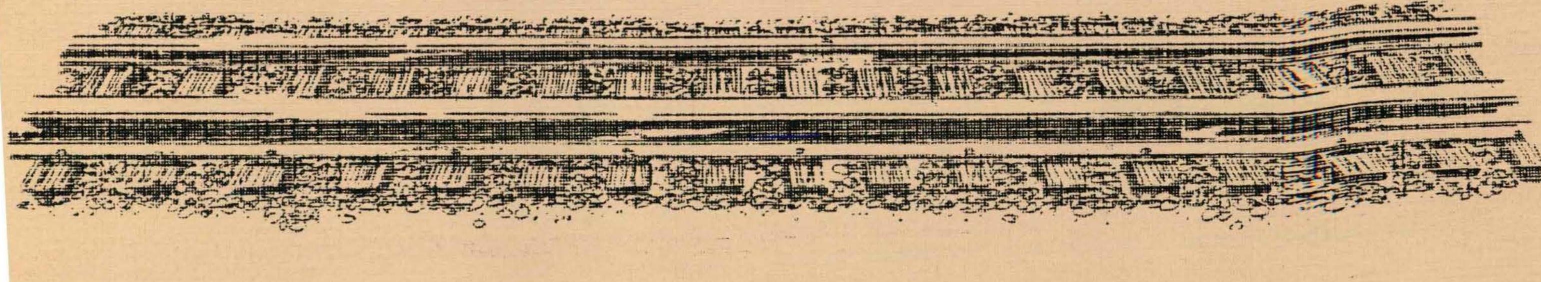
Phase 1

Railroad Rehabilitation Cost Estimating Methodology Study



Presented to

Iowa Department of Transportation

Planning and Research Division

Prepared by

HDR

Henningson, Durham & Richardson, Inc.

February 1979

RAILROAD
REHABILITATION COST ESTIMATING
METHODOLOGY STUDY

PHASE 1 REPORT

Prepared for:

Iowa Department of Transportation
Planning and Research Division
Transportation Research Office

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Henningson, Durham & Richardson, Inc.
Omaha, Nebraska

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SECTION 1
INTRODUCTION

1.1 BACKGROUND

The Iowa Department of Transportation (IDOT) in recent years has been on the forefront of national efforts to improve rail transportation. This involvement in Iowa has taken the form of a track inspection and surveillance program, and more recently a State program to assist railroads to rehabilitate their track structures.

IDOT is currently engaged with the Federal Railroad Administration (FRA) in a research and development project designed, among other things, to expand the capabilities of its Track Geometry Car (TGC) in data collection and track safety inspection activities. This improved utility would enhance IDOT's ability to conduct its rail planning, monitor track condition, prioritize rehabilitation needs, and program its assistance funds.

Of course, any advancements in the usefulness of the TGC in Iowa would have nationwide application toward improved railroad safety and cost-effective deployment of rail rehabilitation funds.

As part of IDOT's research effort focusing on the TGC, it was recognized that a methodology which could convert data gathered by the TGC into an estimate of track rehabilitation costs would be a desirable and beneficial addition to the TGC- based surveillance and assessment package being developed.

1.2 PROBLEM STATEMENT

The principal objective of this study is to determine the feasibility of developing a railroad Rehabilitation Cost Estimating Methodology (RCEM) which would provide reliable cost estimates of rehabilitating track structures from deteriorated states to various classes of improved condition. Specifically, it would be desirable to quantify rehabilitation costs for the following rehabilitation situations:

- deterioriated track to Class 1 condition
- Class 1 to Class 2 condition
- Classes 1 and 2 to Class 3 condition

This study document, the Phase 1 report, addresses the basic structures of such a methodology, its required data inputs, and the feasibility of detailed RCEM development and refinement as Phase 2 of this project.

The development of the RCEM, if feasible, is expected to assist IDOT in establishing reasonable cost estimates for candidate rehabilitation projects. This information, when compared to probable benefits, will enable IDOT to prioritize rehabilitation projects to maximize the cost-effective use of rehabilitation funding.

1.3 LITERATURE REVIEW

As a prelude to RCEM model development, a survey of current literature relating to the use of track geometry data was conducted to identify concepts useful to this project, and to avoid duplication with any prior research findings which would have application to the task at hand.

The search revealed a good chronology of development in measuring various elements of track geometry, and in analyzing track/train dynamics. Other numerous reports investigated the design or performance of track structure components. One research report sponsored by the FRA provided some guidance in generating meaningful track quality measures from TGC data and their relation to track maintenance.

However, research efforts attempting to correlate track geometry measurements with track structure conditions and with estimates of rehabilitation costs were not discovered. The state-of-the-art in this particular facet of research is apparently undeveloped. This is probably due to the fact that railroads have traditionally borne the costs of track maintenance and upgrading. It is only recently that publically-funded rehabilitation programs have come on to the scene, and the proper deployment of these funds requires good project cost estimates. This task hopefully can be assisted by the RCEM model.

1.4 OVERVIEW

The balance of this report addresses the preliminary development of the RCEM model. Section 2 recapitulates the components of the track structure, recognized modes of degradation, FRA track standards, and the track geometry car features.

Section 3 presents a comparison of track geometry car data and field inspection for three sections of track, and the implications of the comparison on model development. Section 4 presents the proposed RCEM modelling approach which would be developed in detail in Phase 2 of this project. The discussion includes the basic model criteria, input requirements, and logic.

Section 4 describes the array of potential causal or empirical relationships which might be hypothesized and examined in Phase 2. Finally, Section 5 presents the conclusions and recommendations relating to the further development of the RCEM model. Various limitations and potential problems in the model are identified, as well as promising findings are also summarized.

SECTION 2

IDENTIFICATION OF CAUSAL FACTORS

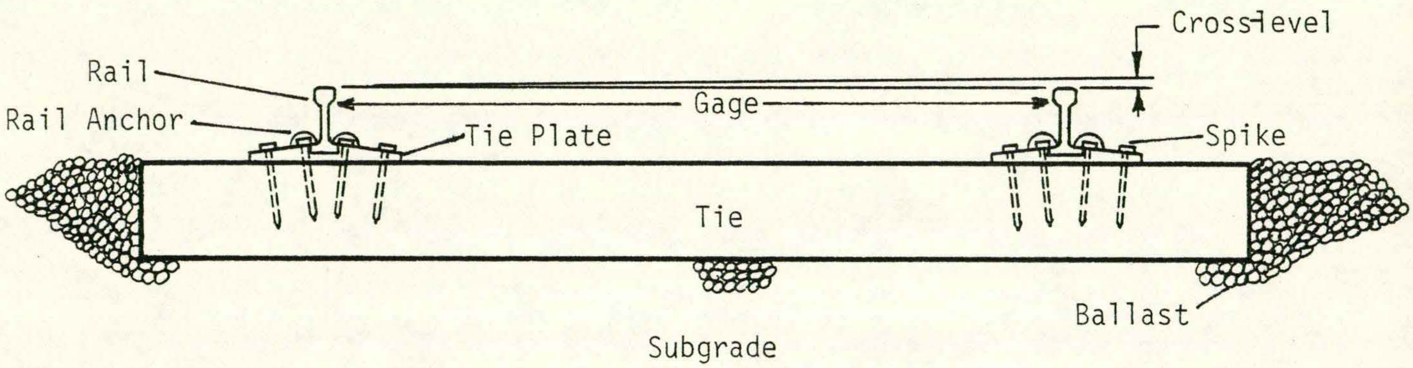
This section of the report summarizes components of the track structure, and how degradation of their quality may be detected by the TGC. As a point of reference, FRA track standards and TGC features are briefly presented. This discussion will set the stage for the sections of the report which follow.

2.1 TRACK COMPONENTS AND MODES OF DEGRADATION

In developing the RCEM, it is useful at the outset to briefly describe the system being dealt with, how its components relate to each other, the ways in which these components deteriorate in quality, and how this deterioration might be reflected in TGC measurements.

Figure 2-1 illustrates the principal track components and certain features which relate to track condition. Track components are all interrelated in terms of the response of the track to train loadings. The track structure responds to load as a system; consequently, a deficiency in one component can cause rapid deterioration of another element. For example, poor ballast can induce relatively rapid degradation of rail and joints.

An old quote of railroad maintenance foremen states that "If you can maintain good line and surface you've got a good railroad." While apparently a simplistic statement, this quote in fact emphasizes that the quality of the track, in terms of alignment (line) and cross-level (surface), is the real determinant of track performance. In other words, gage and cross-level are two primary indicators of track condition. The ways in which the various track components relate to gage and cross-level are discussed in the following sections.



Subgrade -stability -drainage	Ballast -type -condition	Tie Plate -size -type	Spike -type -pattern
Rail Anchor -type -usage	Rail -weight -joints	Geometry -gage -crosslevel -curvature -grade	Traffic -density -speed

FIGURE 2.1
TRACK COMPONENTS

2.1.1. Gage

A properly aligned track is straight and true on tangents and uniformly arced through curves. The gage of the track should be consistent. The gage is established by spiking the rail to the cross tie, with or without a tie plate. The track components most directly connected with gage are:

- cross tie
- spikes
- tie plates
- rail

The most probable cause for wide gage is a result of the cross tie failing to hold the spike in its original position. There are several reasons why this might occur:

1. The tie is split by the spike when it is first driven.
2. The tie is broken, crushed, or damaged in some other way causing it to split at the spike hole.
3. A concentrated lateral force causes the spike to be pressed out against the spike hole, thereby enlarging the spike hole. Poor alignment can produce this concentrated lateral force.
4. A continuous deterioration of the wood cross tie occurs by moisture arising from:
    a. Poor drainage of the track structure, causing the tie to lay in water for a long period of time.
    b. Splits, holes and checks in the top of tie, catching and holding water.
5. Spikes can become rail-cut or plate-cut, due to the rail moving longitudinally, poor anchoring, temperature expansion, or train movement. This rail movement actually wears a groove, called a throat cut, in the side of the spike. Poor drainage around the tie can accelerate this wearing action due to rusting of the spike surface.

In addition to these modes of deterioration, the rail can become worn to the extent that wide gage is created. Rail wears considerably faster on curves.

Ballast which is deficient can also contribute to wide gage if insufficient lateral and longitudinal restraint is provided. Ties may creep or become slued, causing both narrow and wide gage conditions.

Gage problems may also occur at railroad grade crossings where the rail must sustain both train loadings and the impacts of crossing vehicles.

Narrow gage is generally not the problem that wide gage is, and generally occurs much less frequently than wide gage. Newly laid or rehabilitated track is usually installed near the minimum permissable gage, knowing that traffic will tend to widen the gage. Thus, only when the rail has been in place for some time does the narrow gage indicate that problems exist.

In summary, wide gage can be an indicator of various problems in the track structure. These possible problems are:

- cross tie failure
- loose or missing spikes
- throatcut spike
- extremely worn rail
- ballast deficiencies

Potential remedial actions to correct these deficiencies would include:

1. Replacement of the cross tie, or plugging the hole and redriving the spike.
2. Replacement of the spike and installation of anchors to control rail running.
3. Replacement of the rail or transposing and re-anchoring the rail
4. Improvement of drainage around cross ties.

2.1.2 Cross-level

Cross-level refers to the difference in elevation between the two rails. On tangent sections, both rails should be at the same elevation at a given point. On curves, one rail should be a prescribed distance higher for proper superelevation. Cross-level measurements cannot detect dips, humps, or roller-coaster changes in the longitudinal direction of the track which affect both rails in the same manner and to the same extent.

As a rule, when track is out of cross-level, it means that one end of the tie has settled below the opposite end, and the rail deflects down accordingly.

For a cross tie to settle below its original position, the ballast supporting the cross tie originally has to either settle or be displaced. For the ballast to settle, the subgrade (embankment) has to fail. The most common cause of embankment failure is improper drainage. Inadequate embankment is also susceptible to differential heaving from winter freezing, and this condition can aggravate cross-level problems.

The most common location for track to be out of cross-level is at the rail joint. By nature the joint is structurally the weakest point in the track. If left unattended, the continuous deflection of the rail at the point will tend to displace the ballast and start a pumping action in the ballast and subgrade which will draw water up into the ballast along with sediment from the subgrade. Once the ballast is displaced and fouled with sediment, the conditions deteriorate rapidly. If left unattended, the bolted joint will become weak, and the unbalanced load on the track will actually bend the ends of the rail down, or actually fracture the joint.

The biggest contributing factor to deficient cross-level is unbalanced loading of the track structure. As long as both rails are level, the load is distributed equally between the two rails, through the ties and onto the ballast and embankment.

Lack of proper cross-level, then, can be an indication of three important conditions in the track structure:

- cross ties in poor condition or which have failed.
- embankment failure or settlement due to poor drainage or subgrade.
- ballast settlement or displacement.

Potential remedial actions would include:

1. Stabilize the embankment by improving or correcting drainage.
2. Replenish ballast with new clean graded ballast.
3. Raise and surface track on new additional ballast.
4. If the rail joint has failed due to lack of support, any one of the following problems can develop:
   a. broken joint bar
   b. broken rail inside of joint bar
   c. rail end batter
   d. bent rail ends
   e. sheared track bolts

   The corrective action would depend on the actual mode of failure at the joint.

2.2 FRA TRACK SAFETY STANDARDS

The parameters for variation in gage and cross-level as well as other track conditions are based on the maximum allowable operating speed of the track. For tracks carrying freight trains, this classification is as follows:

Class	Max. Speed (mph)
1	10
2	25
3	40
4	60
5	80
6	110

Gage must be within the limits prescribed for each class of track as follows:

Class of Track	Gage of Tangent Track	
	at least	but not more than
1	56.00 inches	57.75 inches
2, 3	56.00 inches	57.50 inches

In addition, the FRA prescribes that the gage through curves on Class 2 or 3 track should be no more than 57.75 inches. The larger premissable gage on Class 2 and 3 curves is not recognized in the TCG exception list.

Deviation from zero cross-level at any point on tangent or from designated elevations on curves between spirals may not be more than:

Class	Deviation
1	3.00 inches
2	2.00 inches
3	1.75 inches

Other parameters (alignment, cross ties, joints, and rails) are also considered when classifying track. However, gage and cross-level are two basic measurable parameters for track evaluation.

2.3 TRACK GEOMETRY CAR DATA

The original Iowa TGC was a truck-type highway vehicle, equipped with a hi-rail attachment. On-board instrumentation permitted the measuring and recording of gage and cross-level while traveling on the track.

The TGC made a measurement of gage and cross level every 4.593 feet along the track. Originally the data was recorded on an analog strip chart. Later, additional hardware was installed to permit storing the data on magnetic tape. This tape can be processed through a computer program to produce a printout of deviations. The deviations are based on the Federal Railroad Administration's track safety standards.

A replacement TGC expected to be serviceable in the Spring of 1979 will measure and record left and right rail profile, and left and right rail alignment, in addition to gage and cross-level. The TGC will also be equipped with a photologging camera to provide a visual inventory record. These additional measurement capabilities make additional evaluations of hazardous conditions such as cross-level curvature mismatch, cross-level reverses, warp, rock and roll, slope changes, and other parameters.

The future availability of such additional data might prove to enhance the workability of an RCEM strategy; however, this report concentrates on those parameters which are presently documented.

Three forms of TGC data records are available for a given section of track. The first is a magnetic tape of all recorded track measurements.

The second, illustrated in Figure 2.2 is an analog strip chart. This strip chart was produced on the TGC as the car traveled along the track. The operator can make various notations on the chart with a felt tip pen. Notations were made for mile posts. A system of letters and abbreviations is used by the operator to identify certain conditions along the track that had caused the TGC to record deviations:

Abbreviation	Track Condition
"P"	Public Grade Crossing
"PR"	Private Grade Crossing
"BR"	Railroad Bridge
"R"	Curve to the right
"L"	Curve to the left
"S" or "SW"	Switch
"Hi Plank"	A wood grade crossing timber protruding above the top of the rail

The third product is the track exception report listing all deviations of gage and cross level, by mile post locations. The data from the magnetic tape is

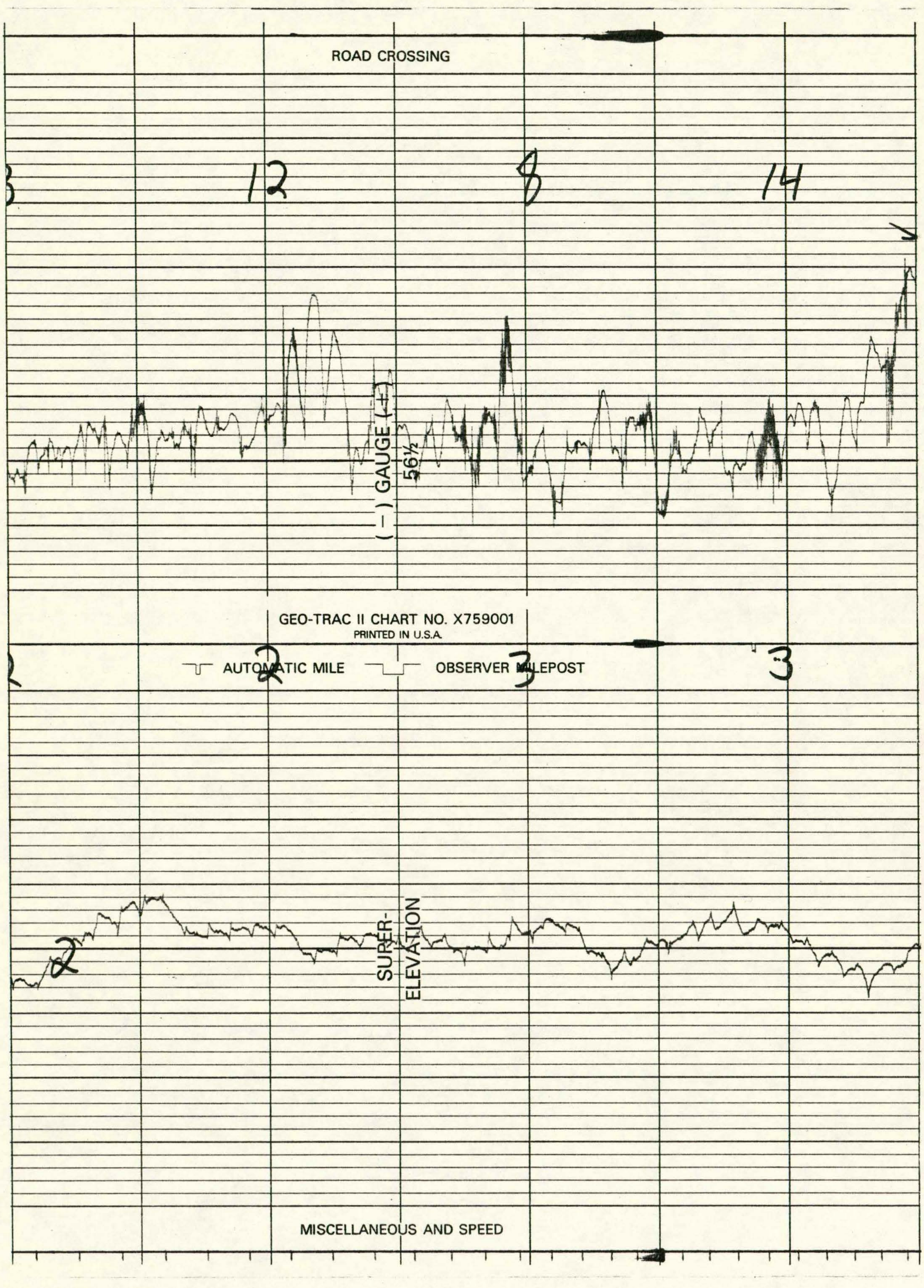


FIGURE 2.2
ANALOG STRIP CHART

TGC TRACK EXCEPTION REPORT

75207 BN OTT 0.78 18.20 REDOAK TO GRISWORD

	MILEPOST	DISTANCE	GAUGE	CROSS LEVEL	X-LEVEL VAR
**BRIDGE	0.78	4123			
**SWITCH	0.85	4490			
**ROAD	0.93	4931			
	0.99	5212	55.92 <--	0.38	0.36
	0.99	5216	55.90 <--	0.58	0.20
**SWITCH	0.99	5230			
**ROAD	0.99	5235			
	0.99	5235	57.59 <--	0.18	0.78
**MILEPOST	1.04	198			
**SWITCH	1.37	1948			
**ROAD	1.41	2159			
**ROAD	1.53	2812			
**SWITCH	1.66	3492			
	1.66	3510	57.60 <--	-0.50	0.24
**BRIDGE	1.74	3933			
	1.78	4144	55.93 <--	0.24	0.14
	1.79	4149	55.97 <--	0.06	0.26
**SWITCH	1.86	4561			
	1.87	4575	57.89 <--	-2.10	1.18
	1.88	4630	56.71	-0.18 <--	2.02
	2.01	44	56.00 <--	0.22	0.38
	2.01	49	55.94 <--	0.28	0.30
	2.01	53	55.98 <--	0.14	0.44
	2.02	90	55.92 <--	0.04	0.32
	2.09	467	56.00 <--	1.02	0.16
	2.09	472	55.92 <--	1.04	0.18
	2.10	509	55.97 <--	1.62	0.70
	2.11	591	55.97 <--	2.38	0.26
	2.12	642	55.97 <--	2.08	0.48
	2.12	646	55.97 <--	1.96	0.60
	2.12	651	55.96 <--	1.92	0.64
	2.12	655	55.94 <--	1.92	0.64
	2.13	683	55.95 <--	1.86	0.44
	2.13	688	55.81 <--	1.80	0.50
	2.13	692	55.97 <--	1.70	0.38
**ROAD	2.18	968			
	2.19	987	55.90 <--	0.06	0.32
**ROAD	2.26	1359			
	2.40	2125	56.09	1.68 <--	2.24
	2.40	2130	56.16	1.64 <--	2.28
	2.40	2134	56.40	1.52 <--	2.20
	2.41	2139	56.53	1.42 <--	2.04
	2.41	2144	56.60	1.34 <--	2.06
	2.41	2148	56.62	1.34 <--	2.00
	2.41	2153	56.42	1.00 <--	2.04
	2.41	2157	56.57	0.82 <--	2.04
**SWITCH	2.41	2162			
	2.41	2162	56.78	0.50 <--	2.24
	2.41	2167	57.02	0.18 <--	2.36
	2.41	2171	57.00	0.00 <--	2.20

Figure 2.3
TYPICAL EXCEPTION REPORT

reduced to those measurements of gage and cross-level that were outside the limits established by the FRA Standards. A typical exception report is shown in Figure 2.3. This report also includes a gage histogram (Figure 2.4) graphically depicting the distribution of the gage measurements.

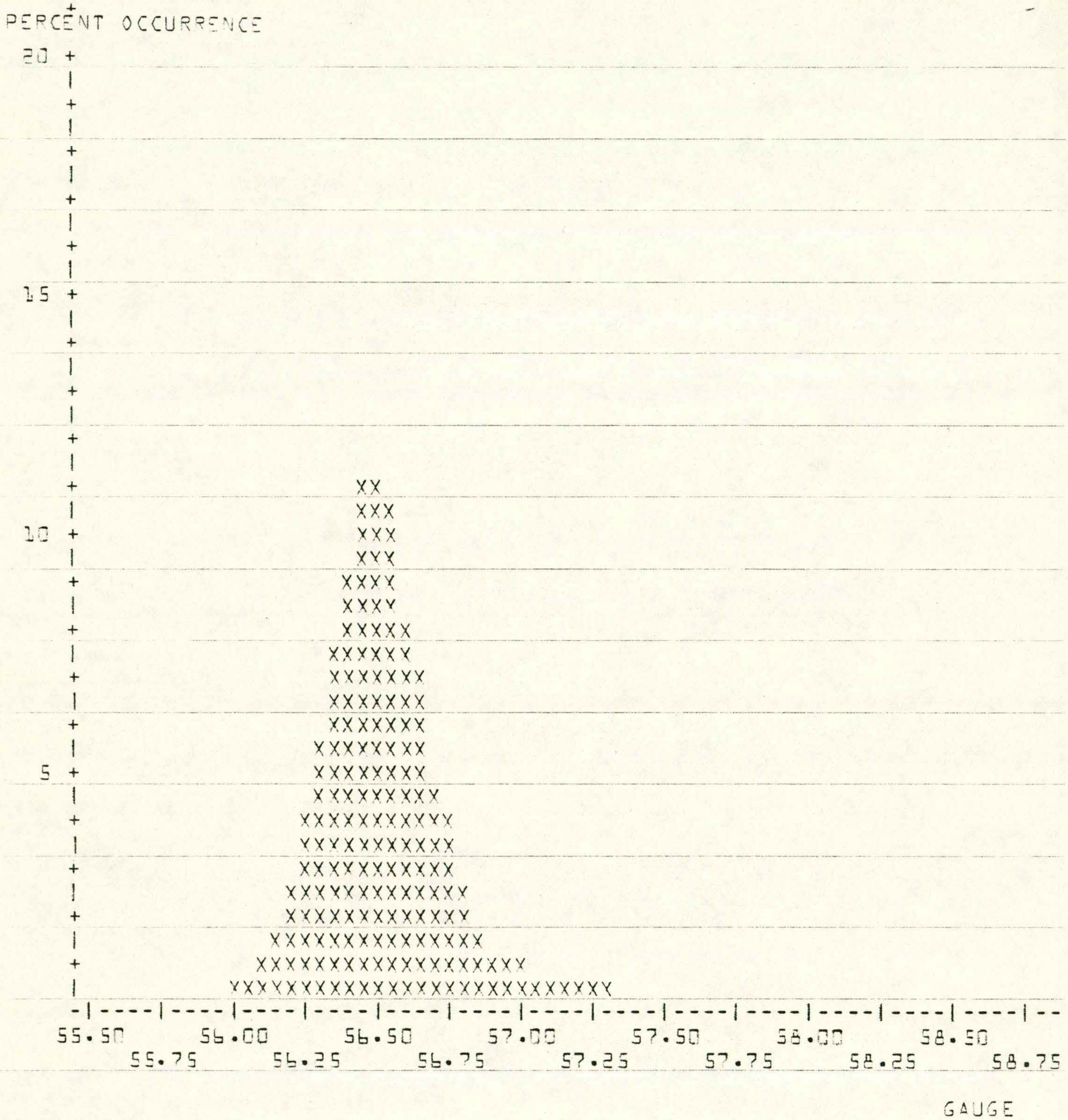


Figure 2.4
TYPICAL GAGE HISTOGRAM

SECTION 3
COMPARISON OF TRACK GEOMETRY CAR DATA AND FIELD INSPECTION

3.1 BASIS FOR COMPARISON

As a prelude to the formulation of general functional relationships in the RCEM model, a comparison of TGC-generated data (exception reports and analog strip charts) and field inspection was performed for three representative sections of track. This task was undertaken for several reasons:

- As a substitute for the originally planned activity of accompanying the TGC crew during actual field operations (which was rendered impossible due to the unfortunate destruction of the TGC by fire).
- To acquire a better understanding of the types and conditions of track structure which are the potential targets of rehabilitation.
- To develop a preliminary data base for initial screening of potential correlations between field conditions and track condition data compiled by the TGC.

The three sections of track selected by the IDOT Planning and Research Division, Transportation Research Office for examination were:

1. Norfolk and Western Railway (N & W)- branch line between Moulton and Moravia, Iowa.
2. Burlington Northern Railroad (BNRR)- branch line between Hastings and Randolph, Iowa.
3. Burlington Northern Railroad, (BNRR)- main line between Pacific Junction and Council Bluffs, Iowa.

These sections of track were inspected and a general evaluation made of their physical features and condition. This data then was compared with the strip chart and exception list for the respective track segment. This comparative analysis and the implications with respect to the RCEM model are discussed below:

3.2 SECTION A: N & W R.R. - MOULTON TO MORAVIA

3.2.1. Field Inspection

The inspection of this section of track yielded the following analysis:

A. Track Classification: Class 1

B. Track Structure:
   - rail: 90 lb., rolled 1922, 31 foot lengths
   - joint bars: 24 inch, 4-hole
   - tie plates: 7 inch X 9 inch single shoulder
   - cross ties: 7 inch X 8 inch X 8 foot , 6 inch spaced 17 to 20 inches on center
   - anchors: no anchors
   - ballast: gravel

C. Observations:

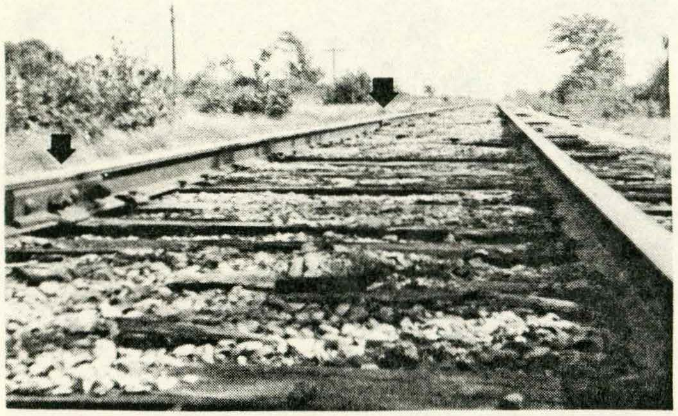
In general, the track has an adequate ballast section and appears to have fairly good drainage. However, a few areas were observed near grade crossings, where the ballast has become fouled due to poor drainage. The tie condition is poor. The majority of the ties were installed in the early 1940's. The absence of anchors has permitted the rail to run, causing many ties to be slued.

The rail exhibited normal wear along the running edge. The most prominent undesirable condition with the rail is in the joint area. Lack of maintenance has permitted the rail ends to be bent down at the joints. Of course, the joint bars are deformed with the rail ends. The old design of the joint bars in conjunction with the rail running due to absence of anchors has caused most of the spikes at the joints to be pulled out or sheared off.

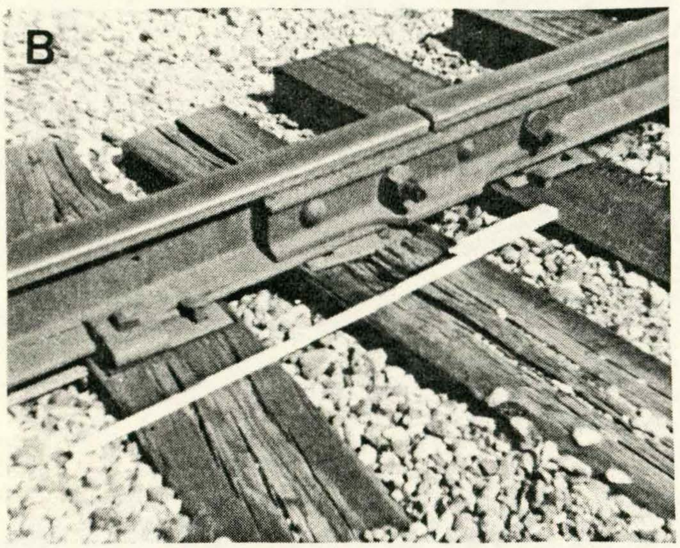
D. Analysis:

The slued ties could cause tight gage. The low joints along with missing spikes at the joints could cause wide gage and cross-level deviations. The

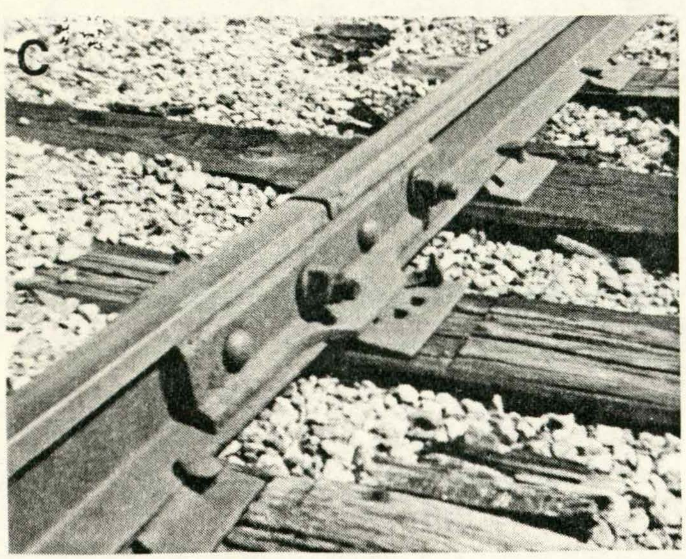
A



A. VIEW OF DEPRESSED RAIL JOINTS



B. SLUED TIE



C. DEPRESSED TIE AT RAIL JOINT

FIGURE 3.1
N & W R.R. BRANCH LINE

generally poor tie conditions could cause gage and cross level deviations.

E. Rehabilitation Recommendations:

1. Replace 20% of the cross ties.
2. Apply additional ballast and surface track.
3. Apply rail anchors.

3.2.2. TGC Data Analysis

On January 12, 1978, the TGC was operated on this track starting at the Iowa Line, M.P. 235.90, and ending at Albia, M.P. 272,43, for a distance of 36.53 miles. A total of 42,000 observations were recorded, of which 248 involved excessive deviations from FRA standards. Of the 248 deviations, 147 were gage deviations and 101 were cross-level deviations. Of the 147 gage deviations, 48 were tight gage (56.0 inches or less), and 99 were wide gage (57.50 inches or more).

A. Tight gage:

Except for 6 consecutive deviations in 23 feet at M.P. 270.74, the tight gage deviations were single and double consecutive deviations scattered throughout the 36.5 mile run. The six consecutive deviations occurred at a grade crossing. Many of the single and double deviations occurred immediately adjacent to wide gage deviations. Some of these tight gage recordings might only be the spring-back action built into the recording pins. As mentioned earlier, several slued ties observed in this track could create an isolated tight gage condition.

B. Wide gage:

By design, the standard highway rubber tires on a hi-rail vehicle ride along the top of the rails. The smaller flange wheels simply guide the vehicle along the track. Since the rubber highway tires are considerably wider than the head of the rail, the rubber tire will ride up on an object that might be higher and adjacent to the rail such as a grade crossing timber or guard rail in a frog, etc. When this occurs, the entire vehicle is raised off of the track momentarily. Judging from the operator's notation on the strip charts, this sudden elevation of one side of the vehicle no doubt produced false indications on the chart, and notation was made to identify what condition had caused the false indications.

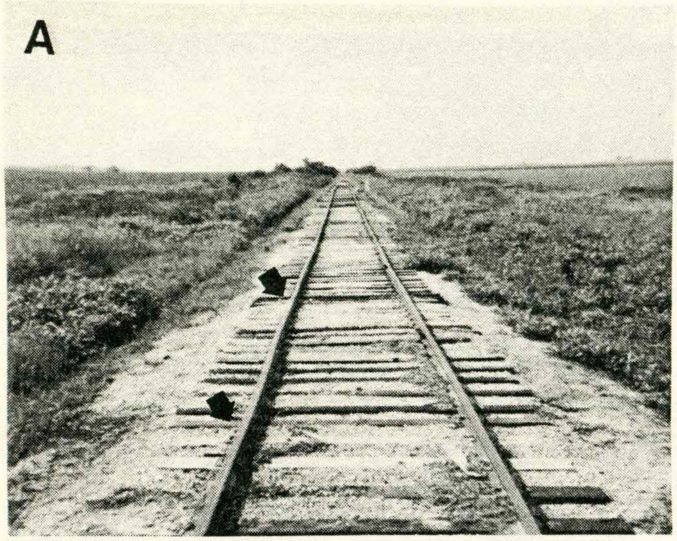
The 99 wide gage deviations occurred as follows:

Mile post location	Number of consecutive deviations	Occurring over a distance of	Operator's notation on strip chart
239.08	33	151 feet	"Mismatch Joint"
245.01	3	9	"Hi Plank"
245.93	2	4	"Hi Plank"
245.94	11	46	"Hi Plank"
253.52	2	9	"Hi Plank"
260.01	7	27	"Milw RR X"
266.96	8	32	"Ice"
171.37	9	37	"Hi Plank"
271.42	9	36	"SW" (switch)
271.47	5	19	"Hi Plank"
271.72	2	5	"Frozen Dirt"
271.78	5	18	"Hi Plank"
272.26	2	5	"BN Track"
TOTAL	99	398 ft.	

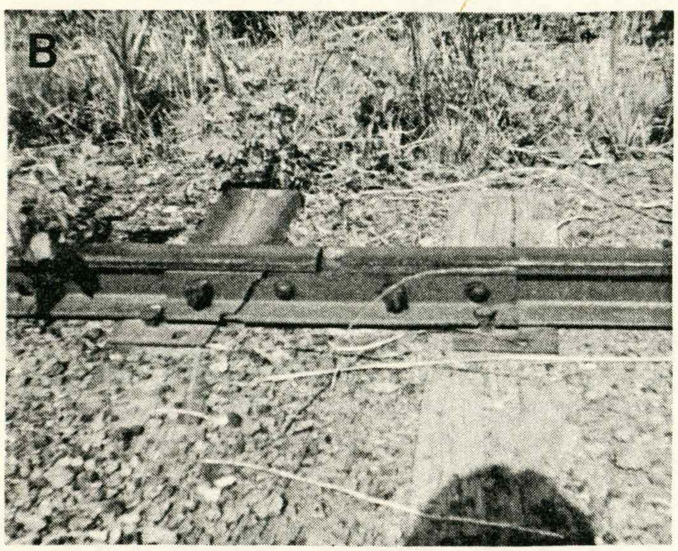
C. Cross-level:

A total of 101 cross level deviations were printed. An analysis of the cross level deviations is somewhat more difficult than for gage deviations.

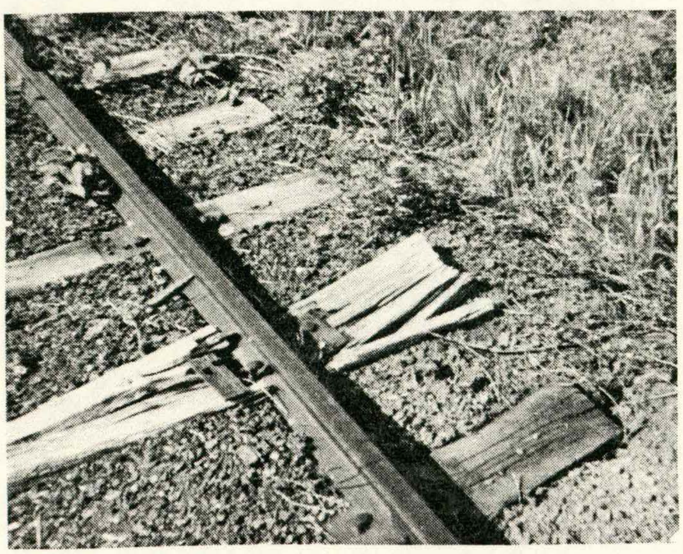
The FRA Standards state, "the difference in cross-level between any two points less than 62 feet apart on tangents and curves between spirals may not be more than 3 inches for Class 1, 2 inches for Class 2, 1-3/4 inches for Class 3, etc." Literature on the Iowa T.G.C. states " ... cross level variations between the current cross level measurement and the previous 12 measurements ...". The distance traversed by the TGC between a given measurement point and the previous 12 measurements would be 13 times 4.593 feet, or 59.709 feet. So it would appear that the TGC data has been programmed to make this comparison as specified in the FRA Standards.



A. VIEW OF DEPRESSED RAIL JOINTS AND POOR TRACK ALIGNMENT



B. FRACTURED RAIL JOINT



C. BROKEN TIE AND TIE PLATE

FIGURE 3.2
BN R.R. BRANCH LINE

The 101 cross-level deviations occurred at 32 locations along the 36.5 mile long run. Ten out of the 101 exceptions were single deviations. The remaining 91 were in groups of 2 to 11 consecutive deviations. Unlike the gage deviations, there were no operator's notations on the strip chart for cross-level deviations.

3.3 SECTION B: BN R.R.- HASTINGS TO RANDOLPH

3.3.1. Field Inspection

Field reconnaissance provided the following information on this section of track:

A. Track Classification: Class 1

B. Track Structure:

- rail: 56/60 lb., rolled 1883/1885
- joint bars: 21 inch, 4 hole
- tie plates: 6 inches X 8-1/2 inches single shoulder
- cross ties: 7 inch X 7 inch X 8 feet spaced 20 inches on center
- anchors: no anchors
- ballast: cinders

C. Observations:

In general, the overall condition of the track is poor, due primarily to the age of the facility and its components. A large number of the ties have been in place since the 1930's.

D. Analysis:

The extremely light section and age of the rail, along with the poor tie condition, practically renders this track unusable under today's wheel loadings. Any attempt to rehabilitate this track on a piece-meal basis would not be cost-effective.

E. Rehabilitation Recommendations:

1. Replace 30% to 50% of the cross ties.
2. Apply additional ballast and surface track.
3. Replace rail with a heavier section.
4. Apply rail anchors.

3.2.2. TGC Data Analysis

On December 28, 1977, the TGC was operated on this track starting at Hastings, M.P. 0.30, and ending at Randolph, M.P. 11.23, for a distance of 10.93 miles. A total of 12,793 observations were recorded, of which 463 exceeded FRA standards. Of the 463 deviations, 185 were gage deviations and 299 were cross level deviations. At 22 locations, both gage and cross level deviations were recorded at the same point of observation. Of the 185 gage deviations, 33 were tight gage and 152 were wide gage.

A. Tight gage:

The 33 tight gage deviations occurred at 22 locations, varying from several single deviations to one group of 4 consecutive deviations at M.P. 0.41.

B. Wide gage:

The 152 wide gage deviations occurred as follows:

Mile post location	Number of consecutive deviations	Occurring over a distance of	Operator's notation on strip chart
2.17	23	101 feet	"Mismatch Joint"
3.01	14	60	"Mismatch Joint"
3.30	11	50	"Full Flange --"
3.38	1	---	
3.44	2	5	"N & W RR X"
4.07	1	---	"PR" (private crossing)
4.32	1	---	
4.33	8	32	"Bad Joint"
4.42	1	---	
5.11	1	---	
5.18	1	---	
6.12	1	---	
6.53	1	---	
6.78	1	---	
7.72	10	42	"Bad Joint"
8.08	10	41	"Bad Joint"
8.10	16	69	"Bad Joint"
8.76	24	105	"Bad Joint"
9.32	1	---	
9.72	1	---	
9.91	11	46	"Bad Joint"
9.93	7	28	"Bad Joint"
11.15	5	18	"Frog Point"
TOTAL	152	597 feet	

C. Cross-level:

The 299 cross-level deviations occurred at 96 locations along the 10.9 mile run.

3.4 SECTION C: BN R.R. - PACIFIC JUNCTION TO COUNCIL BLUFFS

3.4.1. Field Inspection

Field inspection of this section of track provided the following information:

A. Track Classification: Class 4

B. Track Structure:
   - rail: 112 lb., rolled 1950, control cooled
   - joint bars: 36 inch, 6-hole; some 24 inch, 4-hole
   - tie plates: 8 inches X 11 inches doubled shoulder
   - cross ties: 7 inches X 9 inches X 8 feet 6 inches spaced 19-1/2 inches on center
   - anchors: 16 per rail length
   - ballast: crushed stone and slag

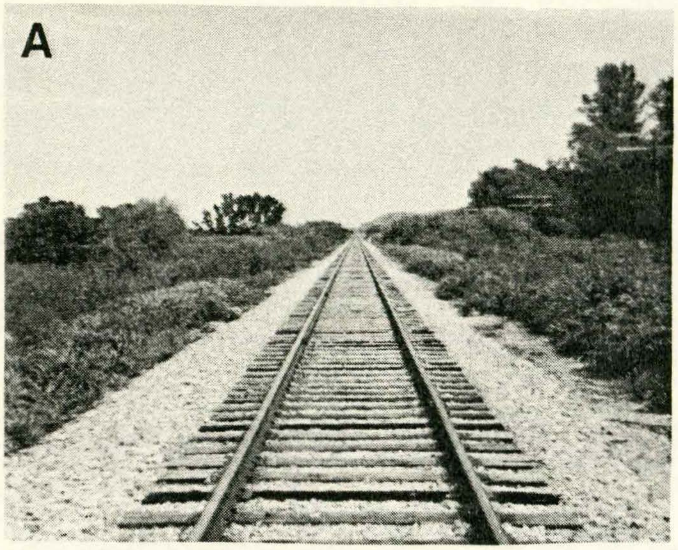
C. Observations:
   The track is constructed on a good ballast section and exhibits good line and surface. The track is bonded for signal operations. The track is apparently well maintained, as evidenced by a few new ties and new spikes. There was evidence that the anchors were not being fully effective. Near the Highway L-31 crossing, a number of anchors had been removed. Additional second-hand anchors had been installed, boxing every other tie.

D. Analysis:
   This track is in good condition.

E. Rehabilitation Recommendations:
   None are considered necessary.

3.4.2. TGC Data Analysis

On January 2, 1978, the T.G.C. was operated on this track starting at Council Bluffs, M.P. 491.00, and ending at Pacific Jct. M.P. 475.05, for a distance of 15.95 miles. A total of 19,229 observations were recorded, of which 51 involved excessive deviations from FRA Standards. Of the 51 deviations, 34 were gage deviations and 17 were cross level deviations. Of the 34 gage



A. VIEW SHOWING GOOD CONDITION OF BALLAST, TIES, AND TRACK

FIGURE 3.3
BNRR MAIN LINE

deviations, 7 were for tight gage and 27 were for wide gage.

A. Tight gage:

The 7 tight gage readings were scattered along the section.

B. Wide gage:

The 27 wide gage deviations were located as follows:

Mile post location	Number of consecutive deviations	Occurring over a distance of	Operator's notation on strip chart
488.48	5	18 feet	"S" (switch)
487.49	1	--	"S" (switch)
487.28	1	--	"S" (switch)
486.59	1	--	"S" (switch)
480.90	1	--	"S" (switch)
479.87	1	--	"S" (switch)
475.40	1	--	"P" (public crossing)
475.39	2	5	"P" (public crossing)
475.36	5	19	"S" (switch)
475.35	8	32	"P" (public crossing)
475.08	1	--	--
TOTAL	27	74 feet	

C. Of the 17 cross level deviations, 14 were situated at locations outside the limits of this test.

3.5 IMPLICATIONS TO THE RCEM MODEL

The preceding comparative analysis serves to both illustrate the character of several representative sections of trackage, and also to identify potential relationships between TGC- measured track parameters and observed field conditions which might be tested as hypotheses for validation and inclusion in the development of an RCEM model.

These observations may help define important considerations to which specific attention should be directed in model development. They may also prescribe some possible limitations or restrictions inherent in the effort to model real-world situationsin which relatively complex interrelationships between system components may exist. The objective of model development is to sort out and identify those relationships, if any, which can provide reliable measures of track condition that are translatable to rehabilitation needs and costs.

It should be recognized at the onset that FRA track standards state definitive limits for what constitutes safe conditions for a given class of track. No standards are provided for what level of deviations is tolerable. The implication is that a given classification is valid only if no deviations are recorded. Therfore, it can be presumed that railroads must maintain a track to satisfy the minimum FRA safety requirements, although a "perfect" track structure is beyond the financial means of most railroads. Satisfying or even surpassing FRA standards somewhat is, however, a reasonable goal for a rehabilitation of the track since deterioration commences as soon as traffic resumes.

Rehabilitation is essentially corrective action to restore a track to a specified classification, and is required because of an accumulation of deferred maintenance. Historically, maintenance has been deferred because of light traffic density, more pressing financial priorities, or a combination of both. It should be recognized that the amount of rehabilitation necessary to upgrade a deteriorated Class 1 track to a Class 2 designation may be difficult to specify precisely, as compared to upgrading the track from Class 1 to Class 3.

Broader standards of track quality as sampled by the TGC over entire subdivisions of track may be needed to practically define performance standards for a particular track classification. Such standards could relate to statistical functions of the sampled data, for example, the variance and the mean. In fact, a statistically based model may yield the most workable model structure.

The three sample sections of track demonstrate that gage and cross-level abnormalities may occur somewhat randomly over a section or may be clustered, depending on the nature of the condition causing or contributing to the deviation. In one case, a light weight rail contributed (along with other factors as well) to a high number of wide gage measurements. In other instances, isolated conditions at grade crossings yielded wide gage deviations.

In general, for these sections of tracks the tight gage deviations were few and scattered. Many of the wide gage deviations were accompanied by operator notations on the strip charts, suggesting that the wide gage reading may have been a false indication, and the remaining deviations were few in number compared to the miles of track inspected. Cross-level deviations were more numerous than gage deviations and may provide a basis for assessing track quality.

The three comparisons of track observation and TGC data call attention to certain hypotheses to be investigated in the detailed phase of model development. The observations below are by no means all-inclusive; rather, they are those more obvious ones which can be inferred or presumed from the limited data base.

- The shape of the distribution of gage and cross-level measurements may be important in quantifying track quality.
- The dispersion or clustering of deviations may indicate whether the deficiencies are localized or are common to the entire segment of track.
- The observations of the TGC operator may provide additional background data in accounting for deviations.
- The pattern of deviations, for example, ratio of cross-level to total deviations or the ratio of wide to tight gage deviations, may be indicative of certain deficiencies.
- A relation between cross-level and wide gage, or the regularity of wide gage readings, may point to a "bad joint" deficiency.
- Deviation statistics should be evaluated not only for lengthy subdivisions but for shorter segments such as a quarter-mile, to help identify localized problems.
- Recognition should be made of superelevation on curves as it affects cross-level measurements.

These potential relationships will be recognized in the next section which addresses the conceptualization of the RCEM model.

SECTION 4
A CONCEPTUAL RCEM MODEL

This section of the report addresses basic considerations in the development of the RCEM, potential input variables, the proposed model structure, and probable data requirements. It begins with a discussion of some desirable general model requirements.

4.1 GENERAL MODEL REQUIREMENTS

On the basis of preceding sections of this report and a general understanding of the modelling process, several broadly stated desirable features of the RCEM model can be noted.

In terms of its input requirements, the methodology should rely heavily on TGC-generated data to minimize the cost and provide objective consistency in input information. Extensive collection of data other than that needed to develop the model would defeat the purpose of exploiting TGC-generated data to the fullest unless the model were to serve only as a check to detailed examination by an experienced track repair estimator.

The model should also be no more complicated than necessary to achieve the desired results. Given the nature of the track structure and TGC data, it would certainly be possible to develop a complex methodology making use of all available data. However, a more prudent and practical approach would be to screen parameters to identify those key factors which best explain most of the relationships. The marginal improvement of the model by inclusion of additional variables would not be worth the additional complexity.

A desirable feature of the model would be specification of the estimated remedial actions necessary to correct track deficiencies. This would be highly dependent on the ability to synthesize the probable track deficiencies from the input data.

Similiarly, the model should recognize that some of the required rehabilitation actions may be determined solely by comparison of certain track components to predetermined standards (for example, replacement of a 60 pound rail with a 100 pound rail).

The methodology might hopefully provide a geographic reference for the scope of application for a rehabilitation treatment as well, recognizing that certain deficiencies may be restricted to a limited section of track.

Finally, the methodology should provide reasonably reliable estimates for the actual costs of rehabilitation actions which are expected to be necessary.

4.2 MEASURED AND DERIVED VARIABLES

It is presumed at this point that the basic input to the proposed methodology will consist of parameters generated by the TGC or subsequently derived from those parameters. These variables, which are not necessarily independent, include the following:

- Gage measurements - continous
- Cross-level measurements - continous
- Gage deviations per unit length
- Cross-level deviations per unit length
- Narrow gage deviations per unit length
- Wide gage deviations per unit length

Various statistical functions such as the mean, standard deviation, percentile values and variance can also be generated and tested. The study of correlation of track geometry indices to human judgement and known track maintenance improvements (Reference 1) has shown that some stable correlations do exist. These correlations would be exploited to the extent possible in model development. This literature also describes the variables warp and rock and roll instability which can be derived from cross-level data. In addition, a gage index and cross-level index are also defined, and could be tested as significant variables in an RCEM model.

The analysis in Section 3 of this report suggests other variables which might be considered initially in model development. These are readily available or can be derived easily. These statistics, presented on Page 3-13, are not reiterated here.

The two basic variables, namely gage and cross-level which are generated by the TGC will be the primary source of input for the statistical prediction model. The TGC records a measurement of gage and a measurement of cross-level every 4.593 feet. Thus in one mile of track which has been recorded by the TGC there will be a sample of "n" measurements of both gage and cross-level where:

$$n = \frac{5280}{4.593} \approx 1150$$

From this sample base several analysis variables (random variables) can be derived. Suppose that $G_1, G_2, \cdots G_n$ and $C_1, C_2, \cdots C_n$ represent the measured (sample) gages and cross-levels respectively. The following variables are proposed for analysis in construction of the predictive model.

4.2.1. Gage Variables

Let DG equal the number of gage samples which exceed a given tolerance from the mean gage for the sample. The mean gage $\bar{G}$ for the sample is:

$$\bar{G} = \frac{\sum_{i=1}^{n} G_i}{n} \text{, so that}$$

$$DG = \frac{\sum_{i=1}^{n} X}{L} \text{, where}$$

$$X = \begin{cases} 1 \text{ if } |G_i - \bar{G}| > T \\ 0 \text{ if } |G_i - \bar{G}| \leq T \end{cases}$$

T is a tolerance factor to be determined from analysis of the data with respect to FRA Standards and L is the length of the TGC sample course in miles.

Let WG equal the number of gage samples which are wider than the acceptable gage for the class of track being considered. Then:

$$WG = \frac{\sum_{i=1}^{n} Y}{L}, \text{ where}$$

$$Y = \begin{cases} 1 \text{ if } (G_i - g) > 0 \\ 0 \text{ if } (G_i - g) \leq 0 \end{cases}$$

and g is the maximum gage as established by FRA track safety standards.

Let NG equal the number of gage samples which are narrower than the acceptable gage for the class of track desired. This variable is defined similar to WG above.

Let TG equal the number of transitions of the gage from less than the mean to greater than the mean or from greater than the mean to less than the mean. Then:

$$TG = \frac{\sum_{i=1}^{n-1} Z}{L}, \text{ where}$$

$$Z = \begin{cases} 1 \text{ if} (\bar{G} - G_i) > 0 \text{ and} (\bar{G} - G_{i+1}) < 0 \\ 1 \text{ if} (\bar{G} - G_i) < 0 \text{ and} (\bar{G} - G_{i+1}) > 0 \\ 0 \text{ otherwise} \end{cases}$$

The standard deviation and variance would be expressed likewise by standard statistical definitions. Other gage-related variables as discussed earlier would be defined, computed, and tested for validity in the model.

4.2.2. Cross-level Variables

Let DC equal the number of cross-level samples per mile which exceed a given tolerance from zero cross-level (level) for the sample. This variable is defined similiarly to DG for the gage:

$$DC = \frac{\sum_{i=1}^{n} V}{L}, \text{ where}$$

$$V = \begin{cases} 1 \text{ if } |C_i| > T \\ 0 \text{ if } |C_i| < T \end{cases}$$

T is a tolerance factor to be determined from analysis of the tapes and L is the length of the TGC sample course in miles.

Let TC equal the number of transistions in crosslevel from slope to left to slope to right or vice versa. This random variable is defined similiarly to TG for the gage:

$$TC = \frac{\sum_{i=1}^{n-1} W}{L}, \text{ where}$$

$$W = \begin{cases} 1 \text{ if} (C_i > 0 \text{ and } C_{i+1} < 0) \text{or} \\ \quad \text{if} (C_i < 0 \text{ and } C_{i+1} > 0) \\ 0 \text{ otherwise} \end{cases}$$

Again, statistics such as standard deviation and variance can be calculated by standard statistical definition for use in the analysis. Other variables such as "cross-level index" may also be computed and tested for validity in the model.

4.2.3 Other Unavailable Variables

It was noted previously that the original TGC was destroyed and is to be replaced by a TGC with greater capabilities. An important feature of the replacement TGC is the measurement of track profile. Other research (Reference 7) has shown that a derivative of profile measurements, namely "slopes per mile" (changes greater than 0.1 inch between adjacent measurements), was statistically correlated to ride quality ratings assigned by track inspectors. This is taken as a sign that profile data may be useful in development of an RCEM.

Profile and other track measurement besides gage and cross-level, however, were not available at the outset of this project. Serious consideration should be given to adjusting the schedule of RCEM development in Phase 2 (if further model development is pursued) so as to permit inclusion of the expanded data base in variable screening and testing procedures.

4.3 BASIC MODEL STRUCTURE

A model which uses preceding variables as input would have the basic structure depicted in Figure 4.1. A,B, or C. These structures indicate the necessary links between data collected by the TGC and the predicted rehabilitation costs. Links 2 and 3 of the model indicated in Figure 4.1.A. can be established through engineering experience and a review of costs of rehabilitation projects. The analysis to establish Link 1 is more difficult and is the key to the success of developing this type model.

Alternatively, the model of Figure 4.1.B could be structured by replacing Links 1 and 2 as shown by a single link. Thus the specifications of probable remedial actions would be derived without detailed specification of track deficiencies. This approach would satisfy the objective of identifying the nature and extent of rehabilitation actions while circumventing the formulation of Link 1.

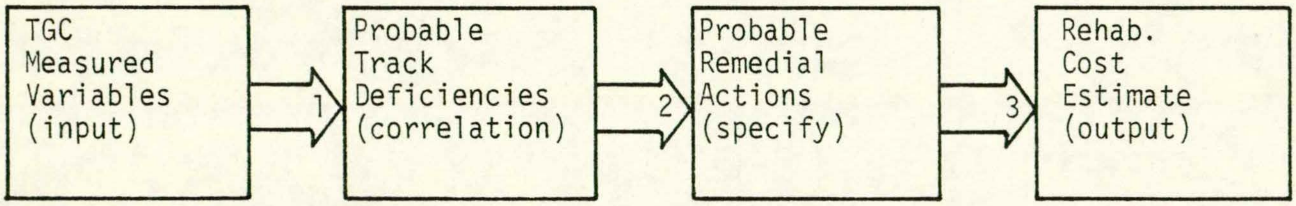
The ultimate purpose of the model is to provide a method of estimating rehabilitation costs from TGC measured variables. Thus a model which would allow the direct calculation of rehabilitation costs without going through the two intermediate steps would meet the objective of the project. Such a direct implication model would have a simplified structure as shown in Figure 4.1.C. However, the lack of specifications of improvement actions would be a serious drawback of this approach. The model output in this case will provide an aggregate rehabilitation cost total, which might be used as a control check against other estimates.

In any case, it is proposed that a multiple linear regression model be developed as the predictive element of the three model structure. Multiple regression is a statistical technique through which the relationship between a dependent variable (say rehabilitation cost) and a set of independent or predictor variables (derived from TGC measurements) can be analyzed. It is proposed that the technique be used to provide two basic types of analysis as follows:

1. Develop the best linear prediction equation of the type:

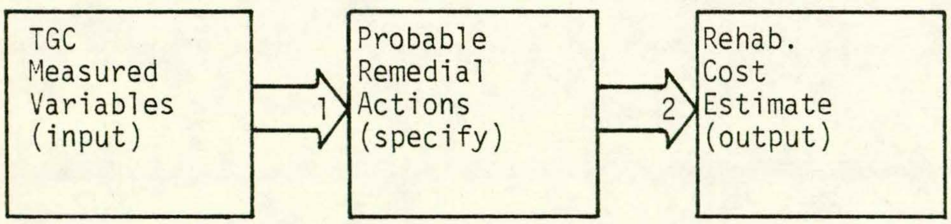
$$Y=A+(K_1 x\ DG)+(K_2\ x\ WG)+(K_3\ x\ NG)+(K_3\ x\ TG)+(K_4\ x\ DC)+(K_5\ x\ TC)+\sum_{i=6}^{k}(k_i\ x\ Si)$$

A BASIC MODEL STRUCTURE



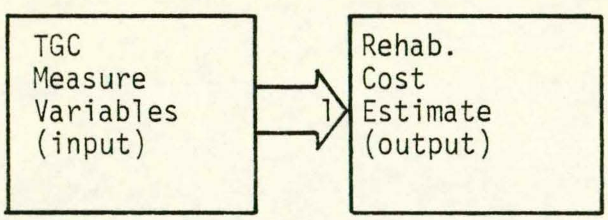
1. Synthesize regression equations
2. Apply railroad engineering practice
3. Utilize historical repair costs

B ALTERNATE MODEL STRUCTURE



1. Synthesize regression equations
2. Utilize historical repair costs

C DIRECT IMPLICATION MODEL STRUCTURE



1. Snythesize regression equations

FIGURE 4.1
RCEM MODEL STRUCTURE

where A equals the value of the regression constant,

where K_i (i=1,k) are coefficients to be derived from the analysis, and

where S_i (i = 6,k) are other statistical variables, such as variance, 98th percentile value, or the"index" parameter, derived from TGC data.

2. Evaluate the predictive accuracy of the developed equations.

The development of the three-link model indicated in Figure 4.1.A would in fact probably result in the development of several sets of equations of the type indicated in 1 above. It is envisioned that a different set of equations may be required for each case of rehabilitation, namely Class 1 to Class 3 deteriorated track to Class 1, and so on. Furthermore, it is possible that within each of these sets of equations, several equations would be developed to define an empirical relationship for each type of basic track deficiency. (for example: slued ties, deteriorated ties, poor ballast, and so on.)

In testing potential independent variables, the stronger ones would be utilized to formulate the required predictive equations. The existence of a particular problem could be correlated to a specific remedial action, and then a rehabilitation cost estimate could be developed by Links 2 and 3. Of course this type of analysis would require a considerable amount of detailed data to be collected in addition to that collected by or derived from the TGC. Moreover, the success of the construction of such a model will depend on the ability to discover and verify correlations between TGC data and various types of track structure defects.

The second type of model, shown in Figure 4.1. B. is a more direct approach. While the development procedure would parallel that for the preceding model structure, this model would attempt to correlate TGC data with the extent of various types of rehabilitation actions to which unit costs would then be applied.

The third type of model, represented in Figure 4.1.C., is a more simplified approach which would result in the direct development of a predictive equation. In this case the dependence of the single dependent variable "rehabilitation cost" on the independent variables (TGC data) would be analyzed and defined. Data requirements for each type of model are discussed below.

4.4 RCEM DATA REQUIREMENTS

4.4.1 Model Data Base

Based on the models outlined, the proposed RCEM would rely heavily on TGC - generated data for its input, and a considerable amount of this raw data is available. The need for corresponding data for the dependent variable (cost) to establish regression equations varies with each model structure.

In the case of the Type A Model, it would be necessary to record data about the types of problems occurring in the TGC recorded track sections. A detailed observation plan designed to identify the extent of various track deficiencies would have to be undertaken to generate the data base. This plan would, for example, have to collect data on the location, frequency, and severity of specific deficiencies on a particular section of track. Collection of this type of data on a sufficiently large number of track sections for model development would result in additional field survey costs.

The development of the B Type of Model would require a large amount of data of a less specific type. The best type of data for the analysis needed to develop this model would be TGC data for sections of track which were subsequently rehabilitated, and for which actual rehabilitation actions and costs are known. Thus pairs of data would be available so that a direct multiple regression analysis could be performed to relate measured TGC data to actual rehabilitation costs.

Another approach would be to use estimates of rehabilitation costs for various rehabilitation actions for lengths of track for which TGC data was available. Thus, a correlation between TGC data and rehabilitation cost estimates would be attempted. Since it is expected that there should be a strong correlation between rehabilitation estimates performed by an experienced estimator and the actual rehabilitation costs,this appears to be an acceptable approach. Because this type of data can be "created" by field inspection,this approach holds considerable promise. The data could be derived in two ways.

First, if rehabilitation cost estimates have already been made for certain lengths of track,the TGC data for those lengths would provide the independent variable data base. Alternatively, if no cost estimates were currently available, lengths of track could be selected and estimates could be made by an experienced estimator and the TGC data could then be correlated with the costs.

For the Type C Model structure, the cost data required would be non-specific with regard to improvement actions, and present an aggregate cost total. The reduced data base necessarily yields a less descriptive model.

In summary, each model structure would rely on TGC records to quantify the potential independent variables, and would require the acquisition of a data base for the dependent variable (cost)side of the regression equation.

4.4.2 Data Base Costs

Based on data requirements and complexity of the various model structures discussed, the acquisition of a data base for the Type B Model represents a compromise between detail and availablity of data versus the explanatory capabilities of the model, and would be the preferred approach, at the outset of Phase 2.

The first consideration in compliling the data base for Type B Model development is the availability of existing data. A certain amount of data is probably available in IDOT rail inventory files. This would desirably include any before-and-after studies linking track improvements to TGC measurements. Alternatively, where before-and-after data is not readily available, a comparative technique could be utilized. Sections of track of various classifications determined to be in good excellent condition would be identified, and their track geometry statistical profiles utilized as targets for rehabilitation of deteriorated tracks.

Finally, where neither of these types of data sources are readily available, additional field inspections could be conducted to provide the required calibration information. The extent of this effort is dependent upon the availability of the preceding data sources.

Two important considerations in compiling the data base for model development are how complete and how current available file information is. As mentioned, the original TGC sampled and measured only two parameters and the resulting data base is simply not as thorough as that which could be obtained by the replacement TGC. Also, file data may not provide a broad enough data base for the purposes of model development.

The age of file data may also restrict its usefulness, particularly if extensive field inspection is required to generate the data base for the dependent variable. The regression of track geometry data that may be several years old against current rehabilitation cost estimates may lead to an inaccurate regression equation. This lends additional weight to the consideration of using track geometry measurements from the replacement TGC for development of an RCEM.

Presuming that model development were to proceed on the basis of TGC data already on file, an initial task of Phase 2 of this project should be an extensive search of IDOT files and records so as to ascertain the extent and usefulness of existing available data. Such a record search should be fairly straightforward and not overly time-consuming, particularly with IDOT's assistance. A matter of one to three mandays should be sufficient to accomplish this task. The form of materials to be acquired would include magnetic tapes of TGC data, corresponding strip charts, and track charts, and rehabilitation cost estimates or cost records. Rehabilitation before-and-after TGC data would also be mose helpful.

Should insufficent rehabiliatation cost estimate data be compiled, it will be necessary to perform inspection of track and estimation of rehabilitation costs as part of Phase 2 of this project. To compile an adequate statistical base, it is estimated that a total of approximately 20 to 25 sections of track fifteen to twenty-five miles in length will need to be examined. This would entail roughly one man-month of effort at a total cost of $5,500 to $7,000 including travel and per diem expenses.

This procedure would be designed to generate rehabilitation cost estimates by specific activities (tie replacements, surfacing, crossings, and so on) so as to permit the development of a Type B Model. Such an investment in time and effort would be required on a one-time initial basis to permit model formulation if file data is incomplete or unusable. Once defined, the model could be periodically updated with fresh data from recent rehabilitation projects.

4.5 RCEM UNIT COST DATA

As a prelude to subsequent development of an RCEM model, various unit costs of track rehabilitation materials and actions were compiled. These include the basic components of the track structure from ballast to the rails. The costs of materials are shown both for new and second-hand (used) items as appropriate. The costs are shown in terms of each item, and per lineal foot of track. A composite of data from the consultant's files, standard cost estimating references, and estimates provided by the Iowa Department of Transportation were utilized. The costs displayed in the following table are intended to be representative of the March, 1979, timeframe.

TRACK WORK COST DATA

Materials		Unit Cost New	Unit Cost Used
Cross Ties - 7"x9"x 8'6", treated hardwood	each	$15.00	$ -
- at 20" centers	lin. ft.	9.00	-
Tie plates - 7 3/4" x 13", double shoulder	each	3.75	1.00
- at 20" centers	lin. ft.	4.50	1.20
Spikes -	each	0.27	0.13
- @ 2 per tie plate	lin. ft.	1.30	0.62
Anchors -	each	0.88	0.38
- @ 16 per 39 foot rail	lin. ft.	0.72	0.31
Joint bars - 36", 6-hole	pair	26.68	3.50
	lin. ft.	0.68	0.09
Bolts - for joint bars, with locknuts	each	1.16	0.58
- @ 6 per joint bar	lin. ft.	0.36	0.18
Rail - 115 pound	rail ft.	7.00	2.26
	lin. ft.	14.00	4.52
Ballast -	ton	3.50	-
- 6" application(.4 ton/ft)	lin. ft.	1.40	-
- 12" application (.8 ton/ft)	lin. ft.	2.80	-
Crossings - replacement including ties, paving	each	750.00	-

Labor and Equipment	Unit	Unit Cost
Surfacing and realigning existing track		
- including ballast placement	lin. ft.	$2.55
- without ballast placement	lin. ft.	1.85
Surfacing only (including ballast unloading) in conjunction with tie replacement	lin. ft.	0.75
Tie replacement (including unloading)	each	7.00
Grade crossing replacement	each	1400.00
Relay rail (including unloading)	lin. ft.	2.80
Construct new track on prepared alignment (includes ballast, tie, and rail installation)	lin. ft.	10.00

The preceding cost figures do not include bridge, signal, switch, grading or ditch repair or improvement. It is also presumed that reasonably large project quantities or stockpiled reserves are available, so that volume discounts from manufacturers apply. Smaller quantity purchases from supply companies will have a higher unit cost.

Most railroads prefer to use second-hand materials when available for rehabilitating their light density lines. This is particularly true for rail, joint bars, and tie plates. The use of second-hand bolts, nut locks and spikes will vary among railroads. Few railroads will attempt to use second-hand cross ties.

Unlike the cost of new track materials, the cost of second-hand material may vary considerably based primarily on supply and demand. Another factor affecting the cost of second-hand track material is the accounting procedure used by the railroads to establish the value of the materials. The salvage value of components removed from the track likewise is dependent upon the market.

When a railroad supplies or transports the materials for track work, the cost of transportation is sometimes neglected if the haul is confined to that railroad. However, in the case of contract work, the cost for transportation can be a sizeable portion of the total material cost. The shipping cost can vary significantly depending upon the quantity (weight) of material being shipped and the distance involved.

The mobilization of work forces and equipment set-up is estimated at 6% over other labor costs. Labor overhead varies by definition and from firm to firm, but a range of 20% to 30% covers most situations. If the work is contracted out, the contractor will require about 10% profit. Finally, a contingency factor of 10% is not unreasonable in rehabilitation work, unless past experience has validated the accuracy of estimates.

The general format of the preceding unit cost data is considered to be compatible with that required for an RCEM model since the methodology seeks to replace specification of rehabilitation needs by an estimator in the field with specification by a mathematical model fed by track geometry data. Once rehabilitation needs are specified by either method, the same unit cost figures may be applied to yield an estimate of rehabilitation costs.

An example of a cost estimate calculation which draws upon the above unit cost data is presented for illustrative purposes as follows:

Situation: Rehabilitate 10 mile section of track. Replace 20% of cross ties (on 20 inch centers). Relay light rail section with 115 pound used rail. Assume replacement of missing or damaged tie plates at rate of 15% (using used plates), joint bars at 10%, spikes at 50%, bolts at 20%, and anchors at 100%. Replace ten grade crossings. Surface with 6 inches of ballast. Assume no bridge or ditch work.

Estimate: For a one-foot segment:

Materials		Cost Per Foot
cross ties	20% x \$9.00	\$1.80
tie plates	15% x \$1.20	.18
spikes	50% x \$1.30	.65
anchors	100% x \$0.72	.72
joint bars	10% x \$0.68	.07
bolts	20% x \$0.36	.07
rail		4.52
ballast		1.40
total		\$9.41

10 miles x 5280 ft/mi x $ 9.41 =	$496,848.00
10 crossings x $750/each	7,500.00
material total	$504,348.00

Labor

grade crossings 10 x $1,400.00	$ 14,000.00
tie placement	
52,800 feet x .6 ties/foot = 31,680 ties	
31,680 ties x 20% x $7.50/tie =	47,520.00
surfacing 52,800 feet x $0.75	39,600.00
relay rail 52,800 feet x $2.80	147,840.00
mobilization (6% of labor costs)	14,938.00
labor total	$ 263,898.00

labor and material subtotal	$ 768,246.00
labor overhead (20%)	52,779.00
	$ 821,025.00
contingency (10%)	82,100.00
Total Rehabilitation Cost:	$ 903,125.00
composite rehabilitation cost/foot:	$ 17.10

4.6 RCEM DEVELOPMENT STRATEGY

This section addresses the basic steps which would be encountered in the Phase 2 development of an RCEM. The basic development procedure if pursued would include three basic elements:

- data collection
- model development
- model assessment

Specific task areas within each of these elements are discussed in the following sections.

4.6.1. Data Collection

Before compiling data for model development, the specific data requirements would be stipulated. These would include the format of cost subcomponent information, the number and length of track sections required for the data base, and the number of cases required for each instance of upgrading to be considered (Class I to Class II, etc.)

A search and examination of IDOT TGC measurement data and related records would then be performed to determine if readily available data meets the requirements for model construction. If such is not the case, then the supplementary field reconnaissance and estimation process outlined previously should be conducted. Upon the compilation of the required data, development of an RCEM model would be undertaken.

4.6.2. Model Development

The first step of this element would involve the description of the model contruct (for a Type B Model) - the organization of the RCEM model regression equations. Basically, it is envisioned that each type of rehabilitation effort (Class I to Class II, etc.) would desirably have its own descriptive cost prediction model, unless it were determined that statistically this approach was not warranted. Within each type of rehabilitation, one equation for each major component of rehabilitation might be generated, the sum of these yielding the total rehabilitation cost.

The second step involves the quantification of independent variables from the TGC source data. For the various gage and cross-level statistics discussed earlier, the numerical values for each subject section of track would be computed and tabulated for use in model development. Dependent variable (rehabilitation cost) data would be arrayed in similar fashion.

In the next task, the development of satisfactory regression equations would be performed. This would be done in an incremental manner with independent variables being added to or deleted from the mathematical relationships depending upon their ability to help statistically predict the appropriate value of the dependent variable. Should the data base not permit the formulation of the disaggregate level of equations, the development of equations would be pursued at a higher level of aggregation.

4.6.3. Model Assessment

This element of model development entails the evaluation of the models resulting from the preceeding process. Specifically, model equations would be reviewed for their logic and consistency, both within a specific equation and in comparison to companion equations. The degree of correlation and level of confidence would be determined, and tested using before-and-after data from IDOT files, or from other compiled data withheld for this purpose. This test would provide an example of practical application as well as helping to determine the practical use of the RCEM model construct and the limits of its realistic application.

SECTION 5

FINDINGS AND RECOMMENDATIONS

5.1 FINDINGS

The further development of the RCEM as proposed can be viewed somewhat optimistically for several reasons:

- Considerable direct and derived input data is readily available from the TGC.
- Other research provides some guidance as to promising track quality indicators, and to some extent mathematized relationships.
- Computer data processing permits relatively rapid screening and validation of hypothesized relationships.

Conversely, it is important to recognize those factors which may tend to hinder model development or limit its application. These are summarized as follows:

- Difficulty in isolating "clean" causal or empirical relationships relating input data to specific field conditions
- The basic presumption that geometric data can identify deficiencies in track structure .
- The problem of model "noise": each step of the methodology is susceptible from TGC sampling, the mathematical relationships, statistical definitions of track class in terms of track geometry parameters, the accuracy in specifying the extent of remedial actions, and finally unit cost estimates.
- The fact that two similarly classified sections of track may differ noticeably in their actual condition within the limits of FRA standards.
- Inability of the model through its input parameters to be sensitive to incipient deficiencies which subsequent field observation determines to need correction.
- Numerous wide gage deviations are explained by operator's notations on the strip charts by "Hi Plank", "Ice", "Frozen Dirt", "RRX", "Full Flange", etc. Such atypical aberrations may tend to cloud meaningful mathematical relations.

-Difficulty in specifying a necessary but sufficient degree of track rehabilitation which will upgrade the track to the desired FRA classification.

-Potential synergistic and non-linear relations in combining individual remedial actions.

-Difference of judgement between IDOT and the railroads as to what constitutes sufficient rehabilitation.

-Conflict between man and machine: traditional railroad practice contends that sophisticated inventory systems can be used to better identify the presence and location of deficiencies, but that determination of corrective actions rests with an experienced track man.

5.2 RECOMMENDATIONS

The preceding sections of Phase 1 analyses and investigations have addressed the potential manner in which an RCEM might be developed, and several related issues which may affect the degree of success in developing a sufficiently descriptive model capable of providing an estimate of rehabilitation costs within a reasonable and tolerable level of accuracy.

Several concerns should be highlighted in assessing the prospects for development of a workable RCEM. First, there is the question as to whether the model development process can overcome the various potential pitfalls noted above and in the preceding sections. Problems in definitions, "noise", specification, and the use of mathematical models of the real world may hamper the formulation of sufficiently accurate regression relationships.

A second concern might be the acceptability of the resultant model, if its development is successful, by those involved as a valid means of estimating railroad repair costs. The notion of determining track rehabilitation costs by experienced estimators is deeply-seated in the railroad industry. It is likely that use of the RCEM model as the prime source of rehabilitation cost estimation may be met by some skepticism unless high degrees of mathematical correlation are achieved.

Another matter for consideration is utilization of data generated by the replacement TGC in quantifying the RCEM. In other studies, profile measurements have displayed some promise in correlation with track quality. A more complete measurement of the track structure would in theory permit the development of a better RCEM, presuming that gage and cross-level data do not totally describe track conditions.

Based on the foregoing Phase 1 analyses and investigations, the following recommendations are made:

1. Various conditions surrounding the modelling process in general and the RCEM model in particular may affect the degree of its successful development. Nevertheless, it is premature to discount the feasibility of RCEM since rigorous, detailed examination of potential causal and empirical relationships has not been conducted. Since the additional effort required to make this determination requires an investment in resources which would be far outweighed by the development of a successful RCEM, it is concluded therefore that the proposed RCEM approach has sufficient potential to warrant more detailed investigation in Phase 2.

2. IDOT should consider the role of the replacement TGC and its expanded capabilities as it relates to this research effort to link track geometry data with potential rehabilitation costs. The new car represents the state-of-the-art, and it enhances the scope and utility of the track geometry data set. It may be prudent to take advantage of its capabilities in further development of the RCEM by deferring the pursuit of Phase 2 until the new TGC is on-line.

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