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RAILER Engineered Management System

Development of Condition Indexes for Low Volume Railroad Track

by
D. R. Uzarski

The U.S. Navy and U.S. Army together own over 5700 miles of railroad track that are vital to the mobilization and operational needs of the Department of Defense. Track managers need a method to assess current track conditions, predict future track conditions, establish track deterioration rates, formulate budgets, and determine and prioritize renewal projects.

In response to this need, the U.S. Army Construction Engineering Research Laboratories (USACERL) developed track component group condition indexes based primarily on visual inspection condition surveys and supplemented by inspection and operating criteria from various track standards and internal rail flaw testing information, if available.

This report describes the development of the indexes. A separate, follow-on report (USACERL Technical Report FM-93/14, July 1993) provides track inspectors with a standard reference for identifying track distresses and calculating condition indexes.

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FOREWORD

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The work was performed by the Engineering and Materials Division (FM) of the Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL) in cooperation with the University of Illinois. Dr. Paul A. Howdyshell is Chief CECER-FM. Dr. Michael J. O'Connor is Chief, CECER-FL. The USACERL technical editor was Gloria J. Wienke, Information Management Office.

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LTC David J. Rehbein is Commander of USACERL and Dr. L.R. Shaffer is Director.

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1 INTRODUCTION

Background

The U.S. Navy and the U.S. Army together own over 5700 miles* of railroad track that are vital to the mobilization and operational needs of the Department of Defense (Naval Facilities Engineering Command [NAVFAC] 1987; Hilsabek 1989; U.S. Army Corps of Engineers 1987). Civilian local railroad companies that conduct switching, terminal, and linehaul activities control another 19,000 miles of track, which is approximately 10 percent of the entire commercial sector (Association of American Railroads 1988). This track is predominately low volume, carrying less than approximately 5 million gross tons per year (MGT/year) and serves a transportation niche essential to the economic well being of the United States.

Regardless of whether the primary motive is mission readiness (military) or profit (commercial), there is a need for a simple and practical condition assessment method that can help maintenance managers perform the following tasks:

- Assess current track conditions,
- Predict future track conditions,
- Establish track deterioration rates,
- Determine and prioritize current and long range maintenance and repair (M&R) needs,
- Formulate budgets, and
- Measure the effectiveness of M&R.

The assessment method also must be objective and repeatable so similar results are obtainable by different people. Such a procedure does not currently exist for low volume track.

In an effort to standardize and add structure to the maintenance management process of military track networks (with a spin-off application to local railroads), the U.S. Army Construction Engineering Research Laboratories (USACERL) has developed a microcomputer-based decision support system called the RAILER Engineered Management System (EMS) (Shahin 1986; Uzarski, Plotkin, and Brown, September 1988; Uzarski and Plotkin 1989; *Modern Railroads* 1989). As an enhancement, a condition assessment method was needed in RAILER to support the needs addressed above. The method chosen took the form of condition indexes to supplement the existing track standards criteria.

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* A metric conversion table is on page 74.

Objective

The research objective was to develop unbiased and repeatable condition indexes for the component groups of rail, joints, and fastenings; wooden cross ties and switch ties; and ballast, subgrade, and roadway; as well as an overall Track Structure Condition Index, based primarily on visual inspection surveys, supplemented by other methods, when appropriate. The indexes must be able to objectively and quantitatively measure the overall condition of track segments. The indexes should be capable of aiding in determining M&R needs on a categorical basis, developing work plans, measuring the effectiveness of work accomplishment, establishing deterioration rates, projecting condition trends, and prioritizing M&R work.

Approach

This report presents the results of work performed during fiscal years 1989 through 1991. Previous work accomplished for RAILER EMS development revealed that there was no existing condition index methodology for railroad track that met the criteria cited in the previous paragraph. Therefore, it was necessary to develop a method.

Early in the development stage, it became apparent that one index for railroad track that encompasses all components would not yield meaningful results for developing M&R strategies. Therefore, separate indexes were developed for the component groups of rail, joints, and fastenings (RJCI); ties (TCI); and ballast, subgrade, and roadway (BSCI). These component indexes were then compiled into an overall track structure condition index (TSCI).

The development of the RJCI, TCI, and BSCI followed, generally, the same concepts used in the development of the pavement condition index (PCI) (Shahin, Darter, and Kohn 1976; Shahin and Kohn 1979), the roofing membrane condition index (MCI), and the roofing flashing condition index (FCI) (Shahin, Bailey, and Brotherson 1987). These indexes are enjoying widespread acceptance and use.

Organization of Report

Chapter 2 outlines the current state-of-the-art regarding track condition evaluation and track management. Chapter 3 describes the condition index concept. The concepts behind the subjective rating panel approach to index development are provided in Chapter 4. Chapter 5 outlines the plan used to actually develop the condition indexes. Chapters 6 through 8 present the research results for rail, joints, and fastenings; ties; and ballast, subgrade, and roadway, respectively. The TSCI, itself, is presented in Chapter 9. Finally, the conclusions and recommendations are provided in Chapter 10.

Technical Report FM-93/14 (Uzarski 1993) is a condition survey and distress manual. The various distresses for rail, joint, and fastenings; ties; and ballast, subgrade, and roadway are defined and pictured. Procedures for condition index calculations are provided.

Mode of Technology Transfer

The condition indexes will be incorporated into the RAILER EMS and released via a future RAILER version. All existing RAILER subscribers will automatically receive the update from the RAILER Support Center. New subscribers will receive RAILER upon receipt of their request and fee. This condition index method will also be documented in a technical manual describing railroad track management. Training on the indexes will be done in conjunction with the established RAILER EMS short course.

2 CURRENT INSPECTION AND CONDITION ASSESSMENT PRACTICES AND THEIR USE IN TRACK MANAGEMENT

Condition assessment implies an inspection process to gather essential information on which to base the assessment. Any method developed for condition assessment must take into account the type and amount of inspection information gathered and the method used for that gathering. Thus, the inspection process itself must contribute to the assessment purpose and method.

Before developing the track condition indexes, a survey of existing track inspection and condition assessment practices was performed. These are described in this chapter. A brief discussion on the use of condition assessment information using the RAILER Engineered Management System (EMS) for track management is also given.

Track Inspection Categories

The term "inspection" has different implications regarding intent and level of effort. With railroad track, inspections are generally divided into two categories: safety and maintenance. Both are discussed below.

Safety

Safety inspections are required per applicable track standards (FRA 1982, Technical Manual [TM] 5-628, NAVFAC 1988 [Draft]). The intent is to inspect the track on a frequency (e.g., weekly) depending on use in order to discover track defects that may result in unsafe train operations. If any significant defects are found, the track or track segment is classified to a lower operating level (with an appropriate reduction in train speed) or perhaps classified "no operations" until the defect is corrected. These inspections generally do not result in the collection of large amounts of data. Rather, "exception" information is desired; changes from the last inspection that would lead to unsafe train operations if not discovered.

Maintenance

Maintenance inspections are broadly classified as those necessary for planning a practical M&R program. The program can range from relatively small projects scheduled for accomplishment by local or section forces to major capital investment projects scheduled for accomplishment by contractors or dedicated work gangs. Inspection frequency varies by agency or company policy, but maintenance inspections will be much less frequent than safety inspections. Maintenance inspections may be performed in conjunction with one or more safety inspections, or separately. The level of detail must be sufficient to plan projects and quantify work needs.

Track Inspection Methods

Two methods for track inspection are currently used by the railroad industry: visual and automated. Both methods and their application to commercial and military railroads are described below.

Commercial Railroad Industry

The commercial (large and small) railroad industry continually conducts visual track inspections. Railroad company road masters and section foremen regularly patrol track either on foot or in a track vehicle at a speed conducive to inspection looking for safety defects that require rapid attention (discussed above) and for minor items that can be scheduled for accomplishment by section M&R workers.

Additionally, well qualified and experienced inspectors from the Federal Railroad Administration (FRA) routinely visually inspect commercial track (FRA 1982). This is done in the public interest for safety. Visual inspections are also used to plan major M&R efforts such as periodic spot tie renewal projects. The inspection process works well.

A small variety of automated inspection procedures have been developed. Mass track geometry inspection information such as gauge, cross level, warp, profile, and alignment is commonly obtained through automated procedures with the use of a high-rail track vehicle or a specially equipped railroad car. Rail flaws not visible with the naked eye are routinely detected through automated induction or ultrasonic means (Sperry Rail Service 1964). Specialized equipment for determining rail profile, wear, and corrugations also exists (*Electronic Rail Eye 1986*; *RAC Rapidly Records Rail Condition 1987*). All of these inspection types are either performed by railroad company personnel or by specialty contractors. Track geometry and rail flaw inspections are performed quite often on large railroads depending on the operating speed and importance of a given track. However, they are used only infrequently (generally, rail flaw more often than geometry) on many small railroads where slow speeds (under 40 miles per hour [mph]) are normal.

Military Trackage

Within the military, a visual approach is also used for identifying both safety defects that require quick corrective action and M&R items that should be scheduled for accomplishment (NAVFAC 1988 [Draft]; NAVFAC 1988; NAVFAC 1977; NAVFAC 1975; NAVFAC 1985; Technical Manual [TM] 5-628 1991; Army Regulation [AR] 420-72; Facilities Engineering Support Agency [FESA] 1979). Automated track geometry information is generally not collected although spot manual checks are performed where deemed necessary. Also, much of the track has not received a rail flaw inspection in many years. When automated track geometry and rail flaw inspections are performed, they are done by contract. The FRA generally does not inspect military trackage.

Condition Assessment Methods

Different inspection-based methods for assessing railroad track conditions have been or are being used. These include condition codes, track standards, and various quality indexes. These are discussed below.

Condition Codes

The use of condition codes has been practiced by the military for assessing an overall track network condition with regard to mission readiness (NAVFAC 1988 [Draft]; FESA 1979; Office of the Chief of Naval Operations 1987 and 1985). Table 1 shows these ratings, which embody subjective opinion. Also, since the ratings represent broad condition category ranges, minor or moderate changes in condition cannot be ascertained. Thus, while this method may serve an intended purpose, it is wholly inadequate for track management.

Track Standards

The track standards approach is widely used in both the commercial and military sectors for condition assessment. Various standards have been developed by different Federal agencies for the primary purpose of ensuring track safety (FRA 1982), and safety combined with specific maintenance levels (NAVFAC 1988 [Draft]; TM 5-628 1991). Commercial railroads (large and small) may also have developed standards for their internal use. The FRA standards are applicable to commercial railroads (FRA 1982). The military services have their own standards (NAVFAC 1988 [Draft]; TM 5-628 1991).

Table 1

Military Trackage Condition Ratings

Rating		Description
	Navy	
1		Facility (trackage) is in a condition to fully meet all demands placed upon it.
2		Facility (trackage) is in a condition to substantially meet all demands placed upon it with only minor difficulties.
3		Facility (trackage) is in condition to only marginally meet the demands placed upon it with major difficulty.
4		Facility (trackage) is in such condition that it cannot meet mission demands.
	Army	
C1		Ties, rail, ballast and other track components are in good condition.
C2		Ties, rail, ballast and other track components are beginning to show excessive wear or deterioration.
C3		Ties, rail, ballast and other track components have deteriorated beyond economical restoration. Operation of the railroad presents continuing hazards to equipment and personnel.

If specific track defects are found during the inspection process, the portion of track is placed into the appropriate condition category associated with the applicable standard. Speed restrictions affiliated with the condition categories are imposed on the affected track portions until the defects are repaired through appropriate M&R. Table 2 shows a comparison of different track standards.

Since the military must be concerned with mission accomplishment, their standards incorporate the concept of minimum operating levels based on intended track use. The goal of the installation maintenance manager is to keep the track at or above certain operating levels through appropriate M&R, thus ensuring mission capability. The military standards represent a minimum desired condition level.

At the other end of the condition spectrum would be the design standards used to originally construct the track. These standards have no value in maintenance management since few, if any, railroads maintain their track to that level (Fazio and Corbin 1986).

These various standards serve the invaluable purposes of setting desired or required condition levels and restricting train speeds if the desired or required condition levels are not met. They do not, however, provide a condition rating reflective of the overall condition of a track network, specific tracks, track portions, or components. Condition can only be classified generally in terms of meeting or not meeting the discreet requirements of a standard. This is because the identification of defects, per se, does not measure condition, even though certain defects may place the track into a specific condition category relative to a set of track standards. Condition should be considered a continuous function and should bridge the gap between the discreet design and safety standards.

Although current M&R needs can be determined with respect to an appropriate standard, condition prediction is not possible nor can future work needs and budgets be determined. This is because deterioration rates cannot be determined nor modeled for predicted performance.

Table 2

Various Track Standards Condition Categories

U.S. Navy Maint/Safety	U.S. Army*	Federal Railroad Administration
A: Mainline/Spurs	Full Compliance (Posted Speed)	Class 6 (110 mph)
B: Sidings/Spurs No Restriction	10 mph	Class 5 (80 mph)
C: Low Use Restricted Operations	5 mph	Class 4 (60 mph)
D: Inactive Stop Operations**	No Operations**	Class 3 (60 mph)
		Class 2 (25 mph)
		Class 1 (10 mph)
		Below Class 1 (Stop Operations**)

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*The U.S. Air Force has adopted the U.S. Army track standards.

**Operations may continue subject to requirements of standard.

Track Quality Indexes

A family of automated track geometry-based condition indexes have been developed that are commonly known as Track Quality Indexes (TQIs) (Fazio and Corbin 1986; Bing and Gross 1982; Bing 1983; Zarembski July 1987; Zarembski August 1987). The various TQIs generally measure different statistically based parameters (e.g., standard deviation) derived from alignment, profile, crosslevel, warp, and gauge measurements. Because of the expense associated with the data collection, TQIs are generally limited to important high-speed and/or high-tonnage lines. However, low speeds, certain track conditions, and car harmonics can lead to derailments. Certain indexes have been developed to measure that potential (Weinstock, Lee, and Greif 1987). TQIs have been useful for M&R planning (Hamid et al. 1980; "Track Inspection Mechanized, Automated, Computerized" 1971; Gary 1973; "CP Rail Projects New Uses for Track Geometry Car" 1975; Fazio and Prybella 1986).

Since military and most local trackage represents a slow-speed, low-volume operation and because automated track geometry typically is not collected (discussed above), these indexes are not applicable or useful (Solverson, Shahin, and Burns 1984). No indexes, based primarily on routine visual inspections, have been developed for low volume (less than approximately 5 MGT/year) track–typical of that found on military and local railroads.

Railroad Track Management System (RAILER)

In an effort to standardize and add structure to the maintenance management process of military track networks (with a spin-off application to local railroads), the U.S. Army Construction Engineering Research Laboratories (USACERL) has developed a microcomputer-based decision support system called

RAILER (Shahin 1986; Uzarski, Plotkin, and Brown August 1988). This development has come about due to the absence of such systems from small railroads (Solverson, Shahin, and Burns 1984). Some large railroads do use computer-based approaches to track management (Hamid et al. 1980; "Track Inspection, Mechanized, Automated, Computerized 1971; Gary 1973; "CP Rail Projects New Uses for Track Geometry Car" 1975; Fazio and Prybella 1986).

RAILER, which consists of field-tested component identification, inventory, and inspection information collection procedures, and software for data analysis, is currently used, in part, to evaluate track against sets of standards and to develop work plans. Essential to RAILER implementation and use is the identification of logical "management units" called track segments (Uzarski, Plotkin, and Brown August 1988; Uzarski, Plotkin, and Wagers 1988). Each segment has relatively uniform inventory elements, construction history, and use. Figure 1 shows an example network divided into segments.

The RAILER approach to track management makes extensive use of the track segment concept. In part, each segment is rated to form the basis for work planning and budgeting. RAILER presently uses track standards for assessing condition. The condition indexes described in this report are planned for early incorporation.

RAILER is designed to permit the user to manage a given track network at two distinct management levels: network and project (Uzarski, Plotkin, and Brown, September 1988). Although RAILER currently uses track standards as the basis for management decisions, the full range of management activities

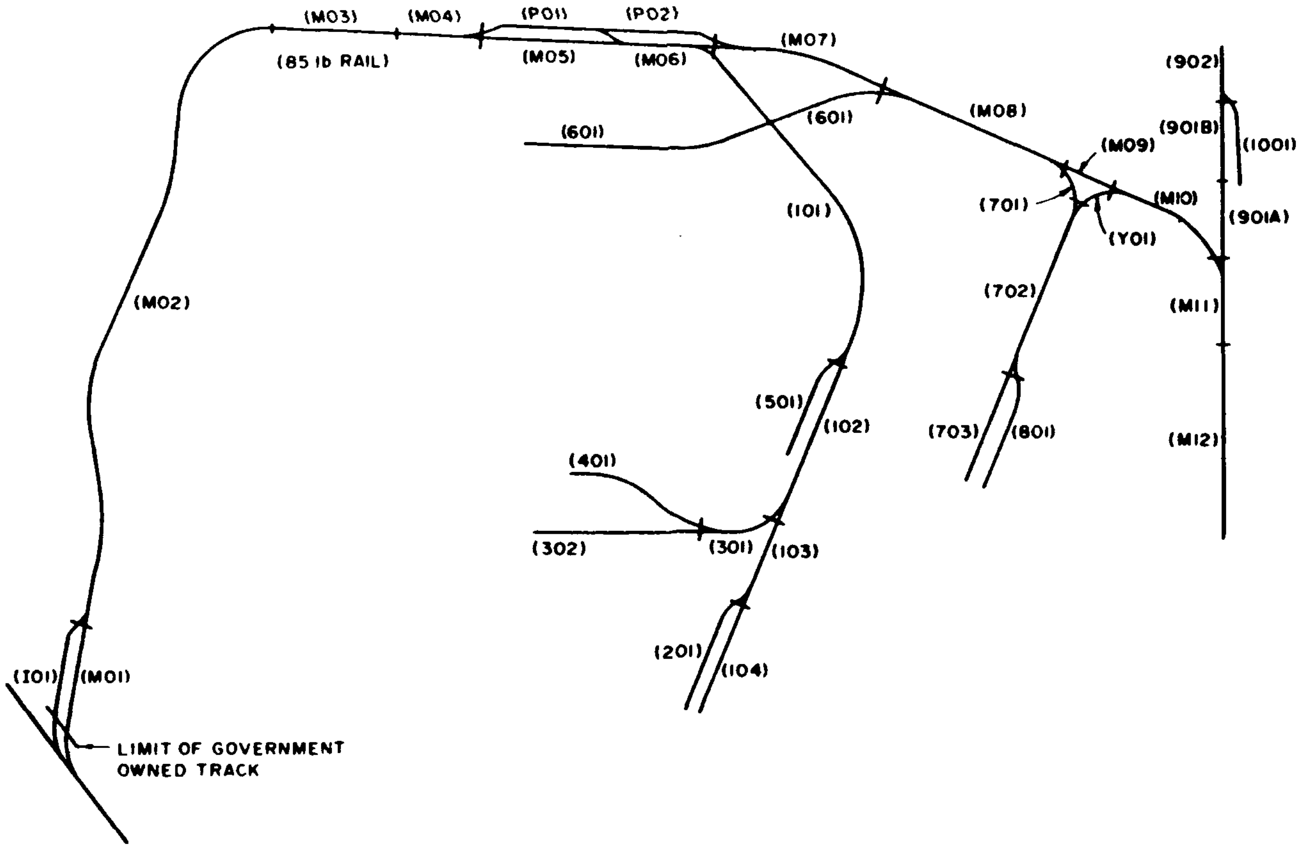


Figure 1. Example Segmented Track Network.

synopsized in Chapter 1 is not possible. Only through the introduction of condition indexes developed specifically for military and local trackage using maintenance inspection procedures routinely employed can these activities be fulfilled. The following discussion briefly explains how condition indexes will be used for track management.

Network Level Management

Network level management focuses on the entire group of track segments that constitute the network. Management at this level encompasses decisions focusing on the "where," "when," and "how much" aspects of track management as well as budget planning.

The developed condition indexes will play a key role at this level. Current condition assessments and future condition projections will be the heart of the management process. Critical index values will be determined whereby track segments that are below the critical value are candidates for scheduled M&R. These candidate track segments will then be prioritized for actual work accomplishment and long range (5 or more years) work plans will result. Budgets will be developed based on anticipated needs by correlating costs to projected future year index values.

Network level management with RAILER will permit "what if" analyses to be made. For example, the costs (budgets) associated with establishing a minimum acceptable condition index at various target levels could be computed. Also, the effects of deferred maintenance or budget cuts, in terms of index value reduction, could be determined.

Periodic maintenance inspection information will be needed to make network level management successful. As part of the condition indexes development, an improved predominately visual inspection procedure called a "condition survey inspection" has also been developed that is conducive to index computation. This will be discussed further in the next chapter.

Project Level Management

Project level management is only performed on specific track segments scheduled for M&R in the next annual work plan. This level focuses on problem diagnosis, cost analyses, and selection of the most appropriate M&R alternative. A detailed condition evaluation is needed for the diagnosis. The RAILER system currently incorporates a visual maintenance inspection procedure (referred to as a "detailed inspection") to aid in this evaluation (Uzarski et al. 1993 [Draft]; Brown, Uzarski, and Harris 1990).

Condition indexes will be used to measure, on a segment basis, the condition gain associated with given alternatives and any expected change in deterioration rate.

Summary

Although useful and meaningful for their intended purpose, current condition assessment practices do not lend themselves to network and project level management activities associated with low density track networks. The development of condition indexes based on inspection procedures that are easily implemented on military and local railroads will permit a full range of network and project level activities to occur. The indexes will further enhance the capabilities of the RAILER EMS.

3 CONDITION INDEX CONCEPT

The need for a condition index was established in Chapter 2. This chapter focuses on the index concept, and provides a discussion on the specific rating scale used in the development. A discussion on the need for track structure component condition indexes and the selection of the components needing indexes follows. The TSCI and the component indexes are defined as to what they are intended to represent. Also, a short narrative on the condition survey inspection procedures to be used with index use is given. Finally, the development criteria used to create the indexes are outlined.

Condition Index Scale

USACERL has developed a variety of condition indexes for different types of facilities over the past few years. These include the Pavement Condition Index (PCI) for airfield and road and street pavements (Shahin, Darter, and Kohn 1976; Shahin and Kohn 1979), the Roof Condition Index (RCI) for built-up roofs (Shahin, Bailey, and Brotherson 1987), and the Corrosion Status Index (CSI) of certain piping systems (Kumar, Riggs, and Blyth 1986). USACERL is also developing a family of condition indexes for different types of civil works structures (Koehn and Kao 1986).

The USACERL condition indexes were designed to provide an objective and quantitative means for facility condition assessment while providing for a common language and interpretation among users. The scale used in all of the USACERL indexes ranges from 0 to 100 and is divided into seven condition categories (Figure 2). Most of the condition indexes are based on the identification of observable distresses.

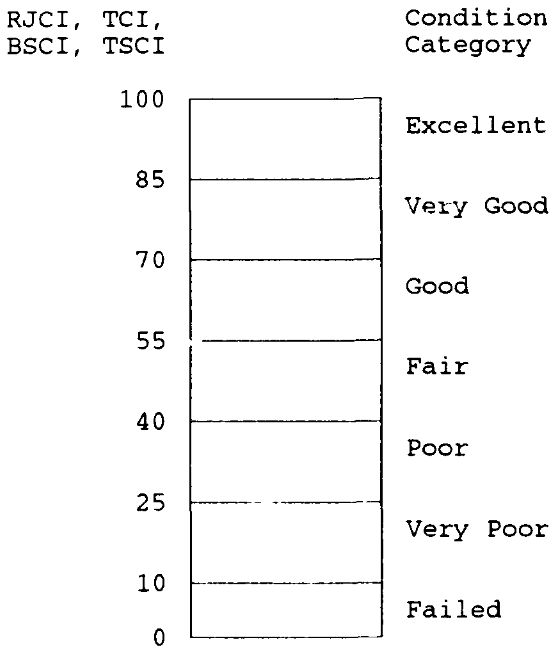


Figure 2. Condition Index Scale.

From an M&R perspective, the USACERL indexes serve to measure the overall condition of the facility and correlate to M&R needs and required budget levels (Shahin, Darter, and Kohn 1977a and 1977b; Reichelt et al. 1987; Bailey et al. 1989). The indexes can also be used to historically map the facility condition over time (Figure 3) so rates of deterioration can be determined. When combined with facility degradation models, the indexes can be used to predict future conditions (Kumar, Riggs, and Blyth 1986; Bailey et al. 1989; Shahin and Walther 1990). Knowing past, current, and projected conditions and deterioration rates, the foundation is established for developing M&R strategies, budgets, and work plans. Deterioration modeling has been recognized as an important element in track maintenance planning (Bing 1983; Hamid et al. 1980; Webb 1985; Tew, Davis, and Dwyer 1986).

An identical 0 to 100 scale is used in this work. Within the military, the track condition indexes will be used in conjunction with other facility condition indexes developed by USACERL. Therefore, a similarity in scale is useful in the track condition indexes, as well.

Track Components

A railroad track structure consists of many different components including the subgrade, subballast, ballast, cross ties, rail, fastenings, and other track material. Special trackwork such as turnouts and crossings may also be considered components. Also, other components may encompass such items as the roadway (right-of-way), drainage ditches and structures, signals, and grade crossings. A discussion of each of these is provided elsewhere (Hay 1982).

The first challenge of index development was to decide what components to consider. The various track components are very different in material type, function, deterioration mode and cause, and required M&R actions. Because of these differences, it became apparent that a single condition index for track

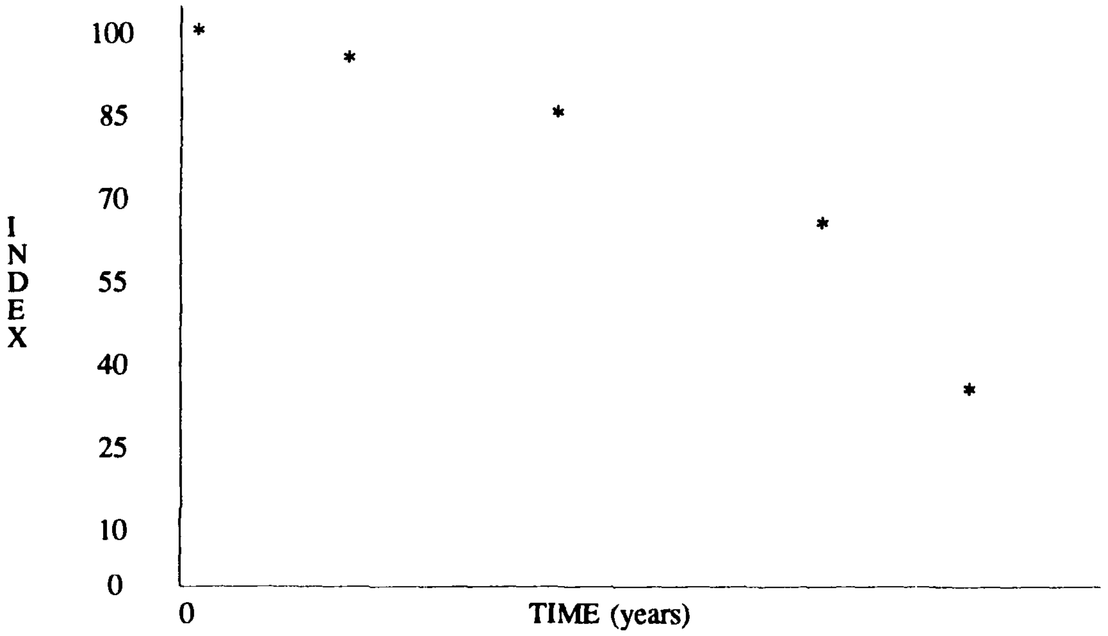


Figure 3. Condition Index Over Time.

would not be adequate because a single number would not indicate in which components the M&R problems occurred. Problems could be in the cross ties, rail, or a combination of components and, thus, it would be very difficult to correlate a single index to M&R needs and budgets. Different indexes for key components are needed as part of the overall TSCI development if accurate and meaningful condition representations are to be made.

Figure 4 shows a typical track cross section. Rail, cross ties, ballast, and subgrade make up the four major structural components. If ballast and subgrade are combined, the resulting three components also consist of vastly different materials; steel for rail, wood (predominately) for cross ties, and soil for ballast and subgrade. Thus, these three components became logical candidates for index development.

Many other components were joined with these three to form component groups around which the indexes were developed. Joint bars, compromise joints, insulated joints, track bolts, hold-down devices (spikes, screws, clips, etc. used to secure rail to the cross ties), tie plates, rail anchors, and gauge rods are all common components directly related to rail and all are made of steel. Thus, these were combined with rail into a single rail, joints, and fastenings component category. Cross ties were expanded to include switch ties (used with turnouts) to form a single category of ties. Likewise, ballast and subgrade were expanded into a category that includes subballast, drainage (ditches and culverts), and roadway (right-of-way) adjacent to track. Component condition indexes were developed for each of these three component groups and are called the RJCI (Rail and Joints Condition Index), TCI (Tie Condition Index), and BSCI (Ballast and Subgrade Condition Index).

Index Representation

Given that the TSCI, RJCI, TCI, and BSCI range from 0 to 100, a definition was developed as to what the indexes are intended to represent. Also, an explanation of the intent of what the different condition categories (see Figure 2) represent was delineated.

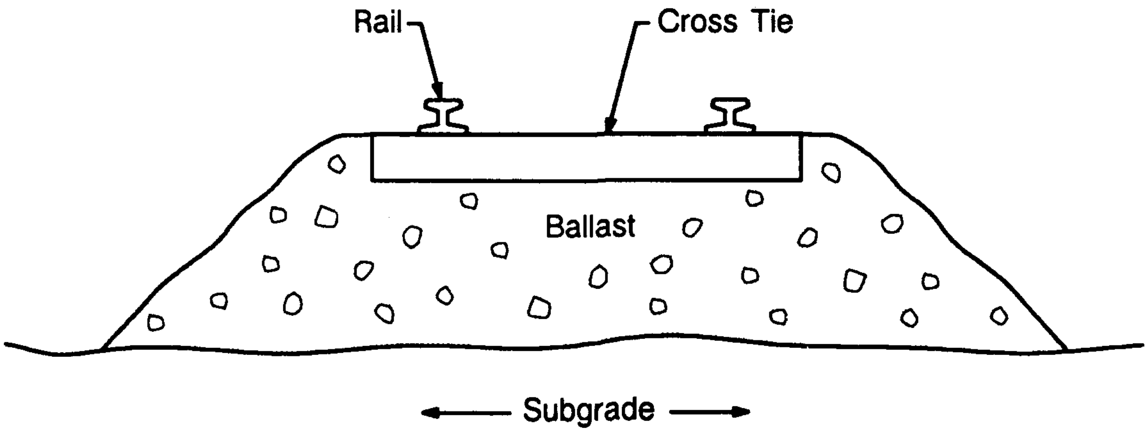


Figure 4. Track Structure Cross Section.

Index Definition

Each component index is intended to reflect (1) the component's current physical ability to support typical military, short line, or industrial traffic and (2) the component's maintenance, repair, or rehabilitation needs to sustain that traffic. The TSCI is intended to do the same, but for the track structure as a whole.

Condition Category Guidelines

The seven condition categories that make up the index scale also required guidelines as to intent so that the computed indexes would indeed meet the index definition given above. Table 3 displays those guidelines.

It is important to note why guidelines, not definitions, are given to represent the categories. This is because the use of definitions would induce rigid constraints on the formulation and use of the indexes. As will be discussed in later chapters, the flexibility of those guidelines was critical to index formulation.

Condition Survey Inspection

Discussed below is an inspection procedure that will serve to collect the required information needed for condition index computation. This procedure is referred to as a "condition survey inspection" or simply "condition survey."

Goal

The concepts of network and project level management were introduced in Chapter 2. Although these two management levels serve different purposes, both require inspection information for the decision-making process. It would be expected that the inspection efforts be different since network level management generally requires less detailed information, more frequently, than project level management (Uzarski, Plotkin, and Brown September 1988).

As discussed in the previous chapter, a project level inspection procedure has already been developed for RAILER. A network level inspection procedure is needed. The goal is to collect the minimum amount of information necessary to make network level decisions. This minimizing is accomplished through two means: inspection by sampling and reduced detail. Both are incorporated in a condition survey inspection.

Sampling

Inspection by sampling is a procedure used to collect information for the computation of the Pavement Condition Index (PCI) (Shahin, Darter, and Kohn 1976; Shahin and Walther 1990). Statistically, the required number of sample units that need to be inspected is a function of how large an error can be tolerated, the probability that the computed PCI is within that error, the PCI variation from sample unit to sample unit, and the total number of sample units in the pavement section. Unfortunately, using a statistical approach for determining the number of sample units for network level inspections leads to a relatively high number being required (frequently 100 percent). In reality, typically only about 10 to 25 percent of the pavement area is actually inspected for network level management. These percentages evolved from field experience based on the goal of expending a minimum inspection effort to collect needed information (Shahin and Walther 1990; Uzarski and Soule 1986).

Table 3

Condition Category Guidelines

Index	Category	Condition Description
86-100	**Excellent**	Very few defects. Track function is not impaired. No immediate work action is required, but routine or preventive maintenance could be scheduled for accomplishment.
71-85	**Very Good**	Minor deterioration. Track function is not impaired. No immediate work action is required, but routine or preventive maintenance could be scheduled for accomplishment.
56-70	**Good**	Moderate deterioration. Track function may be somewhat impaired. Routine maintenance or minor repair may be required.
41-55	**Fair**	Significant deterioration. Track function is impaired, but not seriously. Routine maintenance or minor repair is required.
26-40	**Poor**	Severe deterioration over a small percentage of the track. Less severe deterioration may be present in other portions of the track. Track function is seriously impaired. Major repair is required.
11-25	**Very Poor**	Critical deterioration has occurred over a large percentage or portion of the track. Less severe deterioration may be present in other portions of the track. Track is barely functional. Major repair or less than total reconstruction is required.
0-10	**Failed**	Extreme deterioration has occurred throughout nearly all or the entire track. Track is no longer functional. Major repair, complete restoration, or total reconstruction is required.

Inspection by sampling is virtually unknown for railroad track. However, it is a premise of this work that the same logic used in pavement inspections can be applied to track. The actual percentages of track segment length needed for network level inspections have not yet been established, but certainly the percentages will be less than the current 100 percent.

Sample units must be established for a sampling procedure to be implemented. As a matter of measuring convenience, sample unit lengths of 100 ft may be used in this inspection procedure and as the basis for index development. Appendix A outlines a procedure for dividing a track segment into sample units.

Indexes are computed for each sample unit and the results combined to compute the indexes for the track segment as a whole. This is done by first inspecting a percentage of randomly selected representative sample units and then computing the component group index for each. The sample unit indexes are then simply averaged to compute the track segment indexes. However, if nonrepresentative (either much better or worse condition) sample units are discovered and inspected, the indexes are computed differently so that the effects of the nonrepresentative units do not overly influence the condition indexes of the track segment as a whole. The following equation pertains:

$$CI_{ts} = \frac{(N-A)CI_1 + (A)CI_2}{N} \qquad \text{[Eq 1]}$$

where CI_{ts} = RJCI, TCI, BSCI, or TSCI of the track segment
N = total number of sample units in the track segment
A = number of additional (nonrepresentative) sample units
CI_1 = the average RJCI, TCI, BSCI, or TSCI of the random (representative) sample units
CI_2 = the average RJCI, TCI, BSCI, or TSCI of the additional sample units.

The remaining sample units must be given a quick safety inspection to ensure safe train operations. A safety inspection involves simply walking or driving a track vehicle over the track and spotting serious defects requiring immediate M&R actions. These defects do not enter into the condition index computations.

A step-by-step procedure for the inspection and condition index determination for a track segment is given in Appendix B.

Level of Detail

A very large number of possible defects can be associated with railroad track. RAILER has cataloged over 250 different defects based on the requirements of the Navy, Army, and FRA track standards (FRA 1982; NAVFAC 1988 [Draft]; TM 5-628 1991). A goal was to reduce this number for the condition surveys and for use with the condition indexes. This work accomplished that goal. Later chapters will address the specific component group distresses as they relate to the component group condition indexes.

Development Criteria

The developed indexes, as previously stated, are intended to be used on military and local track networks. As a matter of practicality, the procedures are applicable to portions of larger railroads, as well. These portions include some yards, sidings, branch lines, and other tracks that fit into the development criteria. The development criteria is addressed below.

Track Structure

The first development criteria concerns the track structure. Assumptions were imposed on the material type for ties and the weight of rail.

Wood Ties. Wood ties were assumed in the development of the TCI due to their vast preponderance in track. Thus, if concrete or steel ties or slab track are used, a TCI cannot be computed.

Rail Weight. Rail weight has a pronounced effect on wheel load distribution through the ties and into the ballast/subgrade. Heavier rail is stiffer and distributes a given load to more ties (Hay 1982). Thus, the effects of rail, tie, and ballast/subgrade defects on the ability to support traffic and M&R needs is a function of rail weight because of the load distribution effects. Also, rail less than about 118 lb/yd will experience defects that are predominately bending-stress related.

All of the indexes were developed on the assumption that the rail weight was neither very light (less than about 70 lbs/yd) nor very heavy (greater than about 118 lbs/yd). This is because the rail weight of the vast majority of military and local trackage falls between those limits. Indexes can be computed if the rail weights are outside of those limits, but the computed values may not reflect the intended index definition stated earlier.

Traffic Density and Speed

The indexes were developed based on the criteria that traffic is generally light (1 to 2 trains/day with a mix of car types and axle loads or less than about 5 MGT/year) and that speeds are limited to 40 mph. This work did not establish an absolute upper limit on load repetitions and/or tonnages, but based the development on the low volume traffic operations typically found on military and local railroads. Faster speeds introduce dynamic loadings not considered. Average speeds will generally be well below 40 mph, but well within the range where dynamic loads are significant. This is due, in part, to car roll natural frequency and certain track conditions (Ahlbeck et al. 1976; Weinstock, Lee, and Grief 1987).

The indexes may work very well for trackage subjected to high traffic volumes and speed, but this report does not include that evaluation.

4 RATING SCALE CONCEPTS

Translating physical "track problems" that affect condition into a meaningful numerical rating requires an application of rating scale theory. This chapter discusses that theory and how it was applied in collecting the needed rating data for index development. Additionally, the model used to transform that rating data into the RJCI, TCI, and BSCI is described in this chapter.

Rating Scale Theory

Scales can be developed in various ways depending on the intent and parameter being scaled. One approach uses rating panels for collecting rating information. With this approach, raters are presented with a physical stimuli and a rating is provided in response (Hutchinson 1963). A rating panel approach proved to be an ideal method for developing the track condition indexes.

Rating Scale Classification

Rating scales can be classified in various ways. Although there is no single universally accepted classification system, the work of Stevens provides a good basis for an overview discussion (Stevens 1946). He classifies rating scales as nominal, ordinal, interval, and ratio. Interval scales were used in this development.

With interval rating scales, the size and differences between pairs of numbers have significance. The intervals are equal, but the origin can be located where convenient. Ordering can also be accomplished. The statistics of mean and standard deviation have meaning. However, with interval scales, it is meaningless to imply that any given value is in proportion to any other value on the same scale.

Scaling Methods

Researchers can obtain interval scale ratings either directly or indirectly (Nick and Janoff 1983; Torgerson 1958). Either method must relate the physical stimuli (e.g., erosion of track ballast) to the rater's judgement of the parameter (i.e., condition) to be scaled. The difference in the method is in the assumptions about the rater's ability to describe the stimuli at the desired level of measurement (Nick and Janoff 1983). In the direct approach, the rater quantifies his or her judgement directly on the interval scale. For example, it is assumed that a rater can view "track problems" at three separate locations and provide ratings of 39, 62 and 74. Indirect methods involve collecting the ratings on an ordinal scale and then using statistical methods to convert the data to an interval scale. As applied to the track example above, this would have a rater indicate that one track segment was "better" than another, but "worse" than still another. The direct method was used to develop the track condition indexes.

Rating Scale Development

The development of an interval rating scale using the direct approach in compliance with established principles requires that the rating panel members be thoroughly instructed in the task. Also, the rating sessions must be administered properly (Nick and Janoff 1983; Moore, Clark, and Plumb 1987). Failure to do so will introduce error and distort the findings. Proper instruction and administration can also reduce error. Finally, the development of a rating scale requires that certain assumptions be made. Those assumptions as well as the instruction and administration issues as they pertain to the track component group condition ratings follow.

Assumptions

The development of condition indexes through the use of subjective panel ratings represents a psychological model. Certain well-documented assumptions must be invoked for the model to be feasible (Hutchinson 1963; Torgerson 1958). These are:

- Condition is a measurable attribute.
- Raters are capable of making quantitative judgements about condition.
- The judgement of each rater can be expressed directly on an interval scale.
- Variability of judgement is a random error.
- Each rater is equally capable of making the required judgement of condition. Raters are interchangeable.
- Averaging of individual rating values can be used to estimate the rating scale values.

Instruction

Before the raters can provide any meaningful subjective data, they must be given a set of instructions to follow (Moore, Clark, and Plumb 1987; Nick and Janoff 1983; Zaniewshi, S.W. Hudson,and W.R. Hudson 1985; Nakamura 1962; Weaver and Clark 1977; Weaver 1979; Asphalt Institute 1977). The instructions provide guidance and direction on specifically what raters are to do and how they are to do it. The instructional process must include a definition of what the rating scale represents. Also, specific anchors and cues (discussed below) on the scale must be explained. The next chapter of this report will address in detail the topic of instructions given to the raters.

An anchor provides a point of reference from which the ratings are based (Hutchinson 1963; Nick and Janoff 1983; Weaver and Clark 1977; Weaver 1979). As was introduced in the previous chapter, the RJCI, TCI, BSCI, and TSCI use a rating scale that ranges from 0 to 100. For reasons that will become evident later in this chapter, the primary anchor for that scale is 100. By definition, a rating of 100 indicates that the track sample unit is free of observable distress. Table 3 (see Chapter 3) shows the rating scale divided into 15-point intervals (except for one). Each interval boundary also serves as an anchor.

Cues lead the rater to an understanding of what the different portions on a rating scale represent (Hutchinson 1963; Nick and Janoff 1983; Weaver and Clark 1977; Weaver 1979). Referring again to Table 3, each interval has a category label assigned and a condition description. Those condition descriptions provide the cues for the ratings. Note that two sets of cues are superimposed in the descriptions. Because the ratings are intended to relate to both operational and M&R considerations, the raters were advised to consider both in their ratings. Thus, cues for both are provided. The purpose behind these dual considerations is that certain distresses are very detrimental to train operations, but relatively easy and inexpensive to correct. Logically, that track condition situation should be rated differently than one where distresses occur that require the same M&R effort to correct, but have little or no impact on operations.

The category labels do not serve as cues. Those words, when used alone, will lead to a broad interpretation among raters and are generally not recommended (Hutchinson 1963). Their use as cues could also invoke error. Their use in this work was only to provide a common language among all of the condition indexes developed by USACERL. Their meaning was given in Table 3.

Administration

Special care was taken in the administration of the data collection and analysis. The panel was selected based on qualifications and representation. The actual condition ratings were performed randomly and included representation from the entire rating scale. The panel was thoroughly instructed before each rating session. Each individual rated independently without knowing the panel mean or the ratings of any others. Each person rated the identical "track problem." Also, breaks were held during the rating sessions to relieve rater fatigue. Adherence to these principles, including the analyzing of the data, were designed to eliminate certain errors and minimize others (Moore, Clark, and Plumb 1987; Nick and Janoff 1983). Administration details are provided in the next chapter.

Weighted Deduct-Density Model

The collection of rating panel information, in itself, did not result in the desired condition indexes. A model was needed to translate track inspection information on which the ratings were made to condition indexes. In fact, the condition indexes are mathematical models for estimating the mean subjective ratings of an experienced rating panel. For the model to function, track inspection results must be used for input.

The weighted deduct-density model proved to be ideal for this application. It was used to develop the component indexes. A regression analysis was used in conjunction with this model to help develop deduct curves. These curves are discussed later in this chapter. A regression model was used for TSCI development and will be discussed further in Chapter 9.

Model Concepts and Theory

USACERL researchers first used the weighted deduct-density model in the development of the PCI for airfields (Shahin, Darter, and Kohn 1976) and later for the development of the PCI for roads and streets (Shahin and Kohn 1979) and built-up roofs (Shahin, Bailey, and Brotherson 1987). Although each of the aforementioned references provides an excellent description, a summary will be repeated here to illustrate the track application.

The degree of deterioration to a track component group (rail and joints, ties, and ballast and subgrade) is a function of three specific characteristics. These are:

- Types of distress (e.g., defective tie),
- Severity of distress (e.g., two-in-a-row defective ties), and
- Amount of distress, commonly expressed as a percentage to indicate density (e.g., 50 percent of all ties defective).

Each of these will have a profound effect on the determination and quantification of track component group condition. Thus, each must be included in a condition index mathematical model.

Within a given track component group, a multitude of distresses can occur. Different types, severities, and densities can all be present in the same track segment sample unit. The model must consider each type, severity, and density separately and in combination to derive a meaningful index. Since each distress potentially can affect the derivation in an unequal fashion, weighting factors are needed. The model assumes that a track component group condition index can be estimated by summing the appropriate individual component group distress types over their applicable severity and density levels through the use of appropriate weighting factors. The model for this estimation is:

$$\text{RJCI, TCI, or BSCI} = C - \sum_{i=1}^{p} \sum_{j=1}^{m_i} a(T_i, S_j, D_{ij})F(t,d) \qquad \text{[Eq 2]}$$

where C = Constant equal to 100 for this application
a( ) = Deduct weighting value depending on distress type T_i, severity level S_j, and distress density D_{ij}
i = Counter for distress types
j = Counter for severity levels
p = Total number of distress types for component group under consideration
m_i = Number of severity levels for the i^{th} distress type
F(t,d) = Adjustment factor for multiple distresses that vary with total summed deduct value, t, and number of individual deducts over an established minimum value, d.

The next chapter describes the research activities involved in defining the distresses and determining the deduct weighting values and adjustment factors. A brief introduction of those concepts follows.

Distress Types and Severity Levels. The various distress types and severity levels for each component group must be defined in a manner that make them easily identifiable during the inspection process. This is because routine inspections are intended to be used to generate the required data for index computation.

Deduct Weighting Values. The deduct weighting values resulted from the panel's subjective condition ratings of individual "track problems." The panel provided the "weighting" through their ratings. Those same "track problems" corresponded to distress types and severity levels over a range of densities so that the deduct values could be compiled. Since the deduct values are a function of the distress type, severity level, and density, they can be represented graphically though "deduct curves." This concept is shown in Figure 5.

Adjustment Factor for Multiple Distresses. Mathematically, nonlinearity is a requirement for the model; otherwise negative condition indexes conceivably could occur. From a rating perspective, it was found that as additional distress types and/or severity levels occurred in the same sample unit, the impact of any given distress on the condition rating became less. To account for this in the model, an adjustment factor must be applied to the sum of the individual deducts. This results in the necessary correlation between the panel ratings and the computed indexes. The correction factors are a function of the component group, the summed total of the individual deduct values, a minimum individual deduct value, and the number of different distress types and severity level combinations found in the sample unit. These correction factors can be graphed as a family of "correction curves." This concept is presented as Figure 6. The development of those curves resulted from rating panel data.

Model Use Concept

Figure 7 illustrates a conceptual example of how the model is used to compute the TCI. As can be seen, Equation 2 is used in a simplistic fashion. The same process applies to the RJCI and BSCI.

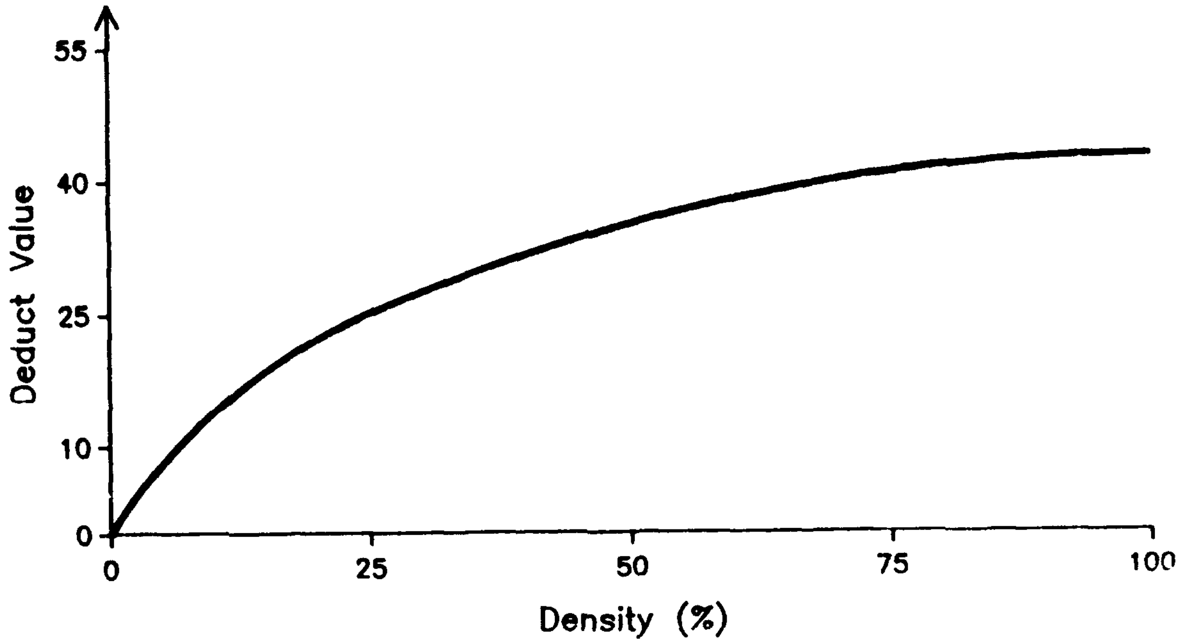
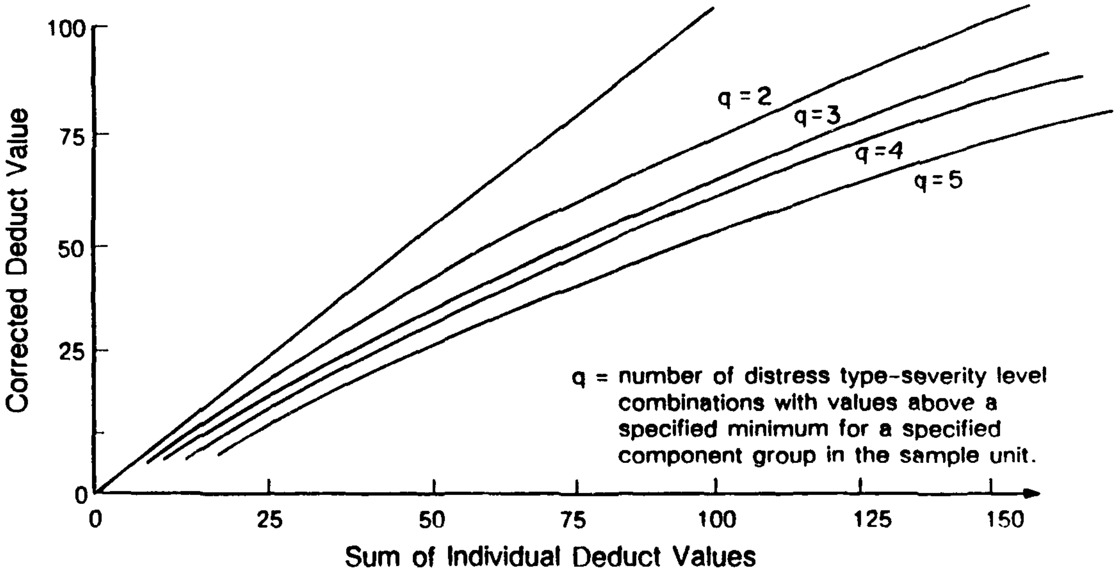


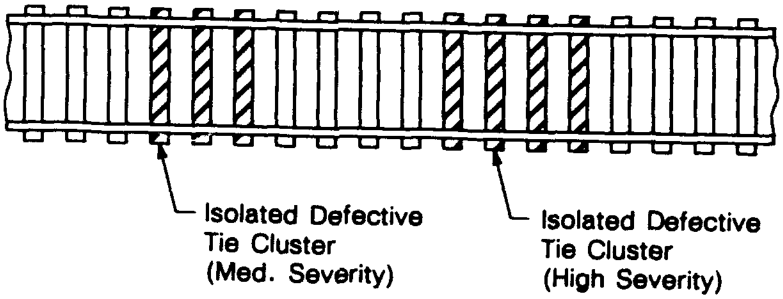
Figure 5. Deduct Curve Concept.



q = number of distress type-severity level combinations with values above a specified minimum for a specified component group in the sample unit.

Figure 6. Correction Curve Concept.

Step 1. Inspect Sample Unit to Determine Distress Type, Severity Level, and Amount



Step 2. Determine Deduct Values from Deduct Curves

a. Medium Severity Isolated Tie Cluster, 29 pts
b. High Severity Isolated Tie Cluster, 45 pts

Step 3. Compute Total Deduct Value (TDV), 29 + 45 = 74 pts

Step 4. Determine Adjustment Factor (F), 0.66
(Back calculated from panel ratings)

Step 5. Compute Corrected Deduct Value (CDV), 74(0.66) = 49

Step 6. Compute Tie Condition Index (TCI), 100 - 49 = 51

Step 7. Determine Tie Condition Category

51 = Fair

Figure 7. Index Computation Concept Example.

5 RESEARCH ACTIVITIES

The decision to use a rating panel approach and the weighted deduct-density model make it necessary to define distresses and determine the deduct weighting values. This chapter discusses the major research activities associated with that accomplishment.

Research Process

Several major activities were identified that, when completed, would bring the idea of developing track condition indexes to realization. Defining the distresses and severity levels, data collection, establishing the deduct and correction curves, and field validation constituted the major activities. Data analysis accompanied all of the activities. Together, those activities made up a logical research process that was repeated in the development of the RJCI, TCI, and BSCI. The TSCI, itself, grew out of those component group indexes development. A diagram of this process is shown in Figure 8.

The activities that made up the research process are discussed in this chapter. The next three chapters of this report will discuss the details of applying this process for each component group index development.

Distress Definitions

Recall that an inspection goal was to reduce the large number of possible defects likely to be found in any network level inspection. Attaining this goal mandated defining a relatively small number of component group distresses for inspection and index use. These definitions were critical. They had to be all-encompassing for thoroughness, easily identifiable for ease and speed of inspection, and directly related to the necessary deduct values so the resulting indexes would be meaningful. The distress definitions consist of two parts: distress types and severity levels.

Distress Types

Many distress types within a given component group (e.g., rail and joints) were defined by combining a variety of possible defects for each different component within the group. An example using rail illustrates the approach. Thirty-three different rail defects are identified for use in RAILER (Uzarski et al. 1988). Examples include bolt hole cracks, broken bases, vertical split heads, corroded bases, crushed heads, detail fractures, and end batter. All 33 possible rail defects were combined into one distress type called "Rail Defects."

Still other distress types within a given component group were defined from the differing defects specific to each component. As an example, two different ballast defects include erosion and settlement. In this example, those defects were defined as separate distresses.

In all, 25 different distress types were defined. These include 6 for the rail and joints component group, 8 for the tie component group, and 11 for the ballast and subgrade component group. All will be described in detail in subsequent chapters.

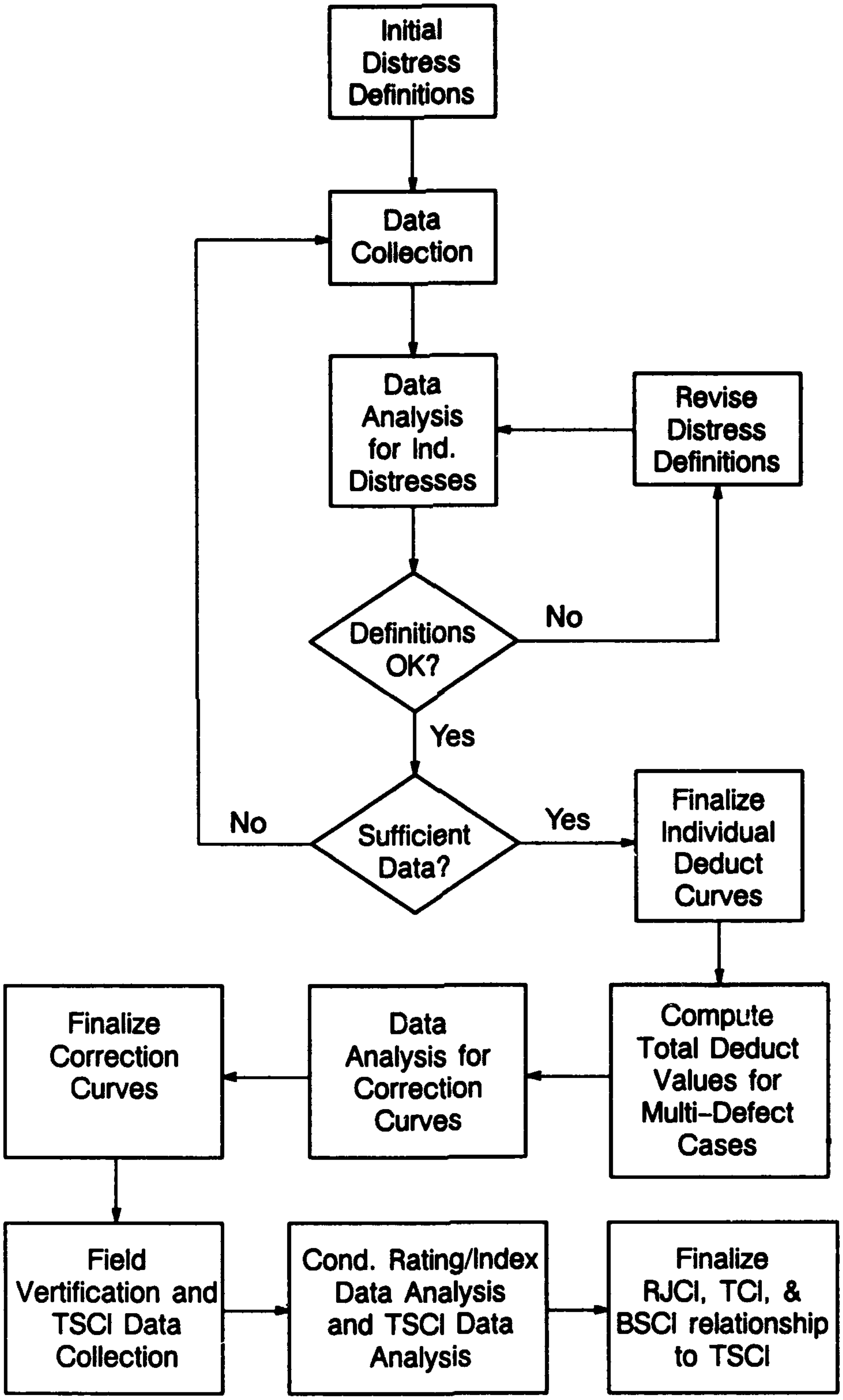


Figure 8. Index Development Process Diagram.

As a matter of developmental philosophy, design deficiencies or current inadequacies such as rail weight that is too light or tight curves that restrict speed or are derailment prone were not considered distresses. If present, those deficiencies will be reflected through relatively fast track deterioration, which will be measured over time by the appropriate condition index.

Severity Levels

Simply having distress types defined was not enough for a complete condition evaluation. A single distress type can have differing degrees of impact on a track's ability to perform as intended. This report defines severity levels as part of the overall distress definition activity to supplement many of the distress types.

Before specific distress severity levels could be defined, a general description of how severity levels would relate to the degree of impact on track performance was needed. The description had to be consistent among the different component groups and provide for a common interpretation among different users. Otherwise, management use of the information would be complex and confusing. Additionally, users desired descriptions that relate to track operational criteria as specified in various track standards (Table 2). Those standards will still impart a very important role in the overall track management process even after the condition indexes are in use. Table 4 describes the four severity levels and their meaning.

Severity levels were added to the various distress types based on the above criteria. Continuing with the rail example cited earlier in this chapter, one of the defects that makes up the distress type of "Rail Defects" is bolt hole cracks. This type of crack is not considered minor so "low severity" does not apply. However, if the crack is less than or equal to 0.5 in. it is defined as "medium severity." Likewise, if the crack is less than or equal to 1.5 in. long it is "high severity." Crack length in excess of 1.5 in. yields

Table 4

Severity Level Descriptions

Severity Level	**Description**
Low (L)	Minor distresses that do not affect train operations. Routine M&R can be scheduled for accomplishment.
Medium (M)	Distresses that may or may not cause an operating restriction on the track. M&R should be scheduled for accomplishment.
High (H)	Distresses that generally would cause an operating restriction on the track. M&R must be accomplished to remove the restriction.
Very High (VH)	Distresses that prevent train operations or place a very severe operating restriction on the track. M&R must be accomplished to restore train operations.

the "very high severity" definition. These crack length limits correspond to the restrictive levels of various track standards (FRA 1982; NAVFAC 1988 [Draft]).

In the final outcome not every distress type required all four severity levels. Some distress types simply cannot become so critical as to restrict or halt train operations. Also, for a few distress types, no severity levels were required because there are no discernable levels that would impact differently on operations or M&R actions.

Definition Evolution

The final distress definitions evolved through an iterative process. First, careful review of the FRA, Navy, and Army track standards (Federal Railroad Administration 1982; NAVFAC 1988 [Draft]; TM 5-628 1991) led to an initial listing. Discussions with track experts provided feedback and revisions followed. This two-step process resulted in the preliminary definitions that formed the basis for collecting the initial set of rating data (discussed below). Discussions held with the raters during the collection process led to definition revisions. Data analysis and the graphing of the deduct curves resulted in still further modifications. As the data collection progressed at different locations with different raters, the revisions became fewer as agreement was reached. Ultimately, the distress definitions that evolved were all-encompassing, easily identifiable in the field, and directly related to the necessary deduct values needed for index computation and use.

Data Collection

The data collection research activity consisted of three major elements. The first was to determine specifically what data were needed and how it would be collected. The second element required the creation of a rating panel. The third and final element involved having the panel actually perform the ratings.

Schematic Rating Sheets

Each combination of distress type and severity level required collecting rating data over a range of densities so the deduct curves could be determined. Ideally, the rating panel would assess these different distress types, severity levels, and densities in the field. However, there were major shortcomings to that approach. Locations were not known that would result in the collection of all of the needed rating data, project funding did not permit sufficient travel for a rating panel to visit widespread locations even if they were known, and getting an entire group of experts together at one time to do the ratings proved impossible. Thus, that approach for data collection was not feasible.

The answer on how to collect the necessary data was to develop schematic rating sheets that display different "track problems" that would be rated. The track problem displayed on each sheet represented a certain distress type and severity level at a density that could be found on a track segment sample unit. Figure 9 displays an example of a two-in-a-row defective tie cluster. A series of sheets were developed for each component group to cover the range of distress types and severity levels at varying densities germane to that group.

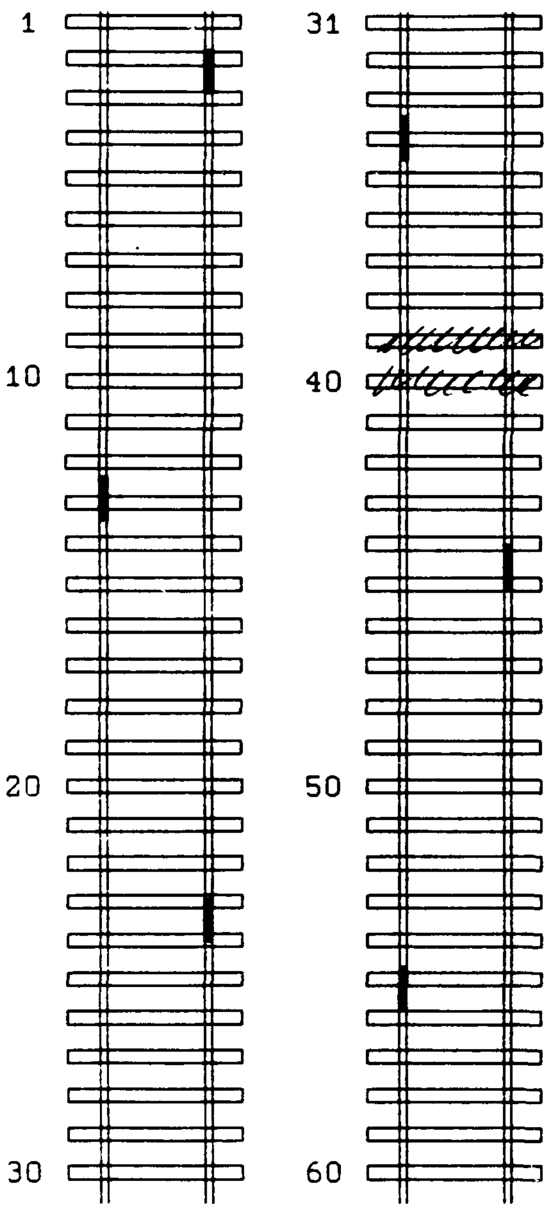
In developing the rating sheets, paired sheets were prepared for selected distress type-severity level-density combinations. The same combinations were presented differently so that they were not duplicates. The purpose was to check rater consistency without having a rater perhaps remember the paired rating.

Schematic Number T22LR

Rater ______________________

Date ______________________

TIE CONDITION RATING SHEET



Instructions:

1. Rate the crossties with regard to the track's current ability to support routine traffic and the maintenance requirements to restore the track to an acceptable condition.

2. Circle the word on the rating scale that best describes the track condition. Then, within that interval, mark the rating on the scale.

3. Comment on major factors influencing your rating.

____

____

____

____

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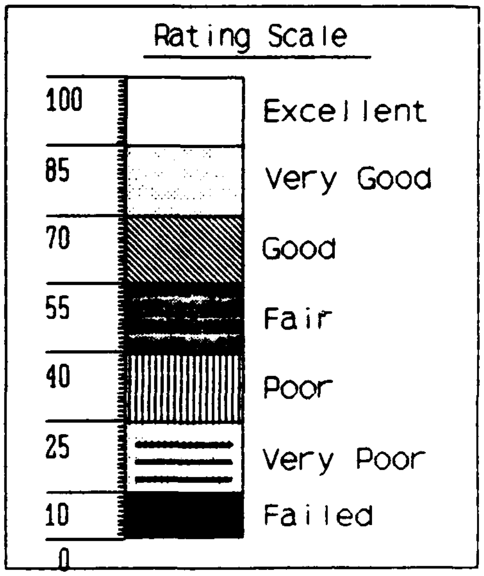

Figure 9. Example Schematic Rating Sheet.

When the schematic rating sheets were prepared, they were coded in a sequential order by component group to ensure that all of the distress types and severity levels were accounted for at sufficient and appropriate densities to develop the deduct curves.

After all of the sheets were created for a given component group, a computerized random number generator assisted in sorting the sheets into a random order for use in the actual rating sessions.

Rating Panel

The rating panel that contributed to this development consisted of 27 members. (Initial membership was 28, but one rater withdrew due to a change in employment.) Approximately half of the panel was formed through personal contacts with known track experts. The remainder of the panel was assembled through the services of a railroad consultant (David Burns). Rating panel size requirements will be discussed later in this chapter.

Since the condition indexes must represent the mean subjective opinions of a group of track experts, a panel with members having varied experiences was sought out so track problems could be rated from different perspectives. The panel did, indeed, represent a broad variety of experiences from commercial railroad companies, military installations, a research laboratory, a university, and a consulting business. Their various position titles included directors and assistant directors of maintenance, track superintendents, roadmasters, track foremen, track inspectors, planners and estimators, civil engineers, railroad engineers, an industrial engineer, and a university professor of civil engineering. The panel experience time averaged 22.5 years and ranged from 4 to 50 years. As a group, the panel had experience in hot, cold, temperate, wet, and dry climatic regions. Appendix C provides the rater listing.

Rating Sessions

The rating sessions took place over several months. Generally, the rating sessions occurred in small groups and at the normal work locations of the raters. Each rating session was facilitated by this author, a research assistant, or a contractor.

All rating sessions were conducted in the same way. The raters were first given general instructions by the facilitator (see Appendix D). Each rater was then given a copy of the rating guidelines to use as rating cues, Table 3, and a set of component rating sheets, one by one, in a previously determined random order that was the same for all raters. As each rater completed a given sheet, it was collected by the facilitator. Raters were not permitted to review completed sheets while rating new sheets nor were they permitted to see the ratings given by other raters. The facilitator answered questions and encouraged the raters to discuss the track problems. This process was repeated for each set of component group sheets.

After a given set of sheets was completed, either the facilitator reviewed the data during the session or a research assistant reviewed the data later. Any rating that was more than 15 points or two standard deviations (whichever was less) from the mean was flagged for a re-rate. This was done to allow raters the opportunity to correct certain ratings that may have been marked by mistake due to misunderstanding, misinterpretation, distraction, or some other reason.

The rerate process was simple. The appropriate sheets were given back to the raters, either during the same session or a later one, to be rated again. Generally, a short discussion about the distress ensued. The raters were never told if they were above or below the panel mean and they were under no obligation to change their marks. To reinforce the "no obligation to change" idea, the facilitator advised each rater that a certain number of sheets were being included that were originally marked close to the panel mean.

Also, since the only intent of the rerates was to catch mistakes, raters were always advised to rate their convictions and not to be concerned about what others rated; differences in opinion were expected.

As discussed above, the schematic rating sheets were developed based on a need to collect a range of data to determine deduct curves. In creating each sheet, the "track problem" was shown with no reference to a defined distress type or severity level (with two exceptions for rail and joints discussed in the next chapter) because it might have introduced a "halo effect" error. For example, if a sheet indicated that the severity level shown was "high severity," the rater may have felt obligated to rate it harshly. Rather, the rater was shown the "track problem" and was simply asked to rate it according to the rating scale cues. Analysis of that data later indicated whether or not that track problem would be considered "high severity," or something else. That analysis showed that in certain instances the resulting deduct curves did not support the proposed definitions. This led to further revisions in the distress definitions (discussed earlier).

Amount and Quality of Data

Development of the deduct curves required establishing a certain degree of accuracy for those curves. A reasonable goal was to have, on the average, the deduct value associated with a given density on the deduct curve with the highest variation be within plus-or-minus five points of the true mean deduct value at a 95 percent width confidence interval. This concept is shown as Figure 10. Several steps were involved in that attainment.

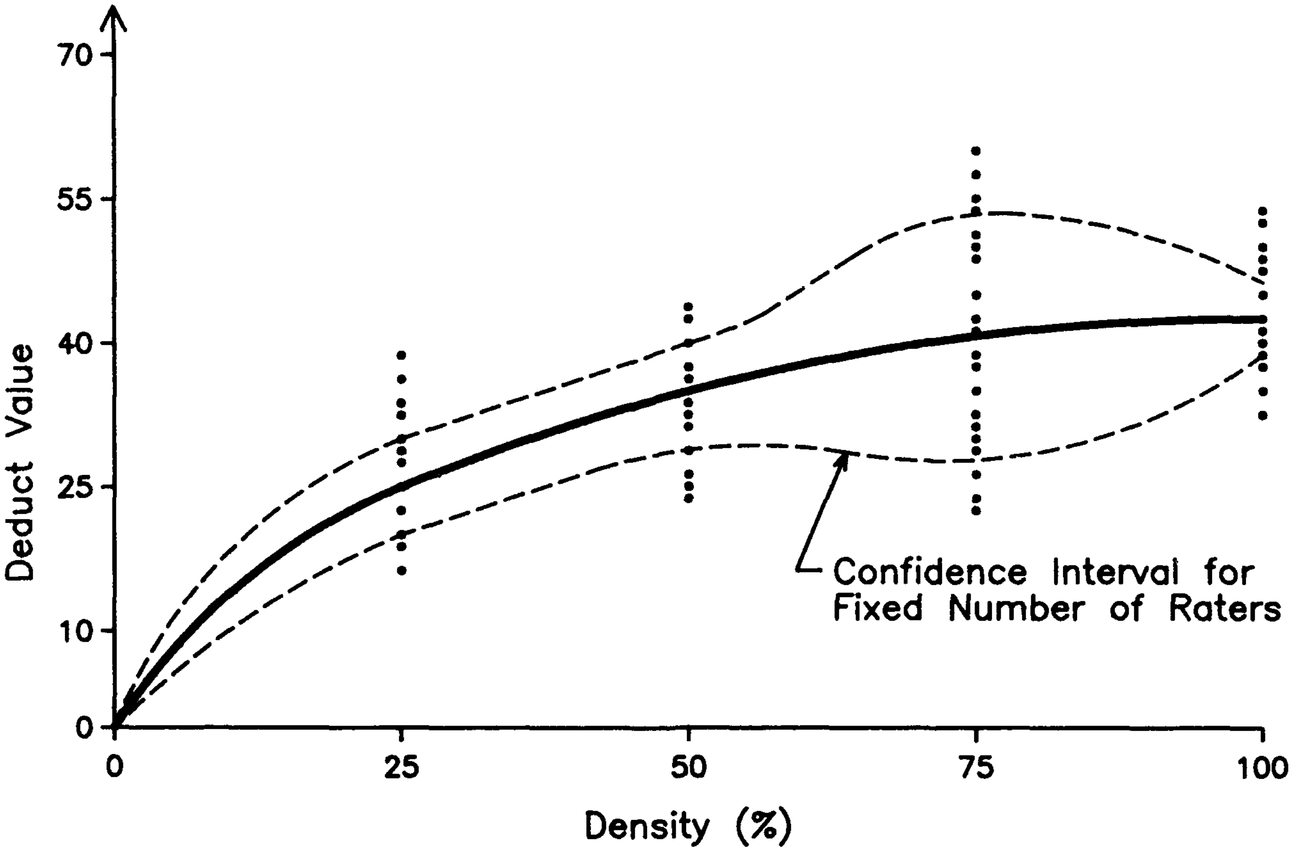

Figure 10. Confidence Interval Concept.

Initial Data Sampling. At the very beginning of the data collection process, there was no way of knowing the statistics (i.e., variance) of the rating data. After five or six raters provided data, initial deduct curves were created as part of the evolution of the distress definitions discussed above. Based on that data, a regression analysis was performed and the variance of the data obtained. That variance determined the required number of raters needed to meet the desired confidence interval and allowable error (Nakamura 1962; Cheremisinoff 1987; Elzey 1971).

Because of the variance differences, each deduct curve theoretically required a different number of raters to meet the statistical requirements. If the rater numbers were based on the maximum width confidence interval (see Figure 10) some curves required as few as two, but other curves required over 50. Basing the number of raters on the average confidence interval width reduces the requirements, but they still differ from curve to curve. Since it would have been impractical to have different numbers of raters for different curves and to assemble a panel based on the maximum required, the panel size was based on the average number of raters needed for the desired statistics for the "worst" deduct curve within a given component group. The procedures for determining the required numbers were developed under contract by Dr. Dennis Cox from the University of Illinois (Cox 1991). Although 27 raters participated, some did not rate all component groups because of individual availability, expertise, and preference. The required and actual number of raters for each component group is presented in the next three chapters.

Outlier Detection. Once all of the rating data were collected, each set was checked for outliers. Any individual data point that was three or more standard deviations from the mean was removed under the assumption that it was a mistake. Assuming a normal distribution, there is only a 0.26 percent probability that a data point above or below the mean by three standard deviations is part of that data set (Cheremisinoff 1987; Elzey 1971).

Developing the Deduct and Correction Curves

As discussed above, this author initially used a regression analysis to determine equations for deduct curves from which variances were computed and panel size estimated. This method, however, was not used to produce the final curves. Rather, the best smooth curve fit approach was taken because regression models a relationship based solely on mathematics. Reliance on mathematics ignores certain engineering logic. The deduct curves for a given distress type form a family, and as such, certain consistent trends for that family are expected. If regression alone was relied on for individual curve development, the family trend can become ragged and actually become a less logical representation of the physical happenings. A best smooth curve fit of the final curves ensures that the trends are correct and consistent with the physical happenings. In the end, the regression curves and the best smooth fit curves were very similar and in most instances, identical.

Deduct Curves

Once the distress definitions were finalized and the outliers removed from the data, graphing the final deduct curves was a simple matter. They are discussed in the next three chapters and presented in TR FM-93/14 (Uzarski, 1993).

Correction Curves

As part of the rating sessions, the facilitator gave each rater sets of schematic rating sheets that illustrated various combinations of distress within the same component group. For example, a defective rail and a defective joint might occur together on the same sheet. The procedures for data collection and analyses were the same as for the individual deducts.

The final deduct curves were used to compute the deduct values for each individual distress found on the combination sheets. These deduct points were summed for each sheet and graphed against the deduct values resulting from the panel ratings. A family of curves resulted for each component group that was based on the number of distress types and severity levels present and a minimum numerical cutoff for individual deduct values. The family of correction curves and the minimum numerical cutoffs varied for the three component groups. A trial-and-error approach was used in their determination. The minimums were varied, the new correction curves drawn, and the results compared. The minimum cutoff that led to the best smooth curve fit for the family of curves was the one selected. These curves are also presented in TR FM-93/14.

Field Verification

This phase of the research consisted of a group of track experts actually inspecting and rating track. The sample units selected provided a wide condition range for the various component groups.

The field procedure was simple. The group of raters would together inspect a selected track segment sample unit so that all would agree on the distresses found. Each rater would then, individually, rate the rail and joints, tie, and ballast and subgrade component groups. Each rater was also asked, individually, to provide an overall track structure condition rating. Upon completion, the facilitator led a group discussion and asked each member to explain his rating to the other members of the group.

After the rating panel inspected and rated the sample units, the condition indexes were computed from the inspection data using the appropriate deduct and correction curves. The individual panel member ratings were averaged to obtain mean condition ratings for each component group. The computed index values were then compared to the mean ratings. As will be shown in the next three chapters, the comparisons were excellent.

The field work lead to minor revisions in the distress definitions and to slight adjustments to a few deduct and correction curves. The numerical cutoffs for the correction curves were also altered by a point or two, depending on the component group. An improved match between the computed condition indexes and the mean panel ratings resulted.

The development of the final TSCI also used the field data. Chapter 9 of this report will explain the mathematical computation of the TSCI from the RJCI, TCI, and BSCI. This data led to the weight factors that were used to establish the relationship.

6 RAIL AND JOINTS CONDITION INDEX (RJCI)

As a follow-on to the general discussion on condition index development given in Chapter 5, this chapter focuses on the specifics for the development and computation of the Rail and Joints Condition Index. The complete topic, encompassing distress definition development, data collection and analysis, deduct and correction curves creation, and field validation is addressed.

Distress Definitions

The rail, joints, and fastenings component group consists of the following track components:

- Rails
- Joints
- Hold-down devices (cut spikes, screw spikes, clips, etc.)
- Tie plates
- Gauge rods
- Rail anchors.

These six components, between them, have a total of 68 specific defects that affect condition (Uzarski et al. 1988 [Draft]). These include such diverse items as broken rails, missing bolts, and cracked tie plates. A complete listing of the specific defects by component is provided in Appendix E. Those 68 defects provided the basis for defining the needed distress types and severity levels.

Distress Types

The rail, joints, and fastenings component group was ideal for using the concept (introduced in the last chapter) of simply grouping the defects for a given component into distress types based on those components. Six distress types resulted from this approach; one created for each component. These are:

- R1. Rail Defects
- R2. Joint Defects
- R3. Hold-Down Device Defects
- R4. Tie Plate Defects
- R5. Gauge Rod Defects
- R6. Rail Anchor Defects.

Before any rating data was collected, this author discussed this grouping approach with several track experts for the purpose of gauging their acceptance. The idea was well received and several positive suggestions were offered. As first conceived, additional components were considered for inclusion within the rail, joints, and fastenings component group. These additional components were derails, guard rails, car stops, and car bumpers. The experts suggested excluding those items from the index because of their infrequent use in track and their lack of impact on track condition even if present and deteriorated.

Throughout the rating process the raters also voiced agreement with the distress definitions. However, as a matter of record, there was slight disagreement on having rail anchor defects included. One rater preferred that the anchors not be included since he felt that they served no real purpose on typical military trackage.

Severity Levels

Severity levels were established in consonance with the descriptions given in Table 4 (see Chapter 5). Judicious review of the Army, Navy, and FRA track standards lead to the initial severity level definitions for the rail and joint defects. For rail and joints, given defects result in different operating restrictions and urgency for M&R (FRA 1982; NAVFAC 1988 [Draft]; TM 5-628 1991). Also, as discussed in Chapter 5, sometimes the size of a given defect results in different operating restrictions. This size criteria is true for most of the rail defects.

The track standards provided little guidance for severity levels for hold-down devices, tie plates, gauge rods, and rail anchors. Rather, common sense and discussions with track experts resulted in an initial division of only one or two severity levels for these components.

The first two rating sessions uncovered a few shortcomings in the definitions. Where needed, defects were shifted from one severity level to another. Revisions to defect size within a given severity level for a small number of rail and joint defects were also made. For tie plates, an initial two-severity level was reduced to one. The severity levels associated with the six distress types are provided in Table 5.

Measurement and Density Determination

No single method for determining density was applicable for all of the distress types. Although the measurement unit of "each" was found to be the easiest and most logical approach for recording all of the distresses, no single number was logical for use as a mathematical denominator for density computation.

The number of rails and joints in a sample unit are a function of rail length, which can vary. It is also convenient to count rail and joint defects on a per rail or per joint basis. Thus, density was established as the number of affected rails or joints divided by the total number of rails in the sample unit.

The number of tie plates, hold-down devices, and rail anchors in a sample unit is a function, in part, of the number of ties present in that same sample unit. Typically, there are two plates per tie and four hold-down devices per tie. Anchors, if used, may be placed in a variety of patterns, but a maximum of four anchors per tie can exist. Therefore, density was established as the number of plates, hold-down devices, or anchors exhibiting distress divided by the number of ties times two, four, and four, respectively.

The process for determining gauge rod density was less logical. A sample unit must have at least one gauge rod; there is no readily established maximum number of gauge rods that can be present. So, a convenient density calculation method simply divides the number of distressed gauge rods by the sample unit length.

Table 5

Distress Type-Severity Level Combinations for Rail, Joints, and Fastenings Component Group

Distress Type	Severity Levels
R1	L M H VH
R2	L M H VH
R3	L M
R4	None
R5	None
R6	None

Complete Definitions

By aligning the various distress types with their respective severity levels and density measurements, the complete distress definitions were produced. Table 6 displays the complete definition for hold-down devices. The complete definitions for all of the distresses in the entire component group may be found in TR FM-93/14.

Table 6

Distress Definition for Hold-Down Devices

R3. Hold-Down Device Defects	
Description:	Hold-down devices are considered defective if they fail to secure the rail properly to the tie or if they are placed in an improper pattern or position.
Severity Levels:	L - Improper pattern or position M - Loose, bent, broken, missing, or otherwise wise defective
Measurement:	Each
Density:	Number of Occcurrences / Number of Ties in Sample Unit x 4
Cause:	Hold-down device defects result from improper installation, defective ties, and vibrations and deflections imposed from train operations

Schematic Rating Sheets

A large number of schematic rating sheets (see Figure 9 in Chapter 5) were needed to adequately represent all of the anticipated distress types and severity levels over a wide range of densities. A total of 94 sheets provided sufficient data to develop the deduct curves. Another 104 sheets were needed for correction curves development. Examples are presented elsewhere (Uzarski 1991).

Earlier, the schematic rating sheets made no reference to severity levels so a rating bias would not be introduced. The exception to that policy was the sheets used to rate rail and joint distresses. Ideally, no reference would have been made for these, but the large number of defects associated with those distresses made the preferred approach impractical. To avoid the reference to distress types and severity levels on the sheets, individual defects would have had to been indicated. However, not all of the defects within a severity level have exactly the same impact on condition. They were grouped for practical convenience for use with the RJCI and were an acceptable compromise for condition evaluation. If specific rail and joint defects were to be referenced for rating, individually, each one would have required a series of sheets to ensure a nonbiased evaluation. This would have required the development of an extremely large number of sheets. Also, if only a single specific defect were used throughout for rating purposes, the ratings might have been too high or too low to represent the group. Therefore, just citing distress types and severity levels on the sheets kept the number of sheets to a reasonable level. When rating, the panel referred to the distress definitions and the facilitator directed each rater to think of the defect of choice from the applicable group. Since different raters would be expected to think of different defects, the resultant ratings could be considered representative of the distress type and severity level.

An example of the schematic rating sheet listing is shown in Table 7. The complete listing is published elsewhere (Uzarski 1991).

Table 7

Sample Rail, Joints, and Fastenings Component Group
Deduct Curves Schematic Rating Sheet Listing

Seq. No.	Ran. No.	Schem. Code #	Description
1	68	R1L11	Rail, Low Sev, 1 Defect, 1 Rail
2	49	R1L13	Rail, Low Sev, 1 Defect, 3 Rails
3	15	R1L16	Rail, Low Sev, 1 Defect, 6 Rails
4	23	R1L13R	Rail, Low Sev, 1 Defect, 3 Rails
5	54	R1L31	Rail, Low Sev, 3 Defects, 1 Rail
6	58	R1L33	Rail, Low Sev, 3 Defects, 3 Rails
7	26	R1L36	Rail, Low Sev, 3 Defects, 6 Rails
8	16	R1L61	Rail, Low Sev, 6 Defects, 1 Rail
9	31	R1L63	Rail, Low Sev, 6 Defects, 3 Rails
10	93	R1L66	Rail, Low Sev, 6 Defects, 6 Rails

Data Collection and Analysis

The data collection process and analysis procedures used in this work have been discussed previously. The discussion is expanded below with specific information concerning the rail, joints, and fastenings component group.

Rating Panel

Twenty-six of the 27 member panel rated the deduct curves schematic rating sheets. Nineteen raters were required as discussed in the section Initial Data Sampling in Chapter 5 and shown in Table 8. Twenty-three rated the correction curves schematic sheets. The deduct and correction curves schematic sheets were rated as two separate groups.

Data Analysis

The rating data received the review and outlier analysis discussed in Chapter 5. A sampling of that data is listed in Table 9. The complete data sets along with a discussion on the analysis are documented elsewhere (Uzarski 1991).

Deduct and Correction Curves

The deduct and correction curves were developed by converting the rating data into deduct values and then plotting those values against an appropriate parameter. In all cases, the deduct values are simply 100 minus the mean rating values.

Deduct Curves

The deduct curves were created by plotting the mean deduct values against their respective densities for each distress type and severity level combination. A sample of that data for distress R1L, Low Severity Rail Defects, is given in Table 10. That same data, when plotted as deduct curves, are displayed as Figure 11. The complete data set for deduct curves development is documented elsewhere (Uzarski 1991). The entire deduct curve family can be found in TR FM-93/14.

An interesting relationship was found in the development of the deduct curves for the rail and joints distresses (R1 and R2, respectively). The number of defects per rail or joint proved to be a rating factor that was separate from severity and density. This resulted in additional deduct curves being required to account for the number of defects in the rails or joints. Figure 11 shows this. Associated with this relationship was the finding that as the severity levels rose, the effects of increased defect numbers became less pronounced (see TR FM-93/14).

Correction Curves

The correction curves were developed by plotting the mean deduct values, called the Corrected Deduct Values (CDV), against a summed total of the individual deduct values that make up the distress combination. The summed total is called the Total Deduct Value (TDV). A family of curves was developed by linking the data points when the number of individual distress type-severity level combinations was the same. This number is denoted "q." The distress type-severity level combination had to be greater than four points. The four-point minimum cutoff resulted in the best curve fitting for the data set. Table 11 displays a sample of this data. The complete set is presented elsewhere (Uzarski 1991). The correction curves are included in TR FM-93/14.

Table 8

Rail, Joints, and Fastenings Component Group Deduct Curves Rater Requirements

Distress Type	Sev Level	Max No.	Ave No.
R1	L(1)	17	5
R1	L(3)	25	12
R1	L(6)	41	19
R1	M(1)	15	5
R1	M(3)	26	12
R1	M(6)	16	8
R1	H(1)	17	6
R1	H(3)	17	8
R1	H(6)	17	8
R1	VH(1)	19	6
R1	VH(3)	22	10
R2	L(1)	23	8
R2	L(2)	23	11
R2	L(4)	31	14
R2	M(1)	18	6
R2	M(2)	28	13
R2	M(4)	24	14
R2	H	20	7
R2	VH(1)	20	7
R2	VH(3)	11	5
R3	L	22	14
R3	M	11	4
R4	-	21	8
R5	-	8	3
R6	-	17	8
	Maximum =	41	19
	Average =	21	9

Table 9

Sample Rail, Joints, and Fastenings Component Group Deduct Curves Rating Data

Schem. Code #	A	B	C	D	F	G	H	I	J	K	M	N	O	P
R1L11	90	92	86		95	99	95	98	87	81	85	70	99	94
R1L13	76	74	83	68	80	80	90	85	70	67	71	67	89	87
R1L16	61	79	60	59	73	90	85	80	59	59	84	42	82	79
R1L13R	72	83	84		78	85	95	85	64	68	80		92	78
R1L31	80	92	85		89	95	90	80	79	67	82		93	87
R1L33	65	70	76		77	90	85	75	56	48	54	40	73	59
R1L36	73	74	62		71	71	70	71	41	42	70	52	69	68
R1L61	67	83	69	67	78	90	82	75	54	46	80	41	82	73
R1L63	74	76	63	46	71	80	70	70	44	38	53	35	67	73
R1L66	57	60	52	43	58	80	60	56	38	42	71	48	57	67

Field Verification

The field verification process was accomplished as described in Chapter 5. A sample of the mean rating data (mean RJCR) and computed RJCI data is shown in Table 12. All of the data are compiled elsewhere (Uzarski 1991), but are compared in Figure 12. An analysis of the data shows:

- a squared correlation coefficient (r^2) of 0.91 and
- a difference between the mean RJCI and mean RJCR of -1.2 points.

These factors indicate that an excellent correlation has been obtained.

Table 10

Sample Deduct Value Data for Distress R1L

Schem. Code #	Distress Type	Sev Level	Density	Mean Rating	DV
R1L11	R1	L	16.67	89	11
R1L13	R1	L	50.00	77	23
R1L16	R1	L	100.00	67	33
R1L13R	R1	L	50.00	78	22
R1L31	R1	L	16.67	83	17
R1L33	R1	L	50.00	69	31
R1L36	R1	L	100.00	62	38
R1L61	R1	L	16.67	68	32
R1L63	R1	L	50.00	63	37
R1L66	R1	L	100.00	59	41

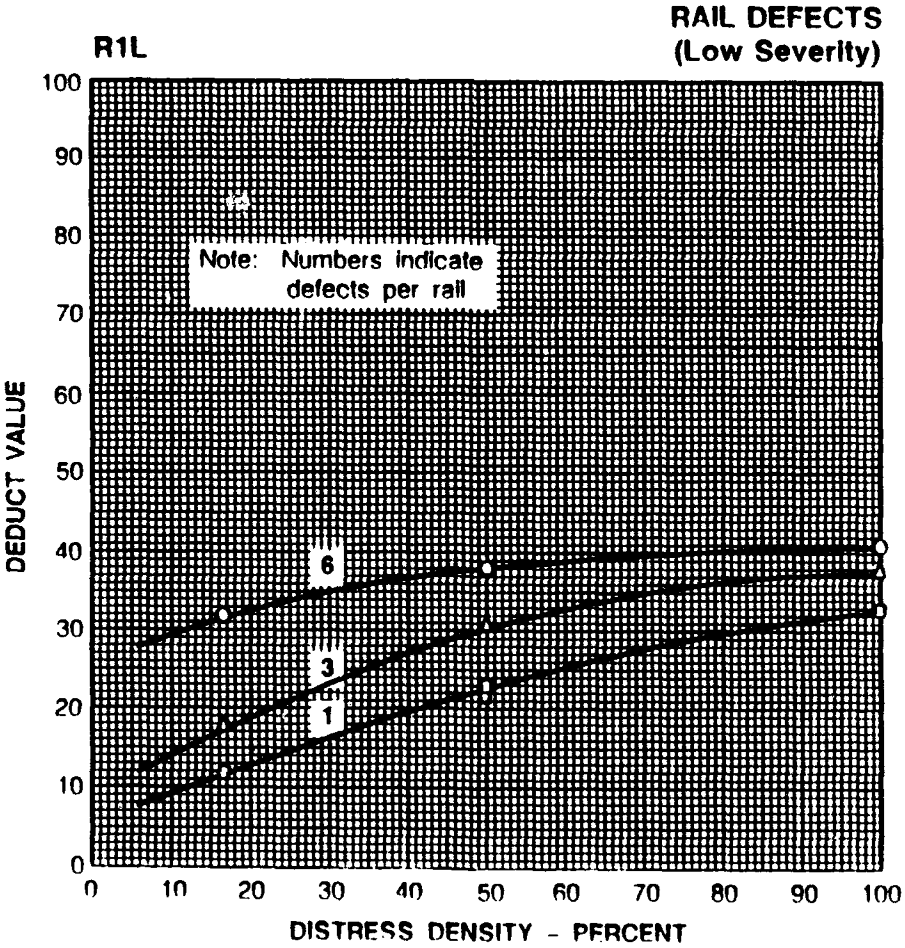

Figure 11. Deduct Curves for Distress R1L.

Table 11

Sample Rail, Joints, and Fastenings Component Group Correction Curves Deduct Value Data

Schem. Code #	Rating Mean	CDV	TDV	q
RC470	62	38	62	2
RC250	75	25	35	2
RC2170	13	87	165	2
RC215	85	15	18	2
RC330	77	23	31	2
RC435	77	23	36	2
RC3190	7	93	183	2
RC220	83	17	24	2
RC260	64	36	60	2
RC325	84	16	26	2

Table 12

Sample RJCI/Mean RJCR Data

Track Segment	Rater				Mean RJCR	RJCI
	A	B	F	O		
S00 Line Lead	44	45	47		45	47
Burns City Siding	57	57	62		57	65
R15601	79	74	53	57	66	59
BT01	100		100	100	100	100
SL01	40		43	51	45	42
SL02	25		34	58	39	37
R101		94	77	73	81	77
R30101		36	53	50	46	62
R2501		65	80	85	77	78
R501		97	95	97	86	92

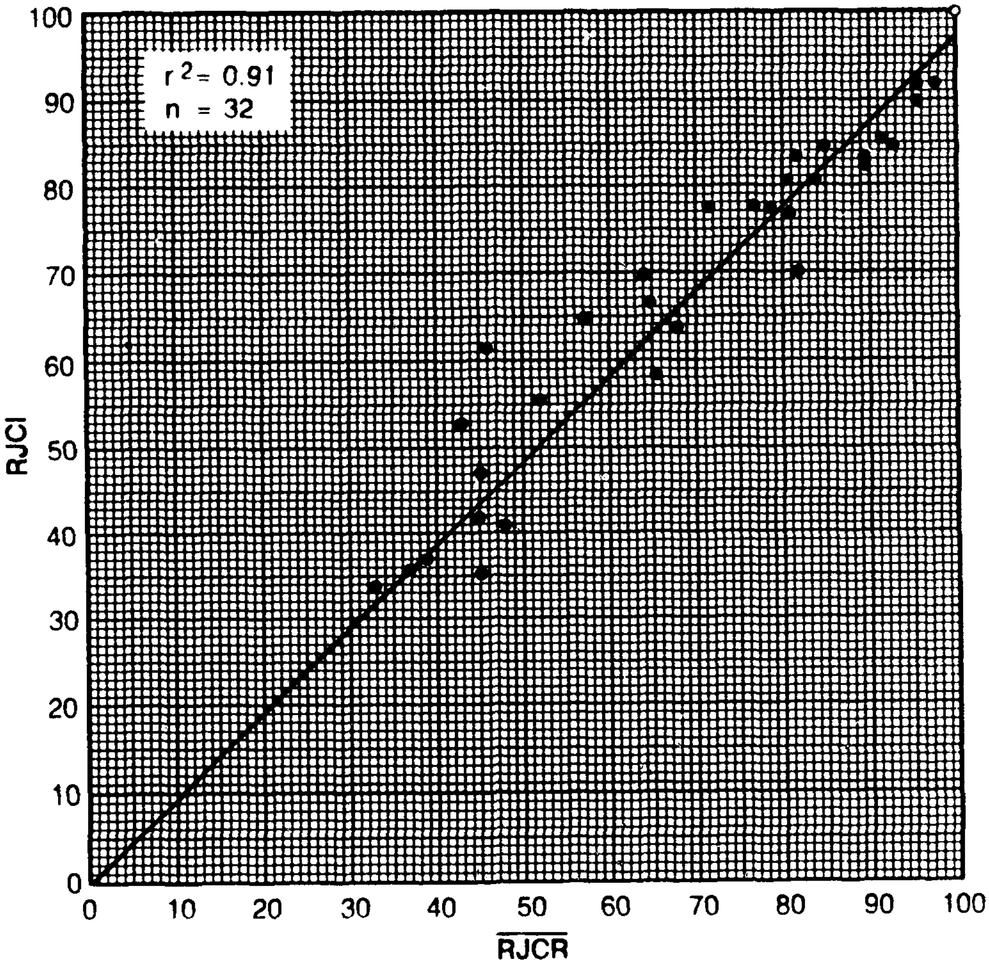

Figure 12. RJCI/Mean RJCR Comparison.

7 TIE CONDITION INDEX (TCI)

A general discussion on condition index development was provided in Chapter 5. This chapter addresses the details for the development and computation of the Tie Condition Index. The discussion encompasses distress definition development, data collection and analysis, deduct and correction curves creation, and field validation.

Distress Definitions

The tie component group consists of the following track components:

- Cross ties (see Figure 4)
- Joint ties (cross ties located under rail joints)
- Switch ties (ties located within the limits of turnouts).

Distress Types

Three basic distress modes are possible for ties. They can become defective, necessitating replacement; they may shift position, requiring repositioning; or they may be missing, compelling installation.

A tie is considered defective if it is rotten, hollow, split or impaired to the extent that spikes or other hold-down devices cannot be secured. It also is considered defective if it is broken through, cut more than 2 in., permits tie plate movement more than 0.5 in., or is generally deteriorated to a degree that it no longer performs as desired (FRA 1982; NAVFAC 1988 [Draft]; TM 5-628 1991; Hay 1982).

A tie has shifted position if it has rotated on its longitudinal axis to the point where the rail does not sit flush on the tie plate and/or tie, if it is skewed over 8 in. or a standard tie width, or if it is bunched over 8 in. or a standard tie width (NAVFAC 1988 [Draft]).

A missing tie is one that has never been installed or has been removed, but never replaced.

The three basic distress modes formed the basis for defining the distress types. However, two other factors exist, that when incorporated, completed the definition of the distress types for the tie component group. These two factors the are clustering effect (the grouping of defective or missing ties) and the proximity of failed ties to rail joints. Eight distress types were ultimately defined. These are:

- T1. Single Defective Tie
- T2. Isolated Defective Tie Cluster
- T3. Isolated Defective Tie Cluster that Includes One Joint Tie
- T4. Adjacent Defective Tie Cluster
- T5. All Joint Ties Defective

- T6. Missing Ties

- T7. All Joint Ties Missing

- T8. Improperly Positioned Tie.

Two or more consecutive defective or missing ties constitute a cluster. The difference between an isolated and an adjacent tie cluster is the spacing between them. Two or more nondefective ties must separate clusters of any size for those clusters to be considered isolated. This spacing criterion evolved from the rating data and will be discussed further in this chapter.

Depending on the track standard, ties located within 18 or 24 inches of a joint are classified as joint ties (FRA 1982; NAVFAC 1988 [Draft]; TM 5-628 1991) . This spatial relationship requires that one or two ties be located at each joint. The "all" criterion applies if all (one or two, as applicable) of the ties at a joint are defective or missing.

When the distress types were first being conceived, only three types were proposed. These were single defective or missing ties, defective or missing tie clusters, and improper tie positioning. Missing and joint ties were considered the same as defective ties in defining the distress type; the differences would be reflected in the severity levels. Cluster spacing was not considered. Defining only three distress types was proposed in an attempt to keep the definitions as simple as possible.

This simplistic approach was discussed, at length, with several track experts during the early phases of the rating sessions for the purpose of soliciting feedback on the idea. The experts were unanimous in their view that defective and missing ties should be treated separately. They also introduced the notion that their ratings of track sample units with clusters would be influenced by the proximity of one cluster to its neighbor. However, there was no consensus on what the spacing criterion should be. This posed no particular problem, as the spacing criterion could be found, experimentally, by having the panel rate track sample units containing clusters with different spacings between them and analyzing the data.

The eight distress types ultimately emerged. This chapter will expand on the topic of distress type evolution later, when the schematic rating sheets and deduct curves are discussed.

Severity Levels

Most of the severity levels were established based on cluster size. The Army, Navy, and FRA track standards all address clustering as a criterion for operating restrictions on track. The FRA and Navy standards focus on the number of nondefective ties per 39-ft rail length as their criterion (FRA 1982; NAVFAC 1988 [Draft]). The Army standards focus on actual cluster size for determining restrictions and urgency for M&R (TM 5-628 1991). The Army methodology provided the basis for many of the tie severity levels used in this report. Table 13 cites that standard. As can be seen, it matches up extremely well with the severity level criteria listed in Table 4. Cluster sizes ranging from two through five were mated to severity levels "Low" through "Very High."

Two other variables factored into establishing the severity level for some of the distress types. One was the degree to which ties were out of position and the other was the influence of joints. Again, the various track standards generally impose operating restrictions when skewing results in a relatively long unsupported rail length and when joint ties are defective, but not necessarily part of a cluster. Table 14 displays the distress type-severity level combinations for this component group.

Table 13

Army Track Standard for Operating Restrictions Due to Defective Tie Clusters

Number of Consecutive Defective Ties	Operating Restriction
0-2	None
3	10 MPH Maximum Speed
4	5 MPH Maximum Speed
5 or More	No Operations

Table 14

Distress Type-Severity Level Combinations for Tie Component Group

Distress Type	Severity Levels
T1	L M
T2	L M H VH
T3	L M H VH
T4	L M H VH
T5	None
T6	L M H
T7	None
T8	L M H

This chapter will also expand on the topic of severity level evolution when the schematic rating sheets and deduct curves are discussed.

Measurement and Density Determination

Measurement for the tie component group is simple. Both single ties and clusters are counted as "each" and totaled by distress type and severity level.

In determining density for single ties, the summed total is divided by the total number of ties in the sample unit. For density determination when clusters are involved, the cluster summed total is first multiplied by the cluster size and then divided by the total number of ties in the sample unit.

Since tie spacing is typically between 19 and 21 inches, the corresponding number of ties per 100-ft sample unit is usually between 57 and 63.

Complete Definitions

Matching the various distress types with their respective severity levels and density measurements completed the distress definitions. Table 15 displays the complete definition for distress T2, Isolated Defective Tie Cluster. The complete definitions for all of the distresses in the entire component group may be found in TR FM-93/14.

As matter of record, in developing the distress type and severity level definitions for the tie component group, consideration was given to separating the "defective tie" distress mode into the specific failure modes of being rotten or hollow, split, spike-killed, broken, or cut. These specific failure modes affect tie performance in different ways and could be a factor when rating (Shahin 1986). Although seriously considered, this approach was rejected. It would have added considerably to the amount of information collected during the inspection and processed afterwards. However, there would not have been a corresponding increase in benefits making the data collection and analysis worthwhile. When managers decide the urgency for tie replacement and set operating restrictions based on cluster sizes, the specific reason for failure serves little purpose. For this reason, a "keep it simple" philosophy was taken. The vast majority of raters agreed, especially since track inspectors typically view ties as simply "good" or "bad." Knowing failure modes may be important for certain aspects of track management, particularly at the project level.

Schematic Rating Sheets

A total of 139 schematic rating sheets (see Figure 9 in Chapter 5) were needed to adequately represent all of the anticipated distress types and severity levels over a wide range of densities required to develop deduct curves. Another 41 sheets were needed to develop correction curves. Several of the schematic rating sheets used for deduct curves development are compiled elsewhere (Uzarski 1991).

The original set of rating sheets was developed based on the premise that defective and missing ties were the same. That set also did not include spacing criteria for clusters. As discussed earlier, raters definitely wanted to separate missing from defective ties and to factor cluster spacing criteria in their ratings. This necessitated additional sheets, which were then prepared and included in the set. Also, as a result of separating defective from missing ties, a small number of sheets were eliminated from the set (e.g. when a defective tie and a missing tie were presented together) because they no longer represented a single potential distress type and severity level.

The complete set of schematic rating sheets were prepared without knowing what the final distress types and severity level definitions would be. The key variables of defective, missing, positioning, clustering, joints, and the proximity of one cluster to another were used as the basis for preparing the set

Table 15

Distress Definition for Isolated Defective Tie Cluster

T2. Isolated Defective Tie Cluster	
Description:	A defective tie cluster of any size is considered isolated if two or more nondefective ties separate it from any other cluster. Notes: 1) If distress T3 or T5 is counted, this distress is not counted for the same cluster. 2) If six-in-a-row defective ties are present in the same cluster, the cluster shall be divided into a cluster of five and the remaining tie treated as distress T1L.
Severity Levels:	L - Two-in-a row defective ties M - Three-in-a-row defective ties H - Four-in-a-row defective ties VH - Five-in-a-row defective ties
Measurement:	Each Cluster
Density:	Number of Defective Ties/Total Number of Ties in sample Unit
Cause:	Same as for single defective ties. As ties deteriorate, wheel loads are transferred to adjacent ties thus accelerating their deterioration.

of rating sheets. The intent was to use the rating data relationships to finalize those definitions. This approach worked superbly.

As discussed in Chapter 5, when the schematic rating sheets were prepared, they were coded in a sequential order. This was done to ensure that all of the key variables were accounted for at sufficient and appropriate densities to develop the distress definitions and emerging deduct curves. Unfortunately, an oversight did occur. This resulted in the need for a third increment of rating sheet development, which added five more sheets to the set.

An example of the schematic rating sheet listing is shown in Table 16. The complete listing is published elsewhere (Uzarski 1991).

Data Collection and Analysis

Chapter 5 discussed the data collection process and analysis procedures used in this work. The discussion is expanded below with specific information concerning the tie component group.

Rating Panel

Twenty-one of the 27 panel members rated both the deduct curves and correction curves schematic rating sheets. Sixteen raters were required (Table 17).

Table 16

Sample Tie Component Group Deduct Curves Schematic Rating Sheet Listing

Seq. No.	Ran. No.	Schem. Code #	Description
8	107	T616J1	Single Defective, 1 Tie at Joint
9	18	T633J1	Single Defective, 2 Ties at Joints
10	41	T65OJ1	Single Defective, 3 Ties at Joints
28	25	T633J2	Two Defective, Two Clusters, Two Jt Ties
27	56	T616J2	Two Defective, One Cluster, Two Jt Ties
29	12	T65OJ2	Two Defective, Three Clusters, Two Jt Ties
49	64	T633J3	Three Defective, Two Clusters, Two Jt Ties
52	68	T633J3R	Three Defective, Two Clusters, Two Jt Ties
50	61	T666J3	Three Defective, Four Clusters, Two Jt Ties
51	60	T61OOJ3	Three Defective, Six Clusters, Two Jt Ties

Data Analysis

The rating data received a complete review and outlier analysis. A sampling of that data is listed in Table 18. The complete data sets and analysis are documented elsewhere (Uzarski 1991).

Deduct and Correction Curves

The deduct and correction curves were developed by converting the rating data into deduct values and then plotting those values against an appropriate parameter. In all cases, the deduct values are simply 100 minus the mean rating values.

Deduct Curves

The deduct curves were created by plotting the mean deduct values against their respective densities on a trial-and-error basis for the purpose of identifying the best data fit to a physical correlate. The intent was to have the distress definitions be data derived. The best relationships lead to the final distress definitions. As an example, all defective tie cluster data was plotted together with the data points labeled. The spacing criterion needed to define isolated clusters became evident. Also, the impact of defective joint ties on isolated cluster ratings was clearly shown. As a surprise finding, defective joint ties were found to have no effect on the ratings for adjacent clusters. Subsequently, definitions and deduct curves for distresses T2, T3, and T4 resulted.

A sample of the data that defined distress T2, Isolated Defective Tie Cluster, is given in Table 19. That same data, when plotted as deduct curves are displayed as Figure 13. All of the data for deduct curves development is documented elsewhere (Uzarski 1991). The complete deduct curve family is found in TR FM-93/14.

Table 17

Tie Component Group Deduct Curves Rater Requirements

Distress Type	Sev Level	Max No.	Ave No.
T1	L	3	2
T1	M	2	1
T2	L	4	3
T2	M	15	3
T2	H	14	4
T2	VH	9	3
T3	L	22	6
T3	M	18	6
T3	H	36	12
T3	VH	40	13
T4	L	16	8
T4	M	24	14
T4	H	54	16
T4	VH	53	16
T5	-	30	8
T6	L	19	11
T6	M	29	9
T6	H	14	4
T7	-	21	6
T8	L	10	3
T8	M	24	14
T8	M	26	14
	Maximum =	54	16
	Average =	22	8

As a point of interest, many of the deduct curves do not begin at zero density and/or end at 100 percent density. Taking distress T2M as an example, the maximum density can be only 60 percent (clusters of three separated by two nondefective ties). The minimum for that same example would be three divided by the total number of ties in the sample unit (about 100 for a 150-ft maximum sized sample unit).

Correction Curves

The correction curves were developed by plotting the Corrected Deduct Values (CDV), against the summed total of the individual deduct values (TDV) that correspond to the distresses on the rating sheets. A family of curves was developed by linking the data points when the number ("q") of individual distress

Table 18

Sample Tie Component Group Deduct Curves Rating Data

Schem.						Rater						
Code #	A	B	C	D	F	H	I	O	p	Q	R	S
T616J1	68	62	84	81	80	80	80	70	86	78	98	85
T633J1	54	43	47	61	72	60	70	69	86	56	60	40
T65OJ1	53	40	52	68	58	60	70	72	75	58	70	35
T633J2	52	41	44	52	50	55	70	68	59	67	65	60
T616J2	54	53	67	54	70	55	56	72	61	68	70	56
T65OJ2	26	40	41	39	58	45	60	47	54	35	25	41
T633J2	42	37	47	42	35	35	30	44	31	48	69	27
T633J3R	44	41	53	38	38	35	30	51	50	37	69	56
T666J3	20	21	23	40	21	31	21	26	22	32	39	40
T61OOJ3	14	18	9	37	19	30	20	28	22	26		25

Table 19

Sample Deduct Value Data for Distress T2

Schem. Code #	Distress Type	Sev Level	Density	Mean Rating	DV
T23DR	T2	L	3.33	87	13
T23D	T2	L	3.33	87	13
T213D	T2	L	13.33	77	23
T213DR	T2	L	13.33	79	21
T226D	T2	L	26.67	71	29
T226DR	T2	L	26.67	70	30
T310DRL	T2	M	10.00	64	36
T31ODL	T2	M	10.00	69	31
T31ODM	T2	M	10.00	66	34
T32ODM	T2	M	20.00	60	40
T325DRL	T2	M	25.00	55	45
T325DL	T2	M	25.00	57	43
T33ODM	T2	M	30.00	49	51
T335DRL	T2	M	35.00	53	47
T335DL	T2	M	35.00	50	50
T34ODL	T2	M	40.00	42	58
T35ODM	T2	M	50.00	37	63

type-severity level combinations was the same. A given distress type-severity level had to have a deduct value greater than 12 to be considered. This 12-point cutoff provided the best data fit. Table 20 displays a sample of this data. The complete set is documented elsewhere (Uzarski 1991). The correction curves are included in TR FM-93/14.

Field Verification

Table 21 presents a sample of the TCI data computed from the inspection results. Also shown are the corresponding mean ratings (mean TCR) compiled from the raters. The complete data set is found elsewhere (Uzarski 1991). Figure 14 shows the comparison. The pertinent statistics show:

- a squared correlation coefficient (r^2) of 0.76 and
- a difference between the mean TCI and the mean TCR of -0.4 points.

These factors indicate that a good correlation has been obtained.

The field verification process brought out a shortcoming with the assumption of simply treating ties "good" or "bad" (see page 52). Many "bad" ties have varying degrees of functionality depending, in part, on the failure mode. This degree of functionality was a factor when rating in the field. This affected the ratings. Some raters made comments like, "this tie is worse than that one" and "this tie, although defective, is not "that bad," so, while the vast majority of raters agreed to the "good" or "bad" concept, it was a prime factor in not having a higher squared correlation coefficient.

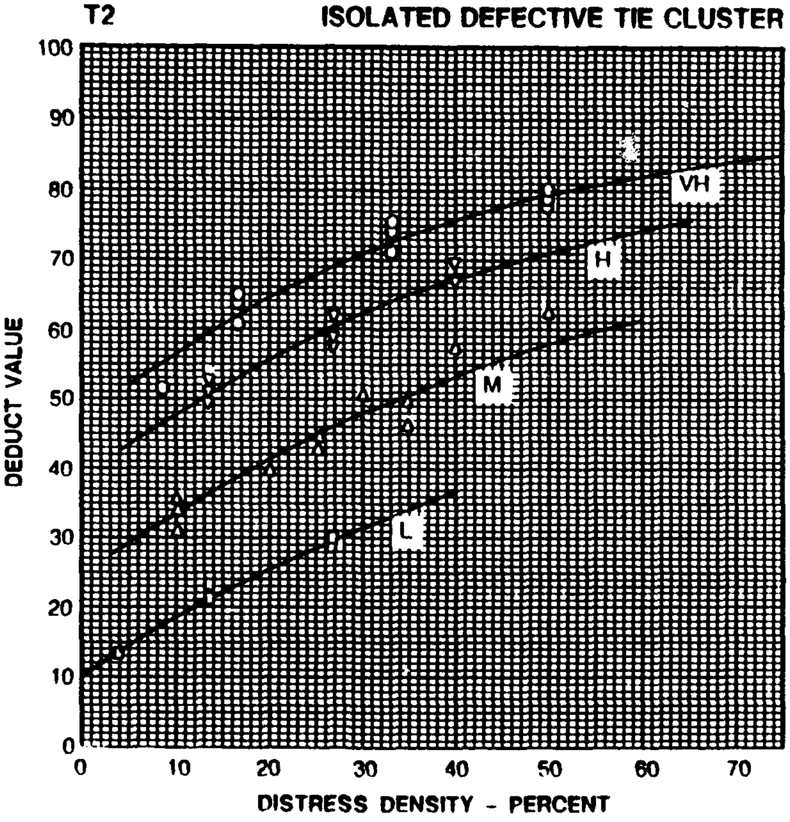

Figure 13. Deduct Curves for Distress B2.

Table 20

Sample Tie Component Group Correction Curves Deduct Value Data

Schem. Code #	Rating Mean	CDV	TDV	q
T213DJ	72	28	40	2
T325DJL	51	49	80	2
T228C	70	30	52	2
T320C3M	35	65	98	2
T716SM	44	56	73	2
T226DJ	63	37	52	2
T345DJL	47	53	97	2
T112C3M	52	48	71	2
T345DJRJ	40	60	95	2
T716SMR	39	61	73	2

Table 21

Sample TCI/Mean TCR Data

Track Segment #	Rater					Mean TCR	TCI
	A	B	F	O	P		
Soo Line Lead	65	70	66			67	72
Burns City Siding	58	64	58			60	71
R15601	51	47	52	58		52	54
W of S6			69	57	64	63	58
W of S6			61	51	60	57	51
W of S4			73	77		75	73
R7401	80	80	80			80	75
BT01		100	100	100		100	100
SL02		80	77	77		78	77

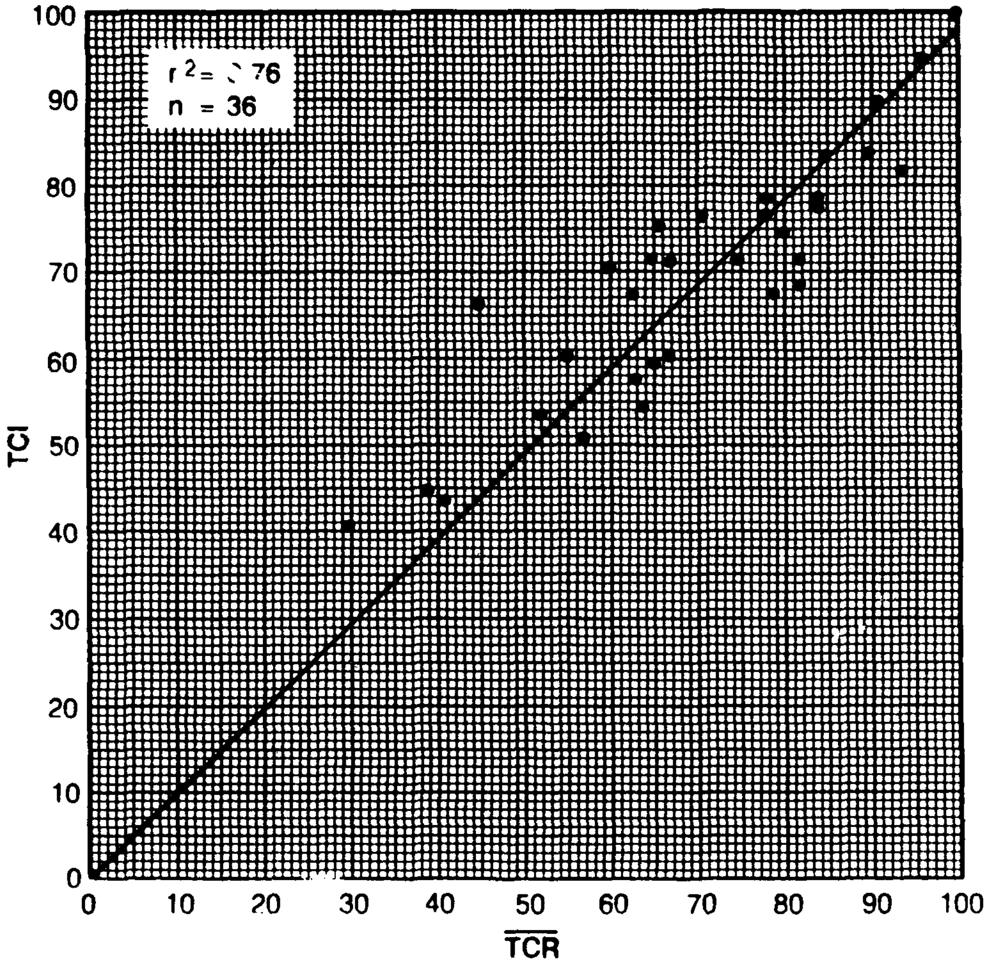

Figure 14. TCI/Mean TCR Comparison.

8 BALLAST AND SUBGRADE CONDITION INDEX (BSCI)

Chapter 5 presented a general discussion on condition index development. This chapter addresses the specifics for the development and computation of the Ballast and Subgrade Condition Index. The topic will be covered in its entirety.

Distress Definitions

The ballast, subgrade, and roadway component group consists of the following track components (see Figure 4):

- Crib Ballast (ballast between ties)
- Support Ballast (ballast under ties)
- Shoulder Ballast (ballast at ends of ties)
- Subgrade
- Roadway
- Drainage Structures (culverts, drains, etc.)
- Trackside Drainage (ditches and slopes).

Distress Types

Defining the ballast, subgrade, and roadway component group distress types combined the approaches used for both the rail and joints component group and the ties component group. Some of the types were based on components (drainage structures and trackside drainage) whereas the others evolved from the various distress modes that are possible for ballast, subgrade, and roadway components. Eleven distress types resulted from this combined approach. These are:

- B1. Dirty (Fouled) Ballast
- B2. Vegetation Growth
- B3. Settlement of Ballast and/or Subgrade
- B4. Hanging Ties at Bridge Approach
- B5. Center Bound Track
- B6. Pumping Ties
- B7. Alignment Deviation
- B8. Insufficient Crib/Shoulder Ballast

- B9. Erosion of Ballast

- B10. Inadequate Trackside Drainage

- B11. Inadequate Water Flow Through Drainage Structures.

The idea of including drainage facilities (ditches, culverts, etc.) as part of the ballast and subgrade component group was discussed, at length, with many track experts at the beginning of this index development. Since these facilities do not have a direct impact on the track structure, per se, their inclusion in the index could be debated. However, due to the importance of drainage to good track performance, the experts were very receptive to including them in the component group.

The ballast and subgrade related distresses were defined based on "track problems" that were easily identifiable and measurable. The literature search, field testing of inspection procedures, and discussions with track experts lead to an identification of several potential distress types that later evolved into the final definitions (FRA 1982; NAVFAC 1988 [Draft]; TM 5-628 1991; Bing 1983; Hamid et al. 1980; Hay 1982; Klassen, Clifton, and Watters 1987). Unfortunately, field testing of inspection procedures and rating data analysis discovered severe shortcomings in many of the original definitions. In fact, many of the revisions were so extreme that the initial effort was, in essence, discarded. A fresh approach lead to the final definitions.

Finally, it should be noted that the ballast distress types do not directly address the strength characteristics or thickness inadequacies of the support ballast. Although techniques are available to determine those important items, they would normally not be used for routine inspection. However, several of the defined distress types do serve as indicators of ballast strength and inadequate thickness.

Severity Levels

The Army, Navy, and FRA track standards lead directly to the severity level definitions for the settlement and vegetation distress types. The standards also contributed to the definitions for inadequate crib/shoulder ballast. The severity levels for the other distress types were developed based on logic, simplicity to identify in the field, and linkage to the severity level definitions in Table 4.

The field identification of the severity levels for erosion and vegetation rely on the judgement of the track inspector. Both distress types can be very minor with no impact on operations or they may result in no train operations, depending on their extent. In developing the definitions, quantification based on the judgement of the inspector was the most practical approach.

When developing the definition for dirty ballast, an attempt was made to quantify different severity levels based on how well the ballast drains and maintains intergranular contact. However, field testing showed that the severity levels were nearly impossible to differentiate. Simply noting whether or not the ballast was dirty worked well. Other distress types (vegetation, pumping ties, and settlement) serve as de facto severity levels to the basic dirty ballast problem.

Crosslevel, alignment, profile deviations and warp are examples of geometry deviations. These deviations can result from bent rail, loose joints, defective ties, and poor ballast support, but most surface deviations can be attributed to deficiencies in the ballast (Hamid et al. 1980; Hay 1982). Consequently, all track geometry parameters are included in this component group. Should the geometry problems found during an inspection be attributable to bent rail, defective or skewed ties, or some other nonballast source, the noting of the appropriate tie or rail distress will account for the problem.

Ballast-derived geometry deviations formed the basis for the severity level definitions for both distress B3, Settlement of Ballast and/or Subgrade and distress B7, Alignment Deviation. Alignment problems are primarily related to crib, shoulder, and support ballast deficiencies. Settlement is caused, primarily, by a failure of the support ballast. Table 22 lists the distress type-severity level combinations for the ballast, subgrade, and roadway component group.

Measurement and Density Determination

Two approaches were used to measure the distresses. Length was used as the measurement criterion for most distresses. Affected ties and drainage structures were measured by "each."

Density, for those distresses that use length as the measurement, is computed by dividing the affected length by the sample unit length. When ties are involved, density is determined by dividing the number of affected ties by the total number of ties in the sample unit.

Density is not applicable to drainage structures.

Complete Definitions

Aligning the various distress types with their respective severity levels and density measurements produced the complete distress definitions. Table 23 shows the complete definition for pumping ties. TR FM-93/14 includes all of the distress definitions for the entire component group.

Schematic Rating Sheets

One hundred and sixty one schematic rating sheets (see Figure 9 in Chapter 5) were needed to adequately represent all of the distress types and severity levels over a wide range of densities. A total of 123 sheets provided sufficient data to develop the deduct curves. Another 38 sheets were needed to develop correction curves. Examples of schematic rating sheets used for deduct curves development are compiled elsewhere (Uzarski 1991).

Table 24 shows an example of the schematic rating sheet listing. The complete listing can be found elsewhere (Uzarski 1991).

Data Collection and Analysis

This report has already discussed the data collection process and analysis procedures used. The discussion is expanded below with specific information concerning the bal'ast, subgrade, and roadway component group.

Rating Panel

Twenty of the 27-member panel rated the complete set of schematic rating sheets. Table 25 lists the rater requirements for each deduct curve. Based on the stated goal (Chapter 5), 20 raters are required. Thus, the goal was met for all but distresses B11 and B5L.

Data Analysis

The rating data received the review and outlier analysis discussed in Chapter 5. A sampling of that data is listed in Table 26. The complete data sets are documented elsewhere (Uzarski 1991).

Table 22

Distress Type-Severity Level Combinations for Ballast, Subgrade, and Roadway Component Group

Distress Type	Severity Levels
B1	None
B2	L
	M
	H
	VH
B3	L
	M
	H
	VH
B4	None
B5	L
	M
B6	L
	M
	H
B7	L
	M
	H
	VH
B8	None
B9	L
	M
	H
	VH
B10	L
	M
B11	L
	M

Table 23

Distress Definition for Pumping Ties

Seq. No.	Ran. No.	Schem. Code #	Description
1	85	B110LR	Dirty Ballast
2	89	B150LRR	Dirty Ballast
3	107	B150LR	Dirty Ballast
4	24	B1100LR	Dirty Ballast
101	7	B710L	Vegetation
102	52	B750L	Vegetation
103	54	B750LR	Vegetation
104	51	B7100L	Vegetation
105	56	B710M	Vegetation Interferes with Inspection
106	12	B750MR	Vegetation Interferes with Inspection

Table 24

Sample Ballast, Subgrade, and Roadway Component Group
Deduct Curves Schematic Rating Sheet Listing

B6. Pumping Ties

Description:	Muddy track or a hard mass of soil material that has formed around ties as a result of being forced out of the ballast section due to tie deflections and water accumulation. Notes: 1) If this distress is present, do not count distresses B5, Center Bound Track. 2) Distress B1, Dirty Ballast, must be counted in addition to this distress.
Severity Levels:	L - Pumping at ony one end of any tie M - Pumping at both ends of any tie H - Pumping at only the end of a joint tie supporting the joint
Measurement:	Each Tie
Density:	Total Number of Pumping Ties/Total Number of Ties in Sample Unit
Cause:	A combination of dirty ballast, water, and traffic results in fine material being liquified from tie deflection and forced through the ballast section leaving a muddy condition that may harden into an impermeable mass.

Table 25

Ballast, Subgrade, and Roadway Component Group Deduct Curves Rater Requirements

Distress Type	Sev Level	Max No.	Ave No.
B1	-	12	5
B2	L	14	5
B2	M	12	5
B2	H	20	12
B2	VH	20	6
B3	L	10	4
B3	M	11	5
B3	H	15	6
B3	VH	12	5
B4	-	36	20
B5	L	18	10
B5	M	12	5
B6	L	26	14
B6	M	23	13
B6	H	18	7
B7	L	23	9
B7	M	12	5
B7	H	11	4
B7	VH	11	4
B8	-	15	6
B9	L	30	16
B9	M	28	8
B9	H	24	14
B9	VH	30	18
B10	L	12	5
B10	M	13	5
B11	L	35	26
B11	M	33	24
	Maximum =	35	26
	Average =	20	10

Table 26

Sample Ballast, Subgrade, and Roadway Component Group Deduct Curves Rating Data

Schem.	Rater										
Code #	A	B	C	F	I	L	O	P	Q	R	S
B110LR	95	91	88	99	80	94	97	84	77	90	85
B150LRR	83	83	77	81	70	88	77	78		87	71
B150LR	83	83	88	84	73	75	73	72	60	84	70
B1100LR	87	70	87	70	67	69	73	69	57	86	71
B710L	87	98	92	92	92	90	89	86		99	85
B750L	68	73	68	79	55	63	74	73	52	69	65
B750LR	43	66	44	78	55	68	73	75	56	60	65
B7100L	53	70	41	58	50	65	62	64	50	60	65
B710M	68	73	52	70	70	90	69	80	67	70	75
B750MR	41	63	53	54	59	65	50	59	59		65

Deduct and Correction Curves

The deduct and correction curves were developed by converting the rating data into deduct values and then plotting those values against an appropriate parameter. In all cases, the deduct values are simply 100 minus the mean rating values.

Deduct Curves

The deduct curves were created by plotting the mean deduct values against their respective densities for each distress type and severity level combination. Table 27 gives a sample of that data for distress B2, Vegetation Growth. Figure 15 displays that same data, when plotted as deduct curves. All of the data for deduct curves development is compiled elsewhere (Uzarski 1991). The complete deduct curve family is found in TR FM-93/14.

Correction Curves

Based on the rating results of the combined distress schematic sheets, the Corrected Deduct Values (CDV) were plotted against the Total Deduct Values (TDV) to obtain the correction curves. A family of curves resulted when the data points were grouped when the number ("q") of individual distress type-severity level combinations were the same. To be counted, any distress type-severity level combination deduct value had to be greater than 10 points. The 10-point minimum cutoff resulted in the best curve fitting for the data set. Table 28 displays a sample of this data. The complete set is found elsewhere (Uzarski 1991). TR FM-93/14 includes the correction curves.

Table 27

Sample Deduct Value Data for Distress B2

Schem. Code #	Distress Type	Sev Level	Density	Mean Rating	DV
B710L	B9	L	10.00	87	13
B750L	B9	L	50.00	66	34
B750LR	B9	L	50.00	61	39
B7100L	B9	L	100.00	57	43
B710M	B9	M	10.00	70	30
B750MR	B9	M	50.00	58	42
B750M	B9	M	50.00	56	44
B7100M	B9	M	100.00	51	49
B710HR	B9	H	10.00	56	44
B750HR	B9	H	50.00	48	52
B7100HR	B9	H	100.00	36	64
B710VH	B9	VH	10.00	48	52
B750VH	B9	VH	50.00	16	84
B750VHR	B9	VH	50.00	18	82
B7100VH	B9	VH	100.00	12	88

Field Verification

The BSCI procedures were verified as discussed in Chapter 5. A sample of the field data is shown in Table 29. All of the data are compiled elsewhere (Uzarski 1991), but compared in Figure 16. Pertinent statistics show:

- a squared correlation coefficient (r^2) of 0.94 and
- a difference between the mean BSCI and the mean BSCR of -0.5 points

These factors indicate that an excellent correlation has been obtained.

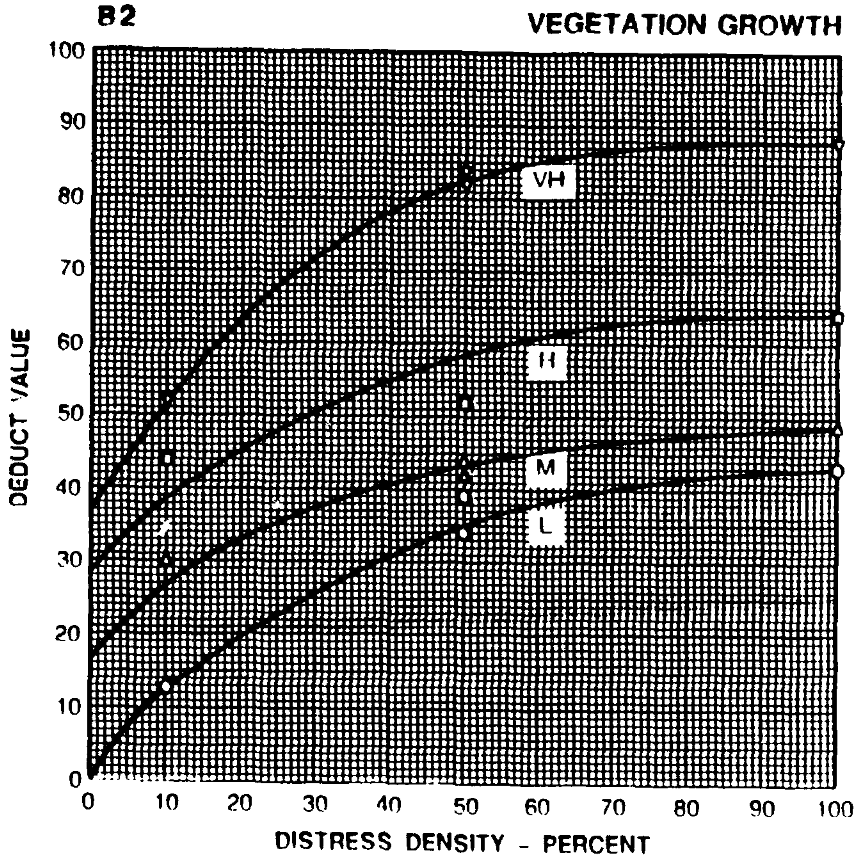

Figure 15. Deduct Curves for Distress B2.

Table 28

Sample Ballast, Subgrade, and Roadway Component Group Correction Curves Deduct Value Data

Schem. Code #	Rating Mean	CDV	TDV	q
BSC06	59	41	82	3
BSC13	60	40	73	3
BSC09	59	41	68	3
BSC20	23	77	221	4
BSC17	11	89	192	4
BSC11	11	89	175	4
BSC26	25	75	158	4
BSC19	43	57	154	4
BSC18	49	51	110	4
BSC16	58	42	106	4

Table 29

Sample BSCI/Mean BSCR Data

Track Segment #	Rater				Ave BSCR	BSCI
	A	B	F	O		
Soo Line Lead	57	57	76		63	63
Burns City Siding	54	50	69		58	58
R15601	80	84	82	83	82	68
SL01	40		42	21	34	24
SL02	45		55	53	51	51
BT01	85		89	89	88	88
R101		100	100	100	100	100
R30101		42	55	58	52	52
R2501		60	68	62	63	67
R501		100	100	100	100	100

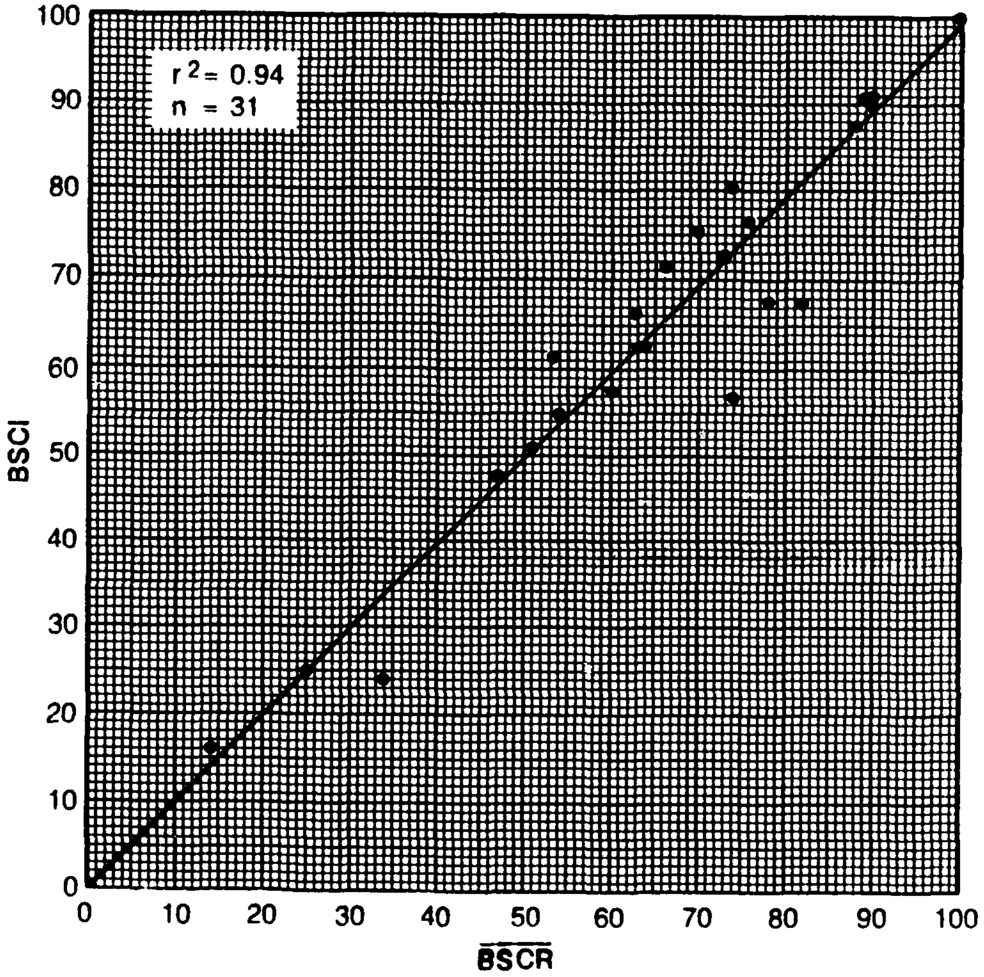

Figure 16. BSCI/Mean BSCR Comparison.

9 TRACK STRUCTURE CONDITION INDEX (TSCI)

Chapter 5 explained that the TSCI was an outgrowth of the component indexes. This chapter explains how that was accomplished and presents the relationship between the TSCI and the component indexes.

Rating Data

The rating data for TSCI development was collected at the same time the component indexes were being validated in the field. All raters were asked to provide a TSCR after they inspected selected track segment sample units and the RJCR, TCR, and BSCR given. Later, the inspection data were used to compute the RJCI, TCI, and BSCI for each sample unit. All of this information would be used to formulate the TSCI. A sample of this information is shown in Table 30. The complete data set is presented elsewhere (Uzarski 1991).

Aggregation of Component Indexes

Different approaches were investigated for aggregating the RJCI, TCI, and BSCI into the TSCI. The goal was to select the approach that lead to the best correlation of predicted TSCI to the rating panel's mean TSCR. The different approaches simply involve weighting the component indexes differently. The method that was selected is presented below. A complete documentation of the other approaches can be found elsewhere (Uzarski 1991).

Weight by Relative Index Value Using Regression

This approach looks at the relationship on how the mean TSCR's are influenced by the relative values of the component group ratings. That is, if any component group rating was low, such as ties or ballast and subgrade, the overall mean TSCR was also low. A linear regression model was used to determine the weightings from the rating data. The mean ratings, sorted by the lowest, middle, and highest values for each inspected sample unit were taken as the independent variables and the mean TSCR for those same sample units as the dependent variable in the regression model. The data from all of the inspected sample units were included in the analysis.

The equation that evolved from the regression is:

$$TSCI = 5.54 + 0.58\overline{CR}_{\mathrm{Low}} + 0.49\overline{CR}_{\mathrm{Mid}} - 0.10\overline{CR}_{\mathrm{High}} \qquad \text{[Eq 3]}$$

This equation had a resultant squared correlation coefficient (r^2) of 0.98. Since the component group indexes are predictors of the mean ratings, they were substituted into Equation 3 to produce Equation 4 as follows:

$$\mathrm{TSCI} = 5.54 + 0.58(\mathrm{CI}_{\mathrm{Low}}) + 0.49(\mathrm{CI}_{\mathrm{Mid}}) - 0.10(\mathrm{CI}_{\mathrm{High}}) \qquad \text{[Eq 4]}$$

Equation 4 produced a squared correlation coefficient (r^2) of 0.90 when the computed TSCIs were compared to the mean TSCRs of the inspected sample units. That data are compared elsewhere (Uzarski 1991).

Athough a good correlation was obtained by this method, two shortcomings are apparent. One is that the relationship does not allow for a zero value for the TSCI. The other is that a negative term exists

Table 30

Sample TSCI Data

Track Segment #	**Rater**				**Mean TSCR**
	A	**B**	**F**	**O**	
Soo Line Lead	55	55	55		55
Burns City Siding	55	55	57		56
R15601	55	66	53	68	61
B'ı01	91		89	93	91
SL01	35		42	43	40
SL02	27		40	53	40
R101		93	84	81	85
R30101		47	55	51	51

in the equation. One would expect that if a component were repaired, an overall increase in the TSCI would occur. However, by this relationship if the component in the best condition (reflected by the highest index value) were repaired, the TSCI would actually decrease. Therefore, a modification to the method was needed to rectify these shortcomings.

Weight by Relative Index Value

The solution was to modify Equation 4. A basic three-term linear equation was desired. Recognizing that the lowest component group index influenced the TSCI the most and that the hightest component group index influenced the TSCI the least, the task was to determine the term coefficients weighted appropriately. Each term coefficient, to be weighted properly, is a value less than 1.0 and the sum of the coefficients equals 1.0. This approach results in a lower squared correlation coefficient than Equation 4 (since this deviates from the least squares fit). However, if the reduction is not excessive the problems cited above will be overcome and a very practical relationship will be established.

The analysis was done using trial-and-error with the goal of having the mean TSCI match the mean TSCR. The following equation resulted:

$$\text{TSCI} = 0.50(\text{CI}_{\text{Low}}) + 0.35(\text{CI}_{\text{Mid}}) + 0.15(\text{CI}_{\text{High}}) \qquad \text{[Eq 5]}$$

Equation 5 produced the following pertinent statistics.

- A squared correlation coefficient (r^2) of 0.86
- A difference between the mean TSCI and the mean TSCR of 0.0 points.

Thus, an excellent correlation has been obtained.

The computed TSCIs are graphically compared in Figure 17 to the mean TSCRs of the inspected sample units.

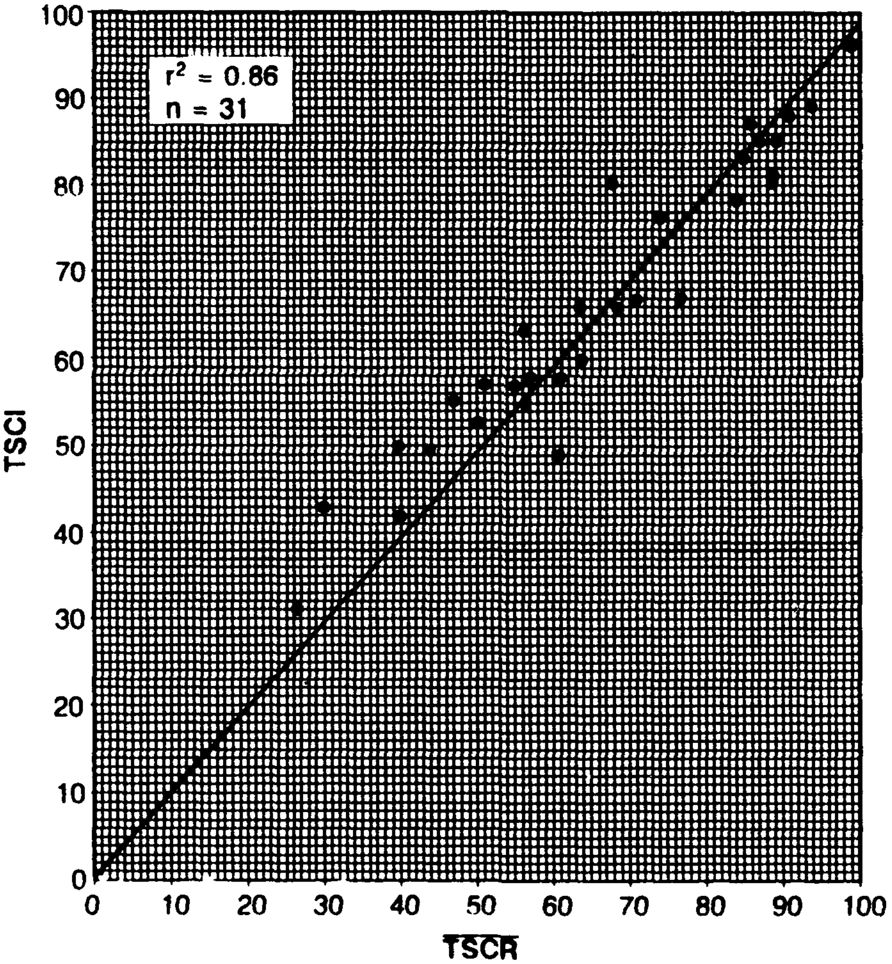

Figure 17. TSCI/Mean TSCR Comparison for Weight by Relative Index Value Approach.

10 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

This work was initiated to develop condition indexes for railroad track and that development was accomplished. Specifically, indexes were developed for the rail and joints component group (RJCI), tie component group (TCI), ballast and subgrade component group (BSCI), and the track structure in general (TSCI). Several conclusions resulted from this development.

1. Field testing demonstrated that the computed indexes match very well with the average ratings of a panel consisting of track experts.

2. The idea of combining several track components into logical component groups proved to be a valid basis for index development.

3. Reducing over 250 specific track defects into 25 distress types with each having 1 to 4 severity levels was an effective approach for developing inspection-based condition indexes for track.

4. This work also developed a network level condition survey inspection procedure. It was shown to work very well for use in collecting condition survey information needed for index computation. In field testing, the condition surveys progressed relatively quickly. The use of aggregated distresses and sampling techniques resulted in a procedure that requires a minimum amount of inspection effort.

5. An interval rating scale proved to be a proper selection for developing track condition indexes.

6. The development of an interval rating scale using the direct approach also proved to be workable for this application.

7. The use of a weighted deduct-density model was a valid application for RJCI, TCI, and BSCI development.

8. A linear regression approach was not valid for the TSCI development. However, by modifying a regression developed equation, an overall TSCI can be computed from the component index values by a relative weighting of the ranked component group indexes.

9. The use of schematic rating sheets was shown to be a practical method for data collection. Their use also overcame several logistical shortcomings of locating all of the needed distress types and severity levels and getting the entire panel to the various sites at the same time.

10. A sufficient number of track experts rated the various distress types and severity levels so that, statistically, the developed individual deduct curves are within plus-or-minus 5 points of the true deduct curves with 95 percent confidence.

Recommendations

This work puts forth several recommendations that should be followed by USACERL to foster the use of these indexes and/or enhance their application.

1. These index procedures should be incorporated into the computer programming for the RAILER system as soon as possible.

2. Research should be pursued to develop condition prediction models that incorporate these indexes. Predicting future conditions is required for developing long range work plans and overall M&R strategies.

3. The shape of the performance curve (condition index vs time or age) should be established so that remaining life and cost relationships can be estimated.

4. Different uses for the indexes should be studied. This will maximize their management value. This includes developing a correlation between index values and required budget level based on future conditions.

5. Research currently is being accomplished within the railroad industry to quantify the condition of individual ties. Once that work is completed, the need for TCI modifications should be studied.

6. The use of various electronic handheld data recording tools such as electronic clipboards, handheld computers and voice recording devices should be investigated. If successful, some of these will reduce the time and labor costs for the condition survey inspection effort.

7. Additional field validation should be pursued. Testing in different geographical areas with different rating panel members will serve to confirm the condition index application at a wide variety of locations.

8. The condition index procedures should be implemented at a RAILER site to demonstrate the full value of the indexes in an actual management environment.

9. The number of sample units that should be inspected for network level management needs to be established.

10. Condition index use on Class 1 and regional railroads should be investigated for applicability and acceptability.

11. Condition index applicability on heavy tonnage and/or high density lines should also be investigated.

METRIC CONVERSION TABLE

1 ft = 0.305 m
1 in. = 2.54 cm
1 mile = 1.61 km
1 ton = 1016 kg

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APPENDIX A: DIVIDING A TRACK SEGMENT INTO SAMPLE UNITS

1. A location reference system should be applied to the track. The use of 100-ft "stations" are recommended. Each track segment will have a beginning and ending station location.

2. Sample units are to be 100-ft long with each one beginning at a x + 00 station location (except for the first sample unit as noted below).

3. Since track segments rarely begin and end at 00 stations, beginning and ending sample units must be adjusted. If the distance from the beginning of the segment is less than 50 ft to the first 00 station, this distance is to be included with the first 100-ft distance (that begins at the 00 station) forming a sample unit less than 150 ft in length. If the distance from the beginning of the segment is greater than or equal to 50 ft to the first 00 station, this portion of the segment will form its own sample unit. The same is true at the end of a segment.

4. Very short segments may have only one sample unit. Depending on where the 00 stations are located, the sample unit size may vary. They may be a minimum of 50 ft and a maximum of 150 ft long. By RAILER inventory definition, segments must be at least 50 ft long.

5. Turnouts will reside in a single sample unit.

6. Sample units will be numbered consecutively.

APPENDIX B: INSPECTION AND CONDITION INDEX DETERMINATION FOR A TRACK SEGMENT

Step 1 - Divide track segment into sample units.

Step 2 - Determine which representative sample units shall be inspected. This can be done on a random or systematic random basis.

Step 3 - Inspect the component groups of each selected sample unit.

Rail and Joints

Ties

Ballast and Subgrade

Step 4 - Sample units not selected for inspection should be walked or driven over in a track vehicle to identify any safety defects that require immediate M&R attention. These are noted for corrective action, but will not enter into the index determinations. Also, any "nonrepresentative" sample units should be noted for additional inspection.

Step 5 - Inspect the additional sample units as in Step 3.

Step 6 - Determine the RJCI, TCI, and BSCI for each inspected sample unit.

Step 7 - Average the RJCI, TCI, and BSCI for each sample unit inspected to obtain the RJCI, TCI, and BSCI for the entire track segment. If only random sample units are inspected, the track segment condition indexes (CIs) are simply the mean of the sample unit CIs. If additional sample units are inspected, the following equation is to be used:

$$CI_{ts} = \frac{(N-A)CI_R + (A)CI_A}{N} \qquad [Eq\ B1]$$

where:
CI_{ts} = RJCI, TCI, or BSCI of the track segment
N = total number of sample units in the track segment
A = number of additional (nonrepresentative) sample units
CI_R = the average RJCI, TCI, or BSCI of the random (representative) sample units
CI_A = the average RJCI, TCI, or BSCI of the additional sample units.

Step 8 - Rank the track segment RJCI, TCI, and BSCI low to high.

Step 9 - Compute the TSCI for the track segment using the following equation:

$$TSCI = 0.5(CI_{Low})+0.35(CI_{Mid})+0.15(CI_{High}) \qquad [Eq\ B2]$$

APPENDIX C: RATER LISTING

Name	Code	Employer	Yrs Exp
1. Keith Parsons	A	Crane Naval Weapons Ctr, IN	18
2. Tom Pinnick	B	Crane Naval Weapons Ctr, IN	10
3. Rick Hawkins	C	Crane Naval Weapons Ctr, IN	11
4. Tommy Houston	D	Fort Stewart, GA	30
5. James Davis	E	Fort Stewart, GA (withdrew)	--
6. Don Uzarski	F	USACERL, IL	6
7. Don Plotkin	G	USACERL, IL	16
8. Dave Brown	H	NPWC Norfolk, VA	10
9. Bill Gannon	I	SOUTHNAVFACENGCOM, SC	11
10. Roger Simmons	J	Red River Army Depot, TX	10
11. Roswell Clark	K	Red River Army Depot, TX	10
12. Marshall Thompson	L	Univ. of Illinois	15
13. Paul T. Gegg	M	Union Pacific R.R.	18
14. Curewood Wells	N	Union Pacific R.R.	20
15. Rich Harris	O	USACERL, IL	4
16. Lorin Wright	P	Tooele Army Depot, UT	23
17. David Burns	Q	Railroad Consultant, IL	14
18. Richard W. Bailey	R	Chicago & North Western R.R. (ret)	36
19. Robert J. Brueske	S	Milwaukee Road R.R. (ret)	40
20. Walter E. Fuhr	T	Milwaukee Road R.R. (ret)	50
21. William D. Lewis	U	Soo Line R.R. (ret)	35
22. Samuel J. Levy	V	Belt Railway of Chicago (ret)	41
23. Warren G. Taylor	W	Belt Railway of Chicago (ret)	26
24. Valentine Arcudi	X	Canadian Pacific R.R. (ret)	38
25. James Jardine	Y	Canadian Pacific R.R. (ret)	36
26. Russell Abbott	Z	Chessie System	19
27. Arthur Hall	AA	Chessie System	28
28. Lester Kelly	BB	Chessie System (ret)	34
		Average	= 22.5

APPENDIX D: RATING INSTRUCTIONS

A. Rail and Joints Component Group Rating Instructions

1. Ratings are to be done in a random order.

2. Raters will rate independently.

3. Schematic sheets will be distributed by the facilitator one-at-a-time and collected immediately after the rating is assigned.

4. Assume no ties are defective or missing.

5. Assume ballast and subgrade is adequate.

6. Assume no track geometry problems.

7. A rail weight is not specified, but it could be assumed to be between about 70 and 115 lb/yd (not very light or heavy).

8. When each sheet is given to the rater, an explanation as to what the distress is must be given by the facilitator. The distress list for rail and joint defects must be given to the raters. The number of rails, joints, etc. affected may also be given by the facilitator (if asked).

9. The rail and joints component group is to be rated with regard to the track's current ability to support typical short line, military, or industrial traffic and/or the track's maintenance, repair, or rehabilitation needs to sustain that traffic.

10. The origin of the scale is 100. By definition, if the component group is defect free, a condition rating of 100 shall be assigned. For any combination of distress type, severity, and density, an appropriate condition rating shall be assigned by the rater based on his/her best judgement.

11. Rail defects may be assumed to be distributed throughout the rail. Some defects may cover an entire rail (e.g., rail head wear) whereas some may be very localized (e.g., complete break).

12. The guidelines of the rating intervals are to be used in the rating process.

13. When rating, the appropriate rating interval should be first determined. Then, an appropriate numeric value within that interval should be assigned.

14. Any distresses not covered during the session that the raters feel have been overlooked should be listed by the facilitator and additional rating sheets prepared. Raters should then provide rating values for those types at various severity and density levels (as appropriate).

B. Tie Component Group Rating Instructions

1. Ratings are to be done in a random order.

2. Raters will rate independently.

3. Schematic sheets will be distributed by the facilitator one-at-a-time and collected immediately after the rating is assigned.

4. Assume ballast is clean and free-draining.

5. Assume no rail or joint defects.

6. A rail weight is not specified, but it could be assumed to be between about 70 and 115 lb/yd (not very light or heavy).

7. Definition of symbols:
   a. Defective tie: Wavy line
   b. Missing tie: M
   c. Rotated tie: R
   d. Skewed tie: S

8. The ties component group is to be rated with regard to the track's <u>current</u> ability to support typical short line, military, or industrial traffic and/or the track's maintenance, repair, or rehabilitation needs to sustain that traffic.

9. The origin of the scale is 100. By definition, if the ties are defect free, a condition rating of 100 shall be assigned. For any combination of distress type, severity, and density, an appropriate condition rating shall be assigned by the rater based on his/her best judgement.

10. The guidelines of the rating intervals are to be used in the rating process.

11. When rating, the appropriate rating interval should be first determined. Then, an appropriate numeric value within that interval should be assigned.

12. Any distresses not covered during the session that the raters feel have been overlooked should be listed by the facilitator and additional rating sheets prepared. Raters should then provide rating values for those types at various severity and density levels (as appropriate).

C. Ballast and Subgrade Component Group Rating Instructions

1. Ratings are to be done in a <u>random</u> order.

2. Raters will rate independently.

3. Schematic sheets will be distributed by the facilitator one-at-a-time and collected immediately after the rating is assigned.

4. Assume no ties are defective or missing.

5. Assume no rail or joint defects.

6. A rail weight is not specified, but it could be assumed to be between about 70 and 115 lb/yd (not very light or heavy).

7. When each sheet is given to the rater, an explanation as to what the distress is must be given by the facilitator. The percent area affected may also be given by the facilitator (if asked).

8. The ballast and subgrade component group is to be rated with regard to the track's <u>current</u> ability to support typical short line, military, or industrial traffic and/or the track's maintenance, repair, or rehabilitation needs to sustain that traffic.

9. The origin of the scale is 100. By definition, if the ties are defect free, a condition rating of 100 shall be assigned. For any combination of distress type, severity, and density, an appropriate condition rating shall be assigned by the rater based on his/her best judgement.

10. The guidelines of the rating intervals are to be used in the rating process.

11. When rating, the appropriate rating interval should be first determined. Then, an appropriate numeric value within that interval should be assigned.

12. Any distresses not covered during the session that the raters feel have been overlooked should be listed by the facilitator and additional rating sheets prepared. Raters should then provide rating values for those types at various severity and density levels (as appropriate).

APPENDIX E: RAIL AND JOINTS COMPONENT GROUP DEFECTS

- Rail Defects

  - Bent Rail
  - Bolt Hole Crack
  - Broken Base
  - Chips or Dents in Head
  - Complete Break
  - Compound Fissure
  - Corroded Base
  - Corrugations
  - Crushed Head
  - Detail Fracture
  - End Batter
  - Engine Burns
  - Engine Burn Fracture
  - Flaking
  - Head Checks (surface cracks)
  - Head Web Separation
  - Horizontal Split Head
  - Mill Defects
  - Overflow
  - Piped Rail
  - Running Surface Damage
  - Shelling
  - Short Rails
  - Side Wear
  - Slivers
  - Split Web
  - Surface Spalls
  - Torch Cut Hole
  - Torch Cut Rail
  - Transverse Fissure
  - Vertical Split Head
  - Vertical Wear
  - Weld Defects

- Joint Defects

  - All Bolts at Joint Loose
  - All Bolts on a Rail End Broken or Missing
  - Both Bars Broken or Missing
  - Both Bars Center Cracked
  - Broken or Cracked Bar (not through center)
  - Corroded Bar
  - Defective or Missing Bolt
  - Improper Size or Type of Bar
  - Improper Size or Type of Bolt
  - Loose Bars
  - Loose Bolt
  - One Bar Center Broken or Missing

    One Bar Center Cracked
    Only One Bolt per Rail End
    Rail End Gap
    Rail End Mismatch
    Torch Cut or Altered Bar

- Hold-Down Devices Defects

  - Improper Pattern or Position
  - Loose
  - Bent
  - Broken
  - Missing
  - Otherwise Defective

- Tie Plate Defects

  - Bent
  - Broken
  - Corroded
  - Cracked
  - Improper Position

- Gauge Rod Defects

  - Bent
  - Broken
  - Cracked
  - Loose

- Rail Anchor Defects

  - Improper Position
  - Loose
  - Missing (if originally installed)

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