in pad movement, excessive vibration, insulation breakage, tie skewing and rail creep. Knowledge of optimum track system parameters (e.g., tie spacing, ballast type and depth, ballast degradation and anchorage requirements) for given track conditions is also inadequate.

Objective--Determine if concrete tie track has at least 100 percent greater tie life, 50 percent lower maintenance costs, and 40 percent higher rail wear life relative to conventional wood tie track.

State-of-the-Art--Although concrete tie performance in field tests conducted prior to 1970 was relatively poor, new specifications have been good to date. The U.S. is capitalizing on the experience of foreign railroads and is presently developing design specifications and laboratory test plans for heavier wheel loads.

R&D Projects Required--Six R&D projects have been identified for this subprogram:

1. Laboratory Test Planning--develop plan for laboratory testing of concrete tie/fastener systems including establishment of requirements for test duration, data reduction and analysis.

2. Laboratory Testing and Analysis--perform the required laboratory tests developed in Project 1.

3. Test Planning--develop plan for conducting FAST and in-service tests for the more promising tie/fastener systems analysed in Project 2.

4. In-Service and FAST Tests--perform the required in-service and FAST tests according to the test plan specifications developed in Project 3.

5. Analysis and Report--estimates cost and performance parameters of leading concrete tie/fastener system candidates in various track configurations and compare with conventional wood tie/fastener systems.

6. Results Dissemination--summarize the results of previous projects in a final report and conduct research utilization seminars.

The estimated R&D costs and schedule to complete this subprogram are: $1,900,000 and between 6 and 6.5 years.

5.0 SUBPROGRAM EVALUATION AND RANKING

The subprogram evaluation and ranking approach adopted for this study was primarily quantitative rather than qualitative. The quantitative portion of the work was based on objective analyses performed by the study staff while the qualitative portion was based on the subjective judgment of some 20 evaluators convened solely for the purpose of evaluating the subprograms. The evaluators were selected jointly by the study staff and FRA, and included the TRP members, some of the individuals interviewed earlier in the study; FRA staff, the study staff, and several others experienced in track system R&D. Detailed descriptions of the evaluation and ranking components of the method, as well as the names of the evaluators, are in Appendix F. Brief descriptions follow.

The cornerstone of the method was the set of criteria against which the subprograms were evaluated. The criteria, described briefly in Table 5-1, reflect multiple objectives. They consider the Improved Track Structures Research program objectives of safer and more cost-effective track; they reflect the need to maximize the return on FRA's limited R&D budget; and they account for benefits accruing to the railroads which might not be readily quantifiable.

For each subprogram, values for the five objective measures shown in Table 5-1 (all except "Other Impacts") were estimated by the MITRE staff. In a few instances as described in Section 6, critical parameters were subjectively estimated by the evaluators and the average value over all evaluators was used. Values for the "Other Impact" criterion were also subjectively estimated by the evaluators. Table 5-2 shows the values for each subprogram.

In any evaluation process with multiple evaluators, such as in this study, it is likely that there will be disagreement among the evaluators concerning the relative importance of each criterion.

TABLE 5-1

SUBPROGRAM EVALUATION CRITERIA

Criterion	Description
Benefit-Cost Ratio	Present value of net dollar benefit to RR industry divided by R&D cost
Safety Impact	Number of accidents prevented in first 5 years of implementation
Capital Savings	Capital expenditures saved in first 5 years of implementation
Timeliness	R&D time in years
Other Impacts	Subjectively selected value from a scale of -5 to +5
R&D Cost	Total subprogram R&D cost

TABLE 5-2

VALUES OF SUBPROGRAM EVALUATION MEASURES

Subprogram	Benefits ($'s in millions)	R&D Costs ($'s in millions)	Benefit-Cost Ratio	Safety Impact (accidents prevented)	Capital Savings ($'s in millions)	R&D Time (years)	Other Impact	Prob. of Success
A	261.4	$5.7	45.9	252	144.0	7.0	1.85	0.67
B	49.4	1.3	37.9	114	11.3	3.8	1.45	0.46
C	1.8	1.4	1.3	1	- 3.0	6.2	1.61	0.51
D	533.8	1.6	340.0	83	- 37.8	4.5	0.71	0.31
E	1.3	0.5	2.6	6	0.2	3.7	0.90	0.54
F	20.6	0.3	65.4	6	10.6	2.2	0.41	0.60
G	422.1	0.6	680.8	0	232.5	3.9	0.31	0.22
H	3.5	0.1	26.9	7	- 1.6	4.8	0.73	0.66
I	6.0	0.7	8.4	0	3.3	3.7	0.29	0.42
J	6.7	1.7	3.9	2	- 4.8	6.0	0.96	0.42
K	3.2	0.9	3.6	0	- 4.7	4.3	1.21	0.44
L	320.4	0.4	781.5	0	321.9	3.7	0.80	0.55
M	9.5	1.9	5.0	0	- 9.3	6.1	0.86	0.52

Rather than force the evaluators to agree, a set of six weighting (or importance) factors was incorporated into the process--one weighting factor for each criterion. Each evaluator subjectively determined values for the six weighting factors independently, and each measure was then normalized and multiplied by its corresponding weighting factor. Once an evaluator determined his set of weighting factors, those values were used in his evaluation of each subprogram.

Implicit in the nature of R&D activities is an element of risk--some efforts fail, other succeed. In effect, the probability of success varies from effort to effort. There is a chance, therefore, that the benefits envisioned from a subprogram might not be achieved. To take this into account, each evaluator was asked to subjectively estimate the probability of success of each subprogram.

For each subprogram, and each evaluator, the criterion measurement values, the weighting factors and the risk or probability of success factor were linearly combined as described in Appendix F to yield a single subprogram score. The score became the basis for rank-ordering the subprograms for each evaluator. It is worth noting that the probability of success, or risk, factor played an important role in determining a subprogram's score. It is a multiplier of all the evaluation measures indicative of benefit (i.e., all but R&D Cost). Since its value is almost always less than one, it reduces the expected benefit--sometimes substantially if the probability of success is judged to be low.

The sum of each subprogram's score across all evaluators was used as a basis for obtaining an overall, or group, rank ordering. Tables 5-3 and 5-4 show the results. It should be kept in mind that the scores received by each subprogram are the sole basis for the

TABLE 5-3

RANKING OF SUBPROGRAMS BY EVALUATORS

EVALUATOR	SUB-PROG./ SCORE	SUBPROGRAM 1	2	3	4	5	6	7	8	9	10	11	12	13
1	SUB.	L	B	F	H	A	K	E	J	G	I	D	M	G
	SCORE	156	132	104	95	93	73	70	69	55	41	39	38	34
2	SUB.	L	D	G	F	B	H	A	E	K	I	M	J	C
	SCORE	175	128	100	91	80	70	66	64	54	48	47	39	37
3	SUB.	A	L	F	D	G	H	E	B	M	C	I	J	K
	SCORE	149	128	85	79	77	76	71	67	60	59	59	49	39
4	SUB.	L	A	H	G	J	B	D	F	E	I	K	C	M
	SCORE	162	130	120	109	107	91	77	66	62	24	22	17	15
5	SUB.	L	B	F	G	E	H	D	I	A	C	K	M	J
	SCORE	517	94	77	74	57	57	39	34	19	16	7	6	3
6	SUB.	L	A	G	F	H	E	I	M	D	C	K	B	J
	SCORE	264	197	100	95	86	65	64	34	30	29	23	11	4
7	SUB.	L	A	G	B	H	D	F	E	K	J	I	C	M
	SCORE	307	116	90	67	60	56	55	51	45	42	39	38	34
8	SUB.	A	E	L	H	B	F	K	D	G	J	C	I	M
	SCORE	176	121	118	116	106	73	62	48	43	41	40	37	20

TABLE 5-3 (continued)

EVALUATOR	SUB-PROG./SCORE	SUBPROGRAM 1	2	3	4	5	6	7	8	9	10	11	12	13
9	SUB.	L	F	H	A	G	D	I	C	E	J	B	M	K
	SCORE	154	133	98	97	86	83	63	54	51	50	47	43	41
10	SUB.	L	A	F	H	G	E	D	B	I	M	K	C	J
	SCORE	183	95	95	83	75	72	68	68	64	58	50	46	45
11	SUB.	L	A	F	G	E	B	H	K	D	I	C	J	M
	SCORE	230	92	79	77	68	68	65	62	61	57	52	49	42
12	SUB.	L	G	D	B	A	F	H	E	I	K	C	M	J
	SCORE	181	161	113	85	82	77	61	60	54	42	32	27	25
13	SUB.	L	D	G	F	H	B	K	I	E	M	C	J	A
	SCORE	231	158	108	73	64	61	59	50	50	43	42	36	25
14	SUB.	L	A	K	C	H	F	I	E	J	G	D	B	M
	SCORE	378	161	83	76	61	61	52	47	33	19	12	8	8
15	SUB.	L	B	G	K	A	F	E	H	I	C	D	J	M
	SCORE	375	99	95	83	81	71	52	40	37	18	17	17	16
16	SUB.	L	G	F	B	H	E	K	I	A	C	D	M	J
	SCORE	114	102	90	88	83	79	74	71	64	62	61	58	55
17	SUB.	B	G	L	M	D	H	A	F	C	E	I	J	K
	SCORE	144	119	95	93	86	75	72	62	58	56	54	45	42

TABLE 5-3 (continued)

EVALUATOR	SUB-PROG./SCORE	SUBPROGRAM 1	2	3	4	5	6	7	8	9	10	11	12	13
18	SUB.	L	A	G	D	E	B	C	F	J	I	H	M	K
	SCORE	189	112	101	89	87	69	67	53	51	50	49	49	34
19	SUB.	A	H	B	E	L	D	I	G	K	C	F	M	J
	SCORE	139	104	96	85	77	73	70	69	65	64	59	56	43
20	SUB.	L	G	A	F	E	K	B	C	H	D	I	M	J
	SCORE	295	117	116	116	56	53	41	38	38	37	35	30	29
GROUP RANK		L	A	G	F	B	H	D	E	K	I	C	J	M
GROUP SCORE		216	104	88	81	76	75	68	66	51	50	45	42	39

TABLE 5-4

EVALUATION CONFERENCE RESULTS

RANK	SCORE	SUBPROGRAM	
1	216	L	In-Place Repair of Spike-Killed Ties
2	104	A	Track System Handbook
3	88	G	In-Place Rail Welding
4	81	F	On-Site Electric Flash-Butt Welding
5	76	B	Improved Lateral Track Stability
6	75	H	Bolt Hole Crack Prevention
7	68	D	In-Place Rail Hardening
8	66	E	Improved Thermite Welding
9	51	K	Improved Wood Based Tie
10	50	I	In-Place Bolt Hole Crack Restraint
11	45	C	Improved Rail Metallurgy
12	42	J	Improved Wood Tie Fastening System
13	39	M	Improved Concrete Tie & Fastener Selection & Utilization

ranked list. For practical purposes, differences in score of 10 points or less between subprograms are probably not justifiable for fixing the rank of any subprogram. Subprogram funding decisions should take this observation into account.

6.0 SENSITIVITY ANALYSIS

Since adequate information for quantifying the objectives for two subprograms (A--Track System Handbook and B--Improved Lateral Track Stability) could not be established by project staff, several evaluators suggested at the conclusion of the evaluation conference, that a sensitivity analysis be performed of the key evaluation parameters for these two subprograms. The project staff and FRA concurred. However, a more comprehensive analysis was suggested including four additional variables affecting three other subprograms (C--Improved Rail Metallurgy, J--Improved Wood Tie Fastening System, and L--In-Place Repair of Spike-Killed Ties). As above, these additional parameters were selected because of uncertainty in the accuracy of the estimates used thus far. In all, six parameters affecting the above mentioned subprograms were varied. Table 6-1 lists the parameters and the corresponding subprograms.

For each parameter, one high (more beneficial) and one low (less beneficial) value was established in addition to a middle or nominal value. Table 6-1 summarizes these values for each of the five subprograms. The subprogram evaluation measures were then recalculated for both the low and high values. Table 6-2 contains the results illustrating the effect on the subprogram evaluation measures produced by varying the six parameters between their extreme values. For Subprogram A, varying P_a from 0.5 to 3.0 (a factor of 6) results in values for each of the three evaluation measures--benefit-cost ratio, safety impact, and capital savings--in which the higher value is six times the lower. Thus, the effects are linear and proportional consistently. For Subprogram B, however, varying P_b from 5.0 to 20.0 (a factor of 4) results in the following effects on the evaluation measures:

- benefit-cost ratio--increases about 50 percent
- capital savings--increases over 80 percent
- safety impact--remains constant.

Obviously, the interrelationships between parameter P_b and the evaluation measures are more complex than those for Subprogram A.

TABLE 6-1

SENSITIVITY ANALYSIS PARAMETERS

	Parameter		Value		
Subprogram	Symbol	Description	Hi	Mid	Lo
A	P_a	% of total annual track maintenance and rehabilitation cost saved by track system handbook	3.0	1.2	0.5
B	P_b	% of additional cost required to restrain CWR which can be saved by accurate knowledge of buckling conditions	20.0	10.0	5.0
C	M_c	Miles of track in which it is economical to install improved rail	5000	2200	1000
J	P_j	% increase in cost of an improved wood-tie fastening system	30.0	44.0	44.0
L	M_l	Number of ties spike-killed annually	2.9	2.9	1.0
	T_l	Number of years tie life can be extended by resin plug	8.0	8.0	4.0

TABLE 6-2

PARAMETER EFFECT ON SUBPROGRAM EVALUATION MEASURES

Subprogram	Parameter ID	Parameter Range	Parameter Value	Benefit-Cost Ratio (Present Value)	Safety Impact (1st 5 Years)	Capital Savings (1st 5 Years)
A	P_a	Hi	3.0	114.7	630.0	360.0
		Mid	1.2	45.9	252.0	144.0
		Lo	0.5	19.1	105.0	60.0
B	P_b	Hi	20.0	52.9	113.6	16.1
		Mid	10.0	37.9	113.6	11.3
		Lo	5.0	35.1	113.6	8.8
C	M_c	Hi	5000	2.9	3.1	- 6.9
		Mid	2200	1.3	1.4	- 3.0
		Lo	1000	0.6	0.3	- 1.4
J	P_j	Hi	30.0	11.0	9.1	-12.8
		Mid	44.0	3.9	2.3	- 4.8
		Lo	44.0	3.9	2.3	- 4.8
L	M_l	Hi	2.9		(See T_l)	
		Mid	2.9			
		Lo	1.0			
	T_l	Hi	8.0	781.5	0.0	321.9
		Mid	8.0	781.5	0.0	321.9
		Lo	4.0	157.1	0.0	88.5

Of interest, ultimately, is the effect the parameter values could produce on the overall ranking of subprograms. To determine these effects, twelve high/low combinations of parameter values were selected, the corresponding evaluation measures for each combination were entered into the computer program, and the subprogram scores and ranks calculated. Table 6-3 shows these results compared to the base case which used mid or nominal parameter values. Although scores change and some shifting in relative rank occurs between a few subprograms, the net result is that subprogram ranks are relatively insensitive to the variations in parameter values. In almost all cases, the ranking was similar to the base case using nominal values.

Finally, an analysis was conducted to determine what effect all high or all low parameter values for the five subprograms would have on the relative ranking of the thirteen subprograms. Table 6-4 illustrates these results. Compared to the base case (all mid or nominal parameter values) again, the overall ranking of subprograms appear to be highly insensitive irrespective of parameter value extremes.

The sensitivity analysis appears to have divided the subprograms into three groups: high rank, medium rank, and low rank. In the high rank group are:

- Subprogram L--In-Place Repair of Spike-Killed Ties
- Subprogram A--Track System Handbook
- Subprogram G--In-Place Rail Welding

In ten of the twelve variations tried in the sensitivity analysis, these three subprograms emerged as the three with highest rank.

The medium rank group consists of:

- Subprogram F--On-Site Electric Flash-Butt Welding
- Subprogram B--Improved Lateral Track Stability
- Subprogram H--Bolt Hole Crack Prevention

TABLE 6-3

SENSITIVITY ANALYSIS RESULTS: EFFECT OF PARAMETER VALUES ON SUBPROGRAM RANK AND SCORE

Subprogram of Interest	Parameter Values		Subprogram Rank & Score												
	Subprogram of Interest	All Other Subprograms	1	2	3	4	5	6	7	8	9	10	11	12	13
A	Hi	Lo	A	L	G	F	H	B	D	E	K	I	C	J	M
			155	111	102	88	81	74	73	71	55	55	48	44	41
	Lo	Hi	L	B	A	G	F	H	D	E	K	I	C	J	M
			214	93	86	86	81	76	74	66	50	49	45	43	38
B	Hi	Lo	L	G	B	A	F	H	D	E	K	I	C	J	M
			115	104	104	99	91	84	83	73	55	55	49	45	42
	Lo	Hi	L	A	G	F	H	B	E	D	K	I	C	J	M
			211	138	86	78	73	66	64	63	50	49	44	41	38
C	Hi	Lo	L	G	A	B	F	H	D	E	K	I	C	J	M
			116	105	100	100	91	84	84	74	56	55	50	45	42
	Lo	Hi	L	A	G	F	H	B	E	D	K	I	C	J	M
			209	137	85	78	73	69	64	63	50	49	44	41	38
J	Hi	Lo	L	G	B	A	F	H	D	E	K	I	C	J	M
			115	104	100	99	91	84	83	74	56	55	49	47	42
	Lo	Hi	L	A	G	F	H	B	E	D	K	I	C	J	M
			210	137	86	78	72	69	64	63	49	49	44	41	38
L	Hi	Lo	L	B	A	G	F	H	D	E	K	I	C	J	M
			214	91	86	87	81	76	74	67	50	50	45	42	38
	Lo	Hi	A	L	G	F	H	B	D	E	K	I	C	J	M
			155	111	102	88	81	77	73	71	55	54	48	45	41
All (Base Case)	Mid	–	L	A	G	F	B	H	D	E	K	I	C	J	M
			216	104	88	81	76	75	68	66	51	50	45	42	39

TABLE 6-4

SENSITIVITY ANALYSIS RESULTS: EFFECT OF PARAMETER VALUE EXTREMES ON SUBPROGRAM RANK AND SCORES

Parameter Values	Subprogram Rank & Score												
	1	2	3	4	5	6	7	8	9	10	11	12	13
All Hi	L	A	G	F	H	B	E	D	K	I	C	J	M
	210	137	86	78	72	69	64	63	49	49	43	41	38
All Mid	L	A	G	F	B	H	D	E	K	I	C	J	M
	216	104	88	81	76	75	68	66	51	50	45	42	39
All Lo	L	G	A	B	F	H	D	E	K	I	C	J	M
	115	104	100	100	91	85	83	74	56	55	49	45	42

- Subprogram D--In-Place Rail Hardening
- Subprogram E--Improved Thermite Welding

Here again, in ten of twelve sensitivity analysis variations, these five subprograms emerged with ranks in the range of 4 through 8 inclusive.

The low rank group consists of:

- Subprogram K--Improved Wood-Based Tie
- Subprogram I--In-Place Bolt Hole Crack Restraint
- Subprogram C--Improved Rail Metallurgy
- Subprogram J--Improved Wood Tie Fastening System
- Subprogram M--Improved Concrete Tie & Fastener Selection & Utilization

Despite the fact that parameters were varied in Subprograms C and J, the rank of these five subprograms was invariant throughout the sensitivity analysis.

7.0 CONCLUSIONS AND RECOMMENDATIONS

The approach to R&D planning used in this study was somewhat different from that traditionally used by government agencies in general and FRA in particular. By far, the most distinguishing characteristic of the approach is its formality or quantitative orientation. This feature allowed the results of objective analyses to be combined with the subjective judgement of many in a uniform way. The study method, its results and the mere conduct of the study itself have suggested several conclusions and recommendations.

7.1 Conclusions

The study has demonstrated the feasibility and practicality of using a formal subprogram evaluation and ranking methodology in helping to set track system R&D priorities. Undoubtedly, variations which improve upon the basic approach can and will be conceived. For example, federal agencies on occasion conduct R&D planning conferences of several days duration in which there is considerable discussion about problems, solution approaches, costs and benefits, and the only output is a qualitative summary of what a few participants had said. Perhaps a combination of the R&D planning conference approach and the more formal approach followed here would be more cost-effective than either approach pursued alone.

As shown in Table 3-3 the problem of foremost concern to the persons interviewed in this study is one of insufficient understanding of how traffic, the environment, and rehabilitation and maintenance methods affect the track system and its components. A glance at the list of problems in Table 3-1 shows that this general problem statement manifested itself in many ways--four of the top ten problems fall into this category (Problems 1, 3, 8 and 10). Additional insight into the breadth of the general problem can be obtained by examining the various ways in which the four specific problems, as well as other "Insufficient

Information" type problems, were expressed by the interviewees. These are listed in Appendix C.

A distant second in the rank ordered list of important problems is a group of problems associated with the rail itself. The interviewees felt that wear, plastic flow, and failure rates are all excessive. In most cases, these problems were connected to conditions of heavy loads.

Beyond the first two classes of rehabilitation problems are problems associated with excessive longitudinal rail stress (track buckling), inadequate performance of the spike and plate fastening system, and inadequate field welding techniques.

The results of evaluating and ranking subprograms and the subsequent sensitivity analysis indicate that at least two, and perhaps three subprograms should be singled out and given high priority for incorporation into the Improved Track Structures Research Program. There are:

- Subprogram L--In-Place Repair of Spike-Killed Ties
- Subprogram A--Track System Handbook

and perhaps

- Subprogram G--In-Place Rail Welding

A word of caution, however, is in order prior to implementing any subprogram. First, there is uncertainty in the data used to estimate subprogram benefits. Although the data are believed to be sufficiently accurate to allow ranking of one subprogram <u>relative</u> to another, the data, in all likelihood are not sufficiently accurate to allow quoting an <u>absolute</u> benefit or benefit-cost ratio value of a particular subprogram in isolation from values of other subprograms without a long list of qualifications about the data involved. Second, the cost data used in this study are based on 1978 dollars and must be adjusted for inflation rates of future time periods. Third, individual subprogram benefits cannot be arithmetically summed to obtain maximum achievable benefits; to do so would be to overstate benefit expectations. Finally, the quantitative objectives stated for each subprogram should actually be viewed as one point on a cost-benefit curve. Therefore, a subprogram should be considered successful if any point (i.e., any combination of parameters used in the objective) yielding equal or higher benefit is attained.

7.2 Recommendations

The following recommendations address items believed to be important for successful utilization of the results of this study. The recommendations fall into the following major areas:

1. Additional R&D planning.
2. Development and implementation of a comprehensive track structures R&D plan.
3. Evaluation
4. Problem identification and needs assessment.

7.2.1 Additional R&D Planning

It should be recognized that further planning work is necessary before any of the recommended projects are implemented. The greatest need is to coordinate or merge the results of this study--which focus on track rehabilitation R&D--with those of PBQ&D--which are directed at track maintenance issues. The results of this effort would be a rank-ordered list of track maintenance and rehabilitation R&D projects which would be the primary data source for FRA's overall track structures R&D plan. As part of this work, it is recommended that detailed project evaluation criteria (e.g., benefits, accidents prevented, R&D cost, time, etc.) be reviewed and updated.

7.2.2 Plan Implementation

Prior to the completion of the comprehensive R&D plan, FRA should give serious consideration to the best means for activating the plan. Operationally, some R&D projects may be combined and awarded to one contractor if the projects were indeed functionally similar. The advantages and disadvantages of such a contracting arrangement must be carefully weighed in advance for each group of projects. Furthermore, FRA should determine the feasibility of establishing managers for each subprogram or similar subprograms using either in-house staff or on a contract basis. Such an arrangement would help centralize administrative and other requirements.

The benefit calculations performed during this study required many assumptions which require further validation. To assist in this area, Subprogram A (Track System Handbook) projects should begin to be implemented early--especially Project 1--the Requirements Study--which would provide a basis for focusing the information gathering activities in other R&D projects.

The R&D cost estimates and schedules <u>must</u> be continuously monitored and updated between each project. Although subprogram managers may be administratively responsible for this activity, FRA should consider the need for an independent evaluator to develop new R&D cost and timetable estimates or, at the very least, conduct a separate verification of estimates developed by subprogram managers.

7.2.3 Evaluation, Problem Identification and Needs Assessment

The R&D planning process is actually a part of a larger management approach. Problems will change over time. To recognize such change, consideration should be given to establishing a problem identification element into the track structures program. Two recommendations should be considered. The first is to tie the train accident and incident data base into the R&D management process. By monitoring these data and providing information to subprogram managers (and others), the R&D projects can be adjusted either in terms of emphasis, timing or problem scope. The second recommendation is that continuous contact be maintained with the railroads, suppliers, and the AAR to identify changing problems, new requirements and problems for future R&D programs. This liaison effort will help act as an early warning device and lead to a more orderly R&D development activity.

Finally, once subprograms are completed and their results become available some mechanism must be established to monitor the implementation of the results by the industry. Are the projects implemented actually solving the problems intended? What burdens are they imposing on the roads? Are they as cost-effective as predicted? An evaluation framework must be set up to help answer these and other further questions.

REFERENCES

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2. R. J. Barber Associates, "The Railroads, Coal and the National Energy Plan: An Assessment of the Issues," 1977.

3. U.S. Department of Transportation, Federal Railroad Administration, Accident/Incident Bulletin No. 146, Calendar Year 1976, Washington, D.C., December 1977, (Table 3).

4. Ibid (Table 4).

5. A. E. Shulman and C. E. Taylor, Analysis of Nine Years of Railroad Accident Data (1966-1974), Association of American Railroads, Washington, D.C., April 1976.

6. Attachment to letter of November 7, 1975 from G. C. Martin, Director of Dynamics Research, Association of American Railroads to Dr. R. M. McCafferty and the Federal Railroad Administration.

APPENDIX A

TRACK SYSTEM PROBLEM LIST

USED IN INTERVIEWS

APPENDIX A

TRACK SYSTEM PROBLEM LIST USED IN INTERVIEWS

TRACK STRUCTURE PROBLEMS

RANK

I. TRACK SYSTEM

A. Low productivity of capital and labor in MOW ____
B. Track buckling ____
C. Insufficient cost/performance information on the effects of tonnage and wheel loads on the track system ____
D. Insufficient cost/performance data to judge when and how to rehabilitate ____
E. ____
F. ____
G. ____

II. RAIL

A. CWR or Jointed ____
1. Fatigue related defects (fissures, shelling . .) ____
2. Gage face wear ____
3. Plastic flow defects (corrugation, . .) ____
4. Excessive wear due to heavy wheel loads ____
5. Insufficient knowledge for proper rail selection ____
6. Imperfect field flaw detection ____
7. ____
8. ____

B. CWR
1. Field welding too expensive ____
2. Pull aparts ____
3. ____

C. Jointed
1. Bar breakage ____
2. Bar wear ____
3. Bolt/bolt hole problems ____
4. Insulation deterioration on insulated bars ____
5. ____
6. ____

RANK

III. TIES

A. Wood
1. Splitting ____
2. Mechanical wear ____
3. High cost of disposal ____
4. Unknown future availability ____

B. Reconstituted
1. Unknown performance ____
2. ____

C. Concrete
1. High price--first cost and installation ____
2. Rail seat cracking ____
3. Center binding ____
4. Fastener pullout ____
5. ____

D. Other
1. ____

IV. RAIL/TIE INTERFACE

A. Wood tie fasteners
1. Unknown cost/performance of innovative designs ____
2. Inability to hold gage on curves ____
3. ____

B. Concrete tie fasteners
1. Rail seat deterioration ____
2. Pullout ____
3. ____

C. Tie Plates
1. Excessive breakage ____
2. ____

D. Anchors
1. Insufficient knowledge on condition assessment ____
2. Insufficient knowledge of correct patterns ____
3. ____

TRACK STRUCTURE PROBLEMS (Continued)

RANK

E. Tie Pads

1. Insufficient durability ____
2. ____

V. BALLAST

A. Fouling ____
B. Degradation ____
C. Unknown rehabilitation optimum depth ____
D. Pumping ____
E. Insufficient knowledge of compaction ____
F. ____
G. ____

VI. ROADBED

A. Ballast pockets ____
B. Heaving ____
C. Slope stabilization problems ____
D. Vegetation control problems ____
E. Unknown optimum soil stabilization technique per problem area ____
F. Insufficient knowledge of soils ____
G. ____
H. ____

VII. SPECIAL TRACKWORK

A. Insufficient knowledge on proper frog maintenance ____
B. Excessive switch point wear ____
C. Insufficient knowledge on stock rail maintenance ____
D. ____
E. ____

VIII. NON-CONVENTIONAL TRACK STRUCTURES

A. Slabs ____
B. Beams ____
C. ____

TRACK STRUCTURE PROBLEMS (Concluded)

		RANK
IX.	OTHER	
	A. Track system R&D results not properly disseminated	____
	B. Unknown interrelationships between the track system and railroad costs, revenues and profits	____
	C.	____

APPENDIX B

INTERVIEWEES

APPENDIX B

INTERVIEWEES AND THEIR AFFILIATION

Interviewee	Affiliation
J. Lundgren W. So A. Zarembski	Association of American Railroads
H. F. Longhelt A. M. Schofield R. D. Johnson D. F. Sullivan W. Sponseller	AMTRAK
C. C. Herrick	ConRail
T. C. Fuglestad F. C. Weeks W. Hobart	Alaska Railroad
R. Arnlund D. White	Bechtel, Inc.
T. Yang	ENSCO, Inc.
R. Shipley A. Sams G. Mester	Deleuw-Cather & Company
T. K. Dyer	T. K. Dyer & Associates
R. Nayak	A. D. Little, Inc.
R. Prause D. Ahlbeck T. Johns D. Broek	Battelle-Columbus Laboratories
R. Ballard F. McLean	Corps of Engineers

INTERVIEWEES AND THEIR AFFILIATION (Concluded)

Interviewee	Affiliation
T. Anyos	SRI International
D. Lindh	Boeing Company
L. Peckover	L. Peckover, Engineer
E. Selig	State University of New York at Buffalo
M. Thompson	University of Illinois
G. Raymond	Queens University
D. Bray	Texas A&M
J. Blacklock	University of Arkansas
G. Butler	UMTA
J. A. Richards	FRA/RNC
W. Edson	FRA/RPD
R. E. Kleist	FRA/RFA
D. Dancer	FRA/RRD
W. Paxton	FRA/RRS
T. Evans	
T. Patton	
H. Keeler	
T. Comparato	TSC
S. Gozzo	
R. Ehrenbeck	
R. Steele	
D. McConnell	
A. Sluz	
P. Tong	
R. Murphy	
A. Kish	

APPENDIX C

GENERIC TRACK SYSTEM PROBLEMS

AND THEIR EQUIVALENTS

APPENDIX C

PROBLEM NUMBER	PROBLEM
1	INADEQUATE TRACK STRUCTURE COST/PERFORMANCE DATA
	Insufficient Data Relating Track System Costs to Traffic Mix, Speed, etc.
	No Available Quantitative Data Which Relates Track Design to to Track Loads
	Unknown Interrelationships -- Track System/RR Costs, Revenues, Profits
	Insufficient Cost/Performance Data -- Effects of Tonnage, Wheel Loads/Track System
	Insufficient Cost/Performance Data to Judge When and How to Rehabilitate
	Insufficient Cost/Performance Data -- Track Design vs. Long Term Performance
	Track/Train Interaction
	Unknown Optimum Track Design for Traffic, Loading, Terrain, Etc.
	Insufficient Cost/Performance Data -- Effects of Unit Trains on the Track System
	Track Vertical/Lateral Stability vs. Traffic/Construction Quality
	Insufficient Information -- Transfer Function Relating Structural Behavior to Long Term Performance
	Insufficient Fatigue Data on Track Components
	Lack of Criteria on U.S. Load Spectrum
	Lack of Dynamic Performance Standards on Track Strength and Endurance
	Measurement of Track Stress and then Development of Equations to Predict Stress
	Limits and Effectiveness of Construction and Maintenance Tolerances

PROBLEM NUMBER	PROBLEM
1	INADEQUATE TRACK STRUCTURE COST/PERFORMANCE DATA (Continued)
	Cost of Using Better Materials Versus the Decreased Maintenance
	Acceleration and Vibration Measurements of Track Components
	Track Structure Loadings Resulting from Differing Track Structures
	Track Forces from High Speed Passenger and Freight, Slow Speed Freight, etc.
	Fatigue Characteristics of Various Track Components -- Minimize
	Verify Track Models
	Optimum Track Design to Minimize Forces on Various Components
	Develop Lab Test Techniques Which Simulate Actual Loads, Vibrations
	Unknown Cost/Performance Benefits of Improved Track
	Missing Link -- Unknown Long Term Performance Criteria
	Insufficient Knowledge -- Dynamic Interactions of Track System Components
	Correlation of Ballast Depth/Tie-Spacing with Subgrade Strength
2	EXCESSIVE RAIL WEAR
	Excessive Rail Wear Due to Heavy Wheel Loads
	Gage Face Wear
3	INSUFFICIENT COST/PERFORMANCE INFORMATION ON BALLAST
	Unknown Rehabilitation Optimum Depth
	Insufficient Knowledge of Compaction
	Need -- Simplified Test Criteria for Grading Ballast

PROBLEM NUMBER	PROBLEM
3	INSUFFICIENT COST/PERFORMANCE INFORMATION ON BALLAST (Continued)
	Ballast Quality and Depth for Specific Loading
	Ballast -- Assessment and Corrective Action Techniques
	Insufficient Knowledge of Ballast Compaction
	Insufficient Knowledge about Ballast Versus Gradation
	Ballast Shoulder Width/Effect
	Optimum Ballast -- Shoulder Width, Gradation
	Insufficient Knowledge of Ballast Dynamic Pressures
	Ballast Permanent Deformation Behavior
	Unknown Optimum (Time, Depth) -- Roadbed Undercutting & Cleaning
	Insufficient Data -- Ballast Life Versus Gradation
4	EXCESSIVE LONGITUDINAL RAIL STRESS
	Temperature Effects and Control Necessary (CWR)
	CWR Pull Aparts
	Track Buckling
	Installation Temperature Relationship to Tie Resistance
	CWR Pull Aparts -- Stress/Laying
	Stress Release Methods (Laying Rail in Winter)
	Residual Stress Control (Thermal)
	Rail Stress Caused by Temperature, Wheel Loading, Track and Vehicle Irregularities
	Track Lateral Loading from Train Dynamics & Static Temperature Loads

PROBLEM NUMBER	PROBLEM
5	INADEQUATE CONCRETE TIE PERFORMANCE
	Concrete Tie Wear Due to Ballast
	Concrete Tie Center Binding
	Concrete Tie Rail Seat Deterioration
	Concrete Tie Rail Seat Cracking
	Concrete Tie -- Basic Design
	Concrete Tie Chipping and Mechanical Damage
6	INADEQUATE MAINTENANCE OF WAY METHODS
	Low Productivity of Capital and Labor in MOW (Optimal Gang Size, Equipment Configuration)
	Common Railroad Problem -- Inexperienced MOW Personnel
	Uniform MOW Operations by All Railroads
	Need for Standardized MOW Techniques to Reduce Cost, Accidents
	Insufficient Knowledge About Proper MOW Department Organization
	Corrugation Control
	Improved Track Maintenance Systems
	MOW Equipment Seldom Efficiently Designed in This Country
7	INADEQUATE PERFORMANCE OF SPIKES/PLATES AS FASTENERS
	Cut Spike an Inadequate Wood Tie Fastener
	Inability of Wood Tie Fasteners to Hold Gage
	Research on the Effects of Spike Penetration on Holding Power
	Tie Plate Design to Prevent Gage Widening
	Spike Pullout

PROBLEM NUMBER	PROBLEM
7	INADEQUATE PERFORMANCE OF SPIKES/PLATES AS FASTENERS (Continued)
	Excessive Tie Plate Breakage
	Rail Rotation/Translation -- Fastener Problem
	Improve Interface with Fastener/Tie (Tie Plate)
	Method to Determine Lateral Support Cspacity of Spike Holes
	Tie Plate Design -- Cant, Size, Ribs on Bottom
8	INSUFFICIENT COST/PERFORMANCE DATA -- PROPER RAIL SELECTION
	Insufficient Data -- Rail Wear Versus Rail Metallurgy
	Insufficient Cost/Performance Data -- Premium Rail (Cleanliness, Metallurgy, Length)
	Insufficient Knowledge for Proper Rail Selection
	Unknown Cost/Benefit of Premium Rail
	Documentation of Statistics of Rail Failures
	High Cost of Rail -- Too Many Rail Sections Required by Individual Railroads
	Develop Relationships: Speed, Tonnage, Rail Weight, Rail Wear (Failures, Accidents)
9	PREMATURE RAIL FAILURE
	Rail Shelling
	Rail Fatigue Related Defects
	Rail Fatigue Growth -- Most Economical Change Out (Wear or Fatigue)

PROBLEM NUMBER	PROBLEM
10	INSUFFICIENT INFORMATION ABOUT SUBGRADE PERFORMANCE
	Cost/Benefit of Roadbeds with Information Available
	Insufficient Knowledge of Soil
	Permanent Subgrade Deformation Under Repeated Loading
	Effects of Moisture and Temperature on Roadbed
	Relationship of Soil Tests to In-Situ Performance
	Magnitude of Loading to Subgrade
	Track Design Criteria Relating Subgrade Pressure to Long Term Performance
	Environmental Effects on Subgrade (Moisture, Freeze-Thaw)
	Insufficient Information -- Subgrade Engineering
11	INADEQUATE FIELD WELDING TECHNIQUES
	Field Weld Quality
	Improve Field Welding
	Welding Techniques Required
	Field Weld Area Failures Due to Traffic
	Field Welding too Expensive
	Poor Reliability of Field Welds
12	UNKNOWN COST/PERFORMANCE OF SUBGRADE IMPROVEMENT METHODS
	Unknown Optimum Soil Stabilization Technique Per Problem Area
	Application of Existing Soil Stabilization Techniques
	Insufficient Cost/Benefit Data on Drainage Improvement Effects
	Unknown Soil Stabilization Technique per Problem Area

PROBLEM NUMBER	PROBLEM
13	EXCESSIVE RAIL PLASTIC FLOW DEFECTS
	Rail Corrugation
	Rail Plastic Flow Defects
14	INADEQUATE CONCRETE TIE FASTENER DESIGN
	Concrete Tie Insulation
	Concrete Tie Fastener Pullout -- Specifications and Components
	Inadequate Concrete Tie Fasteners
	Optimum Concrete Tie Fastener Design
	Insufficient Durability of Tie Pads
	Concrete Fastener Design to Fit U. S. Wheel Load Requirements
15	INADEQUATE METHODS FOR SUBGRADE IMPROVEMENT
	Methods to Solve Drainage Problems
	Moisture Infiltration Control
	Technology for Improving Subgrade Soils
16	EXCESSIVE BALLAST DEGRADATION
	Ballast Deterioration - Specifications Not Sufficient or Reliable to Predict Performance
	Ballast Degradation
	Ballast Durability (Freeze, Thaw, Wet, Dry)
	Ballast Cementing

PROBLEM NUMBER	PROBLEM
17	EXCESSIVE BALLAST/SUBGRADE INTERACTIONS (PUMPING)
	Necessity of Quality Soils Versus Added Ballast
	Ghost Joints in Newly Laid CWR
	Ballast/Subgrade Interaction Unknown
	Ballast Pumping
	Ballast Pockets
	Effect of Ballast Interaction with Subgrade
18	TRACK SYSTEM R&D RESULTS NOT PROPERLY DISSEMINATED
	Submit Subprogram Description to AAR Before Funding for Evaluation, Recommendations
	Track System R&D Results Not Properly Disseminated
	Current Analytical Tools Not Readily Usable by Practicing Track Designers
	Track System R&D not in Industry Usable Form
	Track System R&D Results not in Form Usable by Field Personnel
19	EXCESSIVE WOOD TIE DEGRADATION
	Wood Tie Splitting
	Wood Tie Mechanical Wear
	Spike Killing
	Wood Tie Splitting from Spike Kill in Shim Areas
	Accelerate Research on Reconstituted Wood Ties
20	BOLT/BOLT HOLE PROBLEMS
	Bolt/Bolt Hole Problems

PROBLEM NUMBER	PROBLEM
21	INADEQUATE WOOD TIE RENEWAL METHODS
	Cost Effective Wood Tie Renewal Systems
	Wood Tie Restoration, Repair, Cascading Techniques
22	HIGH CONCRETE TIE INITIAL/INSTALLATION COSTS
	High Cost of Concrete Ties -- First Cost and Installation
23	INABILITY TO DETERMINE RAIL STRESSES IN THE FIELD
	Inadequate Rail Internal Stress Detection
	Inability to Determine In-Situation Rail Stresses (Buckling Potential)
	Insufficient Data on Stress Distributions along CWR Lengths
	No Non-Destructive Measurement of Longitudinal Rail Stress
	Longitudinal Force Detector
	Residual Stress Determination in Rails (Thermal)
	Insufficient Data on the True Level of Longitudinal Stresses In Rail
24	UNKNOWN ANCHOR EFFECTIVENESS/PERFORMANCE
	Insufficient Knowledge of Correct Anchor Patterns
	Insufficient Knowledge -- Bridge and Trestle Anchoring
	Insufficient Knowledge on Anchor Condition Assessment
	Unknown Anchor Effectiveness/Performance
25	INADEQUATE FIELD RAIL FLAW DETECTION
	Relate Service Failures to Inspection -- Existing Statistics
	R&D Analysis of Flaw Detection by Computer
	Imperfect Field Rail Flaw Detection

PROBLEM NUMBER	PROBLEM
26	UNKNOWN FAILURE COST/AVAILABILITY OF WOOD TIES
	Unknown Future Availability of Wood Ties (Supply, Cost Variability)
	Unknown Wood Tie Future Availability Versus Cost
27	INSUFFICIENT COST/PERFORMANCE DATA -- OPTIMUM WOOD TIE UTILIZATION
	Insufficient Information about Proper Spacing of Non-Defective Ties on Curves
	Optimum Tie Spacing for Speed, Loading, Rail Size
	Wood Tie Size Related to Speed, Tonnage, Stability of Embankment
	Hardwood Versus Fir Ties on Curves (Unknown Cost/Performance)
	Insufficient Cost/Performance Data -- Optimum Tie Spacing/ Size for Conditions
	Optimum Wood Tie to Accommodate Loading -- Width, Depth, Spacing
28	INSUFFICIENT KNOWLEDGE ABOUT COST/PERFORMANCE OF SPECIAL TRACKWORK
	Summarize Existing Frog Design Differences
	Summarize Existing Switch Design Differences
	Special Trackwork -- Design and Application
	Economics of Welded Versus Standard Turnouts
	Insufficient Knowledge on Effects of Stiffness Mismatch through Switches, etc.
	Modifications to Special Trackwork -- Impact, Lat. Loading Considered
	Insufficient Knowledge of Special Trackwork Loading
	Criteria for Rebuilding Frogs

PROBLEM NUMBER	PROBLEM
29	INADEQUATE FROG MAINTENANCE METHODS
	Insufficient Knowledge on Proper Frog Maintenance
	Inadequate Special Trackwork Rehabilitation Methods (Frogs)
30	TRACK GEOMETRY PROBLEMS
	Track Durability and Geometry Retention
	Loss of Line (Non-Buckling)
	Loss of Surface
31	INSUFFICIENT INFORMATION -- COST/PERFORMANCE OF INNOVATIVE WOOD-BASE TIES
	Unknown Cost/Perfromance of Reconstituted Ties
32	EXCESSIVE SWITCH WEAR
	Excessive Switch Point Wear
33	INSUFFICIENT COST/PERFORMANCE DATA -- INNOVATIVE WOOD TIE FASTENERS
	Unknown Optimum Wood Tie Pad Characteristics
	Unknown Cost/Performance of Innovative Wood Tie Fasteners
	Optimum Wood Tie Fasteners (Systems Approach)
34	INADEQUATE SUBGRADE ASSESSMENT TECHNIQUES
	Methods to Detect Drainage Problems
	Identification of Problem Areas Requiring Stabilization
	Exploration/Investigation of Supporting Soils
	Insufficient Information -- Subgrade Evaluation

PROBLEM NUMBER	PROBLEM
35	INSUFFICIENT COST/PERFORMANCE DATA -- WOOD TIE SELECTION
	Unknown Effectiveness of Wood Tie Treating Processes
	Cost/Benefit of Reducing Wood Tie Mechanical Wear
	Develop Quality Control Standards for Wood Ties
36	INADEQUATE CONCRETE TIE COST/PERFORMANCE DATA
	Misuse of Concrete Ties
	Insufficient Cost/Performance Data -- Concrete Tie Utilization
	Unknown Economic Lifespan of Concrete Ties
	Quality Control -- Concrete Ties
	Inadequate Concrete Tie Performance Data
	Unknown Life Cycle Costs of Concrete Ties
	Unknown Effect of Service Load Environment on Concrete Tie Design Life
	Inability of U.S. Railroads to Utilize Foreign Concrete Tie Technology
37	EXCESSIVE BALLAST FOULING
	Ballast Fouling
38	INADEQUATE SLOPE STABILIZATION METHODS
	Slope Stabilization Problems
39	INSUFFICIENT INFORMATION ON THE CAUSES OF RAILWAY ACCIDENTS
	Insufficient Information About Causes of Accidents
	Insufficient Data on Actual Derailments/Failures

PROBLEM NUMBER	PROBLEM
40	INADEQUATE STOCK RAIL MAINTENANCE METHODS
	Insufficient Knowledge on Stock Roil Maintenance
41	INADEQUATE BALLAST MAINTENANCE/REHABILITATION METHODS
	Cost Effective Ballast Corrective Measures
	Need Method for Recycling Ballast Material
	Undercutting and Cleaning too Expensive
42	INADEQUATE MOW METHODS AT CROSSINGS
	Excessive Cost of Rebuilding Highway Crossings
	Develop Improved Method to Stabalize Ballast at Highway Crossings
	Develop Improved MOW Techniques at Grade Crossings
	Inadequate Special Trackwork Rehabilitation Methods (Crossings)
43	INADEQUATE JOINT MAINTENANCE METHODS
	Excessive Maintenance of Track Geometry at Bolted Joints
	Criteria and Methods for Restoring Battered Ends
44	COST/BENEFITS ASSOCIATED WITH TIE PLATE AREA UNKNOWN
	Costs/Benefits Associated with Tie Plate Area
	Insufficient Knowledge for Tie Plate Selection
	Tie Plate Size Versus Tie Wear
	Economic Advantages of Anchor Spiking on Curves (Prevent Gage Widening)
45	SUBGRADE HEAVING
	Roadbed Heaving

PROBELM NUMBER	PROBLEM
46	INADEQUATE MOW METHODS AT SWITCHES
	Inadequate Special Trackwork Rehabilitation Methods (Switches)
47	INADEQUATE METHODS FOR EVALUATING IN-SITU TRACK
	Identification of Weak Joints (Caused By Any Problem)
	Techniques for Evaluating In-Situ Track
48	UNKNOWN COST/PERFORMANCE OF CONCRETE TIE FASTENERS
	Insufficient Cost/Performance Data -- Concrete Tie Fasteners
	Spring Compression and Wear Performance of Slips and Pads
49	INADEQUATE BONDED JOINT MAINTENANCE
	Bonded Insulated Joint Renewal When First Installation Fails
50	INADEQUATE FIELD WELD INSPECTION TECHNIQUES
	Field Welding Testing Procedures (Better and Cheaper)
	Inadequate Methods of Detecting Field Weld Defects
51	TRACK SYSTEM R&D GOALS NOT CLEAR -- GOVERNMENT/PUBLIC/ RAILROAD CONFLICTS
	R&D Goals Not Clearly Defined -- FRA/Public/Railroad Conflicting Needs
52	PREMATURE JOINT BAR BREAKAGE
	Joint Bar Breakage
53	UNKNOWN EFFECTS OF TRACK DESIGN/IRREGULARITIES ON RAIL VEHICLES
	Forces Induced into Rail Vehicles Due to Track Design or Irregularities

PROBLEM NUMBER	PROBLEM
54	HIGH COST OF INSULATED JOINT INSTALLATION METHODS
	Improved Methods to Install Epoxy Insulated Joints (Reduce MOW)
55	INADEQUATE COST/PERFORMANCE DATA -- OPTIMUM JOINT BAR FOR CONDITIONS
	Bar Economics
56	INADEQUATE ANCHOR INSTALLATION METHODS
	Anchor Installation Methods
	Improved Anchor Application Techniques
57	LINE SPEED/YARD CAPABILITY NOT COMPATIBLE
	Modify Line Speed to Fit Yard Capability
58	INADEQUATE FIELD JOINT BAR FLAW DETECTION
	Develop Improved Method of Bar Flaw Detection for Jointed Rails
59	EXCESSIVE JOINT BAR WEAR
	Bar Wear
60	INADEQUATE VEGETATION CONTROL METHODS
	Vegetation Control
61	INADEQUATE METHODS FOR MAINTAINING TRACK GEOMETRY AT SPECIAL TRACKWORK
	Inability to Maintain Track Geometry at Special Trackwork
62	INADEQUATE BOLTED INSULATED JOINT PERFORMANCE
	High Cost of CWR Insulated Joint Maintenance
	Develop Improved Bar Design, Insulating Materials
	Insulation Deterioration on Insulated Joint Bars

PROBLEM NUMBER	PROBLEM
63	INADEQUATE BONDED JOINT PERFORMANCE
	Glued Joints -- Minimize Impact
64	TOO MUCH CURVED TRACK (LINE MODIFICATION NEEDED)
	Line Modification (Reduce Curves)
65	INSUFFICIENT INFORMATION ABOUT NON-CONVENTIONAL STRUCTURES
	General Analysis and Evaluation of Problems in Non-Conventional Track Structures
66	UNREALISTIC GOVERNMENT TRACK STANDARDS REGULATORY ACTION
	Unrealistic Government Regulatory Action on Track System Standards (Geometry and Performance)
67	UNKNOWN FIELD WELD PERFORMANCE -- REGULAR RUNNING RAIL
	Unknown Performance of Field Welds vs. Regular Running Rail
68	ECONOMIC SAVINGS OF PROPER JOINT MAINTENANCE
	Economic Savings Through Proper Joint Maintenance
69	WOOD TIE DISPOSAL -- HIGH COSTS
	High Cost of Wood Tie Disposal -- Techniques and Application
70	SWITCH REBUILDING CRITERIA
	Criteria for Rebuilding Switches

APPENDIX D

DETAILED DESCRIPTIONS OF

TRACK REHABILITATION R&D SUBPROGRAMS

APPENDIX D

DETAILED DESCRIPTIONS OF TRACK REHABILITATION R&D SUBPROGRAMS

This appendix contains detailed descriptions of thirteen subprograms recommended to be included in FRA's Track Rehabilitation R&D Program.

Each subprogram has been prioritized or ranked based on various criteria defined elsewhere in this report. The rank values range from 1 to 13 and appear on the first page of each subprogram section.

The subprograms also contain a statement of the problem and summary of the current state-of-knowledge; R&D objectives and required R&D projects; estimated R&D costs and time tables; and, background information on project benefits, evaluation parameters, and implementation matters.

One of the implementation items deals with the relationship of each subprogram to other subprograms and to other programs involving the track system. Among the relationships identified is one that applies to every subprogram that follows. In the interest of brevity it is noted once here, rather than many times hereafter.

In one form or another, all thirteen subprograms call for test planning, testing and analysis. The Track System Handbook in particular requires cost and performance data about every component, method, and machine used widely to construct, rehabilitate and maintain track. Since all of the other subprograms are aimed at producing either an improved component or method, and since they all require collecting and analyzing data about current as well as improved components and methods, considerable overlap will occur between the Handbook subprogram and every other subprogram. Therefore, in performaing the test planning, test and analysis projects of any "non-handbook" subprogram, consideration should be given to the information needs of the Handbook subprogram so that any overlap, or duplicate testing and analysis, can be eliminated.

SUBPROGRAM A

TRACK SYSTEM HANDBOOK

RANK 2

PROBLEM

In 1975, the nation's Class I railroads spent \$2.0 billion to rehabilitate and maintain 325,000 miles of track. In the same year, approximately 3,200 track-caused train accidents occurred, costing the railroads and shippers another \$230 million. In 1976, expenditures rose to \$2.4 billion on 324,000 miles of track, while accidents increased to 4,200 and cost some \$282 million.

To a large degree, the decisions controlling these massive expenditures and costs are based on engineering judgment. Adequate track system design procedures, and better cost information and analyses showing the true effect of various types of loads on the track system would improve the decision process.

While track engineers have some feel for cost and performance characteristics of some track system components, in general they have insufficient information about the effects of different components on system life-cycle costs. In this sense, they are uncertain in selecting proper rail type, shape and weight; rail-to-tie fastening system; tie type, size and spacing; ballast type and amount; and subgrade stabilization method. Similarly, most maintenance personnel know how to maintain track to a given standard, but they are quite uncertain about how to minimize long-term costs.

The problem of insufficient understanding of the track system and its costs extends beyond railroad engineering and maintenance departments.

It manifests itself in situations where track system costs must be allocated to different classes of traffic either for rate-making purposes or use fees. While it is known that heavy cars damage the system more than light cars, how much more is not known. Rates for coal traffic, for example, cannot be properly developed, nor can costs to passenger service be properly ascertained.

The problem also reaches into government. With the advent of federal financial support to railroads (much of which is destined toward track rehabilitation), government officials are charged with administering these funds prudently. Their tools and information are inadequate. They cannot determine whether a proposed track system design and rehabilitation procedure is the best method for achieving program and project objectives.

Research and development efforts also suffer. Administrators and planners have, at best, sketchy information for evaluating alternative programs and selecting the most cost-effective set.

There was a time when the state-of-knowledge about the track system was adequate. That was when track material and labor unit costs were lower, wheel loads were lighter, and railroad capital was ample. That time has past.

The expected long-term role of railroads in the nation's future, and the massive investment in, and annual expenditures on, the track system, strongly suggest that a better understanding of that system is in order. Only then will design, maintenance, financial support, cost allocation, and R&D program decisions be made properly.

DESCRIPTION OF R&D EFFORT

Objective

A track system handbook will be developed which will help railroads determine optimal, or near optimal, track structures for various loading, environmental and subgrade conditions such that total annual track construction, rehabilitation, maintenance and accident costs are reduced by 1.2 percent relative to their cost without the handbook.

State-of-the-Art

In today's literature, there is no method or model, or integrated set of methods, models or relationships, which could serve as a basis for developing the desired handbook. There is, however, a considerable amount of material which might be utilized for such an effort.

For example, an effort is in progress to characterize wheel loads upon the rail.(1) Hopefully, this characterization will be compatible with the better portion of the large number of models which have been developed to predict various combinations of force, stress, strain, bending moment and displacement in track system components as a function of system configuration and wheel load.(2-30) Excellent summaries and critiques of these models are available.(2,31) However, only one of those models which deals with the complete track system has been calibrated with in-service data.(2) Another has been exercised with hypothetical data to show how it might aid track structure design if it were properly calibrated.(32) As indicated in the critiques, all the models have some deficiencies which may or may not be important in the development of a handbook. In one case, the only cited deficiency is the model's complexity which leads to high computer costs and unusual data requirements.[11] In less comprehensive efforts, ballast depth[30] and tie spacing[33] have been studied, and the forces at work in the ballast and subgrade have been measured.[21]

If true understanding of the track system is necessary, then the force-displacement type models discussed above are but the first step. At least three other kinds of models are needed: degradation, restoration, and cost models. Degradation models would accept forces, stresses, strains, moments and displacements encountered by each component as a result of train passage and predict the change in state of the track system and its components. Along these lines, some work has been done on rail wear rates and life as a function of metallurgy, track curvature, gradient, and annual tonnage in one case,[34] and as a function of rail type, rail metallurgy, train speed, gradient, curvature and wheel load in another case.[50] FRA-sponsored work on predicting rail failures is in progress. Tests at FAST are measuring the degradation characteristics of various rails, fasteners, and ties, one type of ballast, and essentially, one type of subgrade. A formula for predicting tie life as a function of rail weight, type of rail, gradient, wheel load, ballast depth, train speed and type of train service has been derived.[50] The response of several types of ballast materials to repeated load applications has been studied[35] and some ballast material properties related to long term deformation and resistance to weathering have been identified for a small group of materials.[36-38]

Recent studies in the United States, Canada, and England have described the behavior of specific subgrade materials when subjected actual traffic loads and to laboratory simulations of repeated load.[29,31,35,36] Similar work has been done for highway and airport runway subgrades.[39] This work, and work by the American Railway Engineering Association's Roadway and Ballast Committee, recognizes the wide variability of subgrade material, and more research is needed to extend the limited results thus far obtained to more types of subgrade material under a wider variety of environmental conditions.

Restoration models would accept any standard maintenance or rehabilitation practice or procedure (including track inspection) as input, and predict the change in state of the track system and its components. Along these lines, the effect of different degrees of initial ballast compaction on the amount and rate of plastic strain has been observed,[31,36,40,41] and the effect of vibration on ballast density and ballast grading has been studied.[42] Basic research into subgrade stabilization methods and soil mechanisms that make them work is in progress.[43-45] Field applications are going forward cautiously, informed with the partial design data now available, to gain experience with the various stabilization techniques, to reap whatever benefits come from the roadbeds that are treated, and perhaps to provide new avenues for basic understanding of the physical mechanisms involved in stabilization.[43,46,47] The basic mechanisms of frost heave and the load-bearing capabilities of soils subjected to freeze-thaw cycles are not fully known. Research into these phenomena continues, while engineers deal with problems using information at hand.[49]

Cost models would accept as input any standard maintenance or rehabilitation practice, along with the number and type of failed components. Their output would be cost of the practice and cost of replacements. Some work has been done in terms of documenting various maintenance practices and their costs,[50,51] and an analysis of rehabilitation practices and costs has been performed.[52,53] The costs of buying and transporting ballast material, and installing it at a work site has also been studied.[54]

Along another vein, one study attempts to predict rail and wood tie life, and surfacing frequencies as a function of wheel load, tonnage, rail type, gradient, curvature, and other factors.[50] These are coupled to cost models which yield annual track system costs. Another study reveals some interesting relationships between wheel load and maintenance cost.[55]

Interestingly, at least one researcher claims to possess the models necessary to produce "a handbook." He would not, however, reveal the nature or description of the models. Others state that enough elements exist to develop an integrated model for at a relatively modest cost.

R&D Projects Required

This subprogram is composed of 19 projects. Of these, six projects are similar and of one kind, while three others are similar and of another type. These nine projects have been grouped into two project classes. Therefore only 12 brief descriptions follow. Costs and schedule are shown in Figure D-1.

1. Requirements Study

The objective of this project is to determine the kind of information potential users of the handbook want and need, and the kind of information they have available, or can readily obtain, in order to use the handbook. To the extent possible, requirements will be specified in terms of generic classes of variables, the

PROJECT		R & D COST ($1,000)	YEARS AFTER START									
No.	TITLE		1	2	3	4	5	6	7	8	9	10
1	Requirements Study	105										
2	Handbook-Version I	300										
3	Dissemination & Evaluation-Version I	40										
4	Feasibility Conference	20										
5	Macro-Level Model Design	100										
6	Degradation Studies	1,680										
7	Restoration and Cost Studies	1,025										
8	Test Planning	120										
9	In-Service & FAST Tests	1,335										
10	Simplified Structural Model	210										
11	Analysis & Handbook Preparation	665										
12	Dissemination and Evaluation-Version II	84										
	TOTAL R & D COST	5,684										

FIGURE D-1
COST AND SCHEDULE—TRACK SYSTEM HANDBOOK

preferred specified variable for each generic class, and any specific surrogates. The study will also define the range of rail, tie, fastener, ballast and subgrade types to be treated in the handbook. Within the overall set of requirements, some minimal set will be defined which will guide the development of the first version of the handbook. Interviews with potential users in the railroad, railroad supply, government and research communities will form the basis for the requirements. The project output will include a detailed outline of the handbook and suggested formats for presenting its contents.

2. Track System Handbook--Version I

The objective of this project is to produce a handbook which fulfills at least the minimal requirements determined in Project 1, using the best of existing models and only minimal data collection efforts. While it is unlikely that the full set of requirements will be addressed and that all potential users will be satisfied, this version will be valuable in that it will provide a tangible basis for discussion with users. To that extent it will aid in refining the requirements for another version, if necessary, and in suggesting better approaches toward fulfilling those requirements.

3. Results Dissemination and Evaluation--Version I

A common problem noted by railroad and research personnel alike is that useful research results are not widely disseminated; hence their full benefits to the railroad industry are not realized as quickly as possible. To solve this problem, a seminar will be held for managers, engineers and any others who make or influence track system decisions, and who could, therefore, profit from the new knowledge contained in the handbook. The seminar's purposes are three-fold. First, it will ensure wide distribution of the handbook. Second, it will ensure a thorough understanding of the handbook's contents and how it can be used to reduce track system costs. And third, it will provide information which can be used to evaluate the utility of the handbook concept as well as its contents. Good points and bad points will surface which could be used to guide development of new or revised versions. To achieve the latter objective, the handbook should be sent to the attendees well in advance to provide them time to review its contents. To achieve all objectives, the seminar presentation must be clear, concise and well illustrated. Advice from communications experts will be sought.

4. <u>Feasibility Conference--Version II</u>

The objective of this project is to determine the technical feasibility and economic practicality of developing another version of the handbook that will meet more requirements as determined in Project 1 with more accurate information. This will be done by convening experts on track system modeling and research at a two-day workshop. The workshop will be held after the proposals for developing Version I of the handbook have been reviewed, and a decision on whether to develop it, or not, has been made. To take full advantage of the talents available, the workshop objectives will be clearly stated and the method of achieving them will be well planned. It is worth noting that in deciding upon technical feasibility, some general approaches to the problem will have to be considered. These can be prepared by the workshop coordinator or the attendees. In either case, they will be valuable inputs to Project 5 below.

5. Macro-Level Model Design

The objective of this project is to develop a macro-level design of a track system model that when properly calibrated and validated will be capable of generating the information required for the handbook. This is an important undertaking. It will not only guide all subsequent efforts in this subprogram, but will impact all test planning, and data collection efforts in virtually all other subprograms for a long time.

One approach to such a model would be an event-oriented computer simulation of the track system. Inputs to the model would be a one-time description of the track structure and a set of probability distributions or schedules of all important external events affecting the track (e.g., train passage, maintenance work). As each event arises, the change it induces in a set of track state variables is calculated and added to the old set, the resulting new set is stored, and if necessary, statistics are tabulated. Track state variables describe each component, track geometry, and perhaps overall system quality. With this model years of use, maintenance and rehabilitation practices on a section of track could be simulated in minutes.

The overall model would be composed of a structural model and sets of degradation, restoration and cost submodels as discussed in the State-of-the-Art section above. Guided by the results of Project 1, this project would specify overall input and output variables, identify all submodels, and specify all submodel input and output variables. The submodels themselves might or might not be specified. If a submodel exists, it will at least be suggested. If it exists and has been validated with laboratory or track data, it will be specified. The submodel input and output specifications will guide the subsequent submodel development projects and the test planning project.

6. Component and Geometry Degradation Studies

Six separate projects are included here. In general, the objective of five of the projects will be to develop mathematical relationships or submodels which predict how each generic track system component (rail, fastener, tie, ballast and subgrade) degrades in service. The sixth project will predict how track geometry degrades. Predictions will be valid for all of the most commonly used variations (materials, weight, shape, design, etc.) of each component. Either single generic submodels with parameters selected by the variation, or separate submodels for each variation or class of variation, will be acceptable.

More specifically, given the handbook requirements of Project 1 and the submodel input and output specifications of Project 5, these projects will develop preliminary relationships which describe how the output arises from the input. In all likelihood, input variables will be of three types. Some will represent or be derived from the train load, some will represent the climate, and the third will represent the current state of the component and the system. For some components, most notably rail, the output variables will include an indication of sudden failure as well as normal wear. Alternative input and output specifications can be adopted if they can be shown to be more beneficial than the original specification and if they are compatible with the overall macro-level model design. Additional output variables can also be specified.

To achieve the objective, a series of limited laboratory and FAST tests must be planned and performed using component material and design variations that have not been tested in previous or concurrent research projects. The new and old test data will provide the basis for developing hypothetical relationships and providing at least a preliminary validation of those relationships. Additionally, each project will identify the variables for which in-service data must be collected for more thorough validation, and it will suggest: the method or instrumentation needed to measure the variables; the ranges; the conditions under which they should be measured; and places where these conditions might arise. This information will guide test planning in Project 8.

7. Component and Geometry Restoration and Cost Studies

Three separate projects are included here. In general, the objective of each is to develop mathematical relationships which predict the cost and the degree of restoration of various operations which improve the track system. One project will deal with all common maintenance operations, one will deal with all common rehabilitation operations, while the third deals with derailment repairs. Separate submodels are envisioned for each improvement operation and for cost and restoration.

More specifically, given the handbook requirements of Project 1 and the submodel input and output specifications of Project 5, these projects will develop preliminary relationships which describe how the output arises from the input. In the case of the restoration models, the inputs are likely to represent the operation (type, crew size, equipment and time) and the current state of the track system and its components. Outputs will be amount of material added, components replaced and new state of track system.

For each restoration submodel there will be a corresponding cost submodel. Input would describe the operation, material added, and components replaced. Output would of course be cost, divided into various categories (e.g., labor, materials, equipment, total).

Alternative input and output specifications can be adopted if they can be shown to be more beneficial than those specified originally and if they are compatible with the overall macro-level model design. Additional output variables can also be specified.

To achieve the objective, a series of limited tests must be performed, the literature and the railroads must be consulted for cost data, and in-service maintenance operations must be observed. These data will provide a basis for developing hypothetical relationships and preliminary validation of relationships. Additionally, each project will identify the variables for which in-service data must be collected for more thorough validation and it will suggest: the method or instrumentation needed to measure the variables; the ranges; the conditions under which they should be measured; and places where these conditions might arise. This information will guide test planning in Project 8.

8. Test Planning

The objective of this project is to develop a plan for conducting in-service and FAST tests which assures that all needed data are collected at minimal cost. Using the results of the degradation and restoration studies, an experiment will be designed which will specify sites at which data will be collected, and the data to be collected at each site. Also in the plan will be the instrumentation or method of measurement, the collection frequency or schedule, the duration of each test, the format and recording medium, and the disposition of the recorded data. Preliminary approval of participating railroads will also be obtained and their role in the test will be well defined.

9. In-Service and FAST Tests

The objective of this project is to collect the load, climatic, component, degradation, restoration and cost data specified in the test plan and to deliver it to the analysts who will calibrate and validate the submodels and the overall model. The required instrumentation package will be designed, procured, constructed, and calibrated in the laboratory. Read-out and recording devices will also be procured and installed, and data reduction software will be developed. Final arrangements will be made with participating railroads and the instrumentation will be installed at one railroad and recalibrated. Railroad personnel participating in the test will be thoroughly briefed or trained as necessary and a trial run will be conducted with the collected data moving through the reduction process to the end users. If satisfactory, all other sites will be instrumented, personnel trained, and data collected and disposed of according to plan. At the conclusion of the test, the instrumentation will be removed.

10. Simplified Structural Model

The objective of this project is to develop a structural model of the track system which requires much less computer time and storage to operate than the better structural models available today. Existing models are complex and will be too expensive to operate as a submodel in the overall model. Once validated, however, they can be used to generate additional data for conditions not covered in the in-service and FAST tests. The model and test data will then be used as a basis for hypothisizing relationships between the structural variables and for validating those relationships.

11. Track System Analysis and Handbook Preparation

The objective of this task is to produce a track system handbook which fulfills as many of the requirements defined in Project 1 and refined in Projects 3 and 4 as is possible. Most likely, this will entail determining long-term costs as a function of commonly occurring load classes, track structures, maintenance practices, and climatic conditions. This information will be presented in a variety of ways. Among them: cost versus track structure; cost versus maintenance practice; cost versus maximum permissable load; and contribution of various types of load to cost.

To achieve these ends each submodel will be validated using the data from Project 9 and the submodels will be integrated into a single track system model according to the macro-level design of Project 5. The overall model will also be validated. When this is accomplished, an extensive series of computer runs will be made to provide the data needed for the handbook, and the handbook will be written in a clear, easy-to-read, concise style.

Beyond the handbook, the model could be used to evaluate specifications for new components. After component development, only limited testing would be necessary. If the model's prediction is verified by the test results, a full range of model runs would then be made to provide the data which otherwise would have to be collected in an expensive series of tests. Updates or revisions to the handbook could then be issued. This application of the model is presented for information purposes only. Its cost is not included in the R&D cost of this project.

12. Results Dissemination and Evaluation--Version II

Version II of the handbook will be disseminated and evaluated in a manner similar to that described for Version I in Project 3.

JUSTIFICATION FOR RANKING

Benefits Summary

In reality there is no rational way of predicting the dollar benefit of this subprogram to the railroads or the government at this time. The data simply are not available. However, most people agree that such a model will, in fact, lead to a more cost-effective combination of track structure and maintenance practice. If, as stated in the objective, the model leads to changes in track structure and maintenance practices which reduce industry annual costs by 1.2 percent for today's load environment, then the annual savings would approach $29 million, the present worth of such savings over a 25-year period would be $261 million.

The railroads would not benefit equally. The larger railroads typically have substantial engineering and cost accounting personnel who collect and analyze data and keep abreast of R&D results. They are, therefore, more likely to have a more cost-effective track structure and maintenance program than the smaller, marginal railroads. On a percentage basis the smaller, marginal roads will benefit more than the larger marginal roads, who in turn are likely to benefit more than the larger prosperous roads.

Qualitatively, there will be some benefit to a more accurate allocation of track system costs between passenger and freight service, and among TOFC, unit train and conventional freight service. Government personnel administering financial aid and R&D programs and those charged with promulgating and enforcing safety standards will be able to make better decisions. Cost of some R&D programs is likely to be reduced as the model is used to examine a large number of alternatives quickly and substitute for some for the time consuming and expensive tests.

Evaluation Measures

This subprogram had an overall evaluation score of 104 points, giving it a rank of 2. The first, third and last subprograms had scores of 216, 88 and 39 respectively. Values and relative rank of the individual evaluation measures are shown in Table D-1.

IMPLEMENTATION

Incentives

(Not applicable)

Barriers

(Not applicable)

Relationship to Other Efforts

This subprogram is related to all other subprograms. It requires cost and performance data about every component, method and machine used widely to construct, rehabilitate, and maintain track. Since each of the other subprograms is aimed at producing either an improved component or an improved method, and since each subprogram requires collecting and analyzing data about current components or methods as well as the improved ones, considerable overlap occurs. Therefore, as this subprogram progresses and as more and more information about the kind of data and analyses needed for the model is developed, that information should be used in the test planning projects of the other subprograms. Considerable R&D Cost savings can be expected compared to separate and independent pursuit of subprogram objectives.

TABLE D-1

EVALUATION MEASURES, SUBPROGRAM A

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$261 million	4
R&D Costs	Total Subprogram R&D Costs	$5.7 million	13
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	45.9	5
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	252	1
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	$144 million	3
Timeliness	R&D Time in Years	7.0	13
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	1.85	1
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.67	1

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

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SUBPROGRAM B

IMPROVED LATERAL TRACK STABILITY

RANK 5

PROBLEM

The effect of thermal expansion and contraction on the longitudinal stresses in rail is well known. High temperatures lead to rail expansion and excessive longitudinal compressive stresses which can cause the track to buckle. Low temperatures create tensile stresses which can pull welds apart. Rail stresses resulting from production, installation, track shift and wheel loads can accentuate these problems. Currently, the railroad industry has no means of simply and accurately establishing when and where these problem will occur, nor do they have minimum cost guidelines for track design which will prevent their occurrence.

In 1976, 101 railroad accidents (approximately 1 percent of the total number of railroad accidents for that year) were attributed to track buckling. These accidents injured 44 people, including 30 passengers. In the previous year, 5 trainmen were injured in 87 accidents. Damage to track and equipment for the 1975 accidents amounted to 3.2 million dollars. Additional damages sustained by the railroads due to the cost of clearing wrecks, loss and damage to freight, and injury compensation can raise this figure to nearly 10 million dollars.(1) Other costs resulting from buckling incidents which do not lead to accidents, and detection and prevention of buckling (slow orders, extra inspections, etc.) raise the total buckling cost even higher.

Track pull aparts occur much less frequently. Attendant disruption in track signaling and wheel crossover tend to prevent the occurrence of pull apart derailments. Only 6 accidents were attributed to weld failures (not necessaryly pull aparts) in 1975.

Accident statistics alone only hint at the magnitude of the buckling/pull apart phenomena. In this case, they do not even give a clear indication as to what the real problem is. For example, buckling is nominally thought to be a CWR related problem. However, it is apparent from the sketchy data readily available (FRA in-depth accident reports would give more information) that many of the buckling accidents probably occur on jointed track. This can be determined from the fact that 17 percent of the accidents occurred in yards or on sidings, places where CWR is rarely laid. Also, 48 percent of the accidents occurred at speeds less than 20 mph indicating possibly a low class of track and therefore probably jointed. Some railroads with almost no CWR have a number of buckling accidents. If it is indeed the case that much of the buckling occurs on jointed track, then a reevaluation of the economics and procedures for preventing frozen joints, track shift and weak lateral stability of jointed track is necessary.

The accident statistics also indicate that fully one-third of the 1975 buckling accidents occurred on 2 railroads. A number of major railroads had none. Thus, some railroads either fully understand or can afford buckling prevention using current track laying and maintenance techniques. There is, however, among these railroads the very real concern that inaccuracies of mainly visual inspection will not prevent buckling accidents. Some are also concerned that they may be spending too much on excessive trackwork and unneeded special maintenance practices to prevent buckling.

DESCRIPTION OF R&D EFFORT

Objective

This research effort seeks to provide the railroads with information and techniques which will reduce accidents caused by track buckling or by rail pull apart at least 90 percent. It also seeks to reduce unnecessary track restraint and maintenance by 10 percent.

State-of-the-Art

To date, track buckling and track pull apart research in this country has been almost entirely limited to modeling the stability of CWR under thermal stress.[2,3,4] To date none of the models have been validated because of the high cost of implementing large scale buckling tests. Only one paper has made an attempt to put results in a form usable to the railroad industry.[5] Only a small amount of CWR field testing has been reported.[6]

Recently research funds in the U. S. have also been provided for the investigation of the feasibility of a portable ultrasonic rail stress detector.[7] The conclusion of that study is that it may be possible to measure stresses to within ± 1 KSI about the unknown residual stress levels in the rail. Other methods of stress detection have also been conceived and researched to some extent.[8,9,10]

Research in the U. S. has also been directed toward determining the lateral stability of railroad track under various conditions.[11,12] Increased track lateral stability greatly reduces the potential for buckling.

A great deal of experimental work and modeling has been carried out in Europe, Russia and Japan over the last 50 years. Track buckling test facilities in Germany, France, England, Russia and Japan have been used to set standards for laying CWR and to determine how various track parameters affect track lateral stability under thermal stress. But much of these results are peculiar to the foreign track systems with their light axle loadings, concrete ties, stiff fasteners, etc. Also many of the test procedures and observations have been called into question.[13]

Many stability tests have also been conducted abroad on the effects of track component variations on track lateral stability.[14,15] Many such studies have concluded that track lateral stability can be significantly increased by various component changes, but none have sufficiently, if at all, investigated the optimization of the parameter changes in terms of minimizing costs with the attendant prevention of buckling.

R&D Projects Required

This research seeks to clearly define the track buckling/pull apart phenomena in the U. S. After an analysis of the current methods in practice for preventing buckling/pull aparts, it will provide, through testing and analysis, minimum cost guidelines for track construction and rehabilitation which will prevent track buckling and pull aparts.

A second approach must also be considered. The development of a technique for in-situ measurement of rail longitudinal stress would drastically reduce the number of buckling derailments which would otherwise have been prevented if the present procedures for determining potential buckling zones were accurate. Methods for such measurements will be investigated and guidelines for determining when and where buckling/pull aparts will potentially occur and their appropriate correction will be determined.

Both avenues of this research effort should be pursued. This is necessary because:

- The development of a cheap, portable longitudinal stress detector has a fiarly low probability of success. Therefore, track designs which will not fail are essential.

- Even if a stress detector is developed, experimentation is required to determine what stress level is likely to cause track buckling/pull apart.

This subprogram is composed of nine R&D projects. Brief descriptions follow while costs and schedules are shown in Figure D-2.

1. Problem Definition Study

The conditions under which track buckling/pull apart failures occur are not well known. Likewise, the costs and techniques in practice for the prevention and correction of track buckling/pull apart are not documented. This project seeks to gather this information in two ways. First, an analysis of available accident statistics to determine an indication of the extent and conditions of buckling/pull apart problems in the U. S. will be performed. FRA in-depth accident reports will be analyzed for specifics such as type of rail, class of track, locality, temperature, etc. Second, a survey of specific railroads including those with no buckling accidents and those with the most buckling accidents will be conducted to determine individual railroad track characteristics and maintenance procedures with respect to buckling/pull apart prevention. Relevant cost data to prevent and correct track buckling/pull apart will be collected. The results of this project could well be that buckling/pull apart of well maintained CWR track in this country is not a problem. In that case, the need for a buckling test facility as described in Projects 2 through 5 should be carefully examined.

PROJECT No.	PROJECT TITLE	R & D COST ($1,000)	YEARS AFTER START 1	2	3	4	5	6	7	8	9	10
1	Problem Definition Study	60										
2	Track Buckling Test acility Design	45										
3	Track Buckling Test Facility Construction	340										
4	Buckling Test Planning	33										
5	Buckling Tests and Analysis	325										
6	Stress Detector Feasibility Studies	260										
7	Stress Detector Prototype Development & Laboratory Test	100										
8	Stress Detector In-Service Test & Evaluation	100										
9	Results Dissemination	40										
	TOTAL R & D COST	1,303										

FIGURE D-2
COST AND SCHEDULE—IMPROVED TRACK LATERAL STABILITY

2. Track Buckling Test Facility Design

Establish requirements for the design of a track buckling test facility. The requirements might be based on the results of the Problem Definition Study and work by A. D. Kerr.[16] Kerr describes a 1600 foot segment, preferably the siding of a loop for ease of access, with electric current induced axial compressive forces stimulating thermal stresses in the field. Vertical forces on the track are exerted by available locomotives and rail cars. Lateral forces are exerted by mechanical jacks.

3. Track Buckling Test Facility Construction

Construct the buckling test facility at the Transportation Test Center. Make full use of available test loops, supplier equipment, etc. as in the FAST experiment in order to minimize cost.

4. Buckling Test Planning

Carefully assess available test results of foreign buckling facilities to determine results pertinent to U. S. railroad industry. Consider the ensemble of parameters to be tested such as ballast cross section, ballast shoulder width, ballast consolidation, tie spacing, tie shape, tie size, anchor effectiveness, anchor patterns, fastener type, rail car axle loads, track geometry, etc. and plan tests for those which will potentially provide economically viable alternatives to conventional railroad track structures and maintenance practices.

5. Buckling Tests and Analysis

Conduct buckling tests to determine the effect of track parameter variations on the lateral buckling temperature of the track. Determine which track components and maintenance practices are most cost-effective in preventing buckling failures.

6. Stress Detector Feasibility Studies

Conduct feasibility studies of innovative technologies for measuring in-situ rail longitudinal stress. The objective of this study is to determine what the current potential is for the development of a portable instrument which simply and accurately measures rail longitudinal stress in the field. Competing technologies should be judged based upon criteria established with the help of railroad personnel who would use the machine if developed.

7. Stress Detector Prototype Development and Laboratory Test

Based upon criteria established in Project 6, the two highest ranked technologies should be further developed to the point of prototype construction. Laboratory testing to determine accuracy and simplicity of usage is then required, along with revised economic estimates of the potential costs to the railroad industry of the instruments and their usage.

8. Stress Detector In-Service Test and Evaluation

The best performing instrument selected in Project 7 should then be field tested in-service and at the buckling test facility for final evaluation of its technical and economic characteristics. A detailed study of the performance and costs should be made in order that the railroads might be able to appropriately utilize the instrument to their fullest advantage. This study would also include the development of instructions for proper use of the instrument in the field.

9. Results Dissemination

A final summary report, trade literature articles and an industry workshop are to be prepared which will fully present the outcome of this subprogram. The results should also be incorporated into the Track System Handbook. The buckling experimentation data should be in the form of guidelines for track design, maintenance and rail installation which prevent track buckling/pull apart. Emphasis should be on the economic benefits to the railroads of following these guidelines. Information presenting the useage of the stress detector and procedures for corrective actions in measured potential buckling zones should also be included.

JUSTIFICATION FOR RANKING

Benefit Summary

The major benefit of the buckling experimentation and analysis will be the documentation of information which will permit the railroads to cost effectively insure with a high degree of probability that buckling/pull apart failures will not occur in a given stretch of track. For some railroads which are conservatively restraining their track, this could mean a reduction in track materials and maintenance costs; for others, it could mean a reduction in accidents.

If the subprogram objectives are achieved, the present value of the benefits to the railroad industry over a 25 year period is estimated to be \$49.4 million. Of this amount, \$40.6 million savings are due to a reduction in buckling-caused accidents--taking into account the cost of added restraint to counter buckling. The remainder of the savings, \$8.8 million, stems from reduced restraint on newly laid rail on roads which have not had buckling problems for several years.

Increased lateral stability means that track geometry will be held more accurately for a larger period of time, resulting in indirect savings to shippers in the form of faster, more dependable train operations and a smoother, less damaging ride for lading. These goodwill benefits should make the railroad a more competitive shipping mode. The general public will also benefit from the reduced incidence of derailments and serious accidents.

The stress detector is an especially important device to the railroads. Rail longitudinal stress buildup leads to track instability, increased rail fatigue, crack growth and local track geometry irregularities. With the simple measurement of these stresses on a periodic basis to determine where stresses are building up due mainly to track shift, corrective actions can be taken which will virtually eliminate these problems and the attendant accidents. It can also potentially save some capital now spent in over restraint or in special maintenance practices during temperature extremes. Costly slow orders can also be reduced in number because of the known stress distribution.

The stress detector will also be a valuable tool for the track inspector, providing him with a quick accurate assessment of the track condition.

Evaluation Measures

This subprogram had an overall evaluation score of 76, giving it a rank of 5. The first, fourth, sixth and thirteenth ranked subprograms had scores of 216, 81, 75, and 39 respectively. Values and relative rank of the individual evaluation measures are shown in Table D-2.

IMPLEMENTATION

Incentives

The development of the stress detector will be enthusiastically greeted by the railroads. It will provide them with peace of mind regarding the buckling/pull apart accidents.

Barriers

The potential cost of necessary increased track materials and maintenance required to insure track lateral stability could be high

TABLE D-2

EVALUATION MEASURES, SUBPROGRAM B

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$49.4 million	5
R&D Costs	Total Subprogram R&D Costs	$1.3 million	8
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	37.9	6
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	114	2
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	$11.3 million	4
Timeliness	R&D Time in Years	3.8	5
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	1.4	3
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.46	8

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

for some railroads. This cost would presumably fall upon those railroads with the most accidents which are also often in the poorer financial condition.

There are presently no feasible methods for accurate, simple measurement of rail longitudinal stress. The potential for such a development is probably fairly low.

Relationship to Other Efforts

Four of the nine projects in this subprogram are related to the Track System Handbook subprogram. They are the projects concerned with test planning, testing and evaluation (Projects 4, 5, 6, and 7). To the extent that the information needs of the Handbook subprogram are known at the time these projects are started, the needs should be considered.

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SUBPROGRAM C

IMPROVED RAIL METALLURGY

RANK 11

PROBLEM

Until recently, rail life in this country was dictated by wear. With the continuing trend to higher traffic densities and heavier wheel loads, rail deterioration is increasingly due to plastic flow and fatigue of the rail head.

To illustrate, the service life of a 132 lb. normal carbon control-cooled rail is 500 to 600 million gross tons when operating cars of 50-ton capacity having four axles and 33-inch diameter wheels. When using cars of 90-ton capacity with 36-inch wheels the service life is less than 250 million gross tons.(1)

From the safety and financial viewpoints, various forms of rail wear degradation and failure are estimated to have caused 1,000 accidents in 1976 costing the railroads $63,000,000 and to have necessitated the replacement of 250,000 rails at a cost of another $61,000,000. Furthermore, the nation's railroads spent upward of $180,000,000 in 1975 for purchasing and installing new rail and maintaining the rail component of the track system.

DESCRIPTION OF R&D EFFORT

Objective

This research seeks to improve rail properties such that the wear life is increased at least by a factor of 2 and the probability of failure due to any flaw is reduced at least by a factor of 0.2 relative to today's carbon steel rail. The price increase of the improved rail must be less than 10 percent--measured in 1978 dollars.

State-of-the-Art

There is little doubt that rail wear and failure properties can be improved substantially through metallurgy. The principal question is, can it be done at an affordable price to the railroads? The aims of researchers in other countries who have pursued improved rail metallurgy perhaps more vigorously than we in the United States (because of substantially more rail passenger service) suggest that an affordable price might be achievable.

Regarding flaws, railroads in France, Germany, Russia and Japan are known to place great emphasis on rail steel cleanliness as a means of reducing fatigue-type defects.[(2)] Recent research in the U. S. and Australia verifies the direct connection between fatigue-type defects and inclusions in the railhead.[(3,4)] In France, a tenfold reduction in the defect rate has been attributed to increased cleanliness of rail steel.[(5)]

Plastic flow in the railhead results in both increased wear and, through corrugation and the resulting increased dynamic loads, increased probability of rail failure. There is ample evidence that plastic flow can be reduced substantially by increasing the yield strength of rail steel.[(2)] Yield strength, in turn, can be increased by two techniques--heat treatment and the creation of alloys.

Gage face wear is another form of rail deterioration. It can be reduced by increasing the hardness of rail steel--in addition to other methods. Hardness in turn can be increased through the use of alloys and heat treatment.

In foreign countries, heat treated rail has been in use for many years. However, the relative performance of the various rail types remains unknown since few if any railroads have conducted carefully controlled in-track tests. The Soviets, who typically remove rail for defects rather than wear, claim their removal threshold of 4.8 defects per mile is reached at 550 MGT for conventional rail and 824 MGT for head-treated rail. Soviet heat treatment increases rail cost by 8.3 percent. They are also developing a "super rail" with target carrying capacity of 1.3 to 1.7 billion gross tons using heat treatment and alloys.(6)

In the United States, heat treated rail is available form two suppliers, but a t a high price--15 percent higher than standard rail from one supplier and 30 percent higher from the other. At least one railroad has constructed its own heat treatment facility. Its method is different than that of the suppliers, but it has the potential to be less costly. The quality of the product in terms of rail strainghtness and residual stress is in question, however.

In the early 1970's abrasive wear rates of four special metallurgy rails (fully heat treated, flame-hardened head, electric induction hardened head and high silicon) and standard rail were measured under a variety of in-service conditions.(11) These performance data were analyzed together with cost data, and recommendations regarding the least life cycle cost rail for a given annual tonnage and degree of curvature were made. The effects of gradient and of rail failures and other forms of degradation were not considered.

Currently five types of rail are undergoing tests at FAST--standard control-cooled carbon, high silicon, chromium-molybdenum, fully heat treated standard carbon and head hardened standard carbon. The tests have not yet yielded sufficient data to draw conclusions.

Alloyed steel rails with properties equivalent to or better than heat treated rails have recently been developed.(4,7,8) Several are undergoing in-track assessment in other countries and three will soon be tested at FAST--1 percent chromium, chromium-vandium, and chromium-molybdenum-vanadium.

R&D Projects Required

This subprogram is composed of eight R&D projects. Brief descriptions follow while costs and schedule are shown in Figure D-3.

1. Rail Demand Study

The objective of this study is to estimate, via an economic analysis, the national demand for rail as a function of price and rail wear and failure properties. Wear and failure properties could be translated into rail life. This in turn could be combined with various categories of track as determined by curvature, grade, annual tonnage, wheel loads, etc., to yield the conditions under which improved rail is more economical than conventional rail. The amount of rail throughout the nation for which this is the case could also be determin-d with the aid of FRA's track system data base. Past trends in rail procurement,[9] as well as data and relationships from other studies would also be useful.[10,11]

2. Laboratory and FAST Tests

The objective of this project is to reduce the number of alternative rail metallurgical process that must be considered for further research, development and study. Testing alternative rail metallurgies at the AAR facility and at FAST would continue. Wear and failure properties of each alternative under various conditions, as well as shop and field characteristics using conventional welding methods, would be determined. Next, laboratory tests would be correlated with FAST tests so that the former could be used as predictors of rail wear and failure properties. The most promising candidates for an improved production method study would be selected.

3. Rail Supply Study

The objective of this study is to determine the most cost-effective combination of rail metallurgy and production method. For each candidate metallurgical process selected in Project 2, estimate the expected price based on existing and on alternative production methods. A viable

PROJECT		R & D COST ($1,000)	YEARS AFTER START									
No.	TITLE		1	2	3	4	5	6	7	8	9	10
1	Rail Demand Study	100										
2	Laboratory & FAST Tests	250										
3	Rail Supply Study	100										
4	Pilot Plant	250										
5	Test Planning	60										
6	In-Service & FAST Tests	490										
7	Analysis	150										
8	Results Dissemination	40										
TOTAL R & D COST		1,440										

FIGURE D-3
COST AND SCHEDULE—IMPROVED RAIL METALLURGY SUBPROGRAM

option to be considered here is procurement of standard carbon rail and heat treatment at a railroad owned facility prior to installation. Combine this "supply side" study with the demand study of Project 1 to select the most cost-effective combination of metallurgy and production method. Since improved rail will presumably result in less rail production over the long term than would otherwise occur, a key factor which must not be overlooked in this effort is supplier profit.

4. Pilot Plant

If the selected combination is one of heat treated rail and an unproven production method, construct a pilot treatment facility to demonstrate its cost-effectiveness. Perform laboratory tests to determine and assure rail quality.

5. Test Planning

Plan in-service and FAST tests of standard rail and the rail with the most cost effective combination of metallurgy and production method as determined in Project 3. The plan will specify number of samples, track structure, test sites, variables to be measured, type of instrumentation, method and frequency of data collection, recording format and medium, and method of analysis. In addition to rail wear and failure properties, the many other track system, traffic, and environmental variables affecting the rail should be considered in the experiment design. The data on standard rail performance will serve as a baseline against which improved rail performance can be properly compared. The design should consider the information needs of the Track Systems Handbook being produced under a separate subprogram, as well as the information needs of this subprogram, and assure that all data are collected.

6. In-Service & FAST Test

In this project samples of improved rail will be produced, installed and tested along with samples of standard rail in operational service and at FAST according to the tests planned in Project 5. All necessary instrumentation will be obtained and installed. At periodic intervals data will be collected, reduced, and sent to analysts.

7. Analysis & Report

The objective of this project is to estimate the benefits of using improved rail in a variety of track system configurations, grades, and curves. This will include the development of relationships which predict the wear life of improved rail versus standard rail. If relationships predicting failures of standard rail are available, this project will attempt to extrapolate or modify those relationships to accommodate improved rail. The best available information, relationships, and models of other track system components will be utilized to predict the cost and performance characteristics of track structures using improved rail and those using standard rail. The difference will lead to the desired benefit estimates.

8. Results Dissemination

The results of Projects 1, 3 and 7 will be combined into a single, easy-to-read report. The report will be used as a basis for conducting a research utilization seminar aimed at convincing suppliers to produce the improved rail and the railroads to install it. If this objective is to be achieved, the presentation must be clear, concise, and well illustrated. Expert advice will be sought.

JUSTIFICATION FOR RANKING

Benefit Summary

If the objective is achieved, the present value of the total benefit to the railroad industry over a 25 year period would be $1.8 million. Of this amount, $0.1 million would be attributable to the 0.1 accidents prevented per year, $0.1 million would stem from savings in replacing flawed rails, while the remainder would be attributable to increased life.

The monetary benefit and safety impact of this subprogram might seem to be low. This stems from the fact that improved rail with characteristics as stated in the subprogram objective appears to have a rather small market. The estimate used here is 2200 miles of track. But even if it is twice that, the relative rank of this subprogram would change little. This market could grow if the railroads continue to move toward heavier wheel loads. Today, however, standard carbon rail is the proper choice for most of the nation's track.

Other, less tangible, benefits might also accrue. Presumably, inspection frequency could be decreased slightly providing some cost savings. Overall service quality would increase with some increase in revenue. Also, moderately higher tonnage cars might be cost effective. First, however, the effect on total track system costs of the higher tonnage cars would have to be ascertained.

Evaluation Measures

This subprogram had an overall evaluation score of 45, giving it a rank of 11. The first, tenth, twelfth and last subprogram had scores of 216, 50, 42 and 39 respectively. Values and relative rank of the individual evaluation measures are shown in Table D-3.

TABLE D-3

EVALUATION MEASURES, SUBPROGRAM C

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$1.9 million	12
R&D Costs	Total Subprogram R&D Costs	$1.4 million	9
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	1.3	13
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	< 1	8
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	-$3.0 million	9
Timeliness	R&D Time in Years	6.2	12
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	1.6	2
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.51	7

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

IMPLEMENTATION

Incentives

This subprogram contains two projects which help to assure that the research results, if successful, will be utilized. The forecast of the nationwide demand for rail is one such project. If suppliers see a well-done, objective study, they are apt to use it as a basis for deciding to produce improved rail.

The research utilization conference aimed at decision-makers of the railroad and the rail supply industries is another such project. Simple, concise study results, prepared and presented in a professional style will be the key to acceptance.

Still another step toward implementation would be to have the railroad and steel industry participate in the subprogram--either in an advisory or performing role, as appropriate. For example, it would be useful to have representatives of both the Iron and Steel Institute and the Association of American Railroads monitoring Project 1, the rail demand study. The AAR and the railroads should be involved in Projects 2 and 6 (the test efforts) with representatives of the American Railway Engineering Association and the Iron & Steel Institute in monitoring roles. These are merely examples. Both industries can and should participate in the subprogram in many ways.

Barriers

Despite the above incentives, there are at least three barriers which could prevent full utilization of a successful research effort. First, there is a possibility that a few railroads will be unable to afford improved rail, or any other rail in substantial quantities without new federal financial assistance. Current authorizations under the Four R Act will surely be depleted by the time this research effort is completed.

Secondly, it is conceivable that the research objective could be achieved only if modern steel and rail production facilities are used. Domestic suppliers might not be able to produce improved rail at only a 10 percent increase in price if substantial capital is required for new plants. The target price must provide an adequate rate of return in the suppliers' view before such investment will be made. Thus the subprogram could produce a result that is attractive to the railroads, but unattractive to domestic rail suppliers.

Thirdly, some roads simply do not have sufficiently accurate cost accounting systems to enable them to evaluate for themselves the true benefit of utilizing an improved rail. Track and MOW personnel might be "convinced" of its value, but without sound economic analysis, it will be difficult to convince top management. While it is impractical for an R&D effort to perform a case study for every railroad, perhaps a well written, easy-to-use handbook such as that envisioned in the Track System Handbook Subprogram will suffice.

Relationship to Other Efforts

There is a strong relationship to Subprogram D, In-Place Rail Hardening. Results of tests on head-hardened rail in this effort could shed light on the expected results of that effort, and vice versa. Also, successful results here will in all likelihood reduce the benefits there, and vice versa.

Furthermore, there is a relationship to Subprogram H, Bolt Hole Crack Prevention, Subprogram I, Bolt-Hole Crack Restraint, Subprogram J, Improved Wood Tie Fastening Systems and Subprogram M, Improved Concrete Tie and Fastener Selection and Utilization Criteria. Success here will reduce the benefit in all those efforts, and success in any of them would reduce the benefit here.

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SUBPROGRAM D

IN-PLACE RAIL HARDENING

RANK 7

PROBLEM

Until recently, rail life in this country was dictated by wear. With the continuing trend to higher traffic densities and heavier wheel loads, rail deterioration is increasing due to plastic flow and fatigue of the rail head.

To illustrate, the service life of a 132 lb. normal carbon control-cooled rail is 500 to 600 million gross tons when operating cars of 50-ton capacity having four axles and 33-inch diameter wheels. When using cars of 90-ton capacity with 36-inch wheels the service life is less than 250 million gross tons.(1)

From the safety and financial viewpoint, rail wear and various forms of degradation and failure are estimated to have caused 1,000 accidents in 1976 costing the railroads $63,000,000 and to have necessitated the replacement of 250,000 rails at a cost of another $61,000,000. Furthermore, the nation's railroads spent upward of $180,000,000 in 1975 for purchasing and installing new rail and maintaining the rail component of the track system.

DESCRIPTION OF R&D EFFORT

Objective

This research seeks to develop a method for hardening rails in-place such that the resulting wear life is increased at least by a factor of 1.5, and probability of failure is reduced at least by a factor of 0.4 relative to standard carbon rail. Cost must be less than $5.00 per rail in 1978 dollars.

State-of-the-Art

There is little doubt that rail wear and failure properties can be improved substantially through rail hardening.[2,3] The principal question is, can it be done at an affordable price to the railroads?

Plastic flow in the railhead results in both increased wear and, through corrugation and the resulting increased dynamic loads, increased probability of rail failure. There is ample evidence that plastic flow can be reduced substantially by increasing the yield strength of rail steel.[2,3] Yield strength, in turn, can be increased by heat treatment and by addition of alloys.

Increasing the yield strength also increases the time of fatigue crack nucleation and, therefore, extends the life of those rails destined to fail due to fatigue associated defects.[2]

Gage face wear is another form of rail deterioration. It can be reduced by increasing the hardness of rail steel--in addition to other methods. Hardness, in turn, can be increased through heat treatment and through the creation of alloys.[2]

In foreign countries, heat treated rail has been in use for many years. However, the relative performance of the various rail types remains unknown since few if any railroads have conducted carefully controlled in-track tests. The Soviets, who typically remove rail for defects rather than wear, claim their removal threshold of 4.8 defects per mile is reached at 550 MGT for conventional rail and 824 MGT for heat-treated rail. Soviet heat treatment increases rail cost by 8.3 percent. They are also developing a "super rail" with target carrying capacity of 1.3 to 1.7 billion gross tons using heat treatment and alloys.[4]

In the United States, heat treated rail is available from two suppliers, but at a high price--15 percent higher than standard rail from one supplier and 30 percent higher from the other. At least one railroad has constructed its own heat treatment facility. Its method is different than that of the suppliers, but it has the potential to be less costly. The quality of the product in terms of rail straightness and residual stress is in question, however.

In the early 1970's abrasive wear rates of three types of hardened rails (fully heat treated, flame-hardened head, electric induction hardened head) were measured along with wear rates of high silicon and standard carbon rail under a variety of in-service conditions.[5] These performance data were analyzed together with cost data, and recommendations regarding the least life cycle cost rail for a given annual tonnage and degree of curvature were made. The effects of gradient and of rail failures and other forms of degradation were not considered.

A recent preliminary study indicates that it is technically feasible to flame harden railroad tracks in the field by towing an array of fuel gas torches along the track at constant speed.[6] The approach envisioned unfastening the rail, heat treating, then refastening. Unfastening and refastening rail is expensive--so much so that the benefits of hardening might well be negated. It may, however, be possible to treat the rail in-place. If so, the benefits should be large.

Currently, the Association of American Railroads is constructing a fixed, rather than mobile, pilot plant to demonstrate that rail can be heat-treated at a price substantially less than that being paid by railroads today.

<u>R&D Projects Required</u>

This subprogram is composed of six R&D projects. Brief descriptions follow. Costs and schedule are shown in Figure D-4.

PROJECT		R & D COST ($1,000)	YEARS AFTER START									
No.	TITLE		1	2	3	4	5	6	7	8	9	10
1	Heat Flow Analysis	60										
2	Laboratory Tests & Analysis	200										
3	Prototype Equipment Specification	70										
4	Prototype Equipment Construction	1,000										
5	Field Tests & Analysis	200										
6	Results Dissemination	40										
TOTAL R & D COST		1,570										

1. <u>Heat Flow Analysis</u>

The objective of this project is to predict the temperature at the rail and tie-plate interface and the tie-plate and tie interface when hardening rail in-place. This will be achieved through slight modification of existing models of heat flow in steel and using the information in the preliminary feasibility study as a base.[6] Depending upon the results, the process might have to be modified or the subprogram terminated.

2. <u>Laboratory Test and Analysis</u>

The objective of this project is to further establish the technical and economic feasibility of in-place rail hardening. This will be achieved by first planning a series of laboratory tests, conducting those tests (most likely in the AAR's pilot plant), and analyzing the data. The test plan will specify the number and sizes of rail to be tested, the variables to be measured, and method of measurement. Data will be collected which will reveal the quality of the product as well as the cost of the process. Discussions will also be held with rail maintenance equipment suppliers to ascertain their views on feasibility of constructing the desired equipment. The data and information will be combined with detailed estimates of capital, operating and maintenance costs of in-place rail hardening to yield its expected cost and performance characteristics.

3. <u>Prototype Equipment Specification</u>

The objective of this project is to develop a specification in sufficient detail to procure prototype equipment for hardening rail in place. The specification will contain a description of the in-place rail hardening system concept along with details about the vehicle(s), the heating subsystem, a rail straightening subsystem if necessary, and all vehicle and system controls. Specifications will also be provided for vehicle and subsystem maintainability, reliability and acceptance testing. Before final adoption, the specification will be offered to potential suppliers for review and comment.

4. Prototype Equipment

The objective of this project is to design and construct the prototype equipment specified in Project 3. Exceptions or revisions to the specification will be accepted if they can be shown to be beneficial. Before the government accepts the equipment the contractor will be required to show via inspection, analysis, test, or demonstration that the equipment performs as specified.

5. Field Tests & Analysis

The objective of this project is to measure actual cost and performance characteristics of in-place rail hardening. This will be achieved by first developing a detailed test and analysis plan which specifies the test conditions in terms of track curvature and gradient, rail weights, rail type (welded and jointed), fastening systems and climate. The plan will also specify vehicle operating procedures, variables to be measured, method of measurement and method of analysis. Arrangements with participating railroads will also be made. Following approval of the plan, tests will be conducted as specified. Rail samples will be removed for laboratory testing to determine yield strength, hardness and other appropriate variables. These and all other data will then be analyzed and the preliminary cost and performance analysis developed in Project 2 will be updated and expanded as necessary. Equipment specifications and operating procedures will also be revised as necessary. The tests and analysis will be described in one report and the specifications and procedures in another.

6. Results Dissemination

The objective of this project is to disseminate the results of the R&D effort to as many railroad and equipment supply managers, engineers and others who can make or influence the decision to use or produce the equipment. This will be achieved by summarizing the cost-performance data into an easy-to-read report, distributing the three reports (summary, cost and performance, and specifications and procedures) to as much of the proper audience as possible, and conducting a research utilization seminar at four locations around the country. To achieve its objective the seminar presentation must be clear, concise and well illustrated. Therefore, advice from communications experts will be sought.

JUSTIFICATION FOR RANKING

Benefit Summary

The benefits from in-place rail hardening include reducing accidents and extending rail life. The advantage of this process is that it can be economically used on virtually any rail--even on rail with as little as one year of life in it. Improved metallurgy new rails increase rail life also, but the benefit is realized too far in the future to be worth much except in rail applications with a fairly short life. Rail hardening in-place has an advantage over improved rail in that rail can be hardened when its remaining life is such as to maximize benefits. Depending on costs and other assumptions, the savings from hardening rail increase as the rail wears. At some point, these savings begin to decline again. Since the rail can be hardened at any time, the time to harden is when the maximum savings accrue. The process is profitable on virtually all rail since all rail eventually has a short remaining life. Improving new rail is beneficial only in those few places where rail life is sufficiently short for it to be profitable.

The optimum time to harden is at approximately 10 years of life remaining. Decreasing accidents saves \$1.40 per rail, a decrease in flawed rail replacements saves \$1.82 per rail and increasing remaining life by 5 years is worth \$33.44 per rail. Substracting the \$5.00 cost of hardening the rail, a saving with a present value of $31.66 is achieved. If 1/50th of current rail is hardened every year, 6880 track miles of 1,857,600 rails would be hardened. Saving $31.66 on each rail would save $58.8 million per year. Over the course of 25 years, the present value of these annual savings would be $534 million.

Different discount rates and inflation rates would change this value. Higher inflation (lower discount) would lead to rail hardening when more life was left. Benefits would increase. This program would have its greatest benefit to railroads who had not kept up on rail renewal programs.

Although all railroads would benefit from successful completion of this subprogram, the less prosperous roads would benefit proportionately more than the more prosperous roads who can afford the current high price of rail hardened by suppliers.

Evaluation Measures

This subprogram had an overall evaluation score of 68 points, giving it a rank of 7. The first, sixth, eighth and last subprograms had scores of 216, 75, 66 and 39 respectively. Values and relative rank of the individual evaluation measures are shown in Table D-4.

It is worth noting that despite high monetary and safety benefit, this subprogram has only a mid-range rank. The relatively low probability of success and the high capital requirements to heat treat the rail before its actual monetary benefits accrue are the reasons for the mid-range rather than high rank.

IMPLEMENTATION

Incentives

If the subprogram is successful, the research utilization conference, called for as the final step, will greatly facilitate the speed at which the results are implemented.

Still another step toward implementation would be to have the railroads and perhaps the railway equipment supply industry participate in the subprogram. At least one railroad and the Association of American Railroads are involved in rail hardening work. Either or both could serve in an advisory role on all projects and in a performing role on Projects 2, 3, 4 and 5. The railway equipment suppliers should have some input into Project 3 and could construct the prototype unit in Project 4.

However, in the final analysis, the large monetary benefit that would accrue to the railroads in exchange for a relatively modest capital investment will be the principal implementation incentive.

Barriers

Assuming this subprogram is successfully completed, there are no known barriers to prevent implementation.

Relationship to Other Efforts

The efforts in this subprogram are related to those in Subprogram C, Improved Rail Metallurgy. Results of testing head-hardened rail in this effort could shed light on the expected results of testing such rail in that effort, and vice versa. Also, successful results here will undoubtedly alter the economics there, and vice versa.

Furthermore, this effort is related to Subprogram H, Bolt Hole Crack Prevention, Subprogram I, Bolt Hole Crack Restraint, Subprogram J, Improved Wood Tie Fastening Systems and Subprogram M, Improved Concrete Tie and Fastener Selection and Utilization. Success in any of those efforts will reduce the benefit here, and success here will reduce the benefit in all of them.

TABLE D-4

EVALUATION MEASURES, SUBPROGRAM D

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$534 million	1
R&D Costs	Total Subprogram R&D Costs	$1.6 million	10
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	340	3
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	83	3
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	-$37.8 million	13
Timeliness	R&D Time in Years	4.5	8
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	0.7	10
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.31	12

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

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SUBPROGRAM E

IMPROVED THERMITE WELDING

RANK 8

PROBLEM

The growing use of continuously welded rail (CWR) has made field welding an increasingly troublesome problem. Typically, CWR is welded in a plant into about 1/4 mile lengths using an electric flash butt technique. In the field, these lengths are joined usually via a thermite weld, or some other joining technique. While in-plant welds are reliable and reasonably cheap, field welds are neither reliable nor cheap. Thermite field welding costs range from $60 to $150 per weld based on a sample of 22 railroads compared to $10 to $30 for in-plant welds.(1) Furthermore, thermite welds fail anywhere from 3 to 100 times as often as flashbutt welds.

DESCRIPTION OF R&D EFFORT

Objective

This subprogram will attempt to improve thermite weld reliability to that of in-plant flash butt welding with a cost increase of no more than $3.50 a weld.

State of the Art

Thermite welding is the standard field welding technique. Thermite welding produces coalescence "by heating with a superheated liquid metal and slag resulting from a chemical reaction between a metal oxide and aluminum, with or without the application of pressure. Filler metal, when used, is obtained from the liquid metal".(5)

Although extensively used in the U.S., the machanical properties of the weld are such that in Japan, thermite welds are currently used primarily for emergency repairs. The Japanese use enclosed arc welding, an advanced technique, for normal installation of CWR. In the U.S. defective thermite welds are very common, leading some railroads to be dissatisfied with them. The problem seems to be chiefly one of quality control and proper training of personnel. Different railroads report very different levels of success with thermite welds. Several changes in training and in the welding process have been adopted apparently with some success to reduce variability of weld quality.[2]

Thermite welds have several advantages. The technique is portable, requires little capital investment and requires only a short time for weld completion. An additional advantage, if the technique is used to weld track in place, is that the rails need not be pressed together, nor do the ends of the rails have to be as straight as is the case for flash butt welding. Improving the reliability of thermite welding would therefore result in a generally satisfactory welding technique.

R&D Projects Required

This subprogram is composed of four R&D projects. Brief descriptions follow, while costs and schedules are shown in Figure D-5.

1. Analysis of Current Procedures

In general, track workers on various railroads use slightly different procedures when making and inspecting thermite welds. The objective of this project is to identify those procedures and practices which are cost-effective and those which are not, and to suggest improved procedures where necessary. This will be accomplished by obtaining recommended procedures from manufacturers and by monitoring field welding operations on railroads reporting unreliable welds as well as railroads reporting few if any problems. The same welding crews will

PROJECT		R & D COST	YEARS AFTER START									
No.	TITLE	($1,000)	1	2	3	4	5	6	7	8	9	10
1	Current Procedure Analysis	170										
2	Improved Procedure Development	120										
3	FAST & In-Service	170										
4	Results Dissemination	40										
TOTAL R & D COST		500										

FIGURE D-5
COST AND SCHEDULE—IMPROVED THERMITE WELDING SUBPROGRAM

also perform welds on rail samples which will be subjected to laboratory tests to determine weld characteristics. Prior to monitoring welding operations, a test plan will be prepared which will identify participating railroads and specify the number of welds to be monitored, tested and analyzed, the conditions under which they should be made, the variables to be measures, and the method of measurement. Once collected, the data will then be analyzed and the more cost-effective procedures distinguished from those that are less cost-effective. An attempt will be made to explain what it is that makes the less cost-effective procedures less cost-effective. This in turn will provide the basis for recommending changes for improvement. Results will be documented in a report.

2. Improved Procedures

Given the results of Project 1, this project will develop procedures, and, if necessary, equipment which will make thermite welds more cost-effective and less sensitive to the skill of the welding crews. Some steps in the process might require automation or more fool-proof techniques, while others might be addressed through better and more thorough crew training. Whatever the changes, they will be tested for practicality, and results will be described in a set of preliminary guidelines for crew training and for the weld process itself.

The project will also prepare a test plan for testing the new procedures at FAST and in-service. The plan will address the same kind of topics as the plan developed in Project 1.

3. FAST and In-Service Demonstration

The procedures and/or equipment developed in Project 2 will be used to make welds on FAST and cooperating railroads. The performance of the welds will be monitored. Information collected will include weld cost, time required, climatic conditions, training level of personnel and failure experience. The preliminary guidelines of Project 2 will be revised as necessary.

4. Results Dissemination

A report summarizing results in Project 1, 2, and 3 will be prepared and distributed to railroad personnel concerned with field welding so they can put the information to use as soon as possible. In addition, a seminar and training session will be held at several locations or on several occassions to demonstrate the new procedures to key railroad personnel.

JUSTIFICATION FOR RANKING

Benefits Summary

The present value of improving the reliability of thermite welds is estimated to be $143,200 for the 80,000 welds estimated to be the yearly number of thermite welds. Over a span of 25 years using the improved technique, the benefits would have a present value of $1.3 million.

Evaluation Measures

This subprogram had an overall evaluation score of 66 points, giving it a rank of 8. The first, seventh, ninth and last subprograms had scores of 216, 68, 51 and 39 respectively. Values and relative rank of the individual evaluation measures are shown in Table D-5.

IMPLEMENTATION

Incentives

The results of this subprogram face only small hurdles before implementation. Improved procedures for thermite welding should require minimal railroad investment. If the improved procedures are proven to the railroads' satisfaction, they will be adopted readily.

The distribution of reports and the seminars specified in Project 4 are steps toward assuring that the R&D results, if successful, will be utilized. The key to acceptance will be conclusive results, presented clearly, concisely and in a professional manner.

The in-service test project is another such step. At a minimum, the railroads involved in the tests will have first hand experience with the products and methods, and as such be more prone toward utilization then other railroads.

Another step toward successful implementation would be to have the railroad industry and the suppliers participate in the subprogram in other ways. For example, it would be beneficial to have supplier and railroad representatives serve in an advisory role throughout the subprogram. The AAR, with its laboratory facilities and experience in data collection and analysis in other track programs, could play a key role in Projects 1, 2 and 3.

Barriers

There are no known barriers which might prevent or hinder implementing the successful results of this subprogram.

Relationship to Other Factors

This subprogram is directly related to Subprograms F, On-Site Electric Flash-Butt Welding and Subprogram G, In-Place Rail Welding. Successful results in either of those efforts would eliminate the need for this effort, however, success here would not necessarily eliminate the need there. This logic, plus the relative ranks suggest that Subprograms F and G should be pursued to some conclusion before this subprogram is initiated.

TABLE D-5

EVALUATION MEASURES, SUBPROGRAM E

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$1.3 million	13
R&D Costs	Total Subprogram R&D Costs	$500 thousand	4
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	2.6	12
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	6	5
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	$150 thousand	7
Timeliness	R&D Time in Years	3.7	2
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	0.9	6
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.54	5

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

REFERENCES

1. Shaw, A. E., et al, "Economics of Installing Bonded Insulated Joints in Field vs. Shop Fabrication and Economics of Bonded Joints vs. Field Welds to Connect CWR," A.R.E.A. Bulletin, No. 656, January-February, 1976.

2. Hauser, D., Methods for Joining of Rails: Survey Report, Report No. FRA/ORD-77/16, Federal Railroad Administration, Washington, D.C., July, 1977.

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5. Welding Handbook, 6th Edition, Section 3, edited by L. Griffing, American Welding Society, New York, 1971.

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SUBPROGRAM F

ON-SITE ELECTRIC FLASH-BUTT WELDING

RANK 4

PROBLEM

The growing use of continuously welded rail (CWR) has made field welding an increasingly troublesome problem. Typically, CWR is welded in a plant into about 1/4 mile lengths using an electric flash-butt technique. In the field, these lengths are joined, usually via a thermite weld, or some other joining technique. While in-plant welds are reliable and reasonably cheap, field welds are neither reliable nor cheap. Thermite field welding costs ranged from $60 to $150 per weld on a sample of 22 railroads compared to $10 to $30 for in-plant welds.[1] Furthermore, thermite welds fail anywhere from 3 to 100 times as often as flash-butt welds.[2]

DESCRIPTION OF R&D EFFORT

Objective

This subprogram will analyze and improve upon an existing field welding technique such that its reliability is similar to in-plant flash-butt welding. Cost should be approximately the same as in-plant welds, $10 to $30 a weld.

State-of-the-Art

Thermite welding is the standard field welding technique. Thermite welding produces coalescence "by heating with a superheated liquid metal and slag resulting from a chemical reaction between a metal oxide and aluminum, with or without the application of pressure. Filler metal, when used is obtained from the liquid metal."[5]

Although extensively used in the U.S., the mechanical properties of the weld are such that in Japan, thermite welds are currently used primarily for emergency repairs. The Japanese use enclosed arc welding, an advanced technique, for normal CWR installation. In the U.S. defective thermite welds are very common, leading some railroads to be very dissatisfied with them. The problem seems to be chiefly one of quality control and proper training of personnel. Different railroads report very different levels of success with thermite welds. Several changes in training and in the welding process have been adopted, apparently with some success to reduce variability of weld quality.[2]

Thermite welds have several advantages. The technique is portable, requires little capital investment and requires only a short time for weld completion. An additional advantage, if the technique is used to weld track in place, is that the rails need not be pressed together, nor do the ends of the rails have to be as straight as for flash-butt welding.

Flash welding is the technique generally used to join rails in plant to form rail strings. They represent the bulk of welds in U.S. railroad track. Flash welding produces coalescence, "simultaneously over the entire area of abutting surfaces by the heat obtained from resistance to electric current between the two surfaces and by the application of pressure after heating is substantially completed. Flashing and upsetting are accompanied by expulsion of metal from the joint".[6]

Flash welding produces reliable welds fairly cheaply in the plant. In-track flash welding has been tried with success recently. In-track welding, using the electric flash process, usually requires the removal of spikes and anchors so the rails can be pulled together to exert the necessary pressure. The rail ends must be cropped when there is batter, bent rail ends or joint bar wear. In-track welding costs about $30 a weld, not counting unspiking, shifting, cropping and respiking the rails. This price compares favorably with thermite welding and with plant welding when the costs of shipment to and from the welding is considered. It does require a substantial equipment investment ($500,000). For small railroads, without a welding plant, in-track welding may offer great economy.[4]

In-track flash-butt welds have performed satisfactorily so far, and the development of an effective shear for the upset material should improve reliability and increase productivity.

Gas-pressure welding has been used for nearly forty years, although flash-butt welding has largely replaced it in recent years. Gas pressure welding produces coalescence "simultaneously over the entire area of abutting surfaces, by heating with gas flames obtained from the combustion of a fuel gas with oxygen and by the application of pressure, without the use of filler metal".[7]

In-track gas-pressure welding equipment has been developed in Japan and in the U.S. but has not been evaluated. In general, gas pressure welding produces welds almost as reliable as flash-butt welds and superior to thermite welds. In comparison to flash-butt welding, gas-pressure appears to be slower, more expensive and more susceptible to weld defects, although an evaluation of the in-track systems has not been made.

Several arc welding processes have been used to join rails, although generally on an experimental basis. The processes include electroslag welding, submerged-arc welding and "enclosed" welding (metal arc welding with a shield). Arc welding techniques have promise, but they do have drawbacks. The processes currently require a high level of skill on the part of the operator which automation would possibly reduce. Hydrogen, including water, must be kept out of the joint area while welding to avoid underbed cracking. Another difficulty is that welding produces heat-affected zones of low toughness. This problem can be solved by pre-weld and post-weld heat treatment.

R&D Projects Required

This subprogram is composed of four R&D projects. Brief descriptions of the projects follow, while costs and schedules are shown in Figure D-6.

1. Test Planning

The objective of this project is to develop a plan for monitoring existing on-site electric flash-butt welds to allow them to be compared with thermite as well as in-plant welds on the basis of cost, weld quality and operational impacts. In addition, an evaluation of the shears which removed the hot upset metal should be planned.

2. Cost-Effectiveness Study

Existing on-site flash-butt welds will be monitored and their costs and defect experience with regard to tonnage, climate and any other pertinent factors noted. If possible, details about the weld (time, weather, welder identification) will also be collected. Welding in progress will be monitored closely, so that in the case of later defects, likely research areas can be identified.

3. Shear Evaluation Study

The welding process produces hot upset material which needs to be removed. This is usually done by hand after cooling. Though in track flash-butt welding has had very few failures, those that have occurred have been attributed to the upset on the underside of the rail base. An automatic shear to remove the hot upset metal immediately after the weld is completed is felt by some to be a useful way to increase reliability. The Soviet Union has developed such a shear and it is

PROJECT No.	PROJECT TITLE	R & D COST ($1,000)
1	Test Planning	35
2	Cost-Effectiveness Study	150
3	Shear Evaluation Study	100
4	Results Dissemination	30
	TOTAL R & D COST	315

YEARS AFTER START: 1 2 3 4 5 6 7 8 9 10

FIGURE D-6
COST AND SCHEDULE—ON-SITE ELECTRIC FLASH-BUTT WELDING SUBPROGRAM

currently being evaluated privately in this country. The performance of this shear will be monitored and any modifications necessary noted in this project.

4. Results Dissemination

At the conclusion of the program a summary report will be published on all aspects of in-place electric flash-butt field welding, including reliability, costs, techniques and uses, and a seminar will be prepared and conducted to disseminate the results. If other welding subprograms are nearing completion at the same time, the seminar will include their results.

JUSTIFICATION FOR RANKING

Benefit Summary

The present value of the benefits from 50,000 in-place flash-butt welds is $2,264,000. If 50,000 welds are made a year for 25 years the present value of the benefits would be $20.6 million. Aproximately 90 percent of the benefit comes from the $40 per weld saving compared to the cost of the thermite welds replaced. The other 10 percent in benefits comes from reducing accidents caused by weld failures. Approximately 4.5 accidents would be prevented in the first five years of implementation.

Evaluation Measures

This subprogram had an overall evaluation score of 81, giving it a rank of 4. The first, third, fifth and last subprograms had scores of 216, 88, 76 and 39 respectively. Values and relative rank of the individual evaluation measures are shown in Table D-6.

TABLE D-6

EVALUATION MEASURES, SUBPROGRAM F

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$20.6 million	6
R&D Costs	Total Subprogram R&D Costs	$315 thousand	2
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	65.4	4
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	4.5	5
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	$10.6 million	5
Timeliness	R&D Time in Years	2.2	1
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	0.4	11
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.60	3

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

IMPLEMENTATION

Incentives

Improvements in flash-butt welding should require minimal outlays by railroads, expecially if welding is performed by a contractor as it is now. Convincing the contractor to adopt improvements should be the chief problem. In track flash-butt welding is new, but it is rapidly gaining acceptance and any improvements in it should be quickly embraced.

The series of R&D utilization seminars specified in Project 4 is one step toward assuring that the R&D results, if successful, will be utilized. The key to acceptance will be conclusive results, presented clearly, concisely and in a professional manner.

The in-service test project is another such step. At a minimum, the railroads involved in the tests will have first hand experience with the products and methods, and as such will be more prone toward utilization than other railroads.

Another step toward successful implementation would be to have the railroad industry and the suppliers participate in the subprogram in other ways. For example, it would be beneficial to have supplier and railroad representatives serve in an advisory role throughout the subprogram. The AAR, with its laboratory facilities and experience in data collection and analysis in other track programs, could play a key role in Projects 2, 3 and 4.

Barriers

If this subprogram is successfully completed, it would in all likelihood reduce the need for a small number of maintenance-of-way personnel. Unions can be expected to resist the loss or to extract concessions which would reduce the monetary benefit to the railroads. This is the only known potential barrier to implementation.

Relationship to Other Efforts

This subprogram is closely related to Subprogram E, Improved Thermite Welding and Subprogram G, In-Place Rail Welding. Success here would eliminate the need for the former and perhaps alter the economics of the latter. However, success in the latter would eliminate the need for this subprogram. This logic, plus the subprogram ranks, suggests that this effort should not precede Subprogram G, although it could be undertaken concurrently.

REFERENCES

1. Shaw, A. E., et al, "Economics of Installing Bonded Insulated Joints in Field vs. Shop Fabrication and Economics of Bonded Joints vs. Field Welds to Connect CWR," A.R.E.A. Bulletin, No. 656, January-February, 1976.

2. Hauser, D., Methods for Joining of Rails: Survey Report, Report No. FRA/ORD-77/16, Federal Railroad Administration, Washington, D.C., July, 1977.

3. Dick, M. H., "Welded Rail Practices Are Diverse," Railway Age, June, 1972.

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5. Welding Handbook, 6th Edition, Section 3, edited by L. Griffing, American Welding Society, New York, 1971.

6. Welding Handbook, 6th Edition, Section 2, edited by A. L. Phillips, 1969.

7. Welding Handbook, 6th Edition, Section 5, Chapter 89, edited by C. Weisman, 1973.

8. "M/W Probe I: Close-Up of Policies and Practices, Union Pacific", Railway Track and Structure, Vol 69, No. 6, 1973.

SUBPROGRAM G

IN-PLACE RAIL WELDING

RANK 3

PROBLEM

Approximately 85 percent of track is still jointed.[2] Jointed track has much higher maintenance cost than CWR track. If a way could be found to weld track in place, cheaply and reliably, railroad maintenance costs could be cut dramatically. Estimates of savings in maintenance costs from CWR range from $198-$1,200.[3] In addition, welded rail enjoys up to twice the life of jointed rail because the rail can wear beyond the point where wheel flanges contact the joint bar on jointed rail. Therefore a particularly attractive application of field welding would be to weld jointed rail that has reached the wear limits imposed by joint bars, thus saving the cost of new rail.[4] However, with 270 joints in a mile of track, the cost of thermite welds prohibit in-situ conversion of jointed track to CWR.

DESCRIPTION OF R&D EFFORT

Objective

This subprogram will attempt to develop a method of weld rails while leaving them spiked and anchored. The cost of the entire process should be no more than $50, to be competitive with other joining techniques.

State-of-the-Art

Current welding techniques all require the removal of spikes and anchors. Several, heretofore untried, welding techniques may produce less upset material and therefore might be appropriate for in-place welding.

Friction welding in rails could be accomplished by rotating a steel disc between the rail ends.[2] The technique has many attractive features but the process is still in its early stages of development. The technique may be feasible without disrupting the track structure.

Several unconventional welding processes could be used for welding rail. They include electron-beam welding and laser-beam welding. The methods produce far less upset material which would be an advantage for in-track welding.[2] The techniques have not been developed for rail welding, so an important consideration would be the length of time required to develop the system.

R&D Projects Required

This subprogram is composed of seven R&D projects. Brief descriptions of the projects follow, while costs and schedules are shown in Figure D-7.

1. Market Study

The benefits from the subprogram will depend on the market existing when the subprogram is completed. In-place rail welding will require a welding technique not currently used for track welding. Therefore, this is a long term and costly project. Continuously welded rail is being installed at a rate of over 5,000 miles a year. Sixty thousand miles are already in place. At the current rate of installation, in a few years the installation of welded rail will be in track with fairly light density traffic. It may be uneconomical to weld the rail on light density track. The market study would evaluate the trends and cost and determine the market for in-place rail welding.

2. Survey of Techniques

In-place welding requires a technique that does not need rails to be drawn together. This project would search out such techniques that could be adapted to field use.

PROJECT No.	PROJECT TITLE	R & D COST ($1,000)	YEARS AFTER START 1	2	3	4	5	6	7	8	9	10
1	Market Study	100										
2	Survey of Techniques	70										
3	Laboratory Test Plan	20										
4	Laboratory Tests	200										
5	Track Test Plan	20										
6	FAST and In-Service	170										
7	Results Dissemination	40										
TOTAL R & D COST		620										

FIGURE D-7
COST AND SCHEDULE—IN-PLACE RAIL WELDING SUBPROGRAM

3. Laboratory Test Plan

A laboratory evaluation of the most favorable techniques would be planned next. The evaluation plan will identify the factors to be considered and set forth their use to assure that the most promising technique will be selected for in-track testing and demonstration.

4. Laboratory Tests

The tests will determine which of the techniques identified in the survey should be further developed and tried in the field. The factors considered would include cost, practicality for field use, equipment cost, and reliability. Also, the tests would determine special requirements of the systems such as rail end straightness, end batter tolerances and suitability of different rail steels. After the most promising technique is determined, welds performed by the technique would be extensively tested for reliability prior to track installation.

5. Track Test Plan

Based on the information obtained from Project 4, a demonstration test will be planned. The test and demonstration will be designed to ensure that reliability and cost in the field are definitively established.

6. FAST and In-Service Test

The test will be conducted initially at FAST to establish reliability. Once reliability is established well enough to permit in-service use, the technique will be used in railroads. The installations will be monitored to determine performance. The results of the lab tests and FAST test will be distributed to rail welding decision makers to familiarize them with the technique. The demonstration will also be periodically summarized.

7. Results Dissemination

When the demonstration has progressed sufficiently to draw conclusions, a summary report will be published and a seminar held to familiarize rail welding decision makers with the new technique.

JUSTIFICATION FOR RANKING

Benefit Summary

Welding jointed rail in-place, especially when rail wear has progressed to the limits imposed by joint bars would save $46,500 a mile. This saving comes from avoiding installation of relay rail ($60,000/mile) by welding at $50 a weld or $13,500 a mile. Assuming 1,000 miles of such track are converted a year, yearly savings of $46.5 million are achieved. Continued over 25 years welding 1,000 miles of track in-place every year has a present value of $422.1 million.

Evaluation Measures

This subprogram had an overall evaluation score of 88, giving it a rank of 3. The first, second, forth and last subprograms had scores of 216, 104, 81 and 39 respectively. Values and relative rank of the individual evaluation measures are shown in Table D-7.

IMPLEMENTATION

Incentives

Any innovative technique will face greater hurdles. The railroads must accept that the welds have high reliability, requiring demonstration at FAST and on railroads as well as laboratory tests. The next problem is how will the welder be deployed--will the railroads buy their own welder or will they rely on contract services? In the former case, the capital cost of a welder will be a major factor. Large capital costs will slow acceptance and limit use to major railroads. If contractors

TABLE D-7

EVALUATION MEASURES, SUBPROGRAM G

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$422.1 million	2
R&D Costs	Total Subprogram R&D Costs	$620 thousand	5
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	680.8	2
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	0	9
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	$232.5 million	2
Timeliness	R&D Time in Years	3.9	6
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	0.3	12
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.22	13

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

provide the welds, railroads with their own welding equipment might not use the innovative technique. The market study should provide information with which to determine the railroad market for various techniques in the R&D stage. The development should use the information to assure implementation is carried out in the manner that will encourage those railroads needing the innovative technique to use it.

The series of R&D utilization seminars specified in Project 7 is one step toward assuring that the R&D results, if successful, will be utilized. The key to acceptance will be conclusive results, presented clearly, concisely and in a professional manner.

The in-service test project is another such step. At a minimum, the railroads involved in the tests will have first hand experience with the products and methods, and as such will be more prone toward utilization than other railroads.

Another step toward successful implementation would be to have the railroad industry and the suppliers participate in the subprogram in other ways. For example, it would be beneficial to have supplier and railroad representatives serve in an advisory role throughout the subprogram. The AAR, with its laboratory facilities and experience in data collection and analysis in other track programs, could play a key role in Projects 3, 4, 5 and 6.

Barriers

If this subprogram is completed successfully, it would in all likelihood reduce the need for some maintenance-of-way personnel. Unions can be expected to resist the loss or to extract concessions which would reduce the monetary benefit to the railroads. This is the only known potential barrier to implementing the results of a successful R&D effort.

Relationship to Other Efforts

This subprogram is closely related to Subprogram E, Improved Thermite Welding and Subprogram F, On-Site Electric Flash-Butt Welding. If successfully completed, it would eliminate the need for those efforts. This fact, plus the large monetary benefit and capital savings, suggest that the effort should be initiated and completed before either of the others. However, the low probability of success suggests that concurrent efforts are worth considering if sufficient R&D funds are available.

REFERENCES

1. Shaw, A. E., et al, "Economics of Installing Bonded Insulated Joints in Field vs. Shop Fabrication and Economics of Bonded Joints vs. Field Welds to Connect CWR," A.R.E.A. Bulletin, No. 656, January-February, 1976.

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SUBPROGRAM H

BOLT HOLE CRACK PREVENTION

RANK 6

PROBLEM

Despite the widespread acceptance of continuously welded rail (CWR), about 85 percent of total track is still jointed rail.[1,2] At current and predicted rates of CWR installation, large amounts of jointed rail will remain in service in the foreseeable future.

Joints are the weak link of the rail. Bolt holes in the joints are a particular problem. Cracks develop at the bolt holes because of stress concentrations at the holes, the discontinuous structure, and the dynamic loading produced by the rail joint. In 1970 Sperry Rail Service detected 46 bolt hole cracks per 100 miles of track, based on a total of 70,542 cracks in 151,741 miles of track.[3]

Assuming the cost of replacing a defective rail to be $150 (for labor and new rail less salvage value), the cost of replacing rails with bolt hole cracks in about $10,500,000 a year. In 1976 bolt hole cracks led to 101 accidents and 3 injuries.[4] These accidents led to about $3 million in damage to track and equipment. If total damage is assumed to be 2.1 times the damage to track and equipment,[5] total losses due to bolt hole cracks amounted to $6.3 million in 1976.

DESCRIPTION OF R&D EFFORT

Objective

This subprogram is aimed at developing a system to treat uncracked bolt holes in order to eliminate future bolt hole cracks. The cost of treating rail in plant should not exceed $1.00 per bolt hole treated.

State-of-the-Art

Bolt holes can be strengthened by the sleeve cold-expansion process. A split, dry-film lubricated sleeve is placed on a tapered mandrel which is drawn through a bolt hole. The sleeve locks in the hole, providing a smooth, lubricated bore to draw the mandrel through. The oversize mandrel expands the bolt hole 0.05" to 0.08", thereby introducing large compressive stresses in the metal surrounding the bolt hole.(6)

Laboratory tests of sleeve expansion have been conducted. These tests show dramatic improvements in resistance to cracks over non-treated bolt holes. The process has also been tried successfully in the field, but the track was removed for other reasons before a long term evaluation could be made.

Another approach to the problem, shot peening, does not induce stresses deep enough to match the improvements from cold expansion. It is not practical in the field and has higher first costs in plant.(7) Other expansion methods suffer from insufficient tool life due to lack of bolt hole cleanliness. Edge coining does not introduce enough compressive stress to produce significant fatigue improvement.(6) Sleeve expansion is the most promising research area currently.

Sleeve expansion can be performed on uncracked bolt holes to prevent cracks. This could be done either in the field or in the plant for relay rail or new bolted rails. Most new rail is CWR, but many turnouts and crossings have bolt holes so there is a need for expanding new bolted rail. Relay rail is usually welded, but as use of CWR expands, more of the relay rail will go to branch lines where welding is not warranted. In that case, relay rail could be treated at the plant, although there are claims that removing the rail without unbolting it and taking it directly to the relay site is more economical.[8] Rail could be unbolted in the field and expanded but this seems too costly at current prices, unless the joint bars need to be removed for some other reason. In-plant treatment appears most favorable at this time.

The current technique can repair only holes that are not seriously out of round (see (6) for specifications). Since many used rails have bolt holes beyond the tolerance, it is necessary to drill or broach them before expansion.

R&D Projects Required

This subprogram will be directed twoards treating serviceable bolt holes in-plant to make them less susceptiable to cracking. Brief descriptions of its three projects follow. Costs and schedule are shown in Figure D-8.

1. Test Plan

The test plan will design a demonstration of in-plant bolt hole expansion that will establish the capabilities of sleeve expansion as rapidly and economically as possible. The emphasis should be on determining in-track performance, since the process itself is fairly simple.

2. Demonstration

A demonstration will be set up on FAST and other railroads to compare life of rails with expanded bolt holes to those without expanded holes. It is anticipated that most of the rail in the demonstration would be in turnouts and crossings. This heavy service should establish the service characteristics of expanded bolt holes rapidly. It is worth noting that accelerated testing in the laboratory is not

PROJECT No.	PROJECT TITLE	R & D COST ($1,000)	YEARS AFTER START 1	2	3	4	5	6	7	8	9	10
1	Test Plan	20										
2	Demonstration	80										
3	Results Dissemination	30										
	TOTAL R & D COST	130										

FIGURE D-8
COST AND SCHEDULE—BOLT HOLE CRACK PREVENTION SUBPROGRAM

likely to yield data to demonstrate in a conclusive manner the benefit of bolt hole expansion.

Throughout the demonstration, interim reports will be prepared and distributed as widely as possible. This will allow railroads to acquire useful information before the completion of the demonstration, permitting early adoption of the technique if it proves cost-effective. At the conclusion of the demonstration, a final report will be prepared.

3. Results Dissemination

A summary report of the demonstration results will be prepared and seminars will be conducted at several locations. Attendees will be railroad personnel who make or influence maintenance or rehabilitation decisions. If other subprograms related to rail, fasteners, joints, etc. are nearing completion at the same time, this seminar might be combined with one of those. Additionally, articles suitable for publication in the trade press will be prepared.

JUSTIFICATION FOR RANKING

Benefits Summary

In-plant bolt hole expansion reduces accidents as well as rail replacement due to bolt hole cracks. Expanding 750 miles of track a year, including crossing and turnouts, results in future accident and rail replacement cost savings having a present value of $382,000. Continuing the program for 25 years would have a present value of $3.5 million. One accident would be prevented every year for every 1,500 miles of track expanded or 2 years of installation at the assumed rate. During the first 5 years in which this technique would be available, 7 accidents can be expected to be prevented.

Evaluation Measures

This subprogram had an overall evaluation score of 75, giving it a rank of 6. The first, fifth, seventh and last subprograms had scores of 216, 76, 68 and 39 respectively. Value and relative rank of individual evaluation measures are shown in Table D-8.

IMPLEMENTATION

Incentives

The series of R&D utilization seminars specified in Project 3 is one step toward assuring that the R&D results, if successful, will be utilized. The key to acceptance will be conclusive results, presented clearly, concisely and in a professional manner.

The in-service test project is another such step. At a minimum the railroads involved in the tests will have first hand experience with the products and methods, and as such may be more inclined toward utilization than other railroads.

Another step toward successful implementation would be to have the railroad industry and the suppliers participate in the subprogram in other ways. For example, it would be beneficial to have supplier and railroad representatives serve in an advisory role throughout the subprogram. The AAR, with its experience in data collection and analysis in other track programs, could play a key role in Projects 1 and 2.

Barriers

The relatively low monetary benefit might not be sufficient to overcome the combination of inertia, the "not invented here" philosophy, and the need to invest capital far in advance of receiving the benefit. This is the only known barrier to implementing successful results.

Relationship to Other Efforts

The relationship between this effort and that in Subprogram I, Bolt Hole Crack Restraint, extends beyond technique. If the effort is successful and is implemented, it will over a long period alter the economics associated with crack restraint and over a very long period (35 years or so) eliminate bolt hole cracks entirely. Since rail now in place will still be susceptible to to bolt hole cracks, both efforts will be beneficial over the short term.

The subprogram is also related to Subprogram C, Improved Rail Hardening, Subprogram J, Improved Wood Tie Fastening Systems and Subprogram M, Improved Concrete Tie and Fastener Selection and Utilization. Success here will reduce the monetary benefit in all those subprograms and success in any of them will reduce the benefit here.

TABLE D-8

EVALUATION MEASURES, SUBPROGRAM H

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$3.5 million	10
R&D Costs	Total Subprogram to R&D Costs	$130 thousand	1
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	26.9	7
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	7	4
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	-$1.6 million	8
Timeliness	R&D Time in Years	4.8	9
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	0.7	9
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.66	2

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

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SUBPROGRAM I

IN-PLACE BOLT HOLE CRACK RESTRAINT

RANK 10

PROBLEM

Despite the widespread acceptance of continuously welded rail (CWR), about 85 percent of total track is still jointed rail.[1,2] At current and predicted rates of CWR installations, large amounts of jointed rail will remain in service in the foreseeable future.

Joints are the weak link of the rail. Bolt holes in the joints are a particular problem. Cracks develop at the bolt holes due to the pounding received from wheels rolling over the gap in the rail joint. In 1970 Sperry Rail Service detected a total of 70,542 cracks in 151,741 miles of track[3] or an average of 46 bolt hole cracks per 100 miles of track.

Assuming the cost of replacing a defective rail to be $150 (for labor and new rail less salvage value), then the cost of replacing rails with bolt hole cracks is about $10,500,000 a year.

DESCRIPTION OF R&D EFFORT

Objective

This subprogram is aimed at developing a system to repair bolt hole cracks up to 1/2" in length that will allow the rail to continue in service for its normal life. The cost of the repair must be less than 25 percent of the cost of rail replacement in the field.

State of the Art

Bolt hole cracks can be repaired by the sleeve cold-expansion process. A split, dry-film lubricated sleeve is placed on a tapered mandrel which is drawn through a bolt hole. The sleeve locks in the hole, providing a smooth, lubricated bore to draw the mandrel through. The oversize mandrel expands the bolt hole 0.05" to 0.08", thereby introducing large compressive stresses in the metal surrounding the bolt hole.[6]

Laboratory tests of sleeve expansion have been conducted. These tests show dramatic improvements over non-treated rail. The process has also been tried successfully in the field, but the track was removed for other reasons before a long term evaluation could be made.

Another approach to the problem, shot peening, does not induce stresses deep enough to match the improvements from cold expansion. It is not practical in the field and has higher first costs in plant.[7] Other expansion methods suffer from insufficient tool life due to lack of bolt hole cleanliness. Edge coining does not introduce enough compressive stress to produce significant fatigue improvement.[6]

Sleeve expansion is currently the most promising research area. There is a need for a conclusive demonstration of the effectiveness of sleeve expansion on cracked bolt holes. Validation of the effectiveness of expansion on different sized bolt hole cracks is required. As cracks get bigger the effectiveness of expansion declines. Therefore, if bolt hole cracks were discovered earlier, the expansion system would have a higher payoff. Improved detection techniques and/or more frequent inspections are alternatives that would have an impact on the payoff of sleeve expansion.

Another sleeve expansion technique can only repair holes that are not seriously out of round (see (6) for specifications). Since many used rails have bolt holes beyond the tolerance, it is necessary to drill or broach them before expansion.

R&D Projects Required

This subprogram consists of five R&D projects. Some could be grouped and given to a single contractor to perform. Brief descriptions follow. Costs and schedules are shown in Figure D-9.

1. Test Planning

The test plan for both the laboratory and in-service tests must be carefully designed to ensure that the tests will conclusively establish the performance of repaired bolt holes. The tests must determine the effectiveness of repairs on different sizes of cracks so that the range of repairable crack sizes can be established. Since the cost of an accident far exceeds the cost of replacing a cracked rail, repaired rails must have approximately the same reliability as rails with uncracked bolt holes. Given the high reliability of uncracked rail, a very large sample of cracked rails would have to be tested to determine if reliability were in the acceptable range. The test plan must consider the need to establish reliability for different crack sizes in the most economical manner, since the tests will be expensive. Attention must be paid to adequate sample sizes for different crack sizes and economical methods of collecting and testing cracked rails.

2. Laboratory Testing

Sleeve expansion loses its effectiveness as cracks increase in size. Therefore, it is necessary to determine the largest size bolt hole crack that can be satisfactorily repaired by sleeve expansion. This will be done by gathering a large number of rail ends with cracked bolt holes (or fabricating some), expanding them and testing to failure,

PROJECT No.	PROJECT TITLE	R & D COST ($1,000)	YEARS AFTER START 1	2	3	4	5	6	7	8	9	10
1	Test Planning	30										
2	Laboratory Testing	240										
3	Demonstration	360										
4	Crack Detection Guidelines	40										
5	Results Dissemination	40										
	TOTAL R & D COST	710										

FIGURE D-9
COST AND SCHEDULE—IN-PLACE BOLT HOLE CRACK RESTRAINT SUBPROGRAM

as compared with a control group of untreated bolt hole cracks. The information provided would be used to determine the reliability of repairs on different sized cracks and the rate of crack growth (from the control group). Crack growth rate is needed to establish inspection requirements.

The results of the laboratory tests will be used to update the test plan for FAST and in-service tests. The results of the laboratory tests will permit focusing subsequent tests on verifying results of the lab tests. The remaining tests will also be revised to ensure minimum expense consistent with conclusively establishing the performance of bolt hole expansion. Preliminary arrangements will be made with railroads who will participate in an in-service test and demonstrations project.

3. <u>Demonstration</u>

The demonstration would consist of repairing and installing cracked rails obtained from industry in FAST to validate the laboratory work. Once the initial tests were completed, a few railroads would be enlisted to use the equipment to repair bolt holes on their lines. The cracks would be analyzed in the field before and after repair and monitored periodically.

4. <u>Crack Detection Guidelines</u>

Based on the results of Projects 2 and 3, detection requirements would be established. These would specify how sensitive detection equipment needed to be, in light of crack growth and repair performance. Recommended inspection frequencies would also be promulgated.

5. <u>Results Dissemination</u>

The results of the demonstration project should be widely distributed, encouraging rapid adoption of the technique if warranted. A summary report would be produced and a seminar held with the industry to disseminate the results. The trade literature would also be used to print articles describing the subprogram results.

JUSTIFICATION FOR RANKING

Benefits Summary

Repairing detected bolt hole cracks by the sleeve expansion method should save an average of $112.50 per crack repaired. If 5,900 repairable cracks are detected a year, savings of about $664,000 could be achieved. In the course of 25 years, savings with a present value of $6.0 million could be accrued.

Evaluation Measures

This subprogram had an overall evaluation score of 50, giving it a rank of 10. The first, ninth, eleventh and last subprograms had scores of 216, 51, 45 and 39, respectively. Values and relative rank of the individual evaluation measures are shown in Table D-9.

IMPLEMENTATION

Incentives

The seminar specified in Project 5 is one step toward assuring that the R&D results, if successful, will be utilized. The key to acceptance will be conclusive results, presented clearly, concisely and in a professional manner.

The in-service test project is another such step. At a minimum, the railroads involved in the test will have first hand experience with the products and methods, and as such be more prone toward utilization than other railroads.

TABLE D-9

EVALUATION MEASURES, SUBPROGRAM I

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$5.7 million	9
R&D Costs	Total Subprogram R&D Costs	$710 thousand	6
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	8.0	8
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	0	9
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	$3.3 million	6
Timeliness	R&D Time in Years	3.7	2
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	- 0.3	13
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.42	10

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

Another step toward successful implementation would be to have the railroad industry and the suppliers participate in the subprogram in other ways. For example, it would be beneficial to have supplier and railroad representatives serve in an advisory role throughout the subprogram. The AAR, with its laboratory facilities and experience in data collection and analysis in other track programs, could play a key role in the projects.

The low capital cost of the equipment is perhaps the most powerful incentive, especially if the decision makers can be made aware of the subprogram results.

Barriers

The chief barrier is lack of ability to detect flaws before they grow too large to fix. This may result in too few repairable cracks being found to warrant instituting a new technique, buying equipment and training personnel.

Relationship to Other Efforts

This effort is related to Subprogram H, Bolt Hole Crack Prevention. Successful completion and implementation there will gradually diminish the benefit of this subprogram. Over the short term, however, it will still be beneficial to restrain bolt hole cracks in the rail now in place.

The effort is also related to Subprogram C, Improved Rail Metallurgy Subprogram D, In-Place Rail Hardening, Subprogram J, Improved Wood Tie Fastening Systems and Subprogram M, Improved Concrete Tie and Fastener Selection and Utilization. Success here will reduce the benefit of all those efforts, and success in any of them will reduce the benefit here.

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SUBPROGRAM J

IMPROVED WOOD TIE FASTENING SYSTEMS

RANK 12

PROBLEM

The performance of rail/tie fastening assemblies is a matter of considerable economic importance to the railroad industry. Because it is an interconnecting device, it affects several aspects of track design, degradation and reliability. Until recently the conventional wood tie fastening system consisting of the tie plate, base rail anchor, and cut spike was performing well in U.S. tracks. With the advent of heavier wheel loads and higher annual tonnages the conventional system now appears to be operating at the upper limits of its ability to withstand such traffic. Recurrent problems include loss of gage, rail overturning, track shift and reduced track stability. This in turn increases component problems such as rail wear, tie wear due to plate cutting and tie degradation due to spike killing. All of these factors reduce vehicle ride quality and increase the potential for derailments.

FRA accident statistics do not directly present causation data due to fastener problems. However, many of the 1512 accidents in 1976 attributed to track geometry defects have their root cause at the rail/tie interface. The 94 accidents resulting from wide gage (defective or missing spikes or other rail fasteners) are clearly fastener problems. Other causes such as irregular track alignment and wide gage (defective ties) are also directly or indirectly related to the rail/tie interface. Conservatively estimating 486 conventional fastener-related accidents in 1976 at $19,624 per accident yields damages of $9,537,000. Using a multiplier of 2.1 to account for other damages sustained by railroads due to the cost of clearing wrecks, loss and damage to freight and injury compensation results in total losses of more than $20,000,000 annually.(1)

DESCRIPTION OF R&D EFFORT

Objective

This subprogram seeks to provide information about currently available improved systems for fastening rails to wood ties which will allow the industry to save the equivalent of $3.0 million on track system expenditures in today's dollars. A reasonable approach toward achieving this objective would be to consider the potential savings in curves where:

- tie life is increased by 50 percent
- rail wear is reduced by 33 percent
- line and surfacing costs are reduced by 33 percent
- faster-related accidents are reduced by 50 percent

This benefit could be realized even for improved fastening systems which cost 44 percent more than the conventional fastening system.

State-of-the-Art

The total number of wood tie fastener designs in current use and testing throughout the world is staggering. Variations on the usage of even the simple conventional fastener tie plate, cut spike and rail anchor in use in the U.S. include tie plate size and cant, and spiking and anchor patterns. Improved performance systems are even more diverse and include lock spikes, screw spikes, compression clips, elastic plates, elastic clips, etc.(2)

The use of improved fasteners abroad has been much more extensive than in North America. It is only recently that the heavier wheel loads and higher annual tonnages have been exacting their toll on this continent. For example, to counter the severe problem of gage widening on curves, the Louisville and Nashville Railroad has run tests with new spiking patterns, large tie plates and compression clip anchors.[(3)] The Canadian National Railway has also shown in an economic study that resiliant rail fastenings for wood ties are a viable alternative where a stronger track structure is required to accomodate excessive curve wear and curving forces.[(4)] Benefits of the fasteners included increased track stiffness, longer tie life, elimination of the need for rail anchors, and installation on existing partly worn ties.

The Atcheson, Topeka and Santa Fe Railroad has also undertaken a very extensive laboratory and field testing program of improved fasteners to counter curved track problems such as rail wear, gage widening, rail roll-over and the need to transpose or renew rail at relatively frequent intervals.[(5)] Santa Fe is looking for a fastener which, though more costly than the conventional construction, will resist gage widening and rail roll-over, eliminate respiking, and restrain rail longitudinal creep without the use of rail anchors. They are therefore service testing several fastener assemblies in over 14,000 feet of curved track in heavy tonnage areas. Fasteners include the German K, TR&D clamp, D.E. spring chip, Pandrol clip, Portec Curv-Bloc and many varieties of screws, washers, etc.

Other railroads are also service testing various fastener systems. The Alaska Railroad is testing polyethylene tie plates.[(6)] The Union Pacific Railroad has tested gage widening problems on curve and target track.[(7,8,9)] The Long Island Railroad is testing improved fasteners to increase tie life.[(10)]

Testing of five different wood tie fastening schemes is also in progress at FAST.[(11)] The 5 degree curved test section has accumulated

238 MGT as of April 1978. Tie plate cutting and rail profile are being measured. Data should be forthcoming soon.

A recent report gives a survey and description of work performed in the area of rail overturning and gage widening.(12) Mechanisms of these problems include spike pullout, spike bending, tie crushing and bending of the rail head and web. Solution approaches include improved train handling techniques, redesigned locomotive suspensions, and increased track lateral and torsional stiffness (more efficient fasteners, gage rods, etc.).

R&D Projects Required

The fastener assembly affects all aspects of track design. This subprogram seeks to provide information which will allow railroads, for any track/train condition, to make a selection from the various fastener types that will ensure satisfactory and economical performance.

This subprogram is composed of seven R&D projects. Brief descriptions follow while costs and schedule are shown in Figure D-10.

1. Fastener Economic Study

The objective of this project is to prepare, based on best available cost and performance data, a preliminary economic assessment of the use of improved wood tie fasteners for various track/train conditions. This study will provide a basis for the selection of the most promising alternatives for further testing.

The base line for comparison purposes will be the conventional industry fastening practice for the specific track/train conditions. Improved systems will cost more initially but should provide a more stable track system, less tie deterioration, less maintenance, etc.

PROJECT		R & D COST ($1,000)	YEARS AFTER START									
No.	TITLE		1	2	3	4	5	6	7	8	9	10
1	Fastener Economic Study	70										
2	Laboratory Test Planning	70										
3	Laboratory Testing and Analysis	210										
4	Test Planning	105										
5	In-Service and FAST Tests	1,050										
6	Analysis and Report	120										
7	Results Dissemination	40										
TOTAL R & D COST		1,665										

FIGURE D-10
COST AND SCHEDULE—IMPROVED WOOD TIE FASTENING SYSTEM SUBPROGRAM

2. Laboratory Test Planning

The objective of this project is to develop a plan for laboratory testing of improved fastener systems. Laboratory testing is required to select the most promising alternatives for further in-service and FAST testing.

The improved fasteners will be tested in a setup which simulates loadings derived from available field measurements of moving trains for various track/train conditions. In the accelerated testing the vertical and laterial loads will be applied at the rail head of a small wood tie track panel embedded in ballast.

Relative performance of the fastener systems will be based upon tie degradation, gage widening, and rail rotation. AREA specified tests are also required for qualities not tested in this simulated environment such as rail creep.

The test plan will determine the appropriate test setup for the simulated testing based upon a study which assesses present test facilities versus the quality of simulation desired. This will be done in order to minimize cost, and yet maximize test outputs. The test plan will also establish requirements for test duration, data collection, data reduction process and method of analysis.

3. Laboratory Testing and Analysis

The objective of this project is to perform the required laboratory testing, data collection and analysis established in Project 2. The simulated loading test setup will be constructed and calibrated. Tests will be performed as specified in Project 2.

4. Test Planning

The objective of this project is to develop a plan for conducting in-service and FAST tests of the more promising wood tie fastener systems identified in Project 3. Toward this end, the plan will specify the test sites, track structure, variables to be measured, type of instrumentation, data collection frequency or schedule, duration of tests, recording format and medium, data reduction process and method of analysis. The fastener systems will be tested in various track/train environments. Overall system performance will be monitored. The test designs will also consider the needs of the Track System Handbook Subprogram and assure that the data needed will also be collected.

Preliminary approval from the participating railroads will be obtained and their role in the tests will be clearly specified.

5. In-Service and FAST Tests

The objective of this project is to collect the load, climatic and degradation data specified in the test plan and deliver it to the analysts. Toward this end, the required instrumentation package will be designed, equipment procured, and the package constructed, and calibrated in the laboratory. Read-out and recording devices will also be procured and installed, and data reduction software will be developed. Final arrangements will be made with participating railroads and the instrumentation will be installed at one railroad and recalibrated. Railroad personnel participating in the test will be thoroughly briefed or trained as necessary and a trial run will be conducted with the collected data moving through the reduction process to the end users. If satisfactory, all other sites will be instrumented, personnel trained, and data collected and disposed of according to plan. Throughout the test, samples will be removed occasionally for more thorough analysis. At the conclusion of the test, the instrumentation will be removed.

6. Analysis and Report

The objective of this project is to estimate the benefits of using the top performance improved fastener systems in a variety of track system configurations. The best available information, relationships, and track system models will be utilized to predict the cost and performance characteristics of these systems versus those of the conventional track structures. The difference will lead to the desired benefit estimates.

7. Results Dissemination

The results of Project 6 will be presented in a single, easy-to-read report which will also be used as a basis for conducting a research utilization seminar. The presentation must be clear, concise, and well illustrated. Expert advice will be sought.

JUSTIFICATION FOR RANKING

Benefit Summary

The improved fastening system would be most useful in areas where tie and rail life are short, especially where spike killing and maintaining gage are problems. Track with sharp curves and heavy wheel loads has the required characteristics. It is estimated that there are 400 miles of such track where tie life is less than 12 years, 900 miles where it is less than 16 years and 1,800 miles where it is less than 20 years. The preceding are points on a logistic-like curve which has all ties lasting at least 8 years. It can be shown that industry benefit is maximized when improved fastening systems are used with ties with average normal lives of 14 years or less. Under these conditions, improved wood tie fastening systems with the characteristics indicated in the subprogram objective would produce a net benefit of approximately $3.56 per tie. Of this amount, $0.06 per tie is attributable to a reduction in accident costs, $0.18 is attributable to reduced lining and surfacing cost, $1.59 stems from increased rail life, and $1.73 stems from increased tie life.

The annual net benefit to the railroad industry is expected to be $743,784. Over a 25 year period, the present value of this amount is $6.7 million.

Evaluation Measures

This subprogram had an overall evaluation score of 42, giving it a rank of 12. The first, eleventh and thirteenth (last) subprograms had scores of 216, 45 and 39 respectively. Values had relative rank of the individual evaluation measures are shown in Table D-10.

IMPLEMENTATION

Incentives

The research utilization conference (Project 7) aimed at railroad and supply industry decision-makers is one step toward assuring implementation of successful R&D results.

Railroad and supply industry participation in the subprogram is another step that can be taken. Both industries could have performing roles in Projects 2, 5, and 6 if not in the entire subprogram. Ideally, the involvement should be a joint involvement. Short of that, railroad involvement is preferred since railroads will ultimately make the decision to use the improved fastening system(s).

Barriers

The relatively modest benefit might not be sufficient to overcome the combination of inertia, the "not invented here" philosphy and the need to expend capital now for benefit quite distant in the future.

Relationship to Other Efforts

This project is related to all projects involving rail and tie improvement. This includes Subprogram C, D, H, I, K, L and M. Success here will reduce the benefit in each of them, and success in any of them will reduce the benefit here.

TABLE D-10

EVALUATION MEASURES, SUBPROGRAM J

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$6.7 million	8
R&D Costs	Total Subprogram R&D Cost	$1.7 million	11
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	3.9	10
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	2	7
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	-$4.8 million	11
Timeliness	R&D Time in Years	6.0	10
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	1.0	5
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.42	10

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

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SUBPROGRAM K

IMPROVED WOOD-BASED TIE

RANK 9

PROBLEM

It is estimated that Class I railroads inserted 25.8 million new ties in 1977.(1) In 1978, this figure is expected to increase by another half million as it has on average since 1960. Assuming a typical cost of $18.00* to replace one tie,(2) railroads will spend at least $470 million for tie renewal in 1978. This is about one sixth of the total maintenance of way budget for the railroads.

While concrete ties are gaining some acceptance for special situations, the timber tie is by far the mainstay of the industry. Of all ties in place in 1977, less than one percent are concrete, the remainder are wood.(3)

Despite the fact that the timber ties have been improved sufficiently over the years to withstand competition from a variety of other materials and methods of rail support, timber ties deteriorate. In addition to normal decay, heavier wheel loads have accelerated tie deterioration due to crushing, splitting, plate cutting and spike-killing. Although tie deterioration modes are not recorded when ties are removed from track, a recent FRA sponsored study estimated the percentage of ties removed for each mode. These estimates, based on detailed interviews with more than 50 railroad personnel and American Railway Engineering Association Committee 3 members, are shown in Table D-11.

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* Assumes a purchase price of $13 per tie, $1 for shipping and $4 for installation.

TABLE D-11

ESTIMATED PERCENTAGE OF TIE DETERIORATION CAUSES

Deterioration Cause	%
Decay & 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

In addition to total expenditures and deterioration causes, several other factors are now at work which make it desirable to review the role of the conventional timber tie in the track structure. The factors are:

- A sharp increase in the price of timber ties -- from $5 to $6 per tie in 1971 to $11 to $13 tie in 1977.(3)
- Uncertainty in the future supply of timber ties -- at reasonable prices.
- Heavier wheel loads -- bringing into question not only tie strength, but also size, length, shape and spacing.
- Recent advances in technology that have produced materials, equipment and methods which could substantially reduce the industry's tie expenditures.(4)

Responding to this situation, both the railroads and the tie suppliers have initiated a multitude of efforts aimed at replacing or extending the life of the conventional timber tie.(5) These efforts are for the most part independent and uncoordinated. Since some are likely to be more cost effective than others, this approach is at best, inefficient. As such, it adds another dimension to the problem.

DESCRIPTION OF R&D EFFORT

Objective

This R & D effort seeks to increase the useful life of newly installed wood or wood-based ties by at least 33 percent relative to today's conventional, treated, hardwood ties. The price increase must be less than $1.00 per tie measured in 1978 dollars.

State-of-the-Art

A recent study by the General Accounting Office (GAO) attempted to gauge the future availability of railroad ties.(6) The study suggests that hardwood lumber supplies used in the manufacture of ties, as well as sawmill and wood treating capacity, will be adequate to meet future demand. This finding is predicated on a firm commitment and uniform delivery schedule. For the most part, the GAO study relies on a U. S. Department of Agriculture (USDA) report prepared in June, 1974.(7) The USDA report compared supply and demand projections for hardwood timber and concluded that supplies will exceed demand throughout the 1980 - 2000 period. However, the report does project a potential shortage of hardwoods of sufficient size and quality for tie use. Furthermore, the report has several shortcomings. It assumes no price increase beyond the inflation rate; it does not deal quantitatively with the different hardwood submarkets; and it does not deal with the regional nature of supply and demand. The GAO report also casts doubt on its own findings. It states that "as of June, 1976, no organization or individual either within or outside of tie industry has determined the total industry's production capability."

While the Railway Tie Association states that it can meet the expected demand,[2] it too must have some doubts about hardwood supply if not about tie production capacity. Its members are engaged in research and development of alternatives to the conventional, one piece, timber tie. The railroads also have their doubts. They support the research of the tie suppliers through in-service tests, and have looked to foreign suppliers and other woods for ties.[8]

The principal method of extending wood tie life today is to treat the tie with a preservative. The two most common processes use creosote-tar and creosote-oil. The initial stage for creosote treatment is to dry the ties thoroughly. Natural seasoning requires a minimum of six months yard storage. A vapor drying process is being developed for this stage to cut down the time required for natural seasoning. This process dries the ties in about 14 hours in the same chamber used for creosote treatment. A chemical vapor which functions as a drying agent is introduced into the treating chamber to absorb the moisture from the wood. After drying, the vapor is extracted from the ties by evacuating the chamber for several hours. The creosote treatment is then initiated. The vapor drying process, in addition to radically reducing the time for seasoning, is also expected to reduce the splits and checks which develop in ties with natural seasoning. This in turn is expected to extend service life of the tie by approximately three years beyond that of an air-dried tie. This has not been validated with field test results although vapor-dried wood ties have been in place for some time.

Splitting and checking are partially inhibited by the use of S-irons or other anti-splitting devices. The irons are driven into the ends of the ties in such a manner as to hold together split or spreading grain. The tendancy of ties to split due to spiking has been reduced by pre-boring the spike holes. This has the disadvantage of limiting ties so bored to use with the particular tie plates and rail sections for which the holes are spaced. Possibly a more thorough solution is vapor drying; however the results of field tests after long-term wear of vapor-dried woodties have not been compared with naturally seasoned ties with anti-splitting devices. Poor quality control of woodtie is another reason that has been cited for excessive splitting of woodties placed on tracks.

It has also been suggested that it is possible to extend the average life of ties from 20 years to 30 years by treating with a polymer or resin in latex form prior to creosote treatment, thereby increasing its resistance to abrasive wear.[2]

In response to the concern that the average diameter of trees available for producing ties is gradually decreasing, the tie industry has produced test quantities of several ties that use smaller wood sections. Various dowel laminated ties are undergoing tests on the Illinois Central Gulf and the Louisville & Nashville Railroads. The ICG ties were installed in 1961 and the L & N ties in 1967. About all that is known publicly is that some designs are still in excellent condition.[5]

The Railway Tie Association, the Association of American Railroads and the Forest Products Laboratory are involved in a cooperative program to develop reconstituted woodties. The process essentially involves reducing old wood ties to small chips of wood, then bonding them together into boards utilizing a method which orients the chips in one direction. Finally the boards are glued into laminated woodties. Sample ties have been tested at the AAR Laboratory. Work is underway to have about 300 ties made for on-track testing so that their expected life could be determined.[9]

Technology to manufacture laminated wood ties of solid wood is also under development. The process essentially involves cutting thick veneer and gluing it into laminated conventional cross-section wood ties. The advantage of this method would be greater utilization of wood and use of low grade logs. The main disadvantage has been the unavailability of heavy equipment to cut thick veneer, as well as the high cost of resin glue. Some of these ties are being tested at FAST.

The Cedrite Corporation has under development a proprietary process which makes the whole cross-section with wood chips, rather than laminations of single boards. Some wood ties manufactured with early designs of this process have been installed on Santa Fe track and at FAST.[5]

R&D Projects Required

This subprogram is composed of six R&D projects. Brief descriptions follow. Cost and schedule are shown in Figure D-11.

1. Timber Tie Supply Study

The objective of this project is to estimate the expected price of timber ties from the present through the year 2000. The result, together with the result of Project 2, will be a key factor in deciding whether to continue or pursue research and development of alternatives to the conventional wood tie.

The study should consider the supply of the various woods used for the majority of ties, the location of that supply, the expected demand of various industries for the woods and the location of the demand. At a minimum the timber tie, construction, furniture and pallet industries should be considered. Some indication of the sensitivity of price to expected demand should also be provided. The study must be performed by people who have no stake in its outcome other than its thoroughness, quality, and objectivity. The 1974 USDA study will serve as a starting point.[7]

PROJECT No.	PROJECT TITLE	R & D COST ($1,000)	YEARS AFTER START 1	2	3	4	5	6	7	8	9	10
1	Supply & Demand	110										
2	Preliminary Analysis	110										
3	Test Planning	60										
4	In-Service & FAST Tests	440										
5	Analysis & Report	125										
6	Results Dissemination	40										
	TOTAL R & D COST	885										

FIGURE D-11
COST AND SCHEDULE—IMPROVED WOOD-BASED TIE SUBPROGRAM

2. Preliminary Analysis of Alternative Wood-Based Ties

The objective of this project is to select the most promising candidates from among the many alternative wood-based ties currently being tested in laboratories, at FAST, and in-service.[5]

Among the ties being tested are: tropical wood ties, vapor dried ties, ties treated with various preservatives, dowel laminated ties, thick-veneer glue laminated ties, and reconstituted ties with randomly orientated chips and with aligned chips. To achieve the objective, persons responsible for current tests will be contacted and as much data will be obtained from them as possible. Test sites will also be visited to make a current set of consistent performance measurements. These data will provide the basis for a preliminary cost-performance study of the more promisisng alternatives. In arriving at costs, the study will take into account the expected cost of wood suitable for tie use as developed in Project 1.

3. Test Planning

The objective of this project is to develop a plan for conducting at minimal cost in-service and FAST testing of the more promising wood-based tie alternatives identified in Project 2. Toward this end, the plan will specify the test sites, track structure, number of ties to be tested and tie spacing at each site, variables to be measured, type of instrumentation, data collection frequency or schedule, duration of test, recording format and medium, data reduction process, and method of analysis. Standard hardwood and softwood ties with typical preservative treatment will serve as the control group. Hardwood and softwood ties with extended preservative treatment should also be tested. In addition to normal wear and failure properties, the many other track system, traffic and environmental variables affecting wood-based ties will be considered in designing the experiment. The design will also consider the needs of the Track System Handbook Subprogram and assure that the data needed will also be collected.

Preliminary approval from the participating railroads will also be obtained and their role in the tests specified.

4. In-Service and FAST Tests

The objective of this project is to collect the load, climatic and degradation data specified in the test plan and deliver it to the analysts. Toward this end, the required instruments will be procured, and the package instrumentation constructed and calibrated in the laboratory. Read-out and recording devices will also be procured and installed, and data reduction software will be developed. Final arrangements will be made with participating railroads and the instrumentation will be installed at one railroad and recalibrated. Railroad personnel participating in the test will be thoroughly briefed or trained as necessary and a trial run will be conducted with the collected data moving through the reduction process to the end users. If satisfactory, all other sites will be instrumented, personnel trained, and data collected and analyzed according to plan. Throughout the test, samples will be removed occasionally for more thorough analysis. At the conclusion of the test, the instrumentation will be removed.

5. Analysis & Report

The objective of this project is to determine the best wood-based tie to use in different climatic conditions, track system configurations, grades, and curves. This will include the development of relationships which predict the wear life of improved ties versus standard hardwood and softwood ties. If realtionships predicting failures of standard ties are available, this project will attempt to extrapolate or modify those relationships to accomodate improved ties. The best available information, relationships, and models of other track system components will be utilized to predict the cost and performance characteristics of track structures using improved ties and those using standard ties. The difference will lead to the desired benefit estimates.

6. Results Dissemination

The results of Projects 1 and 5 will be combined into a single, easy-to-read report and the report used as a basis for conducting a research utilization seminar. The objective of this seminar will be to convince suppliers to produce the improved ties and railroads to install them. If this objective is to be achieved, the presentation must be clear, concise, and well illustrated. Expert advice will be sought.

JUSTIFICATION FOR RANKING

Benefit Summary

The benefits of improved wood ties are assumed to stem only from their longer life. Since these ties cost more, they will find their most economical application in locations where conventional ties have a short life. If the stated objective of a 33 percent increase in the life at a $1.00 increase in price is achieved, improved ties will be beneficial in locations where conventional ties last 26 years or less. It is estimated this occurs along 6,700 miles of the nation's railroad track. Assuming an average of life of 23 years for these ties, then 950,000 such ties would be replaced annually. With a life of 17 years, each ties saves approximately $0.37, and annual savings would be $350,000. Over a 25 year period, the present value of the expected benefit of improved wood-base ties is therefore $3,180.000.

Evaluation Results

This subprogram had an overall evaluation score of 51, giving it a rank of 9. The first, eighth, tenth and last subprogram had scores of 216, 66, 50 and 39 respectively. Values and relative rank of the individual evaluation measures are shown in Table D-12.

TABLE D-11

EVALUATION MEASURES, SUBPROGRAM K

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$3.2 million	11
R&D Costs	Total Subprogram R&D Cost	$885 thousand	7
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	3.6	11
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	0	9
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	-$4.7 million	10
Timeliness	R&D Time in Years	4.3	7
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	1.2	4
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.44	9

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

IMPLEMENTATION

Incentives

The research utilization conference (Project 6) will be a key step in assuring that the results of this subprogram, if successful, will be implemented by the railroads.

Still another step toward that end would be to build upon the cooperative efforts of the Railway Tie Association, the Association of American Railroads and the Forest Products Laboratory aimed at developing reconstituted wood ties. They can play performing roles in all projects, except perhaps the Project 1, the timber supply study.

Barriers

The relatively low benefit might not be sufficient justification for some railroads to make the capital expenditures needed to achieve it. Available capital is limited and other expenditures might well be more beneficial.

Relationship to Other Efforts

This subprogram is related to Subprogram J, Improved Wood Tie Fastening Systems, and Subprogram M, Improved Concrete Tie and Fastner Selection and Utilization. Success here would reduce the benefit in each of those efforts, and success in any of them would reduce the benefit here. Furthermore, if any three, or any two of the three, subprograms are undertaken, consideration should be given to conducting the in-service and FAST tests on the same track at the same time. This will minimize the chance of traffic effects confounding the test results.

REFERENCES

1. "Seen for 1978: Strong M/W Programs," Railway Tracks and Structures January, 1978.

2. Loomis, A. V. and T. Anyos, Refurbishment of Railroad Crossties-Technical and Economic Analysis, Stanford Research Institute, June, 1977.

3. "Tie Renewals and Costs," American Railway Engineering Association-Bulletin, No. 664, September-October, 1977.

4. Hutcheson, T.B., "Problems and Needs in Tie and Fastener Research," Presented at the 56th Annual Meeting of the Transportation Research Board, Washington, D. C., January, 1977.

5. Burdell, C.C., "Wood Crosstie Technology: Research and Tests Point The Way," Railway Track and Structures, June, 1976.

6. Industry Capability to Produce Rail and Crossties For Nationwide Railroad Track Rehabilitation, Comptroller General of the United States, September, 1976.

7. The Outlook for Timber in the U.S., U.S. Forest Resource Report No. 20, Prepared by the Forest Service of the U.S. Department of Agriculture, July, 1974.

8. "Reports of Committees -- Ties and Wood Preservation (3)," American Railway Engineering Assoication-Bulletin, No. 656, January-February, 1976.

9. "Receiving the Wood Crosstie -- Researchers Develop and Test Laminated Particle Tie," Railway Track & Structures, July, 1977.

SUBPROGRAM L

IN-PLACE REPAIR OF SPIKE-KILLED TIES

RANK 1

PROBLEM

It is estimated that Class I railroads inserted 25.8 million new ties in 1977.(1) In 1978, this figure is expected to increase by another half million as it has on average since 1960. Assuming a typical cost of $18.00* to replace one tie,(2) railroads will spend at least $470 million for tie renewal in 1978. This is about one sixth of the total maintenance of way budget for the railroads.

While concrete ties are gaining some acceptance for special situations, the timber tie is by far the mainstay of the industry. Of all ties in place in 1977, less than one percent are concrete, the remainder are wood.

Despite the fact that timber ties have been improved sufficiently over the years to withstand competition from a variety of other materials and methods of rail support, timber ties deteriorate. In addition to normal decay, heavier wheel loads have accelerated tie deterioration due to crushing, splitting, plate cutting and spike-killing. Although tie deterioration modes are not recorded when ties are removed from track, a recent FRA sponsored study estimated that roughly 14 to 16 percent of all ties removed annually are removed because of spike-kill. The estimate is based on approximately 50 interviews with railroad personnel and American Railway Engineering Association Committee 3 members.

*Assumes a purchase price of $13 per tie, $1 for shipping and $4 for installation.

Based on this estimate and the typical cost of $18.00 to replace a tie, American railroads can be expected to spend $80 million in 1978 to replace 4.5 million spike-killed ties.

From a safety viewpoint, wide gage caused by defective ties is estimated to have resulted in 684 accidents in 1976. If 15 percent, or 102 are attributable to spike-killing, then the cost to railroads and shippers is in the neighborhood of $2.0 million.

Recent technological advances have produced materials and methods which strongly suggest that substantial savings in the industry's expenditures for spike-killed ties can be achieved.

DESCRIPTION OF THE R&D EFFORT

Objective

The objective of this subprogram is to verify experimentally that in-place application of currently available chemical filling materials can extend the life of spike-killed ties by eight years at a cost less than $0.30 per tie in 1978 dollars.

State-of-the-Art

Repair of a spike-killed ties usually requires rework of the old spike hole to allow re-spiking. The typical method for accomplishing this involves driving a peg or dowel into the spike hole and re-spiking. Recently, several chemical filling materials have become commercially available. Typical of these materials is a powdered spike hole filler--a free flowing, dry mixture that is poured into the spike holes after the rail plates have been removed. The compound contains an abrasive material, a bonding substance, and a wood preservative. It is claimed that this process can restore and retain 80 percent of spike-tie bond. Cost per tie (labor and materials) has been estimated at $0.25.[2]

This material is currently being tested by the Santa Fe Railroad and its long term performance requires a close monitoring effort.[4] The Canadian National Railway and the Southern Railway are reported to be considering the material for tests.

Another approach toward the problem utilizes a specially formulated flexible resin for the spike holes combined with a premolded synthetic skin that provides a renewed surface for the tie plate area.[5] This method has been tested on the branch line of a major U.S. railroad. However, considerably more testing is in order.

R&D Projects Required

This subprogram is composed of four R&D projects. Brief descriptions follow while costs and schedules are shown in Figure D-12.

1. Test Planning

The objective of this project is to design a series of laboratory, FAST, and in-service tests which will insure that all data necessary for conclusive results are collected and analyzed at minimal or near-minimal cost. The plan will specify the materials to be tested, number of samples, track structure, test sites, variables to be measured, type of instrumentation, method and frequency of data collection, and method of analysis. Tests will measure spike holding power as well as tie life extension of the chemical and the wood or dowel filler for various types of wood ties under difficult temperature, moisture and traffic conditions. Particular attention will be paid to low temperature tests since spike-killed ties are more prevalent on railroads in northern areas because of their need to combat frost heave.

Attention will also be given to the needs of the Track System Handbook Subprogram where the effect of these methods on the variables used to characterize rail fastening systems will need to be assessed.

PROJECT		R & D COST	YEARS AFTER START									
No.	TITLE	($1,000)	1	2	3	4	5	6	7	8	9	10
1	Test Planning	35										
2	Laboratory & FAST Tests	150										
3	In-Service & FAST Tests & Analysis	200										
4	Results Dissemination	25										
TOTAL R & D COST		410										

FIGURE D-12
COST AND SCHEDULE—IN-PLACE REPAIR OF SPIKE-KILLED TIES SUBPROGRAM

The magnitude of the horizontal forces encountered and the resulting deformation of the filler material are examples of such variables.

2. Laboratory and FAST Tests

The objective of this project is to provide a preliminary indication that the chemical filler material is indeed a worthwhile product.

Given the experimental design, tests will be conducted in a laboratory and at FAST. All necessary instrumentation and test specimens should be procured and installed and the specified data collected at the proper intervals. The data should be analyzed according to plan and a test report indicating preliminary cost and effectiveness should be prepared. If some railroads are conducting in-service tests of their own, an effort should be made to ascertain their findings and incorporate them into the report.

3. In-Service and FAST Tests and Analysis

If the analysis of laboratory, FAST, and independent railroad test results indicate the method(s) to be potentially cost-effective, then a comprehensive set of in-service tests should be conducted under the various conditions defined in the experimental design. Test specimens and instrumentation must be procured and installed, and test data collected and analyzed--all according to plan.

FAST tests should be continued throughout the in-service test period to provide a better estimate of the life extension properties of the method(s)--at least in terms of total tonnage or in years.

All aspects of this subprogram should then be documented in a single report or a three volume series of reports. Included would be the experimental design, the laboratory and FAST test procedure and results, and the in-service test procedure and results.

4. Results Dissemination

Results of the three previous projects should then be summarized into an easy-to-read companion report. This report should be aimed at those railroad personnel who can decide whether or not to utilize the method. It should also serve as the basis for conducting a series of research utilization seminars at several locations around the country, perhaps in conjunction with the dissemination of other R&D results. Again, the seminar audience should be the railroad decision maker.

JUSTIFICATION FOR RANKING

Benefit Summary

If the life of spike-killed ties could indeed be extended by 8 years at a cost of $0.30 per tie, the present value of the savings would be $13.22 per tie--assuming an average tie-life of 25 years before extension. Since approximately 2,900,000 ties are replaced each year due to spike-killing, the annual savings would be $37.5 million. The present value of this amount over a 25 years period is $340 million.

Other benefits will accrue, but they are not readily quantifiable. Qualitatively, the repair would also encourage railroads to tighten up their tolerances on gage, since respiking would not be as harmful as before. This would enhance safety. Savings for railroads which must do extensive shimming would be proportionately greater than on other railroads. The process is not capital intensive at all, indeed it saves capital--$0.30 instead of $18.00 to replace a tie. The capital savings aspect would be a boon to poor railroads with many spike-killed ties.

Evaluation Measures

This subprogram had an overall evaluation score of 216, giving it a rank of 1. The second, third and thirteenth (last) subprogram had scores of 104, 88 and 39 respectively. Values and relative rank of the individual evaluation measures are shown in Table D-13.

IMPLEMENTATION

Incentives

The series of R&D utilization seminars specified in Project 4 is one step toward assuring that the R&D results, if successful, will be utilized. The key to acceptance will be conclusive results, presented clearly, concisely and in a professional manner.

The in-service test project is another such step. At a minimum, the railroads involved in the tests will have first hand experience with the products and methods, and as such be more prone toward utilization than other railroads.

Another step toward successful implementation would be to have the railroad industry and the suppliers participate in the subprogram in other ways. For example, it would be beneficial to have supplier and railroad representatives serve in an advisory role throughout the subprogram. The AAR with its laboratory facilities and experience in data collection and analysis in other track programs, could play a key role in Projects 2, 3 and 4.

Barriers

Other than inertia and the "not invented here" philosophy, which are countered by the incentives discussed above, there are no known barriers to implementing successful R&D results.

Relationship to Other Efforts

This subprogram is related to Subprogram J, Improved Wood Tie Fastening Systems and Subprogram M, Improved Concrete Tie and Fastener Selection and Utilization. Success here would reduce the benefits in each of them, and success in either of them would reduce the benefit here.

TABLE D-12

EVALUATION MEASURES, SUBPROGRAM L

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$320.4 million	3
R&D Costs	Total Subprogram R&D Cost	$410 thousand	3
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	782	1
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	0	9
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	$321.9 million	1
Timeliness	R&D Time in Years	3.7	2
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	0.8	8
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.55	4

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

REFERENCES

1. "Seen for 1978: Strong M/W Programs," Railway Tracks and Structures, January, 1978.

2. Loomis, A. V. and T. Anyos, Refurbishment of Railroad Crossties-Technical and Economic Analysis, Stanford Research Institute, June, 1977.

3. "Tie Renewals and Costs," American Railway Engineering Association-Bulletin, No. 664, September-October, 1977.

4. "Sante Fe Expects Spike-Hole Compound to Extend Tie Life," Railway Track and Structures, March, 1977.

5. "Tie Renewal System," Progressive Railroading, July, 1977.

SUBPROGRAM M

IMPROVED CONCRETE TIE AND FASTENER SELECTION AND UTILIZATION CRITERIA

RANK 13

PROBLEM

Concrete ties designed to the latest American Railway Engineering Association (AREA) specifications have been performing well in U.S. field tests to date.[1,2] However, it is evident from the available data that some components of the concrete tie track system require additional research.

The most critical element in the concrete tie track is the rail fastener. To date, tests show that fastener assemblies cause most of the problems (i.e., pad movement, excessive vibration, insulation breakage, tie skewing and rail creep). Little effort has been exerted in the U.S. in matching the fastener/pad/insulation components into a complete system.[3]

A second problem results from the inadequate knowledge of the optimum concrete tie track system parameters for a given situation. Tie spacing, ballast type, ballast depth, ballast gradation, and anchorage requirements are just some of the unknowns which may vary depending upon track conditions (grades, curves, traffic mix, etc.). The current tests, as they proceed, will yield indications of the best performance concrete tie/fastener under various conditions. But not all possible combinations of concrete tie/fastner systems versus track design and climate conditions are being tested. Thus, the most cost effective tie/fastner system cannot yet be chosen for a particular situation.

Until fastener problems and cost uncertainties are reduced, concrete tie usage by privately operated U.S. railroads will likely remain at the present average levels of between 100,000 and 200,000 units per year.[1]

DESCRIPTION OF R&D EFFORT

Objective

This subprogram seeks to verify that concrete tie track has, relative to conventional wood tie track, at least 100 percent greater tie life, 50 percent lower maintenance cost, and 40 percent higher rail wear life.

State-of-the-Art

Concrete tie performance in U.S. field tests prior to the early 1970's was unequivocally dismal. This poor performance has been attributed to (1) specification for concrete tie design and strengths which were too low for U.S. wheel loads, (2) the unknown important role ballast selection played in overall concrete tie track performance, (3) poor concrete tie installation procedures, and (4) inadequate fastener/pad design. Thus, a re-evaluation of the specifications for concrete ties and their usage was pursued and subsequently published in AREA Bulletins 644 and 644[5] with revisions in Bulletins 650 and 660.[6] Since then concrete ties have been installed in heavy duty track test sections on four U.S. railroads, at the Kansas Test Track (KTT) and at FAST. Two North American railroads have also made commitments to large installations of concrete ties on portions of their track systems. A third is using concrete ties for all new track construction, eventually replacing all wood ties in a three-phase program

Excluding the KTT which was prematurely shut down due to enbankment problems, performance has been good to date. There has been almost no cracking of the ties, at either the rail seat or center. There has been some shallow surface spalling, corner chipping, insulation deterioration, pad movement, rail creep and tie skewing with specific ties and fastener types. At FAST [7] where data is accumulating at the highest rate (235 MGT as of April 1978), problems are basically associated with the fastener/pad assemblies--tie skewing and insulation deterioration.

Foreigh railroads in Europe, Russia and Australia have had very favorable experience with concrete ties. The U.S. is now taking advantage of much of this experience by starting tests with the best concrete tie-fastener assembly designs, proven through a great deal of testing and service abroad. Design specifications [8] and laboratory testing [9] have also been performed in the U.S. The heavier U.S. wheel loadings of course, do create problems not experienced elsewhere, but these are not yet major.

R&D Projects Required

This subprogram seeks to extend the current concrete tie testing to cover a broader matrix of concrete tie/fastener assembly versus track design and environmental conditions. The purpose of the tests will be to further evaluate the overall concrete tie track system problems and costs, and to determine its failure modes under field conditions.

A separate small scale research effort will also evaluate fastener assembly designs through sophisticated laboratory testing. Emphasis will be on solving current problems arising in U.S. tests. Controversial problems such as pad stiffness (soft verses hard) and fastener holddown force (floating versus fixed) will also be investigated.

This subprogram is composed of six R&D projects. Brief descriptions follow while costs and schedule are shown in Figure D-13.

PROJECT		R & D COST ($1,000)	YEARS AFTER START									
No.	TITLE		1	2	3	4	5	6	7	8	9	10
1	Laboratory Test Planning	55										
2	Laboratory Testing and Analysis	165										
3	Test Planning	70										
4	In-Service and FAST Tests	1,450										
5	Analysis and Report	120										
6	Results Dissemination	40										
TOTAL R & D COST		1,900										

FIGURE D-13
COST AND SCHEDULE—IMPROVED CONCRETE TIE AND FASTENER SELECTION AND UTILIZATION CRITERIA

1. Laboratory Test Planning

The objective of this project is to develop a plan for laboratory testing of concrete tie/fastener systems. This testing is required in order to select the most promising alternatives for further in-service and FAST tests.

The concrete tie/fastener system will be tested in a setup which simulates loadings derived from available field measurements [10] of moving trains for various track/train conditions. In the accelerated testing the vertical and lateral loads will be applied at the rail head of a small concrete tie track panel embedded in ballast.

Relative performance of the concrete tie/fastener systems will be based upon tie degradation, pad movement, gage widening, rail rotation and insulation breakage. AREA specified tests are also required for quantities not tested in this simulated environment such as rail creep. Emphasis in judging performance will be on solving current fastener problems occuring in U.S. field tests.

The test plan will determine the appropriate test setup for the simulated testing based upon a study which assesses present test facilities versus the quality of simulation desired. This will be done in order to minimize cost, and yet maximize test outputs. The test plan will also establish requirements for test duration, data collection, data reduction process and method of analysis.

2. Laboratory Testing and Analysis

The objective of this project is to perform the required laboratory testing, data collection and analysis established in Project 1. The simulated loading test setup will be constructed and calibrated. Tests will be performed as specified in Project 1.

3. Test Planning

The objective of this project is to develop a plan for conducting in-service and FAST tests of the more promising concrete tie/fastener systems identified in Project 2. Toward this end, the plan will specify the test sites, track structure, variables to be measured, type of instrumentation, data collection frequency of schedule, duration of test, recording format and medium, data reduction process and method of analysis. The concrete tie/fastener systems will be tested in various track/train environments. Overall system performance will be monitored. The test designs will also consider the needs of the Track System Handbook Subprogram and assure that the data needed will also be collected.

Preliminary approval from the participating railroads will be obtained and their role in the tests will be clearly specified.

4. In-Service and FAST Tests

The objective of this project is to collect the load, climatic and degradation data specified in the test plan and deliver it to the analysts. Toward this end, the required instrumentation package will be designed equipment procured, and the package constructed, and calibrated in the laboratory. Read-out and recording devices will be procured and installed, and data reduction software will be developed. Final arrangements will be made with participating railroads and the instrumentation will be installed at one railroad and recalibrated. Railroad personnel participating in the test will be throroughly briefed or trained as necessary and a trial run will be conducted with the collected data moving through the reduction process to the end users. If satisfactory, all other sites will be instrumented, personnel trained, and data collected and analyzed according to plan. Throughout the test, samples will be removed occasionally for more thorough analysis. At the conclusion of the test, the instrumentation will be removed.

5. Analysis and Report

The objective of this project is to estimate the benefits of using the top performance concrete tie/fastener systems in a variety of track system configurations. The best available information, relationships, and track system models will be utilized to predict the cost and performance characteristics of these systems versus those of the conventional track structures. The difference will lead to the desired benefit estimates.

6. Results Dissemination

The results of Project 5 will be documented in a single, easy-to-read report and used as a basis for conducting a research utilization seminar. The presentation must be clear, concise, and well illustrated. Expert advice will be sought.

JUSTIFICATION FOR RANKING

Benefits Summary

The benefits of a concrete tie track system which achieves the performance goals of this subprogram under various track/train conditions have been extolled for many years. Because the concrete tie track system is more stable in all directions, the rate of track geometry deterioration is not only less but it degrades more uniformly. Buckling track is less likely. Rail wear life is increased. All of these factors imply reduced maintenance requirements, a lower probability of derailment and a smoother ride quality. The latter factor means a reduced rate of vehicle wear as well, thus decreasing vehicle maintenance costs.

Concrete ties with the characteristics stated in the subprogram objective will be cost-effective at sites where current tie life is 19 years or less. There are about 1500 miles of track where this occurs.

If these ties were replaced uniformly over a 19 year period, the savings to the railroads would be $1,041,040 per year. Over a 25 year period, the present value of these savings is $9.5 million. Of this amount, $6.0 million would be attributable to doubling tie life, $3.1 million would accrue from reduced lining and surfacing costs, and $0.4 million would stem from increased rail life.

Evaluation Measures

This subprogram had an overall evaluation score of 39, giving it a rank of 13. The first, eleventh and twelfth subprograms had scores of 216, 45 and 42 respectively. Values and relative rank of the individual evaluation measures are shown in Table D-14.

IMPLEMENTATION

Incentives

The series of R&D utilization seminars specified in Project 6 is one step toward assuring that the R&D results, if successful, will be utilized. The key to acceptance will be conclusive results, presented clearly, concisely and in a professional manner.

The in-service test project is another such step. At a minimum, the railroads involved in the tests will have first hand experience with the products and methods, and as such be more prone toward utilization than other railroads.

Another step toward successful implementation would be to have the railroad industry and the suppliers participate in the subprogram in other ways. For example, it would be beneficial to have supplier and

TABLE D-13

EVALUATION MEASURES, SUBPROGRAM M

EVALUATION MEASURE	DESCRIPTION	VALUE	RELATIVE RANK*
Benefits	Present Value of Economic Benefits to RR's Over 25-year Period	$9.5 million	7
R&D Costs	Total Subprogram R&D Cost	$1.9 million	12
Benefit/Cost Ratio	Ratio of Financial Benefits of Railroads to R&D Costs	5.0	9
Safety Impact	No. of Accidents Avoided During First 5-year Implementation Period	0	9
Capital Savings	Capital Expenditures Saved During First 5-year Implementation Period	-$9.3 million	12
Timeliness	R&D Time in Years	6.1	11
Other Impacts	Subjective Estimate of Subprogram's Impact on RR Operations (-5 to +5)	0.9	7
R&D Risk	Subjective Estimate; Probability of Achieving R&D Effort (0 to 1)	0.52	6

*Relative Rank indicates the priority of each measure relative to all thirteen subprograms. Scores range from 1 (High Priority) to 13 (or Low Priority).

railroad representatives serve in an advisory role throughout the subprogram and the AAR with its laboratory facilities and experience in data collection and analysis in other track programs, could play a key role in Projects 1 through 4.

Barriers

The traditional method of track component replacement used in this country cannot be used for the placement of concrete ties. They do not perform well nor are they easily installed when interspersed on a wood tie track. Wood tie equipment and techniques are not sufficient for concrete tie track. Thus, not only a large capital expenditure is required, but a change in track upgrading philosophy as well.

Relationship To Other Efforts

This subprogram is related to all other subprograms except perhaps those aimed at improving field welding methods (Subprogram E, F and G). Success in any of the related subprograms, except Subprogram B will reduce the benefits of this effort, and success in this effort will alter the benefit in all related efforts.

There is a slightly stronger relationship to Subprogram J, Improved Wood Tie Fastening Systems and Subprogram K, Improved Wood-Based Tie. If this effort and either or both of the related efforts are going to be undertaken, then consideration should be given to conducting the in-service and FAST tests at the same time on the same track. This will minimize the chance of traffic effects confounding the test results.

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APPENDIX E

BENEFIT ESTIMATION

APPENDIX E

E.0 BENEFIT ESTIMATION

If a subprogram is completed successfully--that is the quantitative objective has been achieved--and the results are implemented by the industry, then certain monetary benefits will accrue to the industry. This appendix describes how those benefits were estimated. For each subprogram the estimation process is explained in two ways. First, it is described verbally with references to sources of certain critical data whenever possible and second, the actual calculations are shown in tabular form. This lays bare all assumptions and in so doing highlights the need for better information about the track system. References are listed at the end of the Appendix.

It is worth noting that an implicit assumption in estimating the benefit of a subprogram is that the results of only that one subprogram are available for implementation by the industry. If in fact the results of two or more subprograms become available, the monetary benefit to the industry is likely to be less than the sum of the individual subprogram benefits. For example, a portion of the benefit in the improved rail metallurgy subprogram and in the improved wood-tie fastening systems is attributable to longer rail life. It is unlikely that these two benefits can be added to determine the benefit of implementing both subprogram results concurrently.

In general, the monetary benefit is expressed as the present value of a stream of industry costs with the R&D result being implemented, minus the present value of a stream of industry costs without the R&D result available. Sometimes, however, it is more convenient to estimate the difference in unit costs or the difference in rate of expenditure for the two cases and to apply the present value analysis to the stream of differences. The results are identical.

The assumed cost of capital is 10 percent--a rate suggested by FRA and the Office of Management Budget. Typically, the present value is applied to a cost stream covering the first 25 years after the R&D result is available. This tends to underestimate the benefit slightly since in many cases there will be benefit even in subsequent years. The present value of those distant benefits, however, is quite small.

The data collection and analysis that form the basis in this Appendix was performed by Robert E. Martin.

E.1 Subprogram A--Track System Handbook

In reality there is no rational way of predicting the dollar benefit of this subprogram to the railroads or the government at this time. The data simply are not available. However, most people agree that such a model will, in fact, lead to more cost-effective track structures and track maintenance practices. If, as stated in the objective, the model leads to changes in track structure and track maintenance practices which reduce industry annual costs by 1.2 percent for today's load environment, then the annual savings would approach $28.8 million. The present worth of such savings over a 25 year period would be $261.4 million.

The estimate of 1.2 percent was developed during the subprogram evaluation conference. Each of the 20 evaluators was given written and oral descriptions of this subprogram and was asked to subjectively estimate the percent reduction the handbook or its equivalent might bring in the industry's annual $2.4 billion track system expenditure. The average of the 20 estimates was 1.2 percent.

Table E-1 presents the benefit calculation.

TABLE E-1

BENEFIT CALCULATION

SUBPROGRAM A--TRACK SYSTEM HANDBOOK

Industry Track System Expenditures	\$ 2.4 billion/year
Objective--1.2% Savings	x 0.012
Annual Savings	\$ 28.8 million/year
Equal Payment Series Present Worth Factor (EPSPW) (10%; 25 Years)	x 9.077
Present Value	\$ 261.4 million

E.2 Subprogram B--Improved Lateral Track Stability

The fact that several large railroads have no track buckling accidents, and (2) there is in all likelihood, some over-restraint of the track to prevent buckling. Thus, two types of monetary benefit are assumed to stem from this subprogram: reducing accidents and reducing excessive restraint.

To estimate the savings, it is first necessary to estimate the extra cost of restraining CWR. Assuming 24 anchors per rail (box anchoring every other tie), \$0.80 per anchor, and 270 rails per mile yields an anchoring cost of \$5,184 per mile.(1) Adding to this the cost of 3 inches of extra ballast on each shoulder at \$400 per mile(2) brings the total cost of restraining CWR to \$5,584 per mile. If jointed rail were installed instead, the likely restraint would be 8 anchors per rail for a total cost of \$1,728 per mile. The extra restraining cost for CWR, is, therefore, \$3,856 per mile. In the case of over-restraint, it is assumed that 10 percent of this amount, or \$386 per mile, can be saved. In the case of under-restraint, it is assumed that a significant portion of the required restraint is already in place and that only a small additional amount of restraint costing 3 percent of $3,856 per mile, or $116 per mile, is required to prevent buckling.

For lack of better information, it is assumed that 50 percent of all CWR that has been and is being installed is over-restrained and 50 percent is under-restrained. Since approximately 5,000 miles of rail are installed per year,(5) a savings of $386 per mile would be realized on 2,500 miles. Thus, the savings from less restraint is $965,000 per year. The present value of this amount over a 25 year period is $8.8 million.

Turning to accident reduction savings, there were 101 accidents caused by buckling in 1976 at an average cost of $30,000 each.(3) Increasing the unit cost by a factor of 2.1 to account for all other indirect costs,(4) brings the total cost of buckling caused accidents to $6.3 million per year. Assuming that half of the 60,000 miles of installed CWR(5) is under-restrained, then the cost of buckling accidents is $210 per mile-year. If this cost is avoided on the 2,500 miles per year of CWR that otherwise would have been installed with under-restraint, a saving of $525,000 per year is realized. Over a period of 25 years, the present value of one-year's CWR installation becomes $4.8 million. If the benefit is achieved on each 2,500 miles of CWR installed per year thereafter, the total benefit over a 25 year period would be $43.2 million. The cost of the additional restraint at $116 per mile must be subtracted from this amount. At 2,500 miles per year, this amounts to $290,000 per year, which over 25 years is equivalent to a present value of $2.6 million.

Thus the net monetary benefit of improving lateral track stability is the sum of $8.8 million for reduced restraint costs and $43.2 million for reduced accident costs less $2.6 million in costs of additional restraint required to reduce accidents. The total net benefit is $49.4 million.

Table E-2 presents the benefit calculation.

TABLE E-2

BENEFIT CALCULATION

SUBPROGRAM B--IMPROVED LATERAL TRACK STABILITY

BASELINE CWR COST	
CWR Restraint	
(24 anchors/rail)(270 rails/mile)($0.80/anchor)	$ 5,184/mile
3" Extra Shoulder Ballast @$400/mile	+ 400/mile
Subtotal	$ 5,584/mile
Less Jointed Track Restraining Cost	
(8 anchors/rail)(270 rails/mile)($0.80/anchor)	- 1,728/mile
Extra Cost of Restraining CWR	$ 3,856/mile
OVER-RESTRAINT SAVINGS	
Baseline Cost	$ 3,856/mile
Objective--10% Reduction	x 0.1
Savings	$ 386/mile
50% of 5,000 miles/year Installed	x 2,500 miles/year
Savings	$965,000/year
EPSPW (10%; 25 Years)	x 9.077
Present Value	$ 8.8 million
ACCIDENT SAVINGS	
(101 accidents/year) ($30,000/accident)(2.1)	$ 6.3 million/year
50% of 60,000 miles of Installed CWR	÷ 30,000 miles
Unit Cost Rate	$ 210/mile-year
50% of 5,000 mile/year Installation Rate	x 2,500 miles/year
Annual Cost Rate	$525,000/year-year
EPSPW (10%; 25 Years)	x 9.077
Present Value of Saving from One Installation	$ 4.765 million/year
EPSPW (10%; 25 Years)	x 9.077
	$ 43.2 million

ADDITIONAL COSTS

Baseline Cost	$ 3,856/mile
Assumed 3% Increase	x 0.03
Unit Cost	$ 116/mile
50% of 5,000 mile/year Installation Rate	x 2,500 miles/year
Annual Cost	$290,000/year
EPSWP (10%; 25 Years)	x 9.077
Present Value	$ 2.6 million

TOTAL BENEFIT

Reduced Restraint	$ 8.8 million
Reduced Accidents	+ 43.2 million
Subtotal	$ 52.0 million
Less Additional Cost	- 2.6 million
Total	$ 49.4 million

E.3 Subprogram C--Improved Rail Metallurgy

The benefits from improved rails are longer life and fewer flaws. Since such rails are more expensive than conventional rails, they will be used where conventional rail life is short and will be most advantageous where rail life is shortest. It can be shown that the improved rails, with a 10 percent price premium, offer the lowest cost in areas where conventional rail lasts 28 years or less. It is estimated that approximately 2,200 miles of track have density, grade, curvature and wheel loadings to warrant the use of the improved rails. Assuming that the average life of rails used on these 2,200 miles is 25 years, the present value of savings from using the improved rail is $8.74 for each rail. Assuming 1/25th of such rails are replaced each year, the present value of the savings from installing the 23,760 rails required would be $207,662. Continuing installations over 26 years, the total benefit would be $1,885,000. The benefits can be expected to grow since the market for improved rail will expand as traffic grows and average wheel loadings increase. Coal traffic growth should especially stimulate use of improved metallurgy rails since coal operations with heavy axle loads tend to be those where improved metallurgy is most useful.

Longer life is the most important benefit from improved metallurgy rails. Conventional rails cost $268.55[6] each plus $66.50[7,8] each for installation for a total of $335.05. Improved rails cost 10 percent or $26.85 more. If improved rails are installed where conventional rail last 25 years, the improved rails will be able to avoid a $335.05 rail replacement expenditure 25 years in the future. The present value of avoiding that expenditure is $30.93. By way of illustration, where conventional rails last 28 years, the present value of the extra life is only $23.22.

Improved metallurgy rail is expected to have one-fifth as many flaws as conventional rail. To compute the benefit from this improved flaw resistance it is necessary to determine the flaw experience of conventional rail. Since the improved rail would be used primarily in high-density track as welded rail, the flaw experience of such rail would be more appropriate than the flaw experience of all rail.

Data for three major railroads is available which shows that there are 0.27 flaws per mile per year in high density CWR.[9] In addition, seven derailments have been reported on 4,800 miles of welded track yielding an accident rate of 0.00146 accidents per mile per year.[9] Although the accident sample is very small, it will be used here because it is the only source for this necessary factor.

The cost of both flaws and accidents must be considered. The average cost to repair a flaw is assumed to be $250. This includes rail cost, cutting out the old rail, removing spikes and anchors, welding in new rail (2 welds) and respiking and anchoring. The cost of replacement, at 0.27 flaws a mile is $67.50 a mile or $0.25 a rail.

Rail flaw accidents cost about $30,000 each in damage to track and equipment.[3] Using a multiplier of 2.1 to include all other railroad borne costs,[4] each accident has a total cost of $63,000. The cost from accidents at 0.00146 accidents per mile, is therefore $81.27 per mile or $0.34 per rail.

Adding accident and replacement costs gives a total cost from flaws of $0.59 a rail. Improved metallurgy rails will reduce this cost to $0.12 a rail, saving $0.47 per rail each year. The value of this savings depends on how long the improved rail will last. When replacing a conventional rail that lasts 25 years, the $0.47 a year savings over the 50 years life of an improved rail would be worth $4.66. For illustration purposes only, an improved rail lasting 60 years would have a benefit of $4.68.

Combining the savings from longer life and reduced defects by installing improved rail where conventional rail lasts 25 years saves $30.93 from extra life and $4.66 in reduced flaws, a total of $35.59. Compared to the extra cost $26.85, a net savings of $8.74 is realized. Where conventional rail last 28 years, a savings of $23.22 from extra life and $4.68 from reduced defects saves a total of $27.90 for a net benefit of $1.05. Where conventional rail lasts more than 28 years, there is no benefit.

To find total benefits, the market for this improved rail must be studied. High density track is the most likely application but tangent high density track with heavy axle loads also wears out relatively quickly. If the traffic is predominately 100 ton cars in unit trains, the annual tonnage need only be 35.5 million tons to wear-out the rail in 28 years.[2] There are several routes where track carries this type traffic, the Burlington Northern line from northwestern Wyoming to Lincoln, Nebraska, for example. There are about 33,830 miles of high density (more than 20 MGT/year) track tangent or with less than 1 degree of curvature. If 25 percent of this track carries heavy coal traffic and 10 percent of that has tonnages greater than 35 MGT per year, a total of 846 miles of track are candidates for improved rail.

Curvature has an especially wearing effect on rail. For a 2 degree curve, with unit trains and 100 ton cars, life is estimated at 22.6 years.(2) Assume 25 percent of the 4286 miles of high density track with 2 degree curves has such traffic, then another 1071 miles are added. Following similar reasoning, 3 degree curves add 140 miles and 4 degree or more curves add 155 miles to the improved rail market. In all, the market appears to be 2212 miles.(2) These estimates were made with the hope of being refined when more complete data became available, although such data has not been received, other sources indicate the market might be as large as 4000 miles.

If the average life of this 2212 miles of track is 25 years, 88 miles of track would wear out each year. This would be the potential annual market. It equals 27,760 rails per year, 20,350 tons per year. At a 25 year life, benefits of $8.74 per rail or $207,662 are possible. Over the course of 25 years, a present value of over $1.9 million would be achieved.

It should be noted that increases in total tonnage, wheel loads and unit train operations, all of which enhance the benefits of improved rail, are likely to increase making the $1.9 million figure a conservative estimate.

The metallurgies being considered exist and are in limited use. The chief purpose of this subprogram is to validate their performance and lower their cost. Since the rail is in limited use, the problem caused by double counting benefits of existing improved rail applications at current prices will not be considered, as it is probably small.

TABLE E-3

BENEFIT CALCULATION

SUBPROGRAM C--IMPROVED RAIL METALLURGY

VALUE OF EXTRA LIFE

Cost of Conventional Rails	$ 268.55/rail
Installation Cost	+ 66.50/rail
	$ 335.05/rail
Single Payment Present Worth Factor (SPPW) (10%; 25 years)	x 0.0923
Value of Doubling Rail Life	$ 30.925/rail

VALUE OF AVOIDING FLAWS

Assumed Cost of CWR Flaws, $250 each	$ 250.00/flaw
CWR Flaw Rate	x 0.27 flaws/mile-year
Distance Annual Cost Rate	$ 67.50/mile-year
Number of Rails Per Mile	270 rails/mile
Unit Annual Cost Rate	$ 0.25/rail-year

VALUE OF ACCIDENT REDUCTION

Cost of Rail Defect Accident	$ 30,000/accident
Multiplier	x 2.1
Total Cost of an Accident	$ 63,000/accident
Accidents per Mile	x0.00146 accidents/mi.-year
Distance Annual Accident Cost Rate	$ 91.98/mile-year
Number of Rails per Mile	÷ 270 rails/mile
Unit Annual Accident Cost Rate	$ 0.34/rail-year

VALUE OF REDUCED FLAWS AND ACCIDENTS

Cost of Flaws	$ 0.25/rail-year
Cost of Accidents	+ 0.34/rail-year
Subtotal	$ 0.59/rail-year
Objective--Reduction to 0.2 of Present Failure Rate	x 0.2
Flaw and Accident Cost of Improved Rail	$ 0.12/rail-year
Cost of Flaws and Accidents, Conventional Rail	$ 0.59/rail-year
Cost of Flaws and Accidents, Improved Rail	- 0.12/rail-year
Savings in Reduced Flaws and Accidents	$ 0.47/rail-year
EPSPW (10%; 50 years)	x 9.915
Present Value	$ 4.66/rail

VALUE OF IMPROVED RAIL WHERE RAIL LIFE IS 25 YEARS

Value of Double Rail Life	$	30.93/rail
Value of Flaw and Accident Reduction	+	4.66/rail
Subtotal	$	35.59/rail
Extra Cost of Improved Rail	-	26.85/rail
Total	$	8.74/rail

MARKET

Miles of Track Where Improved Rail is Warranted*		2,200 miles
Average life of Such Track	÷	25 years
Annual Average Market for Improved Rail		88 mile/year
Rail per Mile	x	270 rail/mile
Yearly Demand for Improved Rails		23,760 rail/mile
Present Value of Net Savings from New Rails	x	$8.74/rail
Annual Savings	$	207,662/year
EPSPW (10%; 25 Years)	x	9,077
Present Value	$	1.9 million

*Includes most curves of 3^{o} or more on high density lines (741 miles) and about 6.5 percent of high density lines with over 40 MGTM a year, assumed to have heavy unit train traffic.

E.4 Subprogram D--In-Place Rail Hardening

The benefits from in-place rail hardening include reducing accidents and extending rail life. The advantage of this process is that it can be economically used on virtually any rail-even on rail with one year of remaining life. Improved metallurgy new rails increase rail life also, but the benefit is realized too far in the future to be worth much except in rail applications with a fairly short life. Rail hardening in place has an advantage over improved rail in that rail can be hardened when its remaining life is such as to maximize benefits. Depending on costs and other assumptions, the savings from hardening rail increase as the rail wears. At some point, these savings begin to decline again. Since the rail can be hardened at any time, the time to harden is when the maximum savings accrue. The process is profitable on virtually all rail since all rail eventually has a short remaining life. Improving new rail is beneficial only in those few places where rail life is sufficiently short for it to be profitable.

The process would find its widest application on light density lines. Benefits would stem from three sources: extended wear life, reduced accident costs, and reduced flawed rail replacement costs. Assuming relay rail is laid with 30 years life remaining, the value of this rail is 55.6 percent of new rail,[2] or $149.31 per rail. Adding the installation cost brings the cost of relaid rail to $215.81 per rail.[7,8] This expenditure is equivalent to an expenditure of $22.89 per rail-year over the next 30 years. It can be shown that the optimum time to treat relaid rail is when it has 10 years of life remaining, thus extending it to 15 years. The value of the five additional years in year 10 is $86.78 per rail; its present value is $33.44 per rail.

Turning to accident costs, there were 460 accidents attributed to rail-head failure in 1976. With 93,000,000 rails in place,[10] this is equivalent to a rate 0.0000049 accidents per rail-year. At a direct cost of $30,000 per accident[3] and a total cost factor of 2.1,[4] this amounts to $0.3087 per rail-year, the present value of which is $2.34 per rail over the 15 years of remaining life. If the accident rate were reduced to 40 percent of its current value, the accident cost would only be $0.94 per rail and the savings would be $1.60 per rail.

In 1976, approximately 250,000 rails were removed for flaws.[10] With 93,000,000 rails in place, the flaw rate was 0.0027 flaws per rail-year. Assuming a cost of $150 to replace a flawed rail yields a cost of 0.40 per rail-year. The present value of this amount over a

15 year period is $3.04 per rail. If the flaw rate were reduced to 40 percent of its current value, the savings would be $1.82 per rail.

Summing the savings and subtracting the $5.00 per rail cost of hardening yields a savings of $31.66 per rail. Assuming a market of 344,000 miles of track and assuming that 1/50 is hardened each year, then the annual market is 6,880 miles per year, or, 1,857,600 rails per year. At $31.66 per rail, the savings from one year's hardening is $58.8 million, and from that plus hardening in the next 24 years is $533.8 million.

Different discount rates and inflation rates would change this value. Higher inflation (lower discount) would lead to rail hardening when more life was left. Benefits would increase. This program would have its greatest benefit to railroads who had not kept up on rail renewal programs.

Table E-4 presents the benefit calculation.

TABLE E-4

BENEFIT CALCULATION

SUBPROGRAM D--IN-PLACE RAIL HARDENING

VALUE OF EXTRA LIFE	
Cost of New Rail	$ 268.55/rail
Factor for Determining Value of Second Hand Rail	x 0.556
Value of Relay Rail	$ 149.31/rail
Cost to Install Rail	+ 66.50/rail
Value of Relaid Rail	$ 215.81/rail
Capital Recovery Factor (10%; 30 Years)	x0.10608
Value of Annual Rail Service	$ 22.89/rail-year
EPSPW(10%;5 Years)	x 3.791

VALUE OF EXTRA LIFE (continued)

Value of Extra Rail Life 10 Years From Now	\$ 86.78/rail
SPPW (10%; 10 Years)	x 0.10608
Present Value	\$ 33.44/rail

ACCIDENT SAVINGS

Accidents in 1976	460 accidents/year
Number of Rails in Place	÷ 93,000,000 rails
Accident Rate per Rail	0.0000049 accident/rail-year
Cost per Accident	x \$30,000/accident
Direct Unit Cost Rate	\$ 0.147/rail-year
Total Cost Multiplier	x 2.1
Total Unit Cost Rate	\$ 0.3087/rail-year
(EPSPW (10%; 15 Years)	x 7.606
Present Value of Accident Costs	\$ 2.34/rail
Objective--Reduction to 40T	x 0.60
Present Value	\$ 1.40/rail

FLAWED RAIL SAVINGS

Rails Removed for Flaws in 1976	250.000 flawed rails/year
Number of Rails	÷ 93,000,000 rails
Cost of Rail Replacement (Assumed)	0.0027 flawed rails/rail-year
Unit Cost Rate	x \$150.00/flawed rail
EPSPW (10%; 15 Years)	\$ 0.40/rail-year
Present Value of Flaws	x 7.606
Objective--Reduction to 40%	\$ 3.04/rail
Present Value	x .60
	\$ 1.82/rail

SAVINGS FROM RAIL HARDENING PER RAIL

Value of extra life	\$ 33.44/rail
Value of Reduced Accidents	1.40/rail
Value of Reduced Flaws	+ 1.82/rail
Subtotal	35.66/rail
Objective--Cost of Hardening	5.00/rail
Net Benefit	\$ 31.66/rail

TOTAL SAVINGS FROM HARDENING

Total Track Miles	344,000 miles
Estimate 1/50th Hardened per Year	÷ 50 years
Miles Hardened per Year	6,880 miles/year
Rails per Mile	x 270 rails/mile
Number of Rails Hardened	1,857,600 rails/year

TOTAL SAVINGS FROM HARDENING (continued)

Number of Rails Hardened	1,857,600 rails/year
Savings per Rail	x 31.66/rail
Present Value of Net Savings from One Years Hardening	$ 58,811,616/year
EPSPW (10%; 25 Years)	x 9.077
Present Value	$ 533.8 million

E.5 Subprogram E--Improved Thermite Welding

The benefits from improved thermite welding come from improved reliability. Improved reliability will eliminate the need for re-welding field welds and reduce accidents due to weld failures. Improved reliability has a benefit of about $1.00 per weld while improved safety is worth $4.29 a weld. For every 135,000 improved welds, one accident will be prevented each year.

Since thermite welds require repairing or rewelding between once in every 160 to once in every 275 welds, and repairs are assumed to cost about $250, one dollar per weld was used as the average repair cost.(10) The other $4.29 in savings stem from accident reduction. In 1975 and 1976 a total of 9 accidents were caused by field weld failures.(3) which is equal to $63,000 each when other railroad costs are added.(4) The 9 accidents therefore caused $567,000 in damage for two years or $283,500 per year. With 60,000 miles of CWR installed,(5) this amounts to $4.72 per mile-year, which over a 25 year period has a present value of $42.89 per mile. Assuming 10 welds per mile, this works out to $4.29 per weld. Adding reliability savings ($1.00) to accident prevention, total savings are $5.29 per weld.

This amount must be multiplied by the number of welds per year to obtain the annual savings. Eight field welds are required each mile to join the quarter-mile rail strings and two more are assumed to be required for turnouts, signals and crossings. Ten welds are therefore required for each of the 5,000 miles of CWR installed annually,(5) giving 50,000 welds per year.

In addition thermite welds can be used to install replacement rail when defects necessitate rail removal. Although joint bars are used for this purpose, improved reliability coupled with portability of thermite welding should lead to improved thermite welds being generally used for spot rail installation. Assuming 0.27 defects per mile per year for CWR,(9) approximately 16,200 defects requiring rail removal occur in CWR each year. Replacing these rails would require 32,400 welds a year. As a conservative estimate, assume only 30,000 welds would actually be performed in rail defect repair. The total market for improved thermite welds is therefore 80,000 welds per year; 30,000 for spot rail installation and 50,000 for new rail installation.

The benefits of improved thermite welding would be $423,000, $5.29 times the number of welds, 80,000 a year. Over the course of 25 years of installation, the present value of the process would be $3.8 million. Against this must be set the cost of the improvement. Assume the cost is $3.50 a weld, about a 5 percent increase. If this price increase can achieve the objective, the cost increase per year will be $238,000. The present value of the net benefit will be $143,000 a year. Over 25 years of improved welding the present value of the net benefit would be $1.3 million.

Table E-5 presents the benefit calculation.

TABLE E-5

BENEFIT CALCULATION

SUBPROGRAM E--IMPROVED THERMITE WELDING

COST OF WELD REPAIR		
Cost of weld repair (assumed)	$	250/weld repair
Ratio of welds to repairs	÷	250 welds/weld repair
Average repair cost per weld	$	1/weld

ACCIDENTS SAVINGS

Direct accident cost	\$ 30,000/accident
Total cost multiplier	x 2.1
Total unit cost	\$ 63,000/accident
Accident rate, 9 in 2 years	x 4.5 accidents/year
Annual accident cost	\$283,500/year
Miles of CWR installed	÷ 60,000 miles
Cost rate	\$ 4.72/mile-year
EPSPW (10%; 25 years)	x 9.077
Present value	\$ 42.89/mile
Welds per mile	÷ 10 welds/mile
Present value per weld	\$ 4.29/weld

NUMBER OF WELDS

Welds to repair rail defects:	
Miles of CWR installed	60,000 miles
Rail defects per mile	x 0.27 defective rails/mile-yr.
Rails replaced in CWR	16,200 defective rails/year
2 welds per replacement	÷ 2 welds/defective rail
Welds required to repair defects	32,400 welds/year
Assume	30,000

Welds to install CWR:	
Welds for installing 10/mile(assumed)	10 welds/mile
Miles of CWR per year	x 5,000 miles/year
Welds required	50,000 welds/year

TOTAL VALUE OF IMPROVED WELDS

Total Welds	80,000 welds/year
Savings per weld (\$1+\$4.29=\$5.29)	x \$5.29/weld
Annual savings	\$423,000/year
EPSPW (10%; 25 years)	x 9.077
Present value of improved welds	\$ 3.8 million

COST OF IMPROVED WELDS

Objective--\$3.50/weld	\$ 3.50/weld
Number of welds per year	x 80,000 welds/year
Annual cost	\$280,000/year

SAVINGS FROM IMPROVED WELDS

Annual savings (see above)	\$423,000/year
Annual cost (see above)	-280,000/year
Net benefit from one year's improved welding	\$143,000/year
EPSPW (10%; 25 years)	x 9.077
Present value	\$ 1.3 million

E.6 Subprogram F--On-Site Electric Flash-Butt Welding

The benefit in this subprogram comes chiefly from reducing the field welding cost by \$40, thermite welds are assumed to cost \$70 each while flash-butt welds are assumed to cost \$30. In addition, reliability improvements are worth \$5.29 per weld.

Since thermite welds require repairing or rewelding between one in every 160 to once in every 275 welds, and repairs are assumed to cost about \$250, one dollar per weld was used as the average repair cost.[10] The other \$4.29 in savings stem from accident reduction. In 1975 and 1976 a total of 9 accidents were caused by field weld failures.[3] These accidents cost \$30,000 each in damage to track and equipment[3] which is equal to \$63,000 each when other railroad costs are added in.[4] The 9 accidents therefore caused \$567,000 in damage for two years or \$283,500 per year. With 60,000 miles of CWR installed,[5] this amounts to \$4.72 per mile-year, which over a 25 year period has a present value of \$42.89 per mile. Assuming 10 welds per mile, this works out to \$4.29 a weld. Adding reliability savings (\$1) to accident prevention, total savings are \$5.29 a weld.

This amount must be multiplied by the number of welds per year to obtain the annual savings. Eight field welds are required each mile to join the quarter-mile rail strings and two more are assumed to be required for turnouts, signals and crossings. Ten welds are therefore required for each of the 5,000 miles of CWR installed annually,[5] 50,000 welds a year.

Reducing welding cost by $40.00 and saving $5.29 in reduced flaws and accidents saves $45.29 a weld for a present value $2,264,500 for each year's welding. In the course of 25 years of improved field welding savings, present value of $20.6 million will be realized.

This program is not sensitive to inflation. It will chiefly benefit railroads engaged in rapid CWR installation.

Table E-6 presents the benefit calculation.

TABLE E-6

BENEFIT CALCULATION

SUBPROGRAM F--ELECTRIC FLASH-BUTT WELDING

SAVINGS PER WELD

Reliability improvement (same as Subprogram E)	$ 5.29/weld
Objective--$40.00/weld reduction in cost	+ 40.00/weld
Savings per weld	$ 45.29/weld

MARKET

CWR installation rate	5,000/miles/year
Welds per mile	x 10 welds/mile
	50,000 welds/year

INDUSTRY SAVINGS

Weld rate	50,000 welds/year
Savings per weld	x $45.29/weld
Annual savings	$ 2,264,500/year
EPSPW (10%; 25 years)	x 9.077
Present value	$ 20.6 million

E.7 Subprogram G--In-Place Rail Welding

If a welding technique that would allow rail to be welded in place could be developed to produce welds at $50 each or under, large savings could be achieved. This technique would be applied to branch lines, where welded relay rail is currently not used. The rail would normally be worn to where it would have to be scrapped. By welding, joint bars can be dispensed with, doubling the wear life for light duty rail. The welding would eliminate the need for laying replacement rail, $17,000 per mile in labor[7,8] and $43,000 per mile for the value of the rail and material.[2] Laying CWR is not currently economical for light duty lines because of the extra restraint required to prevent buckling. If the extra restraint costs are assumed to be about equal to the savings in joint maintenance and other spot work, the savings from avoiding rail replacement would be $60,000 per mile. Cost of welding would be $13,500 per mile for a savings of $46,500 per mile. The total market for this type of welding is difficult to gage, especially since it depends on the success of the other welding methods. One thousand miles a year, a conservative estimate, would yield savings of $46.5 million a year. Over 25 years, the present value of savings would be $422.1 million

Table E-7 presents the benefit calculation.

TABLE E-7

BENEFIT CALCULATION

SUBPROGRAM G--IN-PLACE WELDING

COST	
Objective--weld cost	$ 50/weld
Welds per mile	x 270 welds/mile
Cost of welding a mile	$ 13,500/mile

BENEFIT

Avoiding cost of rail laying labor (270 x $66)	$ 17,000/mile
Avoiding cost of relay rail (270 x $159)	+ 43,000/mile
Total savings per mile	$ 60,000/mile

SAVINGS

Benefit/mile	$ 60,000/mile
Cost/mile	- 13,500/mile
Net benefit/mile	$ 46,500/mile
Miles welded per year (assumed)	x 1000 miles/year
Total annual savings	$ 46.5 million/year
EPSPW (10%; 25 years)	x 9.077
Present value	$ 422.1 million

E.8 Subprogram H--Bolt Hole Crack Prevention

The benefits from this subprogram consist of preventing bolt hole cracks, thereby saving on rail replacement and accidents. Expanding bolt holes in-plant could save $382,000 a year if 750 miles of track were treated.

The cost of treating bolt holes in-plant depends primarily on the cost of the sleeve since labor should cost only a few cents per expansion. Assume the cost of end hole expansion is $1.00, since sleeves are estimated to cost between $.75 and $1.00. Expanding only the end bolt hole, the chief source of cracks, would cost $540 a mile[11].

The benefits were computed by combining the savings from preventing cracks and reducing accidents. Replacing rail with bolt hole cracks is assumed to cost $150, $100 for labor plus $50 for the net value of replacement rail minus the value of the replaced rail, which is taken back to the rail plant and cropped. On average, a mile of jointed track experiences 0.5 bolt hole cracks per year[10]. The value of preventing a crack would be $75 per mile (0.5 x the $150 cost of replacing). Average jointed rail has 0.000645 accidents per mile a year due to bolt hole cracks.[3,10] Assuming $63,000 in total railroad cost per accident,[3,4] the value of avoiding an accident is $40.64 per mile. The saving from avoiding rail replacements and accidents is therefore, $115.64 per mile-year which has a present value of $1,049.61 per mile over 25 years.

Expanding a mile of rail in-plant cost $540 yet it saves $1,049.61 per mile for a net benefit of $509.61 per mile.

The market for the technique is difficult to estimate. Turnouts and corssings offer a promising market since they are often bolted in and probably develop cracks more frequently than regular rail in heavy service.

The rail installation programs of several railroads were reviewed and found to include more than 15 percent jointed rail. If 5,000 miles of CWR are installed every year[5] and 15 percent of rail is jointed, about 750 miles of jointed rail would be installed each year. With a savings of $509.61 a year per mile, 750 miles of rail with expanded bolt holes would save $382,207. Continuing the program for 25 years would have a present value of $3,469,297.

The benefits include reducing the accident rate by 0.5 accidents per 750 miles of track expanded. This program would be sensitive to the inflation rate, since high inflation (a low discount rate) would increase the benefits.

Table E-8 presents the benefit calculation.

TABLE E-8

BENEFIT CALCULATION

SUBPROGRAM H--BOLT HOLE CRACK PREVENTION

DEFECTIVE RAIL REPLACEMENT COSTS	
Cost of rail replacement	$ 150/crack
Bolt hole crack rate	x 0.5 cracks/mile-year
Cost of replacing rail due to bolt hole cracks	$ 75/mile-year
ACCIDENT COSTS	
Direct cost in damage to track & equipment	$ 30,000/accident
Indirect multiplier	x 2.1
Accident Cost	$ 63,000/accident
Accident Rate	x .000645 accidents/mile-year
Unit accident cost rate	$ 40.64/mile-year
Cost of bolt hole repair (above)	+ 75.00/mile-year
Value of eliminating bolt hole cracks	$ 115.64/mile-year
EPSPW (10%; 25 years)	x 9.077
Present value of track without cracks	$1,049.61/mile
Cost of eliminating bolt hole cracks	- 540.00/mile
Net present value of eliminating cracks	$ 509.61/mile
SAVINGS	
CWR installation rate	5,000 miles/year
Percent jointed rail to CWR*	x 0.15
Jointed rail installation rate	750 miles/year
Net benefit per mile	x $509.61/mile
Annual benefit	$ 382,207/year
EPSPW (10%; 25 years)	x 9.077
Present value	$ 3.5 million

*Jointed rail is approximately 15 percent of CWR installation, based on two railroads (Source: 1977 annual reports of the Southern Pacific and the Missouri Pacific Railroads).

E.9 Subprogram I--Bolt Hole Crack Restraint

The benefits from this subprogram come from repairing rail with cracked bolt holes, thereby allowing it to remain in service. Sleeve expansion of bolt holes offers an economical way to repair cracks. Based on $112.50 saved for each crack repaired, the total benefit from 25 years of repairs could be $6 million.

Benefits from repairing cracked bolt holes in-place were determined by calculating the value of repairing a crack and multiplying it by the number of cracks likely to be repairable. The value of a repair includes the value of the rail saved. A defective rail is likely to be replaced by a second-hand rail, worth $150. The defective rail will either be shipped back to a shop and scrapped or cropped. Assume its average value is $100. The net cost of the rail is $50. Assuming the replacement costs $100 in labor and equipment, the total cost of a cracked bolt hole is about $150, although this number will vary widely.

The cost of repairing the crack is taken as $37.50.[11] This covers removing the joint bar, expanding the hole and reapplying the joint bar. Only a small crew is required, perhaps 3 men, and little equipment. The cost would vary greatly but this figure seems reasonable. The saving is thus $112.50 ($150 - $37.50).

The number of cracks that are repairable is difficult to determine currently. It was assumed that a crack goes from detectable to too large to repair in 24 days. Unfortunately, there are no good data to support any particular rate of crack growth. Using inspection frequencies for several railroads and types of track, it was estimated that about 8 percent of the cracks would be repairable. Since there are about 70,000 cracks per year,[10] 8 percent means that 5,600 cracks could be repaired for a savings of $630,000 per year. Repairing cracks at this rate for 25 years would result in savings with a present value of $5.7 million.

Table E-9 presents the benefit calculation.

TABLE E-9

BENEFIT CALCULATION

SUBPROGRAM I--BOLT HOLE CRACK RESTRAINT

NET BENEFIT PER BOLT HOLE CRACK	
Cost of bolt hole failure	$ 150.00/crack
Cost of repair	- 37.50/crack
Net benefit per bolt hole repair	$ 112.50/crack
SAVINGS	
Bolt hole crack rate	70,000 cracks/year
Percent repairable*	x 0.08
Repair rate	5,600 cracks/year
Value of each repair	x 112.50/crack
Annual savings	$ 630,000/year
EPSPW (10%; 25 years)	x 9.077
Present value	$ 5.7 million

*If it is assumed that cracks grow from detectable to too large to repair in 24 days, then inspection frequencies of slightly more than one inspection a year[9] indicate that 8 percent of cracks will be discovered while repairable.

E.10 Subprogram J--Improved Wood-Tie Fastening System

The improved fastening system will increase tie life by 50 percent, rail life by 33 percent, reduce lining and surfacing costs by 33 percent, and reduce fastener caused accidents by 50 percent. On the other hand, the improved system costs 44 percent more than current plates, anchors, and spikes.

The improved fastening system would be most useful in areas where tie and rail life are short, especially where spike killing and maintaining gauge are problems. Track with sharp curves and heavy wheel loads has the required characteristics. It is assumed that there are 400 miles of such track where tie life is less than 12 years, 900 miles where it is less than 16 years and 1800 miles where it is less than 20 years. The preceding are points on a logistic-like curve which has all ties lasting at least 8 years.

Some benefit stems from reducing accidents. There are several categories of track geometry defect caused accidents attributable, at least in part, to fastener defects.(3) Wide gauge due to defective or missing spikes, irregular track allignment and wide gauge due to defective cross ties were considered accident causes due partially to inadequate fasteners. From these causes, 486 accidents were assumed to be due to inadequate fasteners in 1976.(3) Using this as an annual rate, half of these accidents, 243, were assumed to occur on curves. Curved track was assumed to be 52,000 miles,(12) so the $10.2 million in accident damage that occurs on curves was equal to $99.42 per mile per year.(3,4) Improved fasteners would halve the cost to $0.015 per tie per year. Over a 25 year period, the present value would be $0.13 per tie.

Other benefit stems from extending tie life. Given the market as specified above and the allowable increase in price of a new fastening system of 44 percent, it can be shown that maximum benefit occurs at places where tie life is 16 years or less. Average tie-life in such places is estimated to be 14 years. Since an in-place tie costs $22.50 per tie,[2,13] the equivalent annual cost over 14 years is $3.05 per tie-year. The value, 14 years in the future, of extending that life an additional 50 percent, or 7 years, is $14.87 per tie. The present value is $3.91 per tie.

Benefit also stems from extending rail life. Since the value of in-place rail is $335 per rail and there are 12 ties per rail, the cost of in-place rail is $27.92 per tie. This is equivalent to an annual cost of $3.79 per tie-year over a 14 year period. Thus, the value, 14 years in the future, of extending rail life an additional 33 percent, or 4.67 years, is $13.67 per tie. The present value of this amount is $3.60 per tie.

Currently, lining and surfacing is done approximately once each three to four years. A 33 percent reduction would bring the frequency down to about once each six years. Since lining and surfacing costs $1,170 per mile,[14] the cost per tie is $0.36. The benefits of avoiding lining and surfacing in the third and ninth years (while retaining it in the sixth and twelfth years) are $0.27 and $0.15 per tie respectively, or $0.42 per tie total.

To obtain the preceding benefits, an improved fastening system must be bought at a price no more than $4.50 per tie--44 percent greater than the $10.22 cost per tie of a conventional wood-tie fastening system. Thus, net savings per tie equals the sum of the four types of savings, $8.06 per tie, less the cost of the improved fastening system, $4.50 per tie. This amounts to $3.56 per tie.

As indicated earlier, there are approximately 900 miles of track where tie life is 16 years or less, and average life is 14 years. This is equivalent to 2.9 million ties or to an average replacement rate of 209,000 ties per year. The savings at $3.39 per tie amounts to $743,784 per year, and the prevent value of this amount, year after year, for 25 years of $6.7 million.

TABLE E-10

BENEFIT CALCULATION

SUBPROGRAM J--IMPROVED WOOD-TIE FASTENING SYSTEM

ACCIDENTS PREVENTED

Wide guage due to defective cross ties & defective spikes and track alignment irregular caused accidents	486 accidents/year
Assumed half accidents on curves	x 0.5
Accidents on curves due to fastening	243 accidents/year

MILES OF CURVED TRACK

Miles of track in U.S.	344,000 miles
15 per cent of Class A mainline is curved	x 0.15
Miles of curved track	52,000 miles

ACCIDENT COST SAVINGS

Direct cost per accident	$19,988/accident
Total cost multiplier	x 2.1
Total cost per accident	$42,000/accident
Accident rate on curved track	x 243 accidents/year
Total annual accident cost	$ 10.2 million/year
Miles of curves	÷52,000 miles
Unit cost rate (per mile)	$ 99.42/mile-year
Ties per mile	÷ 3250 ties/mile
Unit cost rate (per tie)	$0.0306/tie-year
Objective--reduce cost by 50 per cent	x 0.5
Unit saving rate	$ 0.015/tie-year
EPSPW (10 per cent; 25 years)	x 9.077
Present value	$ 0.13/tie

SAVINGS FROM EXTRA TIE LIFE

In place tie costs (see Subprogram K)	$ 22.50/tie
CRF (10 per cent; 14 years)	x0.13575
Yearly value of tie service	$ 3.054/tie-year
EPSPW (10 per cent; 7 years)	x 4.868
Value of 7 years tie service	$ 14.87/tie
SPPW (10 per cent; 14 years)	x0.2633
Present value	$ 3.91/tie

SAVINGS FROM EXTRA RAIL LIFE

Value of rail per tie (see Subprogram M)	$ 27.92/tie
CRF (10 per cent; 14 years)	x0.13575
Yearly value of rail service	$ 3.79/tie-year
EPSPW (10 percent; 4.67 years)	x 3.607
Value of 4 years rail service	$ 13.67/tie
SPPW (10 percent; 14 years)	x0.2633
Present value	3.60/tie

VALUE OF REDUCED LINING & SURFACING

L&S cost per mile	$ 1170/mile
Ties per mile	÷ 3250
Cost of L&S per tie	0.36/tie
SPPW (10 percent; 3 years)	x0.7513
Value of avoiding L&S at 3 years	$ 0.27/tie
Cost of L&S per tie	$ 0.36/tie
SPPW (10 percent; 9 years)	x0.4241
Value of avoiding L&S at 9 years	$ 0.15/tie
Value of avoiding L&S at 3 years	+ 0.27
Present value	$ 0.42/tie

NET SAVINGS PER TIE

Tie savings per tie	$ 3.91/tie
Rail saving	3.60/tie
L&S	0.42/tie
Safety	0.13/tie
Subtotal	$ 8.06/tie
Less cost of improvement (0.44 x $10.63)	- 4.50/tie
Savings per tie	$ 3.56/tie

MARKET & SAVINGS

Assume 900 miles	900 miles
Ties per mile	x 3250 ties/mile
Ties	2,925,000 ties
Useful tie and rail life	÷ 14 years
Annual replacement rate	208,928 ties/year
Savings per tie	3.56/tie
Annual savings	$743,784/year
EPSPW (10 percent; 25 years)	x 9.077
Present value	$ 6.7 million

E.11 Subprogram K--Improved Wood-Based Tie

The benefits of improved wood-based ties are assumed to stem only from their longer life relative to current ties. Since these ties cost more, they will find their most economical application in locations where conventional ties have a short life. Using the improvement objective of a 30 percent increase in life at a $1.00 increase in price, it can be shown that improved ties should be installed where current tie life is 26 years or less. The shorter the life the greater the savings from improved ties. If the number of ties that last 26 years or less can be determined, as well as their average life, the benefits can be computed.

Identifying the extent of the market is the key determinant of benefit. On normal tangent track, ties last 36 years with 20MGT annual traffic. Only if the track is curved 3^o, does life drop to 25 years [(2)]. Track with ties that last 26 years or less must have heavy wheel loads, curves or bad track support. There are 741 miles of Class A mainline track with curves 3^o or sharper. If we assume 10 percent of tangent Class A track has heavy wheel loads and/or bad track support, another 6,000 miles of track also have tie life short enough to warrant use of improved ties. The total market is approximately 6,7000 miles of track where it is assumed ties last an average of 23 years.

A typical treated wood tie costs $14.25 to purchase and $8.25 to install for an in-place cost of $22.50 per tie[2,13]. This is equivalent to an annual cost of $2.53 per tie-year over the 23 year life of the average tie. If tie life can be extended 30 percent, or 7 years, the value of that 7 year extension, 23 years in the future, is $12.33 per tie. Its present value, however, is only $1.37 per tie. To achieve this benefit, an improved tie costing $1.00 more must be purchased. The net saving, therefore, is $0.37 per tie.

If 6,700 miles of track have an average life of 23 years, 290 miles or 950,000 ties would be replaced a year. If each tie saves $0.37, annual installations have a present value of $348,725. The present value of installing improved ties over 25 years is $3.17 million.

Table E-11 presents the benefit calculation.

TABLE E-11

BENEFIT CALCUALTION

SUBPROGRAM K--IMPROVED WOOD BASED TIE

VALUE OF TIE IN-PLACE	
Tie cost	$ 14.25/tie
Installation cost	x 8.25/tie
	$ 22.50/tie
SAVINGS PER TIE FROM EXTENDED LIFE	
Tie value (in-place)	$ 22.50/tie
CRF (10%; 23 years)	x0.11257
Value of annual tie service	$ 2.53/tie-year
EPSPW (10%; 7 years)	x 4.868
Value of 7 years extra life	$ 12.33/tie
SPPW (10%; 23 years)	x 0.1117
Present value of 7 extra years tie life	$ 1.37/tie
Cost of improved tie (assumed)	- 1.00
Net present value	$ 0.37/tie

TOTAL SAVINGS

Track with tie life less than 26 years	$ 6,700 miles
Average tie life	÷ 23 years
Tie replacement rate	290 miles/year
Ties per mile	x 3,250 ties/mile
Ties replacement rate	942,500 ties/year
Net savings per tie	x$ 0.37/tie
Savings	$348,725/year
EPSPW (10%; 25 years)	x 9.077
Present value	$ 3.17 million

E.12 Subprogram L--In-Place Repair of Spike-Killed Ties

The benefits from in-place repair of spike-killed ties stem from extending the life of ties by 8 years.

The benefit from keeping a tie in service for 8 additional years depends on tie life at the particular location. If ties installed cost $22.50 and last 35 years,[2,13] the annual cost of the tie is $2.33. In-place repair can be thought of as providing 8 years of tie service, or 8 years of $2.33 in savings on tie cost (or whatever annual tie costs are with a particular location and tie life).

The present value, where tie life is 35 years, of an 8 year stream of $2.33 in benefits is $12.45 ($13.22 for 25 years tie-life). There are approximately 2,900,000 ties replaced each year because of spike killing.[15] The total savings from repairing the ties spike-killed in a year is $36.2 million--assuming the ties would otherwise last 35 years ($38.4 million if they last 25 years). The present value of repairing spike-killed ties over a 25 year period would be $328.5 million.

The cost of repair, $0.30, must be subtracted from these benefits. The repair cost per year would be $870,000, while over 25 years the present value of the cost would be $7.9 million. Subtracting the repair costs from the benefits, the net present value for one year's repairs would be $35.3 million while for 25 years of repairs the present value would be $320.4 million.

The repair would also encourage railroads to tighten up their tolerances on gauge, since respiking would not be as harmful as before. This would enhance safety. Savings for railroads which must do extensive shimming would be proportionately greater than on other railroads. The process is not capital intensive at all, indeed it saves capital--$0.30 instead of $22.50 to replace a tie. The capital saving aspect would be a boon to poor railroads with many spike-killed ties.

Table E-12 presents the benefit calculation.

TABLE E-12

BENEFIT CALCULATION

SUBPROGRAM L--IN-PLACE REPAIR OF SPIKE-KILLED TIES

VALUE OF REPAIR	
Tie cost	$ 14.25/tie
Installation cost	+ 8.25/tie
Value of tie in place	$ 22.50/tie
(CRF (10%; 35 years)	x0.10369
Value of annual tie service	$ 2.333/tie-year
EPSPW (10%; 8 years)	x 5.335
Present value of 8 years tie service	$ 12.45/tie
Number of spike-killed ties replaced annually	2.9 million ties
Gross benefit from annual repair	$ 36.2 million
COST OF REPAIR	
Unit cost	$ 0.30/tie
Ties repaired annually	2.9 million ties
Annual cost of repair	$ 0.87 million

NET BENEFIT

Annual gross benefit	\$ 36.20 million
Annual cost	- 0.87 million
Annual net benefit	\$ 35.33 million
EPSPW (10%; 25 years)	x 9.077
Present value	\$ 320.4 million

E.13 Subprogram M--Improved Concrete Tie and Fastener Selection Criteria and Utilization

The benefits from using concrete ties are longer tie life (twice as long as wood), a doubling of the line and surfacing cycle time, a 40 percent increase in rail life, and the wider spacing that concrete ties permit. The price of a concrete tie including pads and fasteners has recently been estimated at \$40.38.[16] Installation can be expected to increase the cost to \$48.63. In contrast, the price of an installed wood tie, including plates, spikes, and anchors is estimated at \$32.77. However, when concrete ties replace wood-ties, only 81 percent as many ties are required due to increased tie spacing.[2] The effective price of a concrete tie is, therefore, \$39.39 for each wood tie replaced, and the effective cost difference is \$6.62.

Concrete ties cost more but last longer, therefore their use is indicated at sites where current tie life is short. Using the assumptions mentioned above, ties that last 19 years or less are likely candidates for replacement with concrete ties. Assuming the average tie life of those that last 19 years or less is 17 years, then the benefits per tie average \$3.64. If 1500 miles of track are assumed to have a tie life of 17 years or less and therefore to warrant installation of concrete ties, 88 miles of ties would be installed each year (1/17th of 1500). The present value of savings from installing 88 miles of concrete ties would be \$1,041,040 for the 286,000 wood ties replaced. In the course of 25 years of installations, the present value of the savings would be $9,500,000. The benefits would increase if expected traffic growth leads to greater traffic density and/or higher speeds.

The benefits were calculated by determining the worth of each of the advantageous properties of concrete ties. The values of each benefit vary depending on tie life. The value of concrete ties having twice the life of wooden ties is $6.48 per tie when wooden ties last 17 years and only $4.87 when ties last 20 years. The method used to determine this value is to multiply $32.77 (the value of a wooden tie) by the single payment present worth factor associated with the normal time of tie replacement.

To the value of avoiding a tie replacement must be added the value of avoiding every other line and surfacing cycle. Each wood tie was expected to require 4 lining and surfacings while the concrete ties required but two lining and surfacings. These were spaced evenly over the life of the tie and their cost, $0.36 per tie[14] was multiplied by the single payment present worth factor associated with the year of each surfacing. The saving from the L&S work not required was $0.43 per tie for ties in a 17 year replacement cycle and $0.36 per tie for ties on a 20 year replacement cycle.

Savings from extra rail life are obtained by multiplying the cost of rail (installed = $335) by the capital recovery factor for the life of the rail, rail life being assumed equal to tie life. This gives the annual value of the rail service. The present value factor for the years of extra life was multiplied by the annual value of the rail service. This value of extra rail life was then discounted to the last year of previous rail life, when the benefit of extra life begins. This saving from added rail life, divided by 12 to put it on a per tie basis, equalled $3.35 for ties on a 17 year cycle and $2.60 for ties on a 20 year replacement cycle.

Summing the above benefits shows that ties on the 17 year replacement cycle save a present value of $10.26 per tie over their life which means a net saving of $3.64 per tie since the equated value of concrete is $6.62 per tie more than wood. Concrete ties on a 20 year replacement cycle would save $7.83 per tie, for a net saving of $1.21 per tie.

This analysis is quite sensitive to the discount rate used. If a lower rate were used, higher benefits would result. The benefits would flow primarily to railroads that have high density lines over rough terrain. These would include the major transcontinental railroads and the eastern coal hauling roads.

Table E-13 presents the benefit calculation.

TABLE E-13

BENEFIT CALCULATION
SUBPROGRAM M--IMPROVED CONCRETE TIE AND FASTENER SELECTION

EXTRA COST OF CONCRETE TIES		
Cost of concrete tie and fasteners	$	48.63/tie
Ratio of concrete to wood ties in track	x	0.81
Effective cost of concrete tie & fasteners	$	39.39/tie
Cost of wood tie and fasteners	-	32.77/tie
Cost difference	$	6.62/tie
VALUE OF EXTRA TIE LIFE		
Value of avoiding tie replacement	$	32.77/tie
SPPW (10%; 17 years)	x	0.1978
Present value of new tie 17 years in the future	$	6.48/tie

VALUE OF EXTRA RAIL LIFE

Value of rail in place	$ 335.00/rail
Ties per rail	÷ 12/ties/rail
Cost of rail per tie	$ 27.92/tie
CRF (10%; 17 years)	x 0.12466
Value of annual rail service per tie	3.48/tie-year
EPSPW (10%; 7 years)	x 4.868
Value of 7 years rail service 17 year from now	$ 16.94/tie
SPPW (10%; 17 years)	x 0.1978
Present value of 7 years rail service beginning 17 years in the future	$ 3.35/tie

VALUE OF REDUCED LINE AND SURFACING (L&S)

Cost of line & surface work ($1,170/mile)	0.36/tie
L&S cost avoided in year 4	$ 0.36/tie
SPPW (10%; 4 years)	x 0.6830
Present worth of avoiding L&S in year 4	$ 0.25/tie
L&S cost avoided in year 12	$ 0.36/tie
SPPW (10%; 12 years)	x 0.3186
Present worth of avoiding L&S in year 12	0.11/tie
Present value of L&S cost avoided in 17 years	$ 0.25
	+ 0.11
	$ 0.36/tie
SPPW (10%; 17 years)	x 0.1978
Present value of L&S avoided in next 17 years	0.07/tie
	$ 0.36
Present value of L&S avoided in two conventional tie installations	+ 0.07
	$ 0.43/tie

PRESENT VALUE OF CONCRETE TIES

Extra value of tie life	$ 6.48/tie
Value of extra rail life	3.35/tie
Value of avoiding line and surfacing operations	0.43/tie
Benefits of concrete tie	$ 10.26/tie
Extra cost of concrete ties	- 6.62/tie
Net present value of concrete ties	$ 3.64/tie

MARKET FOR CONCRETE TIES

Assume 1,500 miles of track have an average tie life of 17 years	1,500 miles
	÷ 17 years
Miles of concrete ties per year	88 miles/year
Wood ties per mile	x 3,250 ties/mile
Wood ties replaced	286,000 ties/year

NET BENEFIT

Wood ties replaced	286,000
Net benefit per tie	x $3.64/tie
Annual benefit	$1,041,040/year
EPSPW (10%; 25 years)	9.077
Present Value	$ 9.5 million

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APPENDIX F

SUBPROGRAM EVALUATION AND RANKING

APPENDIX F

F.0 SUBPROGRAM EVALUATION AND RANKING

F.1 Introduction

Given a limited budget and a set of candidate subprograms for improving the U.S. track system with total R&D costs far exceeding the budget, some procedure for prioritizing the candidate subprograms is required.

A review of the literature indicated a variety of methods are available for accomplishing this task.[1-5] In general, methods developed earlier required less data than many of the newer, more esoteric methods such as those based on modern decision theory. The complexity and data requirements of the newer methods, however, are not necessarily advantageous. In fact, there is evidence to the contrary--some R&D managers are reluctant to use such methods because of their complexity and large data requirements.

A common aspect of almost all methods is reliance upon well defined selection criteria and corresponding quantitative measures. Values for some measures were determined through subjective judgment, while values for others (such as R&D cost or net return) were based on simple estimates or on detailed objective analyses. Typically, the subjective judgments and simple estimates are elicited from several individuals in each organization and the resulting measures are combined to provide a single value of the overall acceptability of a particular R&D effort.

The specific types of criteria or measures which reflect R&D program acceptability can vary considerably from method to method. The following examples illustrate criteria used in other studies:

- return on investment
- R&D cost
- R&D cost payout time
- total investment required
- total investment payout time
- R&D state-of-art
- probability of R&D success
- production equipment and facility requirements
- length of product life
- promotional requirements
- product advantage
- similarity to present products
- effect on present products
- number of potential users
- market stability
- market trend
- product serviceability
- accident/injury prevention probability

The subprogram evaluation and ranking approach adopted for this study was a composite of the many options described above. The method was primarily quantitative rather than qualitative. The quantitative portion of the work was based on objective analyses performed by the study staff while the qualitative portion was based on the subjective judgment of some 20 evaluators convened solely for the purpose of evaluating the subprograms. Detailed descriptions of the evaluation and ranking components of the method follow.

F.2 Evaluation

The evaluation component is first described in terms of its four principal elements:

- criteria
- measures
- weight
- risk

These are followed by a description of the procedures used in the evaluation conference.

F.2.1 Criteria

The evaluation criteria are factors reflecting the objectives of the Improved Track Structures Research program, i.e., increased track system efficiency and improved track safety.

In addition to reflecting these objectives, the criteria had to reflect the need to maximize the return on FRA's limited R&D budget and the railroad industry's current need for short lead time solutions with modest capital requirements. Furthermore, a criterion was needed to account for monetary benefits accruing to the railroads which might not be readily quantifiable. For example, a successfully completed subprogram could conceivably result in higher train speeds and more reliable service which in time should improve market share and profits.

These considerations led to the adoption of the following set of subprogram evaluation criteria:

- benefit-cost ratio
- safety impact
- capital savings
- timeliness
- other impacts
- R&D cost

In the Benefit-Cost Ratio, benefit refers to monetary benefit accruing to the railroads, while cost refers to R&D cost. The ratio reflects the FRA and industry objective of improved serviceability through more cost-effective track. For example, subprograms whose results allow the track system to be made more effective (e.g., greater tonnage over the useful life of its components) at little or no increase in cost, or less costly at little or no decrease in effectiveness would show high monetary benefit to the railroad and have a high ratio value, provided that R&D costs were not excessive.

Safety Impact reflects the FRA and industry objective and need to constantly improve the safety of train operations. The implication here is that safer track is better for the railroads and the public. While this is more likely to be true in the case of passenger service, as opposed to freight service, it is not a foregone conclusion. Greater safety is apt to come only at a higher price. Ultimately, the public will pay that price--through higher cost of travel or of shipped goods. What is needed is hard to find--a safer, less expensive track system.

Capital Savings refers to the amount of capital saved by the industry when it implements the R&D results. It reflects the need of many railroads to conserve capital.

Timeliness reflects the need of the industry to improve its track system sooner rather than later.

Other Impacts is a "catch-all" criterion. It reflects the fact that some benefits of an R&D effort will not be readily and objectively determinable. It encompasses all such benefits not included under other criteria. Examples include: enhanced industry image; reduced track occupancy due to maintenance; increased service reliability; improved track safety standards.

R&D Cost is, of course, important to both the FRA and the industry. Both need to extract the maximum from every R&D dollar. Since R&D cost was already considered in the benefit-cost ratio, its use as a separate criterion might be questioned. The rationale behind the criterion is the following. Considerable risk is often associated with R&D efforts. Given that the effort might fail, it is better to fail with a small or modest R&D investment than with a large one.

F.2.2 Measures

The evaluation measures were quantitative indicators of the extent to which each criterion was fulfilled by a subprogram. To the extent that the criteria represented the program objectives, the set of measures provided a basis for distinguishing the more desirable subprograms from the less desirable ones.

For each criterion, a single corresponding direct measure was adopted. The measures, designated z_1, z_2, ..., z_6, are listed in Table F-1.

Descriptions of each evaluation measure and the method for estimating its value follow.

As indicated earlier, the benefit term in the benefit-cost measure, z_1, refers only to monetary benefit. Monetary benefit is defined here as the present value of the stream of railroad industry costs with the R&D result available, less the present value of the industry cost stream without the R&D result. Following Office of Management and Budget guidelines, an interest rate of ten percent was used in the present value calculations.

TABLE F-1

DIRECT SUBPROGRAM EVALUATION MEASURES

Criterion	Direct Measure	
	Description	Symbol
Benefit-Cost Ratio	Present value of net dollar benefit to RR industry divided by R&D cost	z_1
Safety Impact	Number of accidents prevented in first 5 years of implementation	z_2
Capital Savings	Capital expenditures saved in first 5 years of implementation	z_3
Timeliness	R&D time in years	z_4
Other Impacts	Subjectively selected value from a scale of -5 to +5	z_5
R&D Cost	Total subprogram R&D cost	z_6

Depending upon the subprogram, several types of monetary benefits were calculated, among them:

- Reduced accident cost
- Reduced material or replacement cost
- Reduced maintenance cost
- Reduced installation cost

To estimate these costs for the case in which the R&D product is not available to the industry, it was necessary to obtain information on current industry practices and unit costs. These were obtained from a variety of sources. Accident costs and rates were obtained from the annual FRA Accident/Incident Bulletins, while unit costs, wear rates, failure rates, and replacement rates were obtained from research reports, trade literature, interviews and conversations with researchers and industry personnel. A number of research reports were particularly useful in this regard. These are listed at the end of Appendix E.

In those cases where the R&D product is assumed to be available to the industry, the quantified subprogram objective provided the additional data which, when used with the above information, enabled industry costs to be estimated.

Benefit calculation details for each subprogram appear in Appendix E while a summary description of the benefits appears in each detailed description of the subprogram in Appendix D.

The safety impact measure, z_2, defined as the number of accidents prevented in the five year period immediately after the R&D product is implemented, was calculated by subtracting the number of accidents occurring with the R&D product implemented from the total number of accidents which would have occurred without the R&D product during the five year time period. To avoid the unrealistic case of instantaneous implementation, the study team estimated the new product phase-in or implementation rate for each subprogram.

The capital savings measure, z_3, was estimated by subtracting total industry costs with the R&D product available from total railroad industry costs without the R&D product during a five year period. Present value calculations were not utilized. For some subprograms, z_3 could be negative, implying high R&D product implementation costs.

R&D time (z_4) estimates were provided by the study team using their experience as the basic source of information. The literature, schedules of other comparable R&D efforts, and conversations with researchers and other experts augmented the basic information source.

As indicated earlier, values for z_5 (other impacts), were determined subjectively for each subprogram by each evaluator at the subprogram evaluation conference (Section F.2.5). To assist the evaluators, a scale such as that shown in Figure F-1 was used. The scale was restricted to a range of +5 to -5 with the high positive value representing a very large positive impact, and the high negative value representing a very large negative impact.

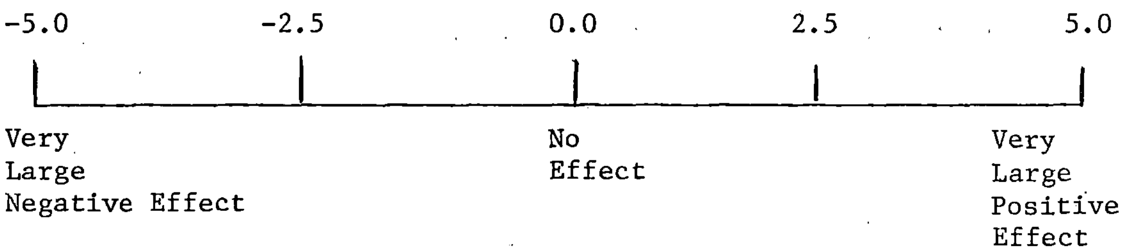

FIGURE F-1
SCALE FOR ESTIMATING OTHER IMPACTS (z_5)

R&D cost estimates (z_6) were also determined subjectively. Manpower estimates for each project were developed concurrently with estimates of R&D time (z_4) using study team experience as the basic information source. Again, the literature, cost estimates of other comparable R&D projects and conversations with individuals responsible for track system R&D projects augmented the basic data source. The latter individuals were particularly helpful in determining test instrumentation and test facility costs.

Since five of the measures are direct indicators of the evaluation criteria (e.g., R&D cost, capital savings), their values have different ranges and different units. As such, they could not be readily combined into a single overall measure in an understandable way.

To facilitate combination and comparison of subprograms, each direct measure was converted to a unitless derived measure with a range of zero to 1000 by the study staff. The conversion was done by examining the values of a direct measure (e.g., benefit-cost ratio) for all subprograms. The subprogram with the most desirable value (e.g., benefit-cost ratio) was assigned a derived measure value of 1000, while the subprogram with the least desirable value was assigned a derived measure value zero. Values in between these ranges were converted proportionately. The derived measures were designated $m_1, m_2, \ldots, m_6$.

F.2.3 Weights

In any evaluation process with multiple evaluators, it is likely that there will be disagreement among the evaluators concerning the relative importance of each criterion. Here, rather than force the evaluators to agree, a set of six weighting (or importance) factors was incorporated into the process--one weighting factor for each criterion. Each evaluator determined values for the six weighting factors independently, and each derived measure was then multiplied by its corresponding weighting factor. Once an evaluator determined his set of weighting factors, those values were used in his evaluation of each subprogram. The factors, designated $w_1, w_2, \ldots, w_6$, had the following two restrictions: each value had to be between zero and one, and the sum of the values had to equal one. That is:

$$0 \leq w_k \leq 1.0 \quad \text{for} \quad k = 1, 2, \ldots, 6 \quad \text{and,}$$

$$w_1 + w_2 + w_3 + w_4 + w_5 + w_6 = 1.0$$

Table F-2 shows a sample of weights and their values.

TABLE F-2

SAMPLE WEIGHT VALUES

CRITERION	WEIGHT Value	WEIGHT Symbol
Benefit-Cost Ratio	0.40	w_1
Safety Impact	0.10	w_2
Capital Savings	0.20	w_3
Timeliness	0.15	w_4
Other Impact	0.10	w_5
R&D Cost	0.05	w_6
Total	1.00	

F.2.4 Risk

Implicit in the nature of R&D activities is an element of risk--some efforts fail, others succeed. In effect, the probability of success varies from effort to effort. There is a chance, therefore, that the benefits envisioned from a subprogram might not be achieved. Any meaningful evaluation and ranking procedure must take this fact into account.

An intuitively appealing and often used method of dealing with this matter is to estimate the subprogram's probability of success and then multiply the benefit measures by that probability factor. The appeal lies in the fact that subprograms with either high benefit and low probability of success, or low benefit and high probability of success will be rated higher than those with both factors low, but not as high as those with both factors high.

For each subprogram then, each evaluator was asked to subjectively estimate the probability of success. The estimate had to have a value between zero and one. A zero implied that there was no chance that the R&D objective would be achieved; a 0.5 implied a 50-50 chance; and a 1.0 implied that the objective definitely would be achieved.

F.2.5 Evaluation Conference

Given the objective subprogram evaluation measures, a panel of 20 evaluators met for a full day at FRA to provide the subjective input into the subprogram evaluation process. The panel members were selected jointly by the study staff and FRA, and included the TRP members, some of the individuals interviewed earlier in the study, FRA staff, the study staff, and several others experienced in track system R&D. The panelists are listed below:

- J. Lundgren--Association of American Railroads
- G. H. Way--Association of American Railroads
- M. B. Miller--ConRail
- C. S. Webb--Southern Railway Company
- C. E. Godfrey--Abex Corporation
- W. F. Hamilton--Portec, Incorporated

- R. C. Arnlund--Bechtel, Incorporated
- W. M. Kaufman--ENSCO, Incorporated
- R. H. Prause--Battelle Columbus Laboratories
- A. Kish--Transportation Systems Center
- R. A. Smith--Transportation Systems Center
- R. E. Kleist--FRA Office of Federal Assistance
- H. G. Moody--FRA Office of Research and Development
- P. Olekszyk--FRA Office of Research and Development
- W. B. O'Sullivan--FRA Office of Research and Development
- W. R. Paxton--FRA Office of Rail Safety
- J. K. Anderes--The MITRE Corporation
- R. A. Martin--The MITRE Corporation
- J. L. Milner--The MITRE Corporation
- M. J. Zobrak--The MITRE Corporation

A two-round evaluation procedure was followed at the conference. In the first round, the panelists provided estimates of other impacts, criterion weights, and subprogram risk based on a review of track system problems, corresponding subprograms and the objective evaluation measures. In the second round, the panel was given an opportunity to revise their estimates based on a comparison of individual estimates with those of the group as a whole. The results of round two became the principal output of this study.

Prior to the conference, each panelist was sent a notebook containing the following:

- description of how the conference would be conducted
- description of the evaluation and ranking process
- subprogram summary descriptions containing the objectively determined evaluation measure (see Section 4.0)
- subprogram detailed description (see Appendix D)
- benefit calculation details

The panelists were asked to review at least the first three of these items before arriving at the conference.

At the conference, the initial step was to provide the panelists with enough background information to perform their task. Toward that end, the following items were reviewed:

1. Process and results of identifying and ranking track system problems.
2. Process and results of defining subprograms.
3. Process and results of determining the objective evaluation measures.
4. Process of obtaining and incorporating the subjective judgement of the panel.

A brief question and answer period followed, after which each panelist was given an evaluation form such as that shown in Figure F-2 and asked to provide estimates of the 32 factors listed on it. Upon completion, the forms were collected by the study staff and the data was entered into a computer via a portable, remote terminal. The program produced a set of tables with the following information:

1. For each subprogram, the score and rank for each evaluator and for the entire group.
2. For each criterion, the weight assigned by each evaluator and the group average.
3. For each subprogram, the estimate of other impacts made by each evaluator and the group average.
4. For each subprogram, the estimated probability of success by each evaluator and the group average.

The latter three tables were reviewed by the study staff and the extreme estimates identified. The tables were then reproduced and distributed to the panelists. Panelists who made the extreme extimates were given an opportunity to state their rationale for the extreme values. After the rationales were presented, and changes made, the forms were again collected and the data entered into the computer. A

Criteria Weighting Factors	
Criterion	Weight w_k $0<w_k<1$
Benefit-Cost Ratio	0.50
Safety Impact	0.20
Capital Savings	0.15
Timeliness	0.05
Other Impact	0.05
R&D Cost	0.05
Total	1.00

Subprogram Risk and Other Impact Measures			
ID	Title	Probability of Success q $0\leq q\leq 1$	Other Impacts m_6 $-5\leq m_6\leq +5$
A	Track System Handbook	0.75	2.5
B	Improved Lateral Track Stability.	0.60	1.0
C	Improved Rail Metallurgy.	0.70	2.5
D	In-Place Rail Hardening	0.25	2.5
E	Improved Thermite Welding	0.75	2.0
F	On-Site Electric Flash-Butt Welding	0.60	2.5
G	In-Place Rail Welding	0.25	2.5
H	Bolt-Hole Crack Prevention.	0.90	2.0
I	In-Place Bolt-Hole Crack Restraint.	0.75	0.0
J	Improved Wood-Tie Fasteners	0.75	3.0
K	Improved Wood-Based Tie	0.85	1.5
L	In-Place Repair of Spike-Killed Ties.	0.90	1.5
M	Improved Concrete Tie and Fastener Selection Criteria and Utilization.	0.75	2.0

FIGURE F-2
SAMPLE: EVALUATOR SCORING SHEET

TABLE F-3

ESTIMATED WEIGHTS OF EVALUATION CRITERIA BY EVALUATOR

EVALUATOR	WEIGHTS					
	BENEFIT-COST RATIO	SAFETY IMPACT	CAPITAL SAVINGS	TIMELINESS	OTHER IMPACTS	R&D COST
1	0.15	0.10	0.25	0.25	0.15	0.10
2	0.50	0.10	0.10	0.15	0.15	0.10
3	0.30	0.20	0.15	0.10	0.15	0.10
4	0.30	0.10	0.15	0.05	0.35	0.05
5	0.70	0.10	0.10	0.10	0.0	0.0
6	0.40	0.25	0.05	0.25	0.05	0.0
7	0.50	0.20	0.15	0.05	0.05	0.05
8	0.05	0.20	0.25	0.30	0.15	0.05
9	0.50	0.15	0.15	0.10	0.05	0.05
10	0.30	0.20	0.20	0.10	0.05	0.15
11	0.40	0.15	0.20	0.05	0.05	0.15
12	0.50	0.15	0.10	0.15	0.05	0.05
13	0.60	0.05	0.10	0.10	0.05	0.10
14	0.50	0.20	0.10	0.10	0.10	0.0
15	0.50	0.10	0.20	0.05	0.10	0.05
16	0.30	0.20	0.20	0.10	0.05	0.15
17	0.30	0.25	0.10	0.05	0.20	0.10
18	0.40	0.10	0.25	0.10	0.10	0.05
19	0.30	0.10	0.30	0.10	0.10	0.10
20	0.50	0.15	0.15	0.10	0.05	0.05
GROUP AVE.	0.40	0.14	0.16	0.12	0.09	0.07

TABLE F-4

ESTIMATED VALUE OF OTHER IMPACTS CRITERION* BY SUBPROGRAM

EVALUATOR	SUBPROGRAM												
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	1.0	0.5	0.0	0.0	0.5	0.0	0.0	0.0	-1.0	1.0	1.0	0.0	-1.0
2	2.0	0.5	1.0	1.0	0.5	2.0	1.0	1.0	-4.0	0.5	1.5	0.5	3.0
3	4.0	2.0	2.0	1.0	0.5	0.5	0.5	1.0	1.0	1.0	0.0	0.0	2.0
4	2.5	3.0	0.0	2.5	2.5	2.5	2.5	2.5	0.0	3.0	0.0	0.0	0.0
5	1.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
6	3.0	0.0	2.0	2.0	0.0	0.0	1.0	2.0	0.0	0.0	1.0	0.0	0.0
7	2.5	1.0	2.5	2.5	2.0	2.5	2.5	2.0	0.0	3.0	1.5	1.5	2.0
8	2.5	0.0	3.0	0.0	1.5	0.0	0.0	2.0	1.5	1.0	1.0	1.0	1.0
9	3.0	1.5	2.5	1.0	0.0	0.0	1.0	2.5	1.5	3.0	1.0	1.0	2.0
10	3.0	1.5	1.5	-1.0	1.0	0.0	-1.0	2.0	0.0	2.0	0.0	2.0	3.0
11	5.0	4.0	2.0	0.0	0.0	1.0	-5.0	-1.0	-2.0	0.1	0.1	-1.0	2.0
12	1.0	0.1	0.2	0.2	0.1	0.2	0.2	0.1	0.1	0.1	0.1	0.0	0.0
13	1.0	2.5	2.5	1.0	1.0	2.0	2.0	1.0	0.0	0.0	1.5	1.0	1.0
14	-1.0	0.0	4.0	-2.5	-1.0	0.0	-5.0	-1.0	-1.0	1.0	4.0	3.0	-5.0
15	-3.0	5.0	0.0	0.0	2.5	-1.0	-2.5	-2.5	-2.5	0.0	5.0	5.0	0.0
16	3.0	0.5	1.0	2.0	2.5	1.0	1.0	0.0	0.0	1.0	1.5	1.5	1.0
17	0.5	2.0	1.0	0.5	0.5	0.5	0.5	1.0	0.5	0.5	0.1	0.5	2.0
18	1.0	1.0	2.0	1.0	1.0	-1.0	-1.0	0.0	0.0	1.0	0.0	0.0	1.0
19	4.0	3.0	2.0	1.0	2.0	-3.0	-3.0	3.0	0.0	0.0	3.0	-2.0	3.1
20	1.0	1.0	3.0	0.0	1.0	1.0	-1.0	-1.0	0.0	1.0	2.0	2.0	0.0
GROUP AVE.	1.85	1.45	1.61	0.71	0.90	0.41	-0.31	0.73	-0.29	0.96	1.21	0.80	0.86

*Based on a scale of -5 to +5.

TABLE F-5

EVALUATOR ESTIMATED R&D RISKS* BY SUBPROGRAM

EVALUATOR	SUBPROGRAM												
	A	B	C	D	E	F	G	H	I	J	K	L	M
1	0.65	0.75	0.50	0.10	0.30	0.50	0.00	0.70	0.10	0.50	0.35	0.50	0.50
2	0.85	0.70	0.40	0.80	0.60	0.75	0.30	0.75	0.40	0.50	0.50	0.55	0.75
3	0.80	0.30	0.60	0.40	0.70	0.70	0.20	0.70	0.40	0.60	0.10	0.40	0.70
4	0.80	0.50	0.50	0.40	0.40	0.40	0.40	0.90	0.50	0.75	0.50	0.90	0.50
5	0.10	0.60	0.60	0.10	0.70	0.60	0.10	0.70	0.40	0.10	0.10	0.60	0.20
6	0.80	0.05	0.50	1.10	0.50	0.50	0.25	0.70	0.50	0.10	0.20	0.60	0.90
7	0.75	0.60	0.70	0.25	0.75	0.60	0.25	0.90	0.75	0.75	0.85	0.90	0.75
8	0.80	0.55	0.20	0.25	0.65	0.30	0.10	0.70	0.10	0.35	0.35	0.35	0.05
9	0.50	0.10	0.40	0.20	0.20	0.90	0.10	0.60	0.30	0.30	0.10	0.20	0.30
10	0.80	0.40	0.40	0.40	0.70	1.00	0.20	0.90	0.60	0.40	0.30	0.70	0.90
11	0.90	0.50	0.80	0.30	0.90	0.90	0.20	0.70	0.60	0.80	0.90	0.90	0.50
12	0.65	0.70	0.70	0.60	0.70	0.65	0.50	0.80	0.60	0.40	0.50	0.50	0.50
13	0.40	0.40	0.35	0.90	0.30	0.50	0.25	0.60	0.40	0.50	0.60	0.60	0.75
14	0.75	0.05	0.90	0.05	0.50	0.50	0.05	0.75	0.60	0.50	0.75	0.75	0.40
15	0.75	0.75	0.0	0.0	0.50	0.90	0.25	0.50	0.50	0.0	0.90	0.90	0.0
16	0.40	0.40	0.50	0.10	0.30	0.40	0.20	0.50	0.30	0.30	0.40	0.20	0.60
17	0.50	0.75	0.60	0.50	0.50	0.50	0.50	0.60	0.50	0.60	0.50	0.30	0.75
18	0.80	0.50	0.80	0.50	0.90	0.50	0.30	0.50	0.50	0.70	0.30	0.50	0.70
19	0.80	1.50	0.50	0.30	0.50	0.20	0.10	0.70	0.40	0.20	0.30	0.10	0.40
20	0.60	0.10	0.20	0.05	0.30	0.75	0.20	0.05	0.05	0.10	0.30	0.50	0.20
GROUP AVE.	0.67	0.46	0.51	0.31	0.54	0.60	0.22	0.66	0.42	0.42	0.44	0.55	0.52

*Probability of achieving subprogram objective; scale, 0 to 1.

similar set of tables was produced, reproduced and distributed to the panelists. Tables F-3, F-4, and F-5 present the results of this process. Table F-3 presents the evaluation criteria weighting factors. Group averages, used to determine the final rank of each subprogram, indicate that evaluators considered economic criteria (e.g., benefit-cost ratio and capital savings) the most important of all factors. Agreement between evaluators varied depending upon the criterion. For example, more than half of the evaluators tended to exceed the group average for the R&D cost and other impacts measures. The reverse was true for the capital savings and R&D timeliness criteria. For the remaining two measures, benefit-cost ration and safety impact, the evaluators were more evenly distributed around the group average.

Tables F-4 and F-5 show how evaluators rated each subprogram for the more subjective evaluation measures--other impacts and R&D risk, respectively. For all subprograms except G (In-Place Rail Welding) and I (In-Place Bolt-Hole Crack Restraint), evaluators estimates of other impacts were fairly evenly distributed around the group average. For subprograms G and I, the evaluators tended to produce large negative ratings--suggesting that these R&D programs may have rather low effects on RR operation.

On the whole, estimates of R&D risk for all subprograms were somewhat more consistent, although conservative. Subprograms D (In-Place Raid Hardening) and G (In-Place Rail Welding) were the only sub-programs for which evaluators felt the achievement of the R&D objectives was somewhat speculative.

Values of the evaluation measures used as input to the ranking process are shown in Table 5-2. Although presented independently for each subprogram, these values are grouped via the ranking methodology to help arrive at a rank-ordered priority list of subprograms.

F-3 Ranking

There are several methods by which the evaluation parameters discussed above could have been combined to produce the desired rank-ordered list of subprograms. Two had more appeal than the others.

In one method, the objective measures developed by the project staff would be combined with the evaluator's subjective data to yield the evaluator's score for each subprogram. A rank-ordered list of subprograms would then be produced for each evaluator on the basis of each score. To obtain a composite rank-ordered list reflecting the inputs of all evaluators, the individual lists would be combined by assuming each list to be of equal importance or weight, and by adding all evaluator scores, to obtain total score for each subprogram. A rank-ordering on the basis of total score would produce the desired list.

In the second method, an average value of each of the objective measures, R&D risk, and the other impacts measure would be computed for the group of evaluators as a whole. These would then be combined with the objective measures to yield composite subprogram scores from which the desired rank-ordered list would be readily obtained.

There was no significant basis for choosing one method over the other. Since a choice had to be made, and since each evaluator was, in all likelihood, interested in seeing his own rank-ordered list relative to the composite of the group, the former method was chosen over the latter.

The ranking scores mentioned above were determined by a simple linear combination of the weights and measures, modified by the risk factor (q). More specifically, if s denotes the score and q its probability of success, then

$$s = (w_1m_1 + w_2m_2 + w_3m_3 + w_4m_4 + w_5m_5)q + w_6m_6$$

where the w's are the weighting factors and the m's represent the measures derived from the z's which were described in Section 5.2.2.

Note that the probability of success modified only the benefit measures and not the R&D cost measure, m_6. A value of s was computed for each subprogram evaluated by each evaluator. Table 5-3 contains these scores for each evaluator. Table 5-4 summarizes the results of the evaluation conference, listing the score and rank of each of the thirteen subprograms.

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