Development of Condition Indexes for Low-Volume Railroad Trackage

DONALD R. UZARSKI, MICHAEL I. DARTER, AND MARSHALL R. THOMPSON

Track managers of military, local, and industrial railroads as well as low-volume branch lines and yards of larger railroads need an objective and repeatable method to assess track that can be used as a basis to evaluate current conditions, predict future conditions, establish deterioration rates, formulate long-range budgets, and determine and prioritize renewal projects. In response to this need, the U.S. Army Construction Engineering Research Laboratories in conjunction with the University of Illinois developed condition indexes for rail, joint, and fastenings; ties; and ballast, subgrade, and roadway component groups. An overall composite condition index for railroad track, as a whole, was also developed. The indexes are based on data obtained from a panel of track experts assessing a variety of track conditions through the use of numerical ratings. A weighted deduct-density model is used to translate the panel ratings into meaningful indexes that are computed from routinely collected visual and rail flaw inspection information. The development of those indexes is described.

The U.S. Navy and the U.S. Army together own more than 5,700 mi of railroad track (*1,2*) that are vital to the mobilization and operational needs of the Department of Defense. Civilian local (switching, terminal, and line-haul) railroad companies control another 19,000 mi of track (approximately 10 percent of the entire commercial sector) (*3*). That predominantly low-volume ($< \approx 5$ MGT/year) track serves a transportation niche essential to the economic well being of the United States.

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

D. R. Uzarski, U.S. Army Construction Engineering Research Laboratories, P.O. Box 9005, Champaign, Ill. 61826. M. I. Darter and M. R. Thompson, University of Illinois, Newmark Civil Engineering Laboratory, Urbana, Ill. 61801.

NEED FOR CONDITION INDEXES

In an attempt to improve 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 and is enhancing a computer-based decision support system called the RAILER Engineered Management System (EMS) (*4*). A condition assessment method was needed in RAILER to support the needs addressed above. The method chosen took the form of unbiased and repeatable condition indexes for rail, joints, and fastenings (RJCI); cross ties and switch ties (TCI); and ballast, subgrade, and roadway (BSCI) component groups as well as an overall Track Structure Condition Index (TSCI). The indexes are able to objectively and quantitatively measure the overall condition of track segments.

Track management using RAILER is performed at two levels: network and project (*4*). These condition indexes are intended to play a key role at the network level, where roadmasters and others make large-scale decisions focusing on the "where," "when," and "how much" aspects of track management. Current condition assessments and deterioration modeling (prediction models are under development) are the heart of the management process. Deterioration modeling has been recognized as an important element in track maintenance planning (*5–8*). Critical index values can be determined whereby track segments that are below an established critical value are candidates for M&R. The candidate track segments can then be prioritized for actual work accomplishment, and long-range (2 to 10 years) work plans can result. Budgets can be developed on the basis of anticipated needs by correlating costs with projected future year index values.

Network level management using these indexes coupled to prediction models will also 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.

CONDITION ASSESSMENT METHODS

Different methods for assessing railroad track conditions have been or are being used to meet various management objectives. These include track standards and track quality indexes.

Track Standards

Track standards are 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 (*9*) and safety combined with specific maintenance levels (*10,11*). Commercial railroads (large and small) may also have developed standards for their internal use.

Unfortunately, the various standards do not provide for an overall 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 discrete requirements of a standard. Although current M&R needs can be determined with respect to an appropriate standard, condition prediction is not possible, nor can future work needs or budgets be determined. This is because deterioration rates cannot be determined or modeled for predicted performance.

Track Quality Indexes

Automated track geometry–based condition indexes have been developed that are commonly known as track quality indexes (TQIs) (*5,12–16*). The various TQIs generally measure different statistically based parameters (e.g., standard deviation) derived from alignment, profile, cross-level, warp, and gage measurements. Because of the expense associated with the data collection, TQIs are generally used only on important high-speed or high-tonnage lines. However, low speeds, certain track conditions, and car harmonics also can lead to derailments, and certain indexes have been developed to measure that potential (*17*). TQIs have been shown to be useful for M&R planning (*6,18–21*).

Since the military and most local railroad companies do not routinely collect automated track geometry information, these indexes are not applicable or useful (*22*). No TQIs, based primarily on routine visual inspections, have been developed for low-volume track, which is typically found on military and local railroads.

INDEX REPRESENTATION

Index Definition

Each component condition group index reflects (*a*) the current physical ability to support typical military, short-line, or industrial traffic and (*b*) the 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

Condition and M&R guidelines were established for the seven categories that make up the index scale. These were needed to ensure that the computed indexes would meet the intended definition given above. Table 1 gives the seven categories and guidelines. As will be discussed later, the guidelines were essential to developing meaningful indexes.

APPLICATION CRITERIA

The indexes are intended to be used on military trackage, local track networks, some yards, sidings, branch lines, and other tracks of larger railroads that meet the following criteria:

- Track structure: Wood ties were assumed in the development of the TCI because of their preponderance in track. Also, all of the indexes were developed on the assumption that the rail weight was neither very light [less than about 35 kg/m (70 lb/yd)] nor very heavy [greater than about 59 kg/m (118 lb/yd)].
- Traffic density and speed: The indexes were developed on the assumption that traffic is generally light [less than about 5.5 million metric gross tons/year (5 MGT/year)] and that speeds are limited to about 67 km/hr (40 mph).

CONDITION SURVEY CRITERIA

The intended purposes of these indexes require neither very detailed nor extensive condition information. Thus, a research objective was to design a condition survey inspection procedure that collected just the right amount and type of information with a minimum level of effort. The survey is intended to be accomplished primarily through visual means during one or more periodic track safety inspections. Internal rail flaw surveys can be used to supplement the visual surveys. Annual, biannual, or less frequent condition surveys are envisioned depending on several variables, especially the rate of track deterioration.

To further minimize the level of effort associated with the condition surveys, sampling methods may be used. Since the intent is to quantify a generalized condition for the purposes cited above, the entire track segment length need not be surveyed. Rather, surveying a reasonable number of representative sample units for each track segment will suffice. The sample units were defined in the development process to be nominally 30 m (100 ft) in length.

The condition survey process is described elsewhere (*23*).

RATING SCALE DEVELOPMENT CONCEPTS

Rating Panel

Rating scales can be developed in various ways depending on the intent and parameter being scaled. One approach uses rating panels for the collection of rating information. With this approach, raters are presented with a physical stimulus, and a rating is provided in response (*24*). A rating panel approach proved to be an ideal method for developing these indexes.

The panel consisted of 27 track experts from commercial railroad companies, military installations, a research laboratory, a university, and a consulting business. Their experience averaged 22.5 years.

TABLE 1 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 or minor repair could be scheduled for accomplishment.
71-85	**Very Good**	Minor deterioration. Track function may be slightly impaired. No immediate work action is required, but routine or preventive maintenance or minor repair could be scheduled for accomplishment.
56-70	**Good**	Moderate deterioration. Track function is somewhat impaired. Routine maintenance or minor repair may be required.
41-55	**Fair**	Significant deterioration. Track function is impaired, but not severely. Significant 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**	Severe 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**	Severe deterioration has occurred throughout nearly all or the entire track. Track is no longer functional. Major repair, complete restoration, or total reconstruction is required.

Scale Classification and Method

The scale given in Table 1 is an interval scale (*25*). An interval scale lends meaning to number size and the differences between pairs of numbers. Ordering is possible, and mean and standard deviation have meaning. However, values are not proportional.

Interval scale ratings can be obtained directly or indirectly (*26,27*). The direct approach was used, which means that a rater can quantify his or her judgment directly on the scale.

Instruction

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 their task (*25*). The instructions provide guidance and direction on specifically what raters are to do and how they are to do it. This process includes a definition of what the rating scale represents and an explanation of specific anchors and cues on the scale (*24,26*). For this development the primary anchor for that scale is 100, meaning that the track is free of observable distress. Each interval boundary (see Table 1) also serves as an anchor.

Cues lead to rater understanding of what the different portions of a rating scale represent (*24,26*). The condition descriptions in Table 1 provided the cues for the ratings. Two sets of cues were superimposed in the descriptions: operational and M&R considerations. The raters were advised to consider both in their ratings.

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 inspection information into condition indexes based on the ratings. In fact, the condition indexes are mathematical models for estimating the average subjective ratings of an experienced rating panel. The weighted deduct-density model proved to be ideal for computing the component indexes.

Model Concepts and Theory

The degree of deterioration of a track component group is a function of three characteristics:

- Type of distress (e.g., rail defects);
- Severity of distress [e.g., bolt hole crack ≤ 12.7 mm (0.5 in.)]; and
- Amount of distress, commonly expressed as a percentage to indicate density [e.g., 10 percent of rails have bolt hole cracks ≤ 12.7 mm (0.5 in.)].

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 of these potentially affects 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 basic weighted deduct-density model is

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

where

RJCI = rail and joints condition index;
TCI = tie condition index;
BSCI = ballast and subgrade condition index;
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 ith distress type; and
$F(t, d)$ = adjustment factor for multiple distresses that vary with total summed deduct value, t, and number of individual deducts over an established minimum value, d.

Distress Types and Severity Levels

The various distress types and severity levels for each component group were defined in a manner that makes them easily identifiable during the condition survey. The defining process is described later.

Deduct Weighting Values

The deduct weighting values resulted from the panel's subjective condition ratings of individual distress type and severity level combinations. The panel provided the "weighting" through their ratings. The panel averages lead to the creation of deduct curves, which are graphical representations of deduct value versus density for each distress type and severity level combination. This is discussed further later.

Adjustment Factor for Multiple Distresses

Mathematically, nonlinearity is a requirement for the model. Otherwise, negative condition indexes could occur. From a rating perspective, it was found that as additional distress types and severity levels occurred in the same track segment 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. The panel ratings were used to determine these factors.

DISTRESS DEFINITIONS

Distress Types

Many distress types within a given component group were defined by combining a variety of possible defects for each different component within the group. An example using rail illustrates the approach. Within the RAILER EMS, 33 rail defects are identified (*28*). These defects 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 that are component specific. As an example, two different ballast defects include erosion and settlement. In this example, both of those defects were defined as separate distresses.

In all, 25 different distress types were defined. These include 6 for the rail, joints, and fastenings component group, 8 for the tie component group, and 11 for the ballast, subgrade, and roadway component group. They are given in Table 2. Complete definitions are found elsewhere (*23*,*29*).

TABLE 2 Distress Type Listing

Rail, Joints, and Fastenings
R1. Rail Defects
R2. Joint Defects
R3. Hold-Down Device Defects
R4. Tie Plate Defects
R5. Gauge Rod Defects
R6. Rail Anchor Defects
Ties
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 Tie
T7. All Joint Ties Missing
T8. Improperly Positioned Tie
Ballast, Subgrade, and Roadway
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

As a matter of developmental philosophy, design deficiencies or current inadequacies, such as rail that is too light or tight curves (not caused by alignment deviations) that restrict speed or are derailment prone, were *not* considered as 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. The degrees of impact are reflected as severity levels. However, 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. Raters desired descriptions that relate to track operational criteria as specified in various track standards. Four severity levels resulted. Table 3 describes these levels and their meaning.

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

Definition Evolution

The final distress definitions evolved through an iterative process. First, review of the Federal Railroad Administration, Navy, and Army track standards led to an initial listing. Then discussions with track experts for feedback and revisions fol-

TABLE 3 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.

lowed. This two-step process resulted in preliminary definitions that formed the basis for collecting an initial set of rating data. Discussions held with the raters during the collection process led to further definition revisions. Data analysis and the graphing of the deduct curves resulted in still further modifications. For example, Table 2 gives different tie distresses called, in part, "isolated" or "adjacent." The difference is the number of good ties between the clusters. That number (two or more) was derived from the rating data. A compilation of all of the final definitions is published elsewhere (*23,29*), and an example is given in Table 4.

DATA COLLECTION

Each distress type and severity level combination required the collection of rating data over a range of densities so that the deduct curves could be determined. Ideally, the rating panel would assess these different distress types, severity levels, and densities in the field. However, sufficient 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 to-

TABLE 4 Distress Definition for Joint Defects

R2. Joint Defects

Description: Joint defects include all items that reduce the strength or functionality of joints. Fifteen joint defects are possible. They are listed below within specific severity levels.

Severity Levels:

L - The following defects are low severity:

Broken or Cracked Bar (not through center)
Defective or Missing Bolt
Improper Size or Type of Bar
Improper Size or Type of Bolt
Loose Bolt
Torch Cut or Altered Bar

M - The following defects are medium severity:

All Bolts at Joint Loose
One Bar Center Broken or Missing
One Bar Center Cracked
One Bar Corroded
Only One Bolt per Rail End
Rail End Gap > 25.4 mm (1.0 in) and ≤ 50.8 mm (2.0 in)
Rail End Mismatch > 4.8 mm (0.1875 in) and ≤ 6.4 mm (0.25 in)

H - The following defect is high severity:

Both bars center cracked

VH - The following defects are very high severity:

All Bolts on a Rail End Broken or Missing
Both Bars Broken or Missing
Rail End Gap > 50.8 mm (2.0 in)
Rail End Mismatch > 6.4 mm (0.25 in)

Measurement: Each loose bolt, etc. is considered a separate defect occurrence at a given joint. However, as applicable, only the highest severity level shall be recorded for a specific component (i.e. if the VH severity defect of all bolts on a rail end are broken or missing is present, the L severity defect of individual defective or missing bolts is not counted at the same joint). Defects are summed on a per joint basis. Rails longer than 12 m (39 ft) in length shall be divided into the largest number of equivalent rail lengths of 12 m (39 ft) or less. Assume that imaginary joints exist linking those rails and that those joints are defect free.

Density: Number of Affected Joints / Total Number of Joints in Sample Unit gether at one time to do the ratings proved impossible. Thus, that approach for data collection was not feasible.

The answer to how to collect the necessary data was to develop coded schematic rating sheets to 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 1 shows a situation where a single joint has two loose bolts [shown encoded as LBT(2)]. A series of sheets was developed for each component group to cover the range of distress types and severity levels at varying densities germane to that group. For some, particularly ties where the interactions of clusters would surely drive the defining process, various relationships were presented for rating.

All of the sheets were sorted randomly before being given to each member of the panel. Also, the raters were not told of the distress types and severity levels that they were rating. Rather, the track problems were simply presented. Presenting the sheets in a logical sequence or providing descriptions with words like "very high severity" could have influenced the ratings and, thus, introduced undesirable error.

The rating sessions took place over a period of several months. Generally, the sessions occurred in small groups and at the normal work locations of the raters. Thus, the entire group never assembled concurrently, but most raters were involved in several sessions.

At each session, the raters were given general instructions by a facilitator, a copy of the rating guidelines to use as rating cues, Table 1, and a set of the rating sheets. 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. While each sheet was being rated, the facilitator described the track problem, encouraged the raters to discuss the track problem, and answered questions to help ensure understanding of what was to be rated.

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 panel average was flagged for a rerate. This was done to allow raters the opportunity to correct certain ratings that may have been marked by mistake because of misunderstanding, misinterpretation, distraction, or some other reason.

To rerate, the appropriate sheets were given back to the raters to be rated again. Generally, a short discussion about the distress ensued. The raters were never told whether they were above or below the panel average, and they were under no obligation to change their marks. To reinforce the "no obligation to change" idea, typically the panel members present were all given the same sheets to rerate. Raters were

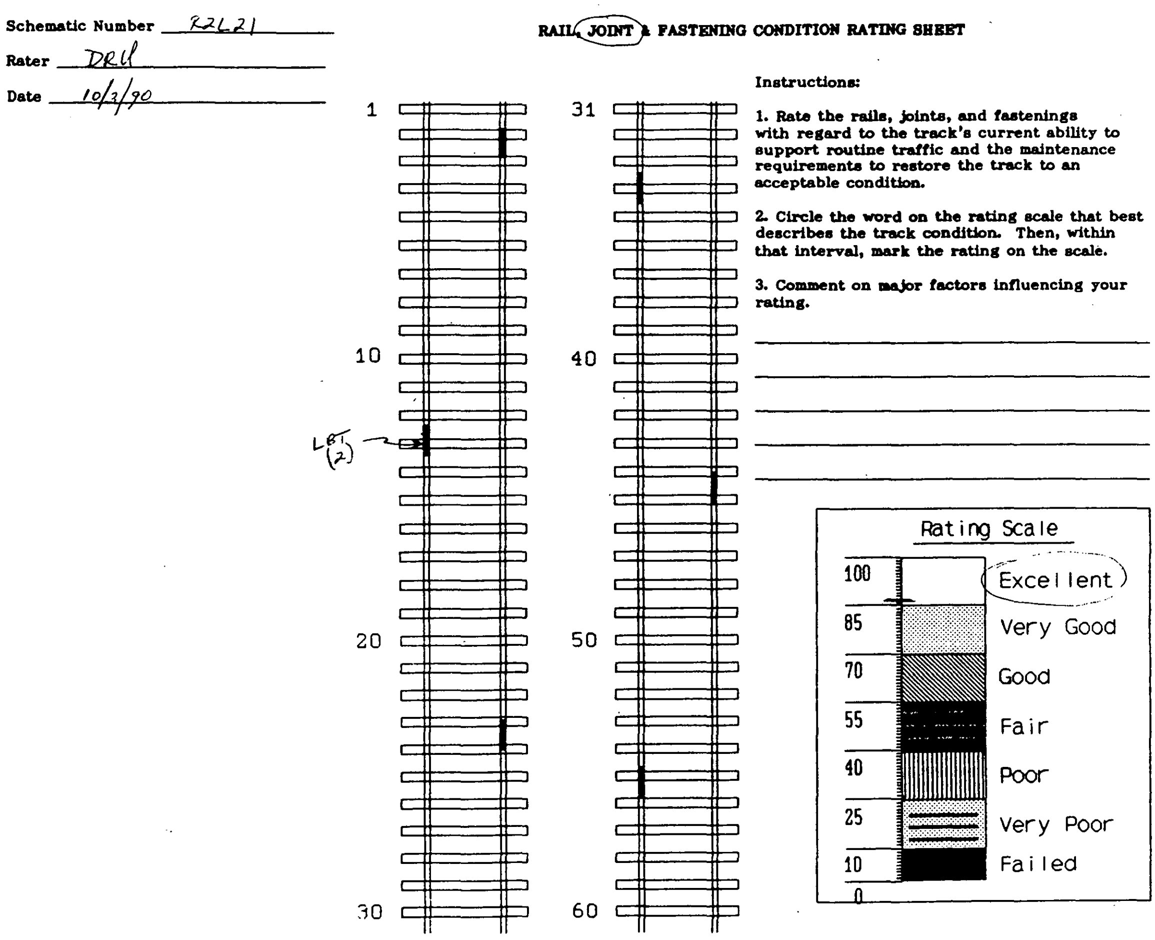

FIGURE 1 Example schematic rating sheet.

always advised to rate their convictions, not to be concerned about what others rated, and that differences in opinion were expected.

The 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 five points of the true average deduct value at a 95 percent confidence interval. This goal was met through the large number of raters employed and amount of data collected (more than 13,000 data points). This is discussed in greater detail elsewhere (*29,30*).

DEVELOPMENT OF THE DEDUCT AND CORRECTION CURVES

A nonlinear regression analysis was used for initial deduct curve determination. Variances and the required rating panel size needed for the desired accuracy were computed from this. In the final form, some smoothing of the curves was performed, because pure reliance on mathematics ignores certain engineering logic. The deduct curves for each severity level within a given distress type form a family, and as such, certain consistent trends for that family are expected. A best smooth curve fit of the final curves ensures that the trends are correct and consistent with the physical happenings. Figure 2 shows the deduct curves for Distress Type R1—rail defects at low severity. The numbers near the curves indicate the number of defects per rail.

As part of the rating sessions, the facilitator gave each rater sets of coded 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. These average rating values were compared with values obtained from summing the deduct points obtained from the deduct curves for all of the distresses present. A family of correction curves resulted. An example set is shown as Figure 3. Note in Figure 3 that there is a numerical cutoff "q" for applying the correction. This cutoff was determined from a best fit analysis and varies for each component group.

FIELD VERIFICATION

The field verification procedure was simple. A group of raters would together survey a selected track segment sample unit so that all agreed on the distresses found. Each rater would rate the rail, joints, and fastenings; tie; and ballast, subgrade, and roadway component groups. Each rater was also asked to provide an overall composite track structure condition rating. Upon completion, the facilitator led a group discussion with each member explaining his rating to the other members of the group. The ratings were then averaged for use in the verification.

After the rating panel surveyed and rated the sample units, the condition indexes were computed from the survey data using the appropriate deduct and correction curves. The computed index values were then compared with the average ratings of the panel. The correlations were excellent. Table 5 gives the correlations.

The field work led to minor distress definition revisions, as appropriate, and to slight adjustments to a few deduct and

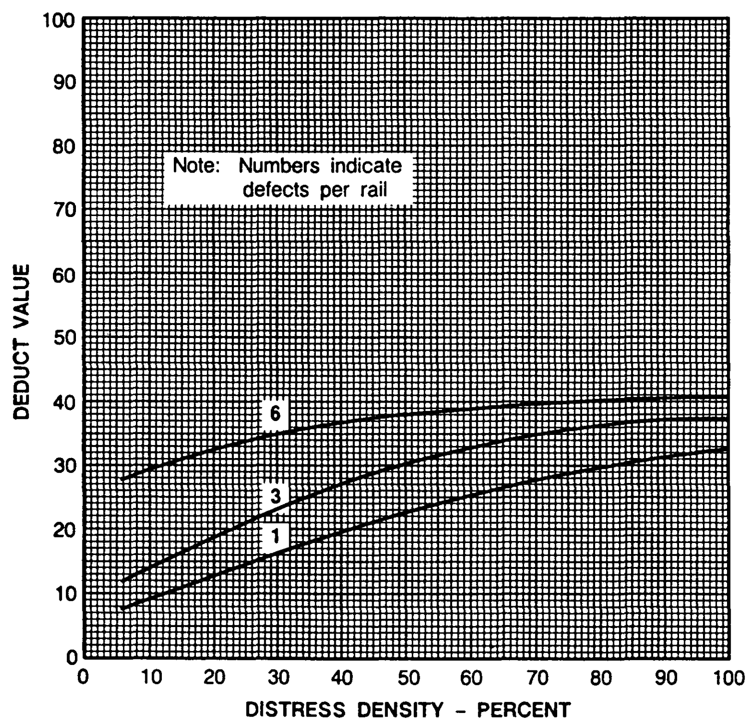

FIGURE 2 Deduct curves for Distress R1L—low severity rail defects.

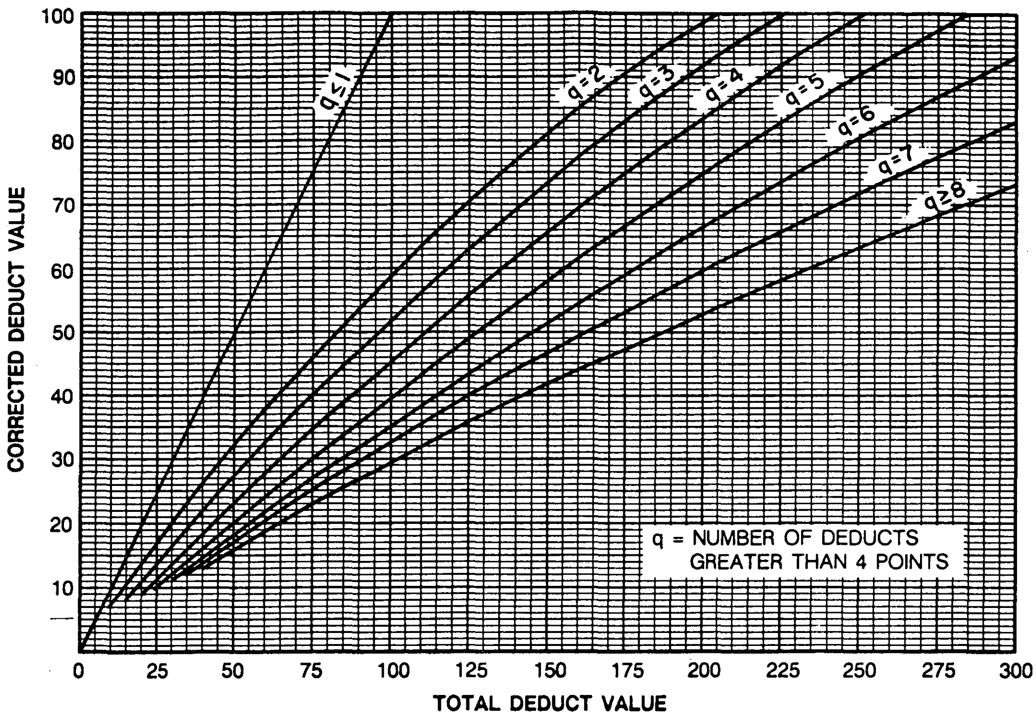

FIGURE 3 Rail, joints, and fastenings component group correction curves.

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 average panel ratings resulted.

TSCI DEVELOPMENT

Different approaches were investigated for aggregating the RJCI, TCI, and BSCI into the TSCI (*29,30*). The goal was to select the approach that led to the best correlation of predicted TSCI with the rating panel's average rating (TSCR) collected during the field validation stage described above.

A basic three-term linear equation was desired. Recognizing that the lowest component group index influenced the TSCI the most and that the highest component group index influenced the TSCI the least, the task was to determine the term coefficients. Each term coefficient, to be weighted properly, is a value less than 1.0, and the sum of the coefficients equals 1.0. The following equation resulted:

$$\text{TSCI} = 0.50\text{LOW} + 0.35\text{MID} + 0.15\text{HIGH} \qquad (2)$$

The values used in Equation 2 are the computed RJCI, TCI, and BSCI, ranked low to high. The correlation between the panel ratings and the computed indexes is shown in Table 5.

CONDITION INDEX DETERMINATION PROCEDURE

Table 6 gives an example of how to compute an RJCI for a sample unit. The same process applies to the TCI and BSCI. A TSCI computation is also given. The indexes for a track segment, as a whole, are averaged from the sample unit indexes.

TABLE 5 Condition Rating/Condition Index Correlations

Index	Statistic: Mean Difference between Computed Index and Panel Ratings, (Δ pts)	Correlation Coefficient (r^2)
RJCI	-1.2	0.91
TCI	-0.4	0.76
BSCI	-0.5	0.94
TSCI	0.0	0.86

TABLE 6 Example RJCI and TSCI Computation

```
Step 1:  Inspect Rail, Joints, and Fastenings Component Group in
         Selected Sample Units

           Summary:

           1 Rail, Single Occurrence of a Low Severity Defect
           2 Joints, Single Occurrence of a Low Severity Defect
           1 Joint, Single Occurrence of a Medium Severity Defect
           24 Occurrences of Improper Spiking Pattern
           9 Occurrences of Improperly Positioned Rail Anchors

Step 2:  Compute Densities

           60 Ties and 6 Rails in Sample Unit

           R1L(1): Density = 1/6 = 16.7%
           R2L(1): Density = 2/6 = 33.3%
           R2M(1): Density = 1/6 = 16.7%
           R3: Density = 24/(60*4) = 10.0%
           R6: Density = 9/60*4) = 3.75%

Step 3:  Compute Deduct Values (DV)

           R1L(1): DV = 11 (from Figure 2)
           R2L(1): DV = 22 (given)
           R2M(1): DV = 35 (given)
           R3: DV = 14 (given)
           T6: DV = 10 (given)

Step 4:  Compute Total Deduct Value (TDV):  TDV = 92

Step 5:  Determine "q"

           q = 5 (total number of deducts greater than 4 pts)

Step 6:  Determine Corrected Deduct Value (CDV)

           CDV = 36 (from Figure 3)

Step 7:  Compute RJCI and Determine Condition Category

           RJCI = 100 - CDV = 64  -->  Good (from Table 1)

Step 8:  Compute TCI and BSCI for Sample Unit (as above); RJCI,
         TCI, and BSCI for all Other Selected Sample Units; and
         Average Results

Step 9:  Rank Track Segment Average Component Group Indexes

           Low  = RJCI = 55 (given)
           Mid  = TCI  = 58 (given)
           High = BSCI = 67 (given)

Step 10:  Substitute into Equation 2 and Compute TSCI

          TSCI = 0.50(55) + 0.35(58) + 0.15(67)
          TSCI = 58  -->  Good (from Table 1)
```

CONCLUSIONS

This work was initiated to develop condition indexes for railroad track, and that development was accomplished. Specifically, indexes were developed for the rail, joints, and fastenings component group (RJCI); tie component group (TCI); ballast, subgrade, and roadway component group (BSCI); and the track structure in general (TSCI). The indexes represent the average subjective judgment of a panel of experienced track experts. The use of an interval rating scale using the direct approach proved workable for this application. The use of schematic rating sheets was shown to be a practical method of data collection as the results were field validated. The weighted deduct-density model was an excellent application for index development and use.

The indexes are intended primarily to help track managers perform a variety of network-level management tasks. These include assessing current condition, predicting future condition, determining deterioration rates, developing and prioritizing long-range work plans and budgets, and measuring the effectiveness of M&R work.

ACKNOWLEDGMENTS

The authors would like to acknowledge Robert Williams of the U.S. Army Engineering and Housing Support Center and

William Gannon of the Southern Division, Naval Facilities Engineering Command, for their continued sponsorship and support of the work.

Richard Harris of USACERL and Samuel Carpenter of the University of Illinois deserve a special mention for their supporting roles in the research. To the RAILER group at USACERL goes the authors' appreciation for the group's efforts in assisting with a myriad of tasks. Finally, the authors' collective thanks are expressed to the entire rating panel, too numerous to mention by name, who devoted countless hours to this effort.

REFERENCES

1. *Detailed Inventory of Naval Shore Facilities.* NAVFAC P-164. Department of the Navy, Naval Facilities Engineering Command, 1987.
2. *Facilities Engineering and Housing Annual Summary of Operations Report, FY86.* U.S. Army Corps of Engineers, Directorate of Military Programs, Office of the Assistant Chief of Engineers, 1987.
3. *Statistics of Regional and Local Railroads.* Association of American Railroads, 1988.
4. D. R. Uzarski and D. E. Plotkin. Interim Method of Maintenance Management for U.S. Army Railroad Track Networks. In *Transportation Research Record 1177*, TRB, National Research Council, Washington, D.C., 1989, pp. 84–94.
5. A. J. Bing. *Development of a Track Degradation Modeling Technique, Volume I.* Final Report. Arthur D. Little, Inc., 1983.
6. A. Hamid, D. Sawyer, M. A. Kenworthy, and K. Rasmussen. *A Prototype Maintenance-of-Way Planning System, Volume I.* Technical Report DOT-FR-80-17. U.S. Department of Transportation, Federal Railroad Administration, 1980.
7. H. G. Webb. Track Maintenance Policy and Planning. In *Transportation Research Record 1029,* TRB, National Research Council, Washington, D.C., 1985, pp. 70–74.
8. G. P. Tew, D. C. Davis, and P. J. Dwyer. The Application of Computer Modelling to Track and Vehicle Maintenance Practices. *Proc., Third International Heavy Haul Railway Conference,* 1986, pp. IIIB-51-1–IIIB-51-9.
9. *Track Safety Standards.* Federal Railroad Administration, U.S. Department of Transportation, 1982.
10. *Railroad Trackage Assessment Field Manual.* NAVFAC MO-103.9. Draft. Department of the Navy, Naval Facilities Engineering Command, 1988.
11. *Railroad Track Standards.* TM 5-628. Department of the Army, 1991.
12. A. E. Fazio and J. L. Corbin. Track Quality Index for High Speed Track. *Journal of Transportation Engineering,* Vol. 112, No. 1, Jan. 1986, pp. 46-61.
13. A. Bing and A. Gross. Development of Railroad Track Degradation Models. In *Transportation Research Record 939*, TRB, National Research Council, Washington, D.C., 1983, pp. 27–31.
14. A. J. Bing. Track Geometry Data for Maintenance Prediction. Proc., Spring Convention, American Society of Civil Engineers, Las Vegas, Nev., April 1982.
15. A. M. Zarembski. TQI's—Part 1, Statistical. *Railway Track and Structures*, July 1987.
16. A. M. Zarembski. TQI's—Part 2, Alternatives. *Railway Track and Structures*, Aug. 1987.
17. H. Weinstock, H. S. Lee, and R. Greif. A Proposed Track Performance Index for Control of Freight Car Harmonic Roll Response. In *Transportation Research Record 1006*, TRB, National Research Council, Washington, D.C., 1987, pp. 9–16.
18. Track Inspection, Mechanized, Automated, Computerized. *Railway Track and Structures*, March 1971, pp. 18–21.
19. A. M. Gary. Maintenance of Way and the Information Explosion. *Progressive Railroading*, March–April 1973, pp. 31–36.
20. CP Rail Projects New Uses for Track Geometry Car. *Railway Age*, April 14, 1975, pp. 38–40.
21. A. E. Fazio and R. Prybella. Development of an Analytical Approach to Track Maintenance Planning. In *Transportation Research Record 744*, TRB, National Research Council, Washington, D.C., 1986, pp. 46–52.
22. S. C. Solverson, M. Y. Shahin, and D. R. Burns. *Development of a Railroad Maintenance Management System for Army Installations: Initial Decision Report*. Technical Report M-85/04. U.S. Army Construction Engineering Research Laboratory, 1984.
23. D. R. Uzarski. *Condition Indexes for Low Volume Railroad Track: Condition Survey Inspection and Distress Manual.* Draft Technical Report. U.S. Army Construction Engineering Research Laboratory, 1992.
24. B. G. Hutchinson. Principles of Subjective Rating Scale Construction. In *Highway Research Record 46*, HRB, National Research Council, Washington, D.C., 1963, pp. 60–70.
25. S. S. Stevens. On the Theory of Scales and Measurement. *Science*, Vol. 103, No. 2684, 1946, pp. 677–680.
26. J. B. Nick and M. S. Janoff. Evaluation of Panel Rating Methods for Assessing Pavement Ride Quality. In *Transportation Research Record 946*, TRB, National Research Council, Washington, D.C., 1983, pp. 5–13.
27. W. S. Torgerson. *Theory and Methods of Scaling*. John Wiley and Sons, New York, 1958.
28. D. R. Uzarski, D. G. Brown, R. W. Harris, and D. E. Plotkin. *Maintenance Management of U.S. Army Railroad Networks—The RAILER system: Detailed Track Inspection Manual.* Draft Technical Report. U.S. Army Construction Engineering Research Laboratory, 1988.
29. D. R. Uzarski. *Development of a Track Structure Condition Index (TSCI).* Ph.D. thesis. University of Illinois, 1991.
30. D. R. Uzarski. *Condition Index Development for Low Volume Railroad Track*. Draft Technical Report. U.S. Army Construction Engineering Research Laboratory, 1992.

The views of the authors do not purport to reflect the position of the Departments of the Army, Navy, or Defense.

Publication of this paper sponsored by Committee on Railway Maintenance.