REPORT NO. FRA/ORD-78/55 PB

TRACK GEOMETRY MEASUREMENT BY HIGH-RAIL VEHICLES

NOVEMBER 1979

FINAL REPORT

Prepared For

U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL RAILROAD ADMINISTRATION
OFFICE OF RESEARCH AND DEVELOPMENT
Washington, D.C. 20590

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N O T I C E

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
FRA/ORD-78/55		

4. Title and Subtitle
Track Geometry Measurement by High-Rail Vehicles

5. Report Date
November 1979

6. Performing Organization Code

7. Author(s)
M. A. Sherfy

8. Performing Organization Report No.

9. Performing Organization Name and Address
Iowa Department of Transportation
Planning and Research Division
Office of Transportation Research
Ames, IA 50010

10. Work Unit No. (TRAIS)

11. Contract or Grant No.
DOT-FR-64243

12. Sponsoring Agency Name and Address
U.S. Department of Transportation
Federal Railroad Administration
Office of Research and Development
Washington, DC 20590

13. Type of Report and Period Covered
Final Report
June 1976 to June 1979

14. Sponsoring Agency Code
DOT/FRA

15. Supplementary Notes
Contract Technical Monitor: Roy T. Liang
Office of Research and Development
Federal Railroad Administration

16. Abstract

This report examines the capabilities of a high-rail track survey vehicle to:

1) Assist in improvement of the track safety inspection program; and

2) Assist in data collection for transportation planning.

The project examines both technical and operational aspects of high-rail vehicle usage as an inspection service and as a data collection tool.

This research project found that measurements of track geometry collected by a high-rail vehicle could be modeled to match measurements collected by a train type vehicle. This finding opens the door to wider utilization of the less costly, highly mobile, easily scheduled, high-rail survey vehicle.

This report is a document which outlines the crew requirements, costs, scheduling procedures, reliability and accuracy levels that are associated with the operation of a high-rail track survey vehicle. This report is intended for use by railroad management, state railroad planners and federal railroad planners who may be interested in the operation of a high-rail track survey program.

17. Key Words
High-Rail Inspection
Track Geometry Vehicles
Track Inspection

18. Distribution Statement
Document is available to the U.S. Public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	289	

Form DOT F 1700.7 (8-72)

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METRIC CONVERSION FACTORS

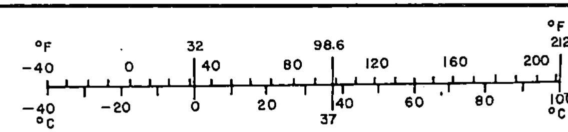
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



SUMMARY

The physical condition of much of the railroad properties in the United States has been deteriorating since the mid-50's. Train accidents serve as a good indicator of the magnitude of this deterioration. In 1976 there were 10,248 reportable train accidents-(damage in excess of $1,750)-an increase of 27% over 1975 data. Nearly 42% of these accidents were caused by poor track conditions.

No clear-cut cause for the escalating trend in derailments due to poor track conditions has been identified. Some causes commonly mentioned are:

1) Economic hardships forced on the railroads by unmatched public assistance to other modes;

2) Alleged antiquated regulatory practices; and

3) Alleged incompetent railroad management.

In the State of Iowa, five Class I railroads operate approximately 3,000 main line and 3,800 branch line miles of railroad trackage. The financial condition of these roads ranges from the bankrupt Rock Island to the fiscally sound Burlington Northern. The state generates enormous amounts of rail traffic, especially grain movements, and serves as a bridge state for a considerable amount of Chicago-West traffic. In a four year period, 1970 to 1974, track-related derailments in Iowa were up 636%.

Efforts are being made to reverse the derailment trends. Iowa has joined a federal cooperative program to increase track inspection efforts and has initiated a program to financially assist the railroad in track rehabilitation. A need for increased track surveillance and data collection capabilities for rail assistance programming led Iowa's Department of Transportation to purchase a high-rail track geometry measurement vehicle.

The most important finding of the research project on Iowa's Track Geometry Car was the discovery that measurements of track geometry collected by a high-rail vehicle could be modeled to match measurements collected by a train type vehicle. This finding opens the door to wider utilization of inexpensive, highly mobile, easily scheduled, reliable, high-rail inspection vehicles.

The reliability and accuracy of the Iowa Track Geometry Car as documentated in this report clearly support the acquisition of similar cars by other states experiencing railroad problems in either service or safety. In fact, the Iowa Department of Transportation has ordered a new track survey vehicle based upon the finding of this study and its past operational experience with the first car.

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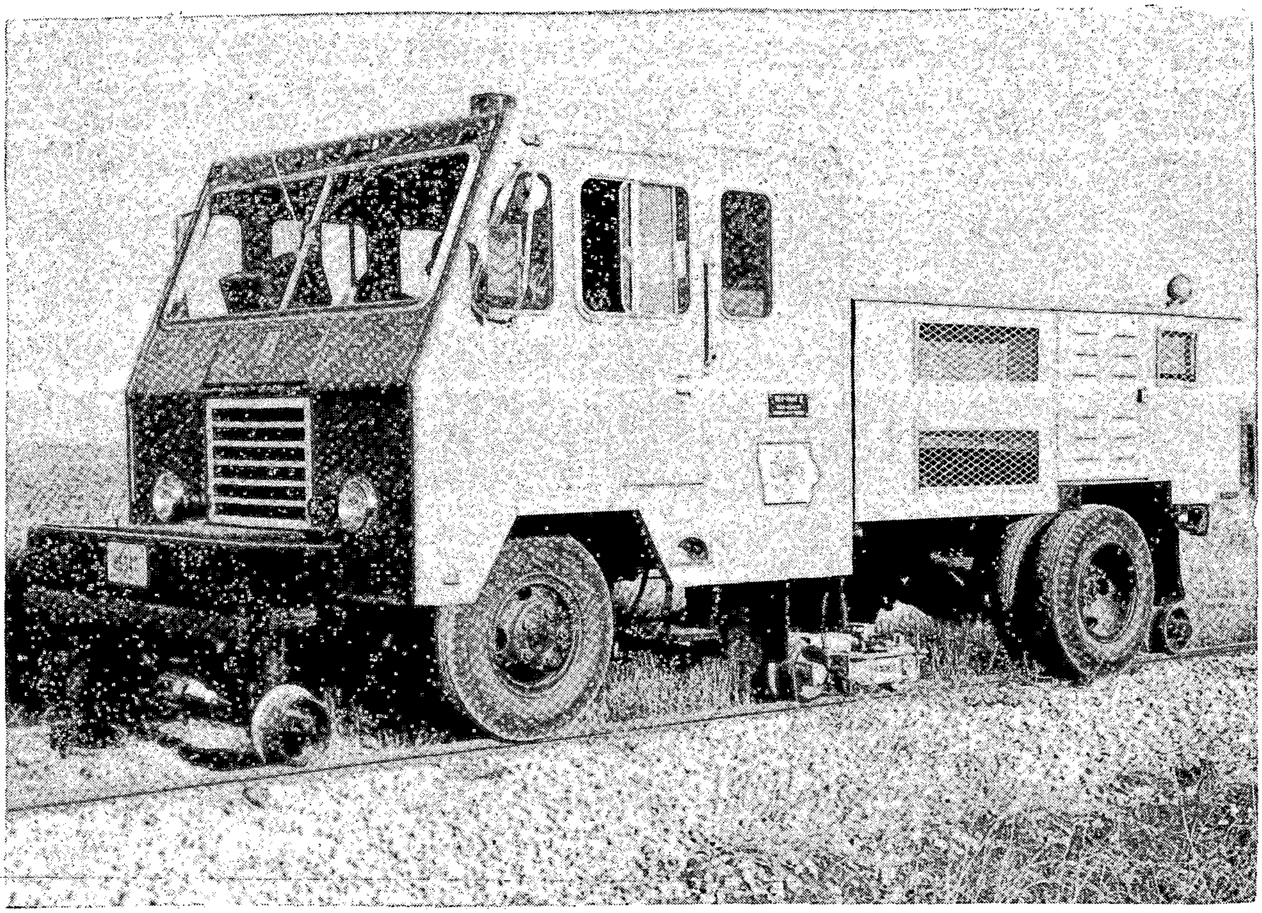
INTRODUCTION

This report fulfills the contractual obligations that the Iowa Department of Transportation incurred with the Federal Railroad Administration under contract number DOT-FR-64243. The objective of this research project was to examine the capabilities of a highway-railroad (high-rail) survey vehicle to assist in improving track safety inspections and in data collection for transportation planning and railroad assistance programming. The project examined both technical and operational aspects of the Iowa Track Geometry Car -- a high-rail survey vehicle.

Members of Governmental agencies on both the State and Federal levels who are interested in improving the quality of rail service and the associated safety levels will find this report beneficial. Railroad management contemplating the acquisition of similar survey equipment can also benefit from this report.

Users of this report will have a better understanding of the capabilities of a high-rail survey vehicle. Those who will eventually acquire similar vehicles will be aware of vehicle shortcoming and operational difficulties. Similarily, people responsible for programming railroad funds will be aware of a valuable tool for maximizing fund allocations.



IOWA TRACK GEOMETRY CAR

CHAPTER I

ACQUISITION, EVALUATION OF ELECTRONIC EQUIPMENT

PART I

ACQUISITION OF EQUIPMENT

One of the principle objectives of the entire research project was to produce a hardware/software system that could collect and record in real time any track deviations as measured by the data sensors on-board the Iowa Track Geometry Car. The hardware/software/recording/processing system that evolved from this study has been named the GeoData Processing System. An evaluation of the hardware comprising this system will be examined in this chapter.

Section II of the report lists the hardware purchased as part of the GeoData Processing System. Section III includes an evaluation and validation of the hardware while Section IV reports on a field test for data reliability and repetitiveness.

DATA PROCESSING

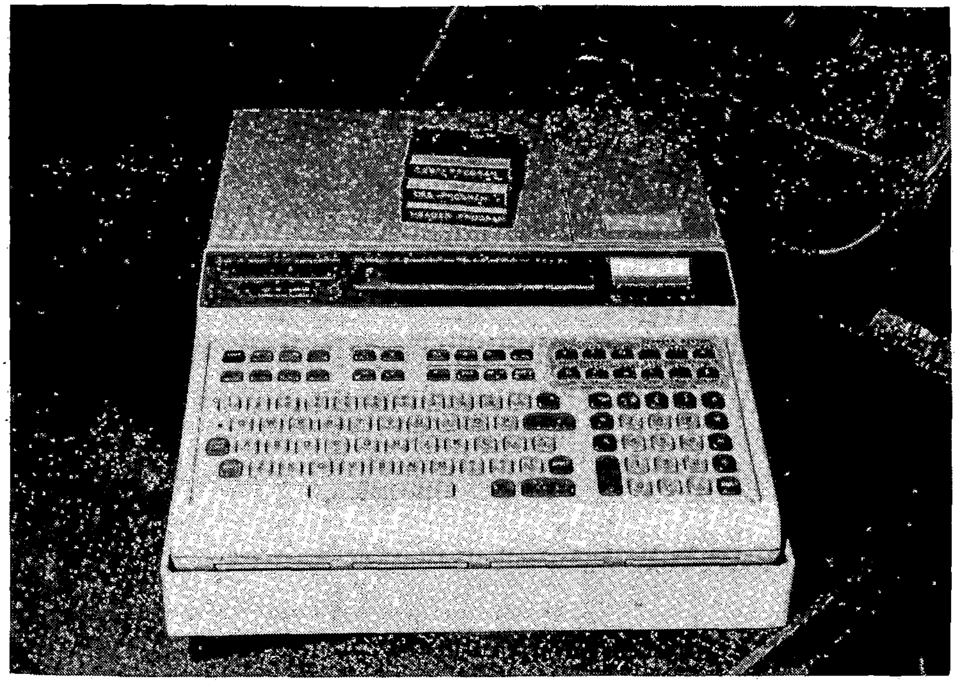
PROGRAMMABLE CALCULATOR MODEL 9825A Option 002 - This Hewlett Packard programmable calculator was selected as the heart of the GeoData Processing System. Designed principally for use in engineering research and statistics this calculator has many features previously found only on minicomputers.

The standard unit has a 32-character LED display, a 16-character thermal strip printer and a typewriter-like keyboard with upper and lower case alphanumerics. It has a built-in, two-track, tape cartridge drive, three I/O slots and four ROM slots. The 9825A can be used as a stand alone calculator or as a system controller.

The high speed bi-directional data cartridges hold 250K bytes of memory. In the GeoData Processing System the tape cartridges are used only to load program statements into the calculator. Track 0, File 0 of each cartridge is automatically loaded whenever the calculator is turned on. This automatic loading reduces the chances of operator error. Figure 1 shows the calculator and the three tape cartridges used to hold the software used in the GeoData Processing System.

FIGURE 1

PROGRAMMABLE CALCULATOR & TAPE CARTRIDGES



SIZE/WEIGHT

Height	5.1 inches
Width	15.1 inches
Depth	19.5 inches
Net Weight	26.0 pounds

Programming is done in HPL, an easy to learn, high level formula orientated language. The structural unit is a line composed of one statement followed by a semicolon. HPL provides subroutine nesting and 16 flags. Up to 26 simple variables and 26 multi-dimentional arrays, limited only by the size of the calculator memory (23,228 bytes), are allowed.

The following ROM's and Interfaces were installed in the calculator.

<u>16 Bit Duplex Interface Card, Model HP 98032A Option 040</u> - This Interface provides the 9825A with a latched 16-bit input data bus and a latched 16-bit output data bus for bi-directional transfer of information. Control of interrupt and priority are provided via select code settings and software commands. Extended control and status lines are available for applications which require more than one signal from the calculator. These signals, combined with full work or byte data transfer modes, allow interfacing to a variety of equipment.

String-Advanced Programming ROM, Model 98210A - The string portion of the 98210A allows the 9825A to accept and manipulate alphabetic and numeric information. This allows the comparison of strings or substrings.

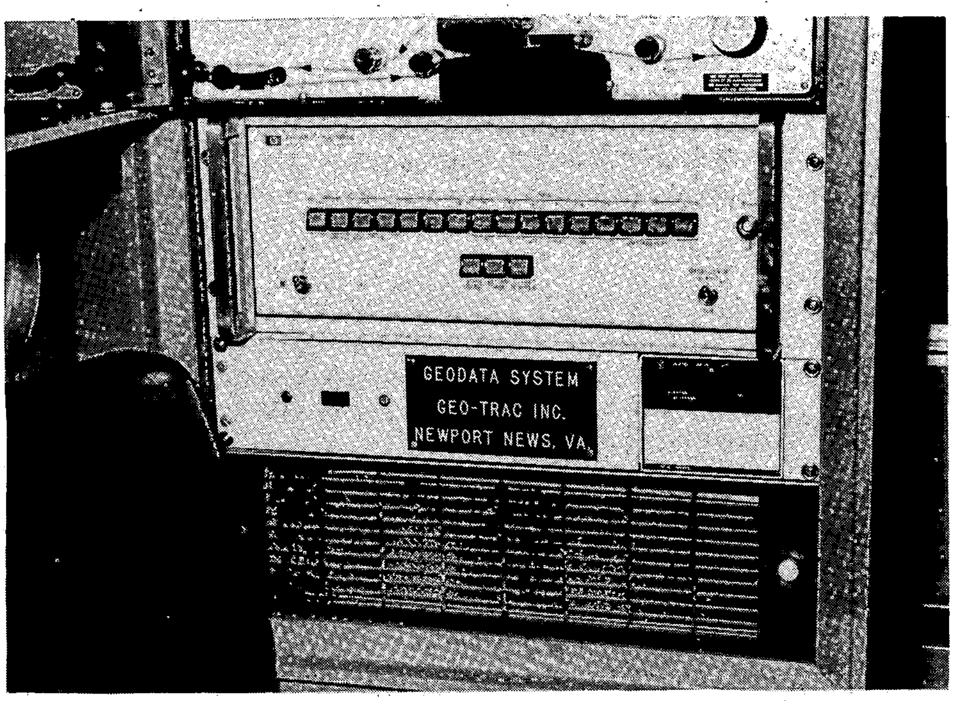
General I/O - Extended I/O ROM, Model Hp98213A - This ROM provides basic I/O capabilities including read/write with format control, binary read/write, status testing and code conversion. In addition to controlling external devices, this ROM can address the calculator printer, display and keyboard.

DATA CONTROL

MULTIPROGRAMMER MODEL 6940B OPT 908 - The multiprogrammer provides flexible and convenient I/O expansion and conversion capacity to the programmable calculator. Bi-directional transfer of data between the calculator and the plug in cards is controlled by the multiprogrammer. Figure 2 shows the multiprogrammer mounted in the Iowa TGC.

FIGURE 2

MULTIPROGRAMMER



SIZE/WEIGHT

Height	6.78 inches
Width	21.25 inches
Depth	16.75 inches
Net Weight	35.00 pounds

The following Input/Output cards are installed in the multi-programmer.

Digital Input Card, Model 69431A Option 069 - This card allows the calculator to read 12-bits of logic level or contact closure data. Card includes gate/flag circuits for exchange of control signals. Return bits to controller reflect the status of 12 input bits.

Three (3) Pulse Counter Cards, Model 69435A - These cards count pulses, up or down, in the range of 0 to 4095. A carry or borrow pulse is generated as the count goes above 4095 or below 0. These pulses allow multiple counter cards to be cascaded for greater counting capability or they can serve as alarm signals. The card can also be used as a pre-set counter.

Two (2) Voltage Monitor Cards, Model 69421A - These cards monitor bi-polar dc voltages in the range of +10.235 to -10.240 V, and return a 12-bit two's complement digital word to the controller to indicate the magnitude and sign of the measured voltage. Up to 150 conversions per second can be performed as commanded by the program or an external gate input.

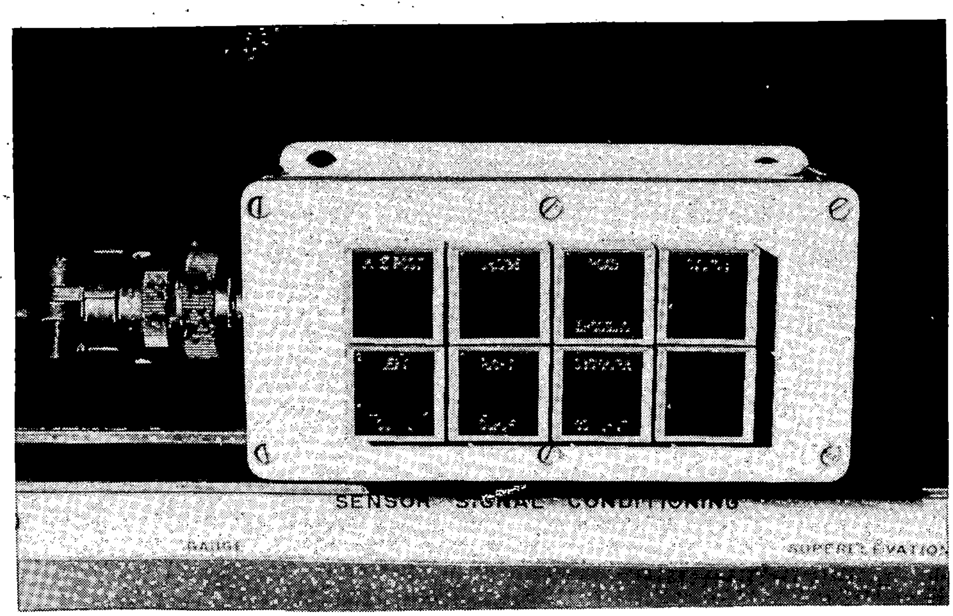
Digital Input Card, Model 69434A - This card monitors up to 12 external contact closures and interrupts the computer when one or more of the contacts change state.

Voltage Regulator Card, Model 69351B - This card provides isolated ± 15-volt power supplies for the 69421A Voltage Monitor Cards.

System Interface Card, Model 517702 - This card will format and observation inputs provided by the Observed Location Switches shown in Figure 3.

FIGURE 3

OBSERVED LOCATION SWITCHES

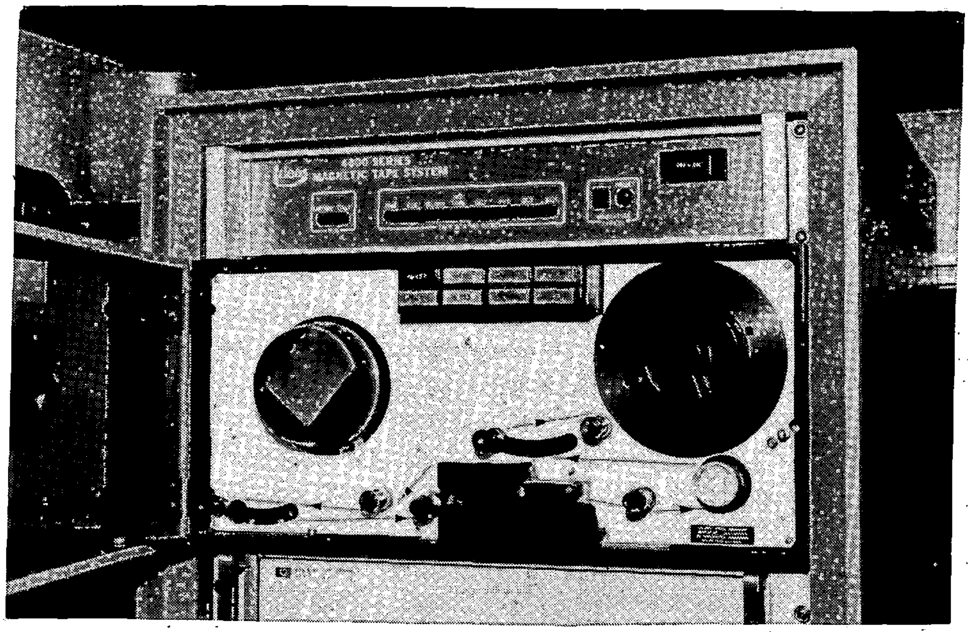


DATA RECORDING

MAGNETIC TAPE SYSTEM, MODEL 4607R-9-4K-CC - The on-board, 800 bpi, magnetic tape system permits the calculator to read and record IBM and ANSI compatible tapes. This capability allows the 9825A to create industrial standard tapes that can be processed by other digital systems. Figure 4 shows the tape system on-board the Iowa TGC.

FIGURE 4

MAGNETIC TAPE SYSTEM



SIZE/WEIGHT

Height	26.75 inches
Width	22.00 inches
Depth	22.00 inches
Net Weight	100.00 pounds

The following equipment was installed in conjunction to the tape system:

HP-IB Interface Card Model 90834A - This Interface allows the 9825A to communicate via the HP-IB Bus to the Magnetic Tape System. It utilizes a controlling processor with ROM to provide management of interface bus protocol.

HP-IB Digital Clock, Model 59309A - This clock displays month, day, minute and second; and on command outputs time via the HP-IB Bus to the logging devices.

HARDWARE INTERFACE AND COSTS

A simplified hardware structure for the GeoData Processing System is shown in Figure 5. The three major components discussed earlier and their interrelationship are clearly identifiable. Hardware cost for the GeoData Processing System are shown in Table 1.

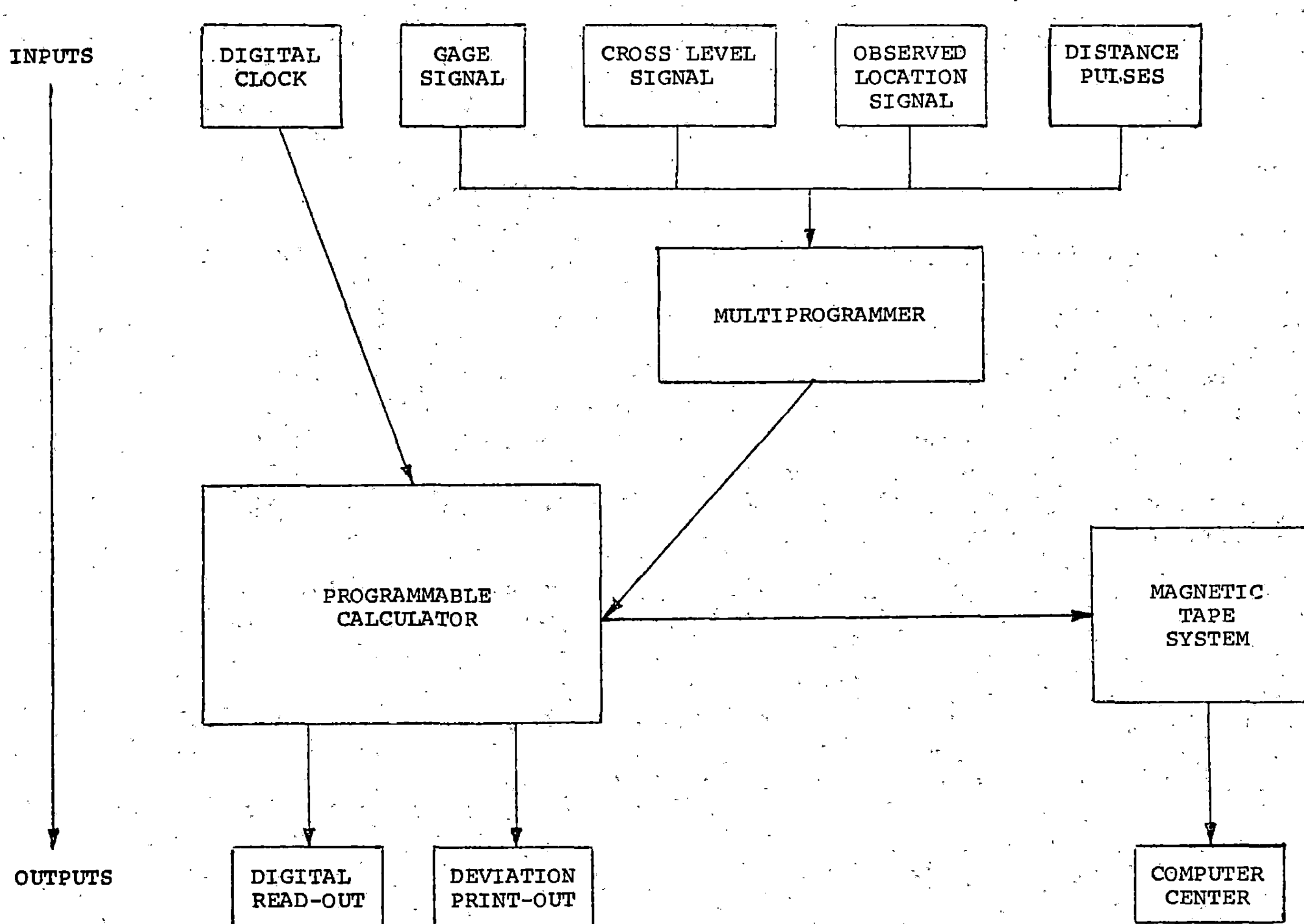
TABLE 1

HARDWARE COSTS

Programmable Calculator, Model 9825A - Option 002	$ 8,490
16-Bit Duplex Interface Card	470
String Advanced Programming ROM	460
General I/O - Extended I/O ROM	690
Subtotal	$10,110
Multiprogrammer Model 6940B - Option 908	1,510
Digital Input Card - Option 069	210
(3) Pulse Counter Cards	670
(2) Voltage Monitor Cards	890
Digital Input Card	400
Voltage Regulator Card	130
System Interface Card	2,200
Subtotal	$ 6,010
Magnetic Tape System, Model 4607R-9-4K-CC	8,700
HP-IP Interface Card	400
HP-IP Digital Clock	1,030
HP-IB Bus	80
Subtotal	$10,210
TOTAL	$26,330

FIGURE 5

SIMPLIFIED HARDWARE COMPONENTS FOR THE GEODATA PROCESSING SYSTEM



PART II

EVALUATION OF EQUIPMENT

TEMPERATURE EFFECTS

Gage System - The Rotary Variable Differential Transformer (RVDT) used as a sensor is exposed to outside ambient temperatures. Manufacturer data indicates an acceptable operating temperature range of -20°F to +200°F. Over the range of 0°F to 100°F the change in output sensitivity is less than 0.03%/°F, and the shift in output zero is less than 0.02%/°F of full scale range.

An analysis of the gate zero shift due to differential expansion or contraction of the cables and other mechanical parts indicates less than 0.008%/°F. The analysis also indicated that the change in sensitivity would be negligible. The signal conditioner is within the cab environment and has been compensated so that the change in sensitivity is less than 0.02%/°F over the temperature range of 0°F to +130°F. A 30 minute warmup time is recommended before using the units in the sub-zero temperature ranges.

Assuming outside temperature changes of ± 25°F and cab temperature changes of ± 10°F from the conditions during calibration result in an overall error due to temperature effects on the gage system of less than 0.0313 inches. The gage system has been operated with outside temperatures of -15°F to 100°F producing data well within tolerance.

Crosslevel System - The gyro-pendulum RVDT is exposed to the cab environment while the car body angle RVDT is exposed to the outside ambient temperature. The same temperature coefficients as those given for gage system RVDT's apply. Assuming the ± 25°F outside and ± 10°F inside temperature changes, the overall error due to temperature on the crosslevel system should be less than 0.125 inch. Temperature effects on the mechanical systems are small compared to those for the car body angle sensor and the signal conditioner. Operation of the crosslevel system to date has not produced data outside this tolerance.

Tachometer System - An incremental encoder is exposed to the outside environment. The manufacturer indicates an operating temperature range of -4°F to 160°F. The unit has been used to -15°F with no noticeable effect due to temperature.

Recorders and Logic Systems - No errors due to temperature effects have been experienced during operation with cab temperatures between 40°F and 90°F. It is recommended that storage temperatures below 0°F should be avoided to prevent the freezing of recorder ink used on the strip charts. Very rapid temperature changes should be avoided to prevent thermal shock damage to the electronic components.

HUMIDITY EFFECTS

Gage & Crosslevel Systems - The RVDT has vacuum impregnated coils so that the effects of humidity are minimized. The manufacturer recommends a maximum operating relative humidity of 95% at 90 F, non-condensing. Humidity effects should be negligible if cab humidity is below 95%.

Recorders and Logic Systems - The Iowa TGC has been operated without adverse effects with an outside humidity of 100% at 95 F. However, it is recommended that the systems are not energized until the cab heater or air conditioner has evaporated any condensation and reduced cab humidity to 95%. This reduces the likelyhood of ink smears when using the strip chart recorder.

SHOCK EFFECTS

Gage & Crosslevel Systems - The RVDT manufacturer indicates that shocks up to 10G for 11 hours will not cause signal degradation or damage. Due to the relatively low frequency response of the mechanical systems and the signal conditioner the gage and crosslevel systems will not respond to the high frequency components of shock and vibration. No out of tolerance errors were noted during operations that could be attributed to shock or vibration.

Recorders and Logic Systems - To date no errors or system failures during operation have been attributed to shock or vibration. It is recommended that all recording and logic system equipment be shock mounted.

LINEARITY

Gage System - Manufacturer's data indicates that the RVDT non-linearity is less than ±0.5% over the angular range of -13 to +26 that is typically used. In the design of the measurement carriage, an analysis was made so that non-linearities in the system could be minimized (Appendix A). The resulting system is linear to within 0.001 inch. The complete gage systems is linear within ± 0.0313 inch.

Crosslevel System - Manufacturer's data indicates that the RVDT non-linearity is less than ±0.2% over the angular range of ±8" that is typically used. Since the measured car body angles are normally less than one degree, the mechanical system is quite linear. The entire crosslevel system is linear within 0.0313 inch.

HYSTERESIS

Gage System - Since the frictional torque of the RVDT is indicated by the manufacturer to be less than 0.02 inch-ounces, the sensors contribution to system hysteresis is negligible. Tests have indicated that the hysteresis due to bearing friction, ect., of the mechanical system, is ± 0.0625 inch or less. Normal vibration reduces this value considerably.

Crosslevel System - Tests have indicated that the car body angle mechanical system can contribute hysteresis errors in cross-level up to ± 0.0625 inch and the gyro-pendulum mechanical system can contribute errors up to 0.0313 inch. System hysteresis due to the mechanical system is only significant in excess of ± 0.0938 inch. Normal vibration also reduces this value considerably.

WORN RAIL EFFECT

Gage System - The gage follower wheel is tilted 30 degrees and normally contacts the side of the rail 0.625 inch below the surface. Heavy top wear resulting in lip projecting of more than 0.25 inch will prevent the wheel from making contact at the gage line.

CURVATURE EFFECTS

Tachometer System - Distance along one rail is sensed instead of distance along the centerline. A small error will occur when measuring distance thru curves. For example, in a ten degree curve an error of 0.4% of the distance traveled is measured. A similar curve in the opposite direction will cancel the error.

RF INTERFERENCE

Logic System - When transmitting on the radio contained in the Iowa TGC the calculator would occasionally dump its buffer to the tape system and then terminate the test program. This makes it impossible to put a header on the tape and requires the replacement of a new tape before a restart is made. Three steps were taken to solve this problem: 1) Remove antenna from cab roof and remount at the back of the vehicle; 2) Shield antenna cable; and 3) Reduce the power output of the radio. RF interference is no longer a problem.

ENVIRONMENTAL EFFECTS

Recorders and Logic Systems - The effect of dust accumulations in the new equipment has not been seen since operation has to date been confined to winter conditions. A slight accumulation of dust in blower filters and on the tape heads has been noticed. Expectations are that during dry summer conditions, with travel on gravel roads, the TGC will require an extensive preventative maintenance program to combat dust build up. It is recommended that travel under dust conditions is not made unless the heater or air conditioner units are operating. These systems will create a pressure build-up within the car which will reduce the dust infiltration. It is further recommended that the air intake on the generator system be filtered and mounted on the roofline instead of below the vehicle.

WEIGHT VEHICLE

Recorders and Logic Systems - The new equipment was mounted behind the driver on the right side of the vehicle. This represents an additional 200 pounds that is not counter balanced. A slight adjustment to the high rail system was needed to adjust for this weight increase. No measurement errors can be attributed to this weight gain.

SYSTEM DRIFT

Gage and Crosslevel Systems - Historical data on the gage system indicates a maximum zero drift of $\pm$0.0625 inch and a maximum gain drift of 3% of full scale. Data on the crosslevel system had a maximum zero drift of $\pm$0.0625 inch and a maximum gain drift of 1% of full scale.

Tachometer System - This digital system is inherently drift free and no drift has been experienced.

SYSTEM RESOLUTION

Recorders,Gage and Crosslevel Systems - The resolution of the RVDT and its signal conditioner is essentially infinite. System resolution of the gage and crosslevel systems is determined by the recorders. Manufacturer's data indicates a resolution of 0.0156 inch in gage and 0.0625 inch in crosslevel for the analog recorder. Resolution of the digital recorder is 0.01 inch.

Tachometer System - System resolution of the tachometer system is better than 0.005 feet of travel along the track.

PART III

DATA RELIABILITY AND REPETITIVENESS

It is important to the overall scope of the research project to prove that the track geometry parameters being measured by the survey vehicle remain stable over repetitive observations on the same segment of track. To test the reliability of the Iowa TGC in generating equivalent measurements a simple test was conducted.

A test track was surveyed in both directions using the Iowa TGC. Since both runs were over the same segment of track and each measurement was taken ostensibly from the same location the statistical test chosen for the analysis of the collected data would be the *t*-test for paired observations. This particular test compares the two groups of data in terms of their mean values μ_1 and μ_2.

t-TEST FOR PAIRED OBSERVATIONS

Test of hypothesis concerning the means of two dependent paired populations are conducted using the *t* distribution.[1]

This particular statistic tests the difference between the means of the two populations. The hypotheses to be tested can be stated as:

$$H_0: \mu^2 - \mu^1 = 0$$

$$H_1: \mu^2 - \mu^1 \neq 0$$

where μ^1 and μ^2 are the measurement values from run one and run two. The null hypothesis (H_0) asserts that there is no difference between the measured values of run one and run two, whereas the alternative hypothesis (H_1) asserts that the average of the measurements for each pair of observations are different.

The critical *t* value for an infinite number of degrees of freedom is 1.96 assuming a 95 percent confidence level. If the calculated value of *t* from the data is greater than 1.96 or less than -1.96 then H_0 will be rejected. The closer the *t* value is to zero, the less likely it is that a false hypothesis will be accepted. For this task a paired Student's *t* value will be calculated separately for gage and cross level measurements.

1. Dixon & Massey, Introduction to Statistical Analysis, McGraw-Hill, pp. 114-123.

STATISTICAL ANALYSIS

The paired t value calculated for the gage measurements was 0.141 which is well within the critical value of t. Therefore, the hypothesis that the two populations are equal (H_0) is not rejected. Since this value is much less than 1.96 and close to zero, we can say with confidence that there is no reason to assume that the paired values for gage are different.

The calculated t value for cross level measurements at 0.482 is also well within the region of a critical t. Again we can assume that there is no difference in the paired values for each cross level test run. The individual parameters for each run are shown in Table 2.

The actual measured values for each run were used in defining the gage and x-level populations as described in Table 2. The raw data from the comparison test should not be used to describe the reliability of the Iowa TGC. From the material in Table 2 we can say that in repetitive surveys on the same locations the Iowa Track Geometry Car would measure the same for both gage and x-level measurements.

TABLE 2

TEST PARAMETERS

PARAMETER	GAGE		X-LEVEL	
	TEST RUN 1	TEST RUN 2	TEST RUN 1	TEST RUN* 2
MEAN	56.442"	56.4439"	-0.2411"	-0.2510"
STANDARD DEVIATION	0.2088	0.2044	1.4672	1.4402
MAXIMUM VALUE	56.97"	56.95"	2.15"	2.19"
MINIMUM VALUE	55.98"	56.01"	-4.11"	-3.93"
RANGE	0.99"	0.94"	6.26"	6.12"
t VALUE	0.141		0.482	

*Sign of all cross level measurements taken on the second run was changed so that data could be compared.

CHAPTER II

ASSESSMENT OF ADDITIONAL MEASUREMENT NEEDS

PART I

INTRODUCTION

The Iowa Department of Transportation subcontracted a study for "Measurement Needs Assessment" of the Iowa Track Geometry Car (TGC) to the firm of Geo-Trac, Incorporated. The specific language of the subcontract is included as Appendix A. In brief the study required three unique tasks:

1. Determine the incremental measurement improvements, benefits, and costs of adding Profile and Alignment test capabilities to the Iowa TGC or a replacement vehicle.

2. Determine benefits in terms of possible reductions in train derailments and a reduction of costs in estimating track and roadbed rehabilitation costs derived from additional measurement capabilities.

3. Assess measurement systems as to the operating cost of the measurement equipment and the TGC modification costs, including a feasability study of modification.

The material in this report presents a synopsis of Geo-Trac, Incorporated's study. Some changes to the parent study report have been made to reflect the views of the author and the position taken by the Iowa DOT.

PART II
MEASUREMENT METHODS

PRESENT TGC MEASUREMENT CAPABILITIES

The existing Iowa TGC has the capability to measure track gauge and cross level. Automated measurement instrumentation plots out in a continuous chart containing both gauge and cross level. Also an on-board computer system automatically prints out all detected violations of FRA Track Safety Standards of any class of track selected by the TGC operator. All data collected at a sample distance of 4.593 feet is stored on magnetic tape for use later at the Iowa DOT's Data Processing Center.

The basic concept behind the present TGC is the assumption that the majority of true derailment conditions in railroad track caused by track geometry would be seen in gauge and/or cross level measurements. This assumption was based on the following suppositions.

1. A bad profile defect would eventually cause open gauge and/or a cross level defect.

2. Alignment defects -- unless thermally induced -- are usually the result of a surface, gauge or cross level defect.

3. An alignment defect in locations of perfect profile, gauge, and cross levels (without thermal forces) would tend to correct itself.

The output of the Iowa TGC was based on the Track Safety Standards of the Federal Railroad Administration (Appendix B). These standards are assumed to be such that a section of track within standards would not constitute a derailment condition. The Standards should not be equated to maintenance standards as they are inadequate for maintenance purposes.

The lack of a sound long term outlook for track maintenance has created Class 1 and Class 2 tracks. Through continuous maintenance patterns Class 1 track will become Class 3 track. The reversal of this self improvement trend is what is currently being experienced by the railroad industry. Classification of track should be based on desired service levels and not on achieved maintenance levels as measured by speed permitted.

In order to objectively relate other unmeasured parameters to gauge and cross levels a 1,160 mile sample was chosen on a well maintained track inventoried by a major U.S. railroad. Table 3 shows the results of the defect occurances. The data used for this comparison and experiences on other test vehicles leaves the alignment channel a question mark to be dealt with later.

TABLE 3

DEVIATION OCCURANCES - MAINTAINED RAILROAD

Parameter	Number of Deviations	Percentage of Deviations
Warp[1]	4442	65.9
Profile	1240	18.4
Gauge	730	10.8
Cross Level	328	4.9
		100.0%

1. A variation in cross level over a Chord distance.

Currently the TGC vehicle is recording a minimum of 1058 of these deviations. The purpose of this study addresses the question -- "Should the TGC capability be extended and what extended measurement capabilities would be cost effective?", both for accident prevention and track rehabilitation cost assessments.

MEASUREMENT CAPABILITIES CONSIDERED

Table 4 shows a summary of the track parameter measurement systems used on other known high-rail inspection vehicles. Table 5 illustrates those additional measurement systems which were considered as candidates for addition to the Iowa TGC. Those additional measurements subjected to detailed analysis were: Alignment, Profile, and Warp.

TABLE 4

HIGH-RAIL TRACK GEOMETRY SYSTEMS - SUMMARY OCTOBER 1977

OWNER	VEHICLE					GEOMETRY		PARAMETERS					DATA HANDLING		REMARKS
	TYPE	WEIGHT, LB.	PROPULSON	SPEED MIN/MAX	CREW SIZE	GAGE	CROSS LEVEL	WARP	PROFILE	ALIGNMENT	CURVATURE	LOCATION	STORAGE	DISPLAY	
U.S. DEPT. OF TRANSPORTATION FRA/TSC	Kraut-kramer TTV-1 Olson	14,500	Self 360 C.I. Gas	0/30	2	Wheel Contact	Damped Pendlum	Yes	No	No	Yes	A.L.D. Axle Tach	Chart Record	Chart Record, Exception Print-Out	System in procurement cycle Vehicle includes ultrasonic rail flaw detection.
U.S. DEPT. OF TRANSPORTATION FRA/TSC	Kraut-kramer TTV-1 Olson	14,500	Self 360 C.I Gas	0/5	2	Wheel Contact	Damped Pendlum	No	No	No	No	A.L.D. Axle Tach.	Chart Record	Chart Record, Gage Defect Print-Out	Speeds up to 20 mph on tangent may be possible depending on track condition. (URFD)
IOWA DEPT. OF TRANSPORTATION	Harmon, Fair-mont	14,000	Self 360 C.I Gas	0/23	2	Wheel Contact	Gryo Pendlum	No	No	No	No	Axle Tach.	Magneti Tape	Chart Record Exception Print-Out, Digital	
LOUISVILLE AND NASHVILLE R.R.	Grey-hound Bus ISCO	32,000	Self 250 HP Diesel	0/30	2	Wheel Contact	Vert. Gyro Uncompensated	No	Mid-Chord Contact 23.4 ft	Mid-Chord Contact 23.4 ft	No	Axle Tach.	Chart Record	Chart Record	Mini-computer addition if being considered.
NORDBERG SYSTEM	Optiona	--	--	0/5	-	Wheel Contact	Damped Pendlum	No	No	No	No	--	--	Analog Meters	Trailer unit.
RACINE SYSTEM	Optiona	--	--	0/5	-	Wheel Contact	Damped Pendlum	No	No	No	No	Axle Tach.	Chart Recorc	Chart Record Digital	Trailer unit.

TABLE 5

CANDIDATE MEASUREMENT SYSTEMS

Parameter	Type of Test Car FRA	Iowa	RR	% Deviations[1] 1,160 Mile Sample	% Deviations[2] Other Way And Structure Accidents	% Deviations[3] National Accidents
Gauge	X	X	X	10.8	6.6	2.9
Cross Level	X	X	X	4.9	22.1	9.7
Alignment	X	?	X	--	16.0	
Profile	X		X	18.4	38.6	16.8
Warp			X	65.9	--	--
TOTAL				100.0%	83.3%[4]	36.4%[4]

1. These percentages are more significant when we delete consideration of "Warp". This deletion is possible since this measurement relates to extended surface capability and cross level changes. New calculated percentages would be; gauge 31.8%; cross level 14.2%; and profile 54.0".

2. Percentages[4] are from the "other way and structure items" category of national accidents. Parameters such as guard rail improvements, dirty ballast and worn car retarders make up the missing 16.7% of the accidents.

3. This percentage[4] includes all categories of national accidents. The difference of 63.6% is made up of "rail flaws" and "tie and tie plate" track deficiencies.

4. Percentages summarized from "Accident Bulletin, Summary and Analysis of Accidents on Railroads in the United States, (No. 142)", Tables 104-A.

Also considered in this report is the use of a Camera System. Its application and therefore its value includes, but is not limited to the detection of the following deficiency measurements:

1. Rail Surface Irregularities
2. Rail Alignment Irregularities
3. Defective Cross Ties
4. Mile Post Synchronization
5. Brush-Cut or Spray Requirements
6. Drainage Requirements
7. Ballast Condition
8. General Roadway Cleanliness

TABLE 6

TABLE OF MEASUREMENT METHODS CONSIDERED

Measurement	Implementation Method	Imple-ment'n Costs	Notes
PROFILE	Accelerometer with large mass or Canadian System (Profilometer) developed by the Canadian Northern R.R.	$50,000	1) High probability of detection 2) Also senses surface condition of joints
	Existing sensors with improved sensitivity/filtering of circuitry and use of 3 point Chord method	$20,000	1) Test set up on existing TGC for approx. $3,000 2) See 1 and 2 above 3) High reliability
ALIGNMENT	Rate Gyro and various correcting methods for accuracy	$24,500	1) High probability of detection
	Angle of Gauge Carriage		1) Inadequate for task
	Rail Position sensor pairs (3 sets)	$40,000	1) Mid Chord offset method with Chord closer to 21' than FRA 62'
	Visual Stop Action System (Video Camera)	$75,000	1) Also relates to several additional rail rehabilitation cost estimate items
WARP OR ADDITIONAL SURFACE CAPABILITY	Derived by software only for variation in cross level over various Chord distances	$ 3,000	1) High probability of detection 2) Requires no additional transducers other than surface-cross level 3) Requires increased sample rates

IMPLEMENTATION COST OF MEASUREMENT SYSTEMS

Table 6 shows the measurement systems considered in this study and the approximate cost for each method. A brief comment upon the operating efficiency and/or comments on installation are also contained in Table 6.

PART III

BENEFITS OF ADDITIONAL MEASUREMENT SYSTEMS

BENEFITS

Installation of the measurement systems that will be recommended in Part V are expected to result in benefits in the following areas:

1. Reduction in Accident Damage Costs.
2. Reduction in Deaths and Injuries.
3. Reduction in Track Inspection Costs.
4. More Efficient Fund Allocation Based on the Quantitative Measurement of Current Track Status.
5. More Efficient Fund Allocation Based on a Quantitative Measurement of the Track Deterioration Rate.

In order for benefits to accrue two assumptions must be made. First, it must be assumed that the detection of defects by the Iowa TGC will induce the correction of the defect. Secondly, the Iowa TGC must be able to detect deviations. In the calculation of benefits 60% effectiveness factor has been used to conservatively relate the Iowa TGC's ability to detect deviations.

BENEFITS OF ACCIDENT PREVENTION

The benefits which can accrue due to prevention - reduction of accidents are the reduction of damage costs and financial losses due to deaths or injuries resulting from accidents. When assessing the ability of the TGC to generate these benefits it is important to use only those loss elements which are directly related to the measured track parameters.

In consideration of those deaths and injuries which may be eliminated through the means of accident reduction, each fatality was considered to result in a savings of $30,000 and each injury in a savings of $17,000. Injury costs consider both time lost from work and hospital expenses. Table 7 shows the estimated benefits from the prevention of accidents by measurement system.

TABLE 7

ESTIMATED ANNUAL MEASUREMENT BENEFITS FROM ACCIDENT PREVENTION

Parameter	Accident[1] Damage Reduction	Death & Injury Reduction[2]	Total
Profile	$113,900	$42,000	155,900
Alignment	47,400	16,800	64,200
Warp[3]	57,600	21,000	78,600
	$218,900	$79,800	$298,700

1. Based on Percent Deviations of National Accidents shown in Table 5 x effectiveness factor x total annual damages ($1.13 million in Iowa in 1973). Example for profile = .168 x .60 x $1.13 million = $113,900.

2. Based on Tables 104-A and 104-B of "Accident Bulletin, Summary and Analysis of Accidents on Railroads in the United States", (# annual fatalities x $30,000) + (# annual injuries x $7,000) x effectiveness factor. Example for profile = (0 x $30,000) + (10 x $7,000) x .60 = $42,000.

3. The following conditions are considered to be in some limited measure detectable by warp measurements.
   Ties & Tie Plates - decayed, worn, splintered, broken, soft timber.
   Rails & Joints - other rail, not wear, joints, less bars, bolts.
   This category of deviations accounts for 8.5% of the national accidents.

REDUCTION IN TRACK INSPECTION COSTS

The cost of a manual inspection should be related to the automatic inspection of the TGC to establishing the operational cost relationship. Estimates of the inspection cost for both approaches were developed as shown below.

AUTOMATIC INSPECTION

Assumptions:

1. Measurements will be made at 17.5 mph.
2. TGC is depreciated across 5 years.
3. Total purchase price of the present TGC plus new measurement systems would be $239,000.

Calculations:

1. Potential TGC operating cost/mile = ($12.50/hr. x 2080 hr./yr.) ÷ 17.5 mi./hr. x 5 hr./day x 200 days) =$1.49/mile
2. TGC depreciation cost/mile = $239,000 ÷ (17,500*miles x 5 yrs.)= $2.73/mile. *The 17,500 miles is the experienced TGC mileage.
3. Total TGC costs per mile = $1.49 + $2.73 = $4.22

MANUAL INSPECTION

Assumptions:

1. The cost of manual inspections depends upon the skill level of the inspector.
2. Manual inspections will locate all the track related causes for accidents compared to the 44.9% (36.4 + 8.5) expected from the modified TGC.
3. Salary and support averages $12.00 per hour.

Calculations:

1. Experience matrix

Experience Level	Estimated Dispersion of Experience	Item	$ COST PER MILE			
			To Ride Rail	To Stop & Inspect	To Measure & Confirm	Total
High	10%	1,3,4,5	$2.40	$ 1.20	$ 1.12	$ 4.72
Average	70%	1,3,6,7	2.40	4.80	6.00	13.20
Low	20%	2,3,8,9	4.80	12.00	15.00	31.80

Items

1 Inspection speed = 5 mi./hr.
2 Inspection speed = 2½ mi./hr.
3 Track averages 6 defects/mile
4 25% of defects require dismount (4 minutes)
5 25% of dismounts require measurement (15 minutes)
6 50% of defects require dismount (8 minutes)
7 50% of dismounts require measurement (20 minutes)
8 All rejects require dismount (10 minutes)
9 50% of dismounts require measurement (25 minutes)

2. Average cost per mile = $\frac{\$4.72 + (7 \times \$13.20) + (2 \times \$31.80)}{10}$ =

$16.07 = Weighted Cost of Manual Inspection

3. Adjusted average cost per mile to eliminate limited low experience personnel = $\frac{\$4.72 + (7 \times \$13.20)}{8}$ = $12.14

4. Cost adjusted to TGC's ability = $12.14 x .449 = $5.45

BENEFITS

Manual Costs*	= 17,500 miles/yr. x $5.45/mile =	$95,375
TGC Costs	= 17,500 miles/yr. x $4.22/mile =	73,850
Savings Per Yr.=		$21,525

*This amount of inspection would require a 14 man staff performing on rail inspections 60% of the time.

TOTAL ESTIMATED BENEFITS

The estimated benefits for accident reduction and track inspection automation are shown in Table 8. Remaining benefits, more efficient fund allocations, are not suitable to assignment.

TABLE 8

ESTIMATED BENEFITS

Parameter	Benefit From Accident Reduction	Benefited From[1] Automated Track Inspection	Total Benefits
Profile	$155,900	$2,200	$158,100
Alignment	64,200	900	65,100
Warp	78,600	1,100	79,700
Total	$298,700	$4,200	$302,900

1. Percent deviations national accidents (Table 5) x effectiveness factor x annual savings. Example for Profile = .168 x .6 x $21,525 = $2,200.

PART IV

COMPARISON OF BENEFITS AND COSTS

BENEFIT-COST ANALYSIS

Table 9 shows the estimated benefits for each of the measurement systems and the estimated annual cost. Implementation costs of the additional measurement systems are depreciated over five years using a $20,000 Profile System, a $40,000 Alignment System, and a $3,000 Warp System. Maintenance of the additional systems was estimated at $3.00 per operational hour on the Profile System and $4.50 per hour on the Alignment System.

TABLE 9

BENEFITS AND COSTS OF TGC MODIFICATIONS

Parameter	(1) Benefits Per Year	(2) Cost Per Year	(1)-(2) Value Per Year	(1)÷(2) Benefit-Cost Ratio
Profile	$158,100	$ 7,000	$151,000	22.6
Alignment	65,100	12,500	52,600	5.2
Warp	79,700	600	79,100	132.8

Because the payback per dollar invested ratios for each measurement system are above 1 the installation of the additional systems should be considered.

PART V

RECOMMENDATIONS

The following measurement systems are recommended for installation on the Iowa TGC vehicle. Installation of all of this equipment will require the acquisition of a new vehicle as documented in Appendix C.

WARP

The benefits in this measurement will involve software modifications to allow various chord lengths relative to variation in cross level. The current sampling rate could be modified for this increased capability.

PROFILE

Surface measurements may be implemented by the addition of a vertical position sensor pair and by assuming a beam length equal to the distance between the TGC's supporting (steel) wheels. This approach is untried, however, it could be tested on the present TGC for about $3,000. If the test set-up is effective the installation of a surface measurement system is estimated to cost $25,000. Measurements could be taken at normal inspection speeds. The alternative approach -- the accelerometer and position transducers would cost $50,000 and possibly hold a penalty at low speeds.

ALIGNMENT

The mid-chord measurement system uses 3 pairs of sensors to identify rail position. While this approach is more expensive than the Rate Gyro ($47,000 vs. $24,500) it does provide a measurement which is closer to the FRA Track Safety Standards. Until the application of a camera system to measure alignment is researched no alignment system should be purchased for the Iowa TGC.

CAMERA SYSTEM

A camera system would be applicable to the detection of the track deficiencies as noted in Part II, Page22. Other applications of the camera system are numerous and include work on the base record, rehabilitation costs and abandonment needs. Each frame would have location information super-imposed so that users would know the exact position. The frames should be taken every 10th of a mile.

A split picture; one shot looking down the rails and one shot looking into the roadbed, could provide suitable information to prepare cost estimates for upgrading. Information on lose spikes, broken ties, rail wear, ballast condition, drainage problems, brush conditions and signalization could be extracted from the photos. It may also be possible to compute alignment deviations from the photos by using computer graphics.

CHAPTER III

COMPARISON OF TRACK GEOMETRY MEASUREMENT VEHICLES

PART I

INTRODUCTION

The Iowa DOT has been studying a special purpose high-rail vehicle equipped to measure track gage and cross level. The measurement accuracy of the Iowa Track Geometry Car (TGC) was demonstrated by over more than two years of operational use and through validation testing prior to the implementation of this research.

The object of this task, one of several under a research contract, sponsored by the Federal Railroad Administration, is to compare the measurements of track gage and cross level taken by a FRA owned track geometry vehicle with those taken by the Iowa TGC. Such comparisons will determine if the measurement values taken by the TGC can be consistently interpreted to indicate what the measurement values would have been if a FRA vehicle was used instead. It may be possible to utilize the lighter and less costly TGC to indicate probable track geometry measurements under heavier rail loadings.

It is normally assumed that a survey vehicle in train consist (locomotive and measurement cars) records larger numeric values for wide gage and cross level deviations than will the lighter TGC. If true, and the numeric values should differ in a consistent pattern. Therefore, it would be possible to infer from the TGC readings the numerical value of measurements taken by the FRA vehicle which represents a heavy load.

The difference in the numerical values of measurements by both vehicles could be without pattern or due to malfunctioning equipment on either vehicle. Presuming the equipment to be in good order and that the values of difference are not random, it should be possible to identify a pattern or relationship between the numeric values of the measurements from both vehicles.

Should such patterns be found, it is likely that the relationship will not remain identical under all conditions. The data analyzed under this task is for values over a number of track segments when track class, vehicle speed, and rail type are varied. The original design of this task was to have considered varied climatic conditions, however, the loss of the TGC in the middle of the research prevented repetition of the data collection process under frozen and thawing track conditions.

PART II

DATA COLLECTION

ISSUES FOR INVESTIGATION

Track geometry data collected for comparing measurements between the Iowa Track Geometry Car and data taken by the FRA T-2/T-4 consist will be used to provide answers to the questions listed below. Details on how the test was conducted can be found in Appendix J.

1 - Is there a valid and reliable relationship between measurement values of track gage taken by each vehicle? Is there a valid and reliable relationship between the measurement values of cross level taken by each vehicle?

2 - At what level of confidence can this relationship, if any, be used to extrapolate the measurement values of the larger heavier measurement vehicles from those obtained by the TGC?

3 - It if exists, what is the expression of this relationship which can be applied in electronic data processing to generate the extrapolated measurement values from the TGC obtained data?

4 - Is there a similar consistant relationship between TGC measures of gage and cross level and the FRA vehicle measurements of surface and alignment?

MATRIX OF VARIABLES

The data collection variables considered in this task include; measurement vehicle speed, track class, type of rail and vehicle order. Since the relationship between vehicles was assumed to change over differed types of track conditions it was necessary to collect 16 different samples to represent the track which was most likely to be found in Iowa.

The track conditions at the measurement test sites can be stratified by the following:

1. Track Class: Tests were conducted on Class I, Class II and Class III track.

2. Vehicle Order: Tests were ran with the TGC following the heavier vehicle and with the TGC proceeding the FRA vehicle.

3. Vehicle Speed: Three speeds 5, 10 and 20 mph. were considered.

4. Rail Type: Tests were conducted on jointed and welded rail.

Approximately 2000 paired observations were taken at each two-mile-long test site. These measurements were further divided into two classes; observations on tangent track and observations on curved track. **Table 10 summarizes the 16 track** segments and lists the amount of observations taken at each test site.

PART III

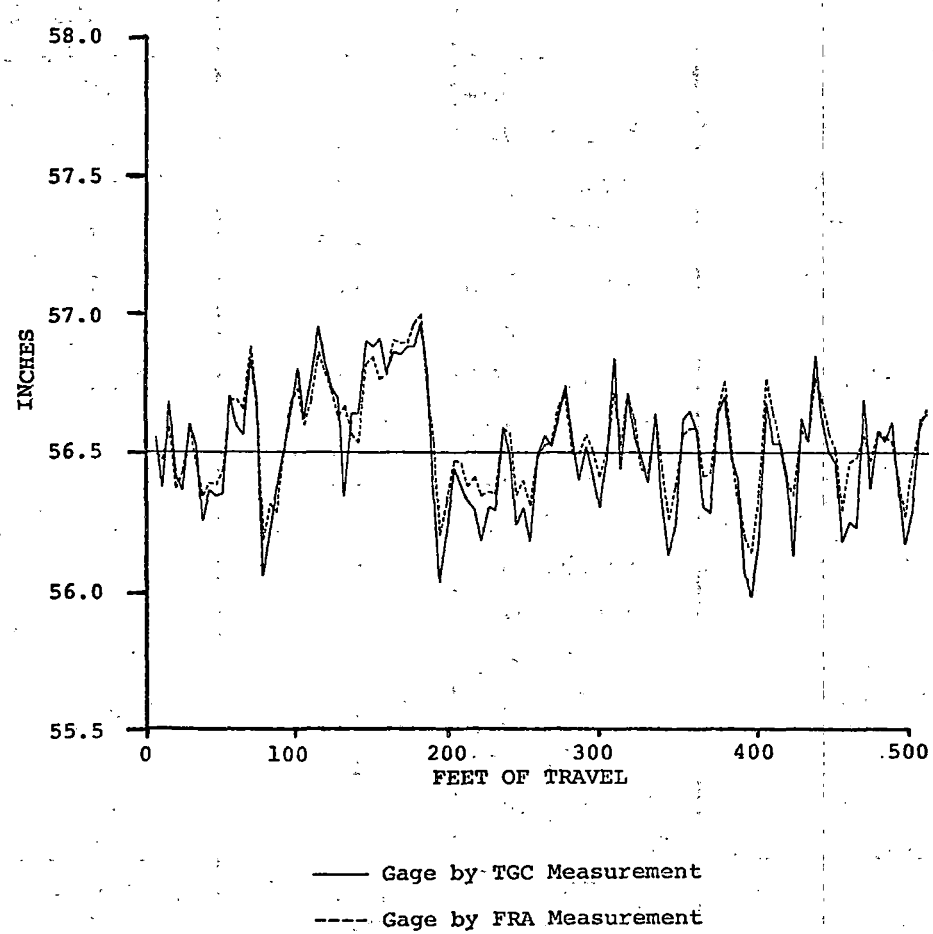
STATISTICAL ANALYSIS

The overall purpose of this endeavor is not so much to compare both vehicles directly as it is to mathematically manipulate the Iowa TGC data so that it's measurements satisfactorily resemble those of the FRA vehicle. To this end correlation and regression analysis are appropriate. However, a simple direct comparison of the test data will point out the magnitude of difference between the Iowa TGC and the FRA test vehicle.

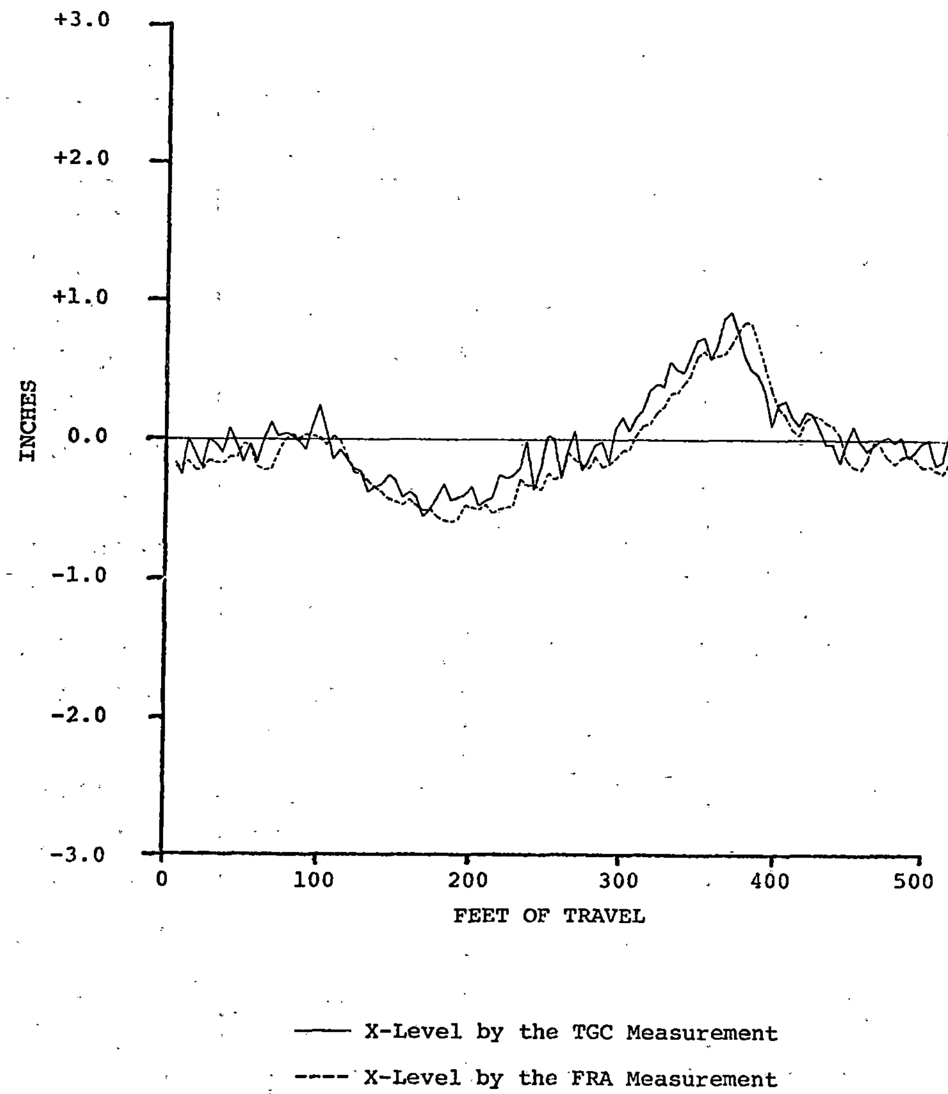
Figure 6 shows a sample computer plot of the analog signals recorded by the FRA test vehicle and the Iowa TGC. This homogeneity is repeated at all of the test sites for both gage and cross level signals. A complete collection of comparison plots for all 16 test segments is shown in Appendix M.

FIGURE 6
ANALOG CHARTS

GAGE
CLASS II-WELDED RAIL
FRA FIRST - 20 MPH



CROSS LEVEL
CLASS II-WELDED RAIL - FRA FIRST-20 MPH



Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

TABLE 10

TRACK SEGMENT SUMMARY

TRACK SEGMENT	TRACK CLASS	VEHICLE ORDER	VEHICLE SPEED (mph)	RAIL TYPE	NUMBER OF OBSERVATIONS ON TANGENT	NUMBER OF OBSERVATIONS ON CURVE	TOTAL OBSERVATIONS
1	I	FRA first	5	Jointed	754	1,349	2,103
2	I	TGC first	5	Jointed	2,169	0	2,169
3	II	FRA first	10	Jointed	1,756	513	2,269
4	II	TGC first	10	Jointed	2,280	0	2,280
5	II	FRA first	20	Jointed	1,778	615	2,393
6	II	TGC first	20	Jointed	2,208	0	2,208
7	II	FRA first	20	Welded	1325	348	1,673
8	II	TGC first	20	Welded	1,832	414	2,246
9	III	FRA first	10	Jointed	1,108	1,112	2,220
10	III	TGC first	10	Jointed	2,232	0	2,232
11	III	FRA first	20	Jointed	1,847	351	2,198
12	III	TGC first	20	Jointed	1,289	974	2,263
13	III	FRA first	10	Welded	319	1,948	2,267
14	III	TGC first	10	Welded	1,608	616	2,224
15	III	FRA first	20	Welded	1,232	1,006	2,238
16	III	TGC first	20	Welded	1,441	732	2,173
TOTAL					25,178	9,978	35,156

A direct comparison of the arithmetic mean and the variance of the measurements from both vehicles yields the data found in Table 11. In general, it appears that the FRA vehicle measures slightly wider gage than the TGC. The variance or range of gage values appears to be the same for both vehicles. Cross level measurements collected by the FRA vehicle seem to have a wider range than those taken by the TGC.

The data presented in Table 11 must be analyzed to determine if the two populations, FRA measurements and TGC measurements, are the same. To test the means for each test segment, μ_{TGC}, μ_{FRA}, the t distribution was used. Due to the large population size, any t value less than 1.645 implies that the two means are the same. The variance of each test segment, σ^2_{TGC}, σ^2_{FRA}, was tested by the distribution of F. Any F value below approximately 1.4 implies that the two variances are the same.[1] The t and F values for the data presented in Table 11 are shown in Table 12.

1 Snedecor & Cochran, Statistical Method, ISU Press, p. 117

μTGC = mean value of TGC measurements

μFRA = mean value of FRA measurements

σTGC = variance of TGC measurements

σFRA = variance of FRA measurements

1.645 = table value of t for .05 probability at α degrees of freedom

TABLE 11

DATA COMPARISONS

TRACK CLASS	TEST SEGMENT		MEAN GAGE		STANDARD DEVIATION GAGE		MEAN X-LEVEL		STANDARD DEVIATION CROSS LEVEL	
			TGC	FRA	TGC	FRA	TGC [1]	FRA	TGC	FRA
I	1	Curved	56.55	56.53	.158	.158	1.66	1.83	1.939	2.057
		Tangent	56.52	56.51	.156	.159	-.25	-.16	1.848	2.230
	2	Curved	----	----	----	----	----	----	----	----
		Tangent	56.63	56.65	.142	.151	.50	.34	1.064	1.295
II	3	Curved	56.60	56.67	.155	.156	-3.06	-3.22	.663	.802
		Tangent	56.47	56.54	.145	.148	-.16	-.11	.357	.414
	4	Curved	----	----	----	----	----	----	----	----
		Tangent	56.39	56.48	.155	.141	-.23	-.27	.425	.568
	5	Curved	56.66	56.71	.155	.183	-2.92	-3.20	.686	.776
		Tangent	56.50	56.53	.160	.175	-.15	-.17	.367	.436
	6	Curved	----	----	----	----	----	----	----	----
		Tangent	56.40	56.49	.145	.136	-.20	-.19	.496	.573
	7	Curved	56.28	56.49	.224	.196	-.41	-.46	.460	.515
		Tangent	56.28	56.48	.202	.175	-.24	-.22	.355	.372
	8	Curved	56.59	56.63	.174	.138	-1.46	-1.67	.874	.963
		Tangent	56.52	56.58	.185	.165	.13	.07	.483	.519
III	9	Curved	56.66	56.69	.194	.186	-1.77	-1.76	.637	.750
		Tangent	56.44	56.48	.142	.145	-.02	.15	.541	.608
	10	Curved	----	----	----	----	----	----	----	----
		Tangent	56.46	56.61	.147	.160	-.24	-.09	.395	.531
	11	Curved	56.63	56.65	.155	.153	-1.36	-1.31	.658	.735
		Tangent	56.50	56.53	.172	.167	-.39	-.24	.713	.808
	12	Curved	56.82	56.96	.172	.155	.38	.51	1.757	2.090
		Tangent	56.74	56.88	.141	.143	-.17	-.16	.398	.546
	13	Curved	56.82	56.81	.142	.136	.84	.77	3.789	3.891
		Tangent	56.80	56.81	.113	.110	.08	.03	.392	.450
	14	Curved	56.95	56.98	.160	.154	2.94	2.89	1.472	1.484
		Tangent	56.82	56.84	.120	.119	-.04	-.16	.235	.239
	15	Curved	56.74	56.76	.147	.146	-.77	-.49	2.717	2.766
		Tangent	56.73	56.75	.109	.110	-.18	.11	.260	.276
	16	Curved	56.73	56.75	.108	.108	-.72	-.63	3.074	3.204
		Tangent	56.66	56.67	.192	.196	-.19	-.08	.322	.346

1. Negative X-level means the left rail is lower than the right rail.

TABLE 12

POPULATION COMPARISONS

TRACK CLASS	TEST SEGMENT		GAGE		CROSS LEVEL	
			t	F	t	F
I	1	Curved	1.27	1.00	.85	1.13
		Tangent	.63	1.04	.44	1.46
	2	Curved	---	---	---	---
		Tangent	1.36	1.13	1.35	1.48
II	3	Curved	1.93	1.00	2.17	1.46
		Tangent	4.78	1.04	1.29	1.34
	4	Curved	---	---	---	---
		Tangent	6.07	1.21	.80	1.79
	5	Curved	2.95	1.39	3.78	1.28
		Tangent	4.17	1.20	.50	1.41
	6	Curved	---	---	---	---
		Tangent	6.40	1.14	.19	1.33
	7	Curved	9.98	1.31	.96	1.25
		Tangent	10.58	1.33	.55	1.10
	8	Curved	2.55	1.59	2.28	1.09
		Tangent	3.42	1.26	1.20	1.15
III	9	Curved	1.74	1.09	.14	1.39
		Tangent	2.79	1.04	2.95	1.26
	10	Curved	---	---	---	---
		Tangent	9.76	1.18	3.21	1.80
	11	Curved	1.30	1.03	.72	1.25
		Tangent	1.77	1.06	1.97	1.28
	12	Curved	8.55	1.23	.67	1.42
		Tangent	9.86	1.01	.21	1.88
	13	Curved	.72	1.09	.18	1.05
		Tangent	.90	1.06	1.18	1.32
	14	Curved	1.91	1.08	.34	1.02
		Tangent	1.67	1.01	5.06	1.03
	15	Curved	1.37	1.01	1.02	1.04
		Tangent	1.83	1.02	10.82	1.13
	16	Curved	1.85	1.00	.29	1.09
		Tangent	.52	1.04	3.29	1.15

In modeling the paired data, the first step was to determine if a correlation exists between the cross level or gage readings from the Iowa TGC and the cross level or gage readings from the FRA test car. A simple linear regression was run to determine if such a correlation exists. The equation used was:

$$Y=\alpha + \beta X + \Sigma$$

Where Y= numeric readings obtained for cross level (XLF) or gage (GAGEF) from the FRA test car.

α= a constant

β= a constant

X= numeric readings obtained for cross level gage from the Iowa TGC (XLT or GAGET)

Σ= an error

By taking the square root of the coefficient of determination the correlation (R) was determined. If there is a high correlation ($R \geq .8$) then the two sets of data, TGC and FRA readings, were considered to be strongly related.

This linear regression analysis was done for each of the 16 test runs listed in Table 10 and for curved track segments extracted from 12 of the original 16 runs. The 28 samples resulted in 56 models or equations since separate equations are required for gage and cross level. Most of the models have an R term that indicates a high correlation. This implies that a linear model could be used to predict the FRA test car reading from a given TGC measurement.

In an effort to simplify and reduce the number of models needed, a different kind of regression model was employed. This new model, called a classification model, can be used to test the significance of different conditions; i.e.; track class, vehicle order, speed and track type. The classification equation to be used is:

$$Y = \alpha + \beta_1 X + \beta_2 C + \beta_3 O + \beta_4 S + \beta_5 T + \Sigma$$

Where Y= numeric readings obtained for cross level (XLF) or gage (GAGEF) from the FRA test car.

α, β_1, β_2, β_3, β_4 and β_5 = constants

X = numeric reading obtained for cross level or gage from the Iowa TGC (XLT) or (GAGET)

C = "dummy" variable for track class

O = "dummy" variable for vehicle order

S = "dummy" variable for vehicle speed

T = "dummy" variable for track type

Σ = an error

The classification model can test the significance of the individual variables. Some of the original 56 linear regression models can be combined by studying the results of the classification equations. For example, the Class II jointed track can be combined for 10 and 20 mph operations since speed on this particular track type and Class is a non-significant variable.

A total of 11 models for gage and 15 models for cross level resulted from the analysis of classification models. The complete listing of the resulting correlations, R values for the linear regression models and the classification models are shown in Table 13.

The magnitude of the corrections required by each of the models can be derived from data displayed in Tables 14 and 15. Some general observations from these tables should be made. These observations include the following:

TABLE 13

A COMPARISON BETWEEN R-VALUES UNDER LINEAR AND CLASSIFICATION MODELS

Track Segment	Track Class	Vehicle Order	Vehicle Speed (mph)	Rail Type	GAGE R-Value Linear		GAGE R-Value classification		X-Level R-Value Linear		X-Level R-Value classification	
1	I	FRA First	5	Jointed	.921		.930		.897		.900	
2	I	TGC First	5	Jointed	(.943)*				(.945)			
3	II	FRA First	10	Jointed								
4	II	TGC First	10	Jointed	.861		.869		.875		.876	
5	II	FRA First	20	Jointed	(.743)		(.738)		(.962)		(.967)	
6	II	TGC First	20	Jointed		.814 (.830)		.836 (.831)		.886 (.998)		.886 (.989)
7	II	FRA First	20	Welded	.797		.818		.919		.926	
8	II	TGC First	20	Welded	(.836)		(.837)		(.986)		(.986)	
9	III	FRA First	10	Jointed								
10	III	TGC First	10	Jointed	.876		.910		.931		.935	
11	III	FRA First	20	Jointed	(.846)		(.891)		(.991)		(.992)	
12	III	TGC First	20	Jointed		.910 (.894)		.931 (.917)		.90 (.996)		.914 (.997)
13	III	FRA First	10	Welded								
14	III	TGC First	10	Welded			.978		.814		.923	
15	III	FRA First	20	Welded	.977 (.962)		(.966)		(.997)		(.999)	
16	III	TGC First	20	Welded								

*( ): the value in the parentheses is the R-Value for the curve section.
There are no observations for track segments #2, 4, 6, 10 in the curve section.

TABLE 14

PREDICTED GAGE VALUES FROM A SEED TGC

MEASUREMENT BY CLASS, TRACK TYPE, RAIL TYPE AND SPEED*

Seed TGC Measurement	Class I Tangent Jointed	Class II Tangent Jointed (10mph)	Class II Tangent Jointed (20mph)	Class III Tangent Jointed	Class II Tangent Welded	Class III Tangent Welded	Class I Curved Jointed	Class II Curved Jointed & Welded	Class III Curved Jointed (10mph)	Class III Curved Jointed (20mph)	Class III Curved Welded
55.80	55.85	55.99	55.97	55.96	56.16	55.83	55.83	56.18	56.14	56.12	55.88
56.00	56.04	56.16	56.14	56.13	56.30	56.03	56.02	56.31	56.31	56.28	56.07
56.20	56.23	56.34	56.32	56.30	56.44	56.22	56.21	56.45	56.48	56.45	56.26
56.40	56.42	56.51	56.49	56.47	56.59	56.42	56.40	56.58	56.64	56.62	56.45
56.60	56.61	56.68	56.66	56.64	56.73	56.62	56.58	56.71	56.81	56.78	56.64
56.80	56.80	56.86	56.84	56.81	56.87	56.81	56.77	56.84	56.98	56.95	56.83
57.00	56.99	57.03	57.01	56.98	57.01	57.01	56.96	56.98	57.14	57.12	57.02
57.20	57.18	57.20	57.18	57.15	57.15	57.21	57.15	57.11	57.31	57.28	57.20
57.40	57.37	57.37	57.35	57.32	57.29	57.40	57,34	57.24	57.48	57.45	57.39
57.60	57.56	57.55	57.53	57.49	57.43	57.60	57.53	57.37	57.64	57.62	57.58
57.80	57.75	57.72	57.70	57.66	57.57	57.80	57.71	57.51	57.81	57.78	57.77

*Unless noted the prediction will not change for other speeds assuming all other conditions remain constant.

GAGE VALUE IN INCHES

TABLE 15

PREDICTED CROSS LEVEL VALUES FROM A SEED TGC MEASUREMENT BY CLASS, TRACK TYPE, RAIL TYPE AND SPEED*

Seed TGC Measurement	Class I Tangent Jointed	Class II Tangent Jointed	Class III Tangent Jointed (10mph)	Class III Tangent Jointed (20mph)	Class II Tangent Welded	Class III Tangent Welded (10mph)	Class III Tangent Welded (20mph)	Class I Curved Jointed	Class II Curved Jointed (10mph)	Class II Curved Jointed (20mph)	Class III Curved Jointed (10mph)	Class III Curved Jointed (20mph)	Class II Curved Welded	Class III Curved Welded (10mph)	Class III Curved Welded (20mph)	Seed TGC Measurement
-3.50	-3.72	-3.67	-3.69	-3.75	-3.51	-3.72	-3.42	-3.49	-3.72	-3.87	-3.96	-4.00	-3.74	-3.77	-3.44	-3.50
-3.00	-3.21	-3.14	-3.14	-3.20	-3.01	-3.21	-2.91	-2.98	-3.15	-3.31	-3.38	-3.42	-3.20	-3.25	-2.92	-3.00
-2.50	-2.69	-2.61	-2.60	-2.66	-2.50	-2.70	-2.40	-2.46	-2.58	-2.74	-2.79	-2.84	-2.67	-2.74	-2.41	2.50
-2.00	-2.18	-2.09	-2.05	-2.11	-1.99	-2.19	-1.89	-1.95	-2.01	-2.17	-2.21	-2.25	-2.14	-2.22	-1.89	2.00
-1.50	-1.67	-1.56	-1.50	-1.56	-1.49	-1.68	-1.38	-1.44	-1.45	-1.60	-1.63	-1.67	-1.61	-1.71	-1.36	1.50
-1.00	-1.16	-1.03	-0.96	-1.02	-0.98	-1.17	-0.87	-0.92	-0.88	-1.03	-1.05	-1.09	-1.07	-1.20	-0.87	1.00
-0.50	-0.64	-0.50	-0.41	-0.47	-0.48	-0.66	-0.36	-0.41	-0.31	-0.47	-0.46	-0.51	-0.54	-0.68	-0.35	0.50
0.00	-0.13	0.03	0.13	0.07	0.03	-0.15	0.16	0.11	0.26	0.10	0.12	0.08	-0.01	-0.17	0.16	0.00
0.50	0.38	0.56	0.68	0.62	0.54	0.36	0.67	0.62	0.83	0.67	0.70	0.66	0.52	0.34	0.67	0.50
1.00	0.90	1.08	1.22	1.16	1.04	0.88	1.18	1.13	1.39	1.24	1.29	1.24	1.06	0.86	1.19	1.00
1.50	1.41	1.61	1.77	1.71	1.55	1.39	1.69	1.65	1.96	1.80	1.87	1.83	1.59	1.37	1.70	1.50
2.00	1.66	2.14	2.31	2.25	2.05	1.90	2.20	2.16	2.53	2.37	2.45	2.41	2.12	1.88	2.21	2.00
2.50	2.44	2.67	2.86	2.80	2.56	2.41	2.71	2.67	3.10	2.94	3.04	2.99	2.66	2.40	2.73	2.50
3.00	2.95	3.20	3.41	3.35	3.07	2.92	3.22	3.19	3.66	3.51	3.62	3.58	3.19	2.91	3.24	3.00
3.50	3.46	3.72	3.95	3.89	3.57	3.43	3.73	3.70	4.23	4.07	4.20	4.16	3.72	3.43	3.76	3.50

*Unless noted the prediction will not change for other speeds assuming all other conditions remain constant.

Negative X-level denotes that the left rail is lower than the right rail.

CROSS LEVEL VALUE IN INCHES

1) TGC measurements of wide gage are not changed to any great degree by the model if one assumes a tolerance of ± 0.10 inch.

   * The two types of survey vehicles under study record essentially the same values when measuring wide gage locations.

2) TGC measurements of tight gage are always reduced by the model.

   * The lighter Iowa TGC records a tighter gage reading than the FRA vehicle when measuring gage locations set below 56.5 inches.

3) TGC measurement of cross level deviations are increased by modeling.

   * The lighter Iowa TGC's measurement of cross level needs to be increased to match readings from the heavy vehicle.

4) TGC measurements of cross levels on welded track have less need of an adjustment model than those on jointed track. The difference in cross level readings between the two cars is not as great when surveying welded track.

Tables 16 and 17 list the 26 models that should be used to adjust the measurements of the Iowa TGC to those taken by the FRA test car. The use of such models implies that the FRA test car is accurate -- an assumption which may or may not be true. What is important is that a light weight vehicle can be equated to a heavy vehicle.

TABLE 16

MODEL ESTIMATIONS FOR EACH CLASS (Tangent Track)

CLASS	TYPE	Y	MODEL	R-VALUE	DOES PARAMETER EFFECT MODEL?			
					GAGET	XLT	ORDER	SPEED
I	J	GAGEF	@GAGEF=2.725 + 0.952 (GAGET)	.930	Yes	No	Yes	
		XLF	@XLF= -.1296 + 1.0259 (XLT)	.900	No	Yes	Yes	
II	J	GAGEF	@GAGEF= 7.78 (S=10) 7.70 (S=20) + 0.864 (GAGET)	.869	Yes	No	Yes	Yes
		XLF	@XLF=.027 + 1.0564 (XLT)	.876	No	Yes	Yes	NO
	W	GAGEF	@GAGEF=16.88 + 0.704 (GAGET)	.818	Yes	No	Yes	
		XLF	@XLF=.03 + 1.012 (XLT)	.926	No	Yes	Yes	
III	J	GAGEF	@GAGEF=8.40 + 0.8523 (GAGET)	.910	Yes	No	Yes	Yes
		XLF	@XLF= 0.132 (S=10) 0.072 (S=20) + 1.091 (XLT)	.935	No	Yes	Yes	Yes
	W	GAGEF	@GAGEF=1.001 + 0.9826 (GAGET)	.978	Yes	No	Yes	Yes
		XLF	@XLF= -0.147 (S=10) 0.155 (S=20) + 1.022 (XLT)	.923	No	Yes	Yes	Yes

Where, J=Jointed W=Welded
XLF, XLT=the cross level measurement of FRA car and TGC car, respectively
GAGEF, GAGET=the gauge measurement of FRA car and TGC car, respectively
@GAGEF, @XLF=the predicted value of gauge and cross level of the FRA cars
S=speed ORDER = which car surveyed the track first, (Note: When developing the model it was necessary to assume that the TGC ran before the FRA vehicle).

TABLE 17

MODEL ESTIMATIONS FOR EACH CLASS (Curved Track)

CLASS	TYPE	Y	MODEL	R-VALUE	DOES PARAMETER EFFECT MODEL? GAGET/XLT	ORDER	SPEED
I	J	GAGEF	@GAGEF=3.358 + 0.9404 (GAGET)	.943	Yes		
		XLF	@XLF=.105 + 1.0273 (XLT)	.945	Yes		
II	J&W	GAGEF	@GAGEF=19.185 +0.663 (GAGET)	.831	Yes	Yes	NO
	J	XLF	@XLF=.258 (S=10) / .101 (S=20) + 1.1354 (XLT)	.967	Yes		Yes
	W	XLF	@XLF= -.0083 + 1.0654 (XLT)	.984	Yes	Yes	
III	J	GAGEF	@GAGEF=9.663 (S=10) / 9.636 (S=20) + 0.833 (GAGET)	.891	Yes	Yes	Yes
		XLF	@XLF=.12 (S=10) / .078 (S=20) + 1.166 (XLT)	.992	Yes	Yes	Yes
	W	GAGEF	@GAGEF=3.248 + 0.9433 (GAGET)	.966	Yes	Yes	Yes
		XLF	@XLF=-.017 (S=10) / 0.16 (S=20) + 1.0272 (XLT)	.999	Yes	Yes	Yes

Where, J = Jointed: W - Welded
GAGEF, GAGET = the gauge measurement of FRA car and TGC car, respectively
XLF, SLT = the cross level measurement of FRA car and TGC car, respectively
@GAGEF, @ XLF = the predicted value of gauge and cross level of the FRA cars
S - speed, ORDER = which car surveyed the track first, (Note: When developing the model it was necessary to assume that the TGC ran before the FRA vehicle).

PART IV

SUPPORTING STATISTICAL CONSIDERATIONS

SAMPLE SIZE

As noted earlier, the models developed for this report are based on two hundred observations taken at random from each test site. In order to show that the sample actually represents the population, three random replications of two hundred observations were generated from the grand populations of each test site.

Each individual replication was then tested against the sample TGC data used to develop the model. The variances of the replications and sample can be tested using the F-statistic. If the higher value variance (either of the sample of of the replication) divided by the lower value variance is less than 1.40, one can assume that the replicates have variances which are the same as that of the standard sample. The means and standard deviations of the modeling sample and three replications are listed in Tables 18 and 19.

The means of the replicates were also tested against the modeling sample. Using a simple t-test, any value less than 1.645 implies that the two means are the same. Table 20 compares the means of the modeling sample and replicated data. Only about 5% of the t-tests had a value greater than 1.645 at the 95% confidence level.

The F-test values for comparing the homogeneity of variances between the modeling sample and the replicates also appear very promising. Ninety-eight percent of the replicates have variances which are the same as that of the standard sample, (see Table 21).

In only one case did any of the modeling samples have more than one replication not having the same mean. Based upon these tests the models presented earlier can be considered valid for the whole test population.

TABLE 18

TGC GAGE COMPARISON

TRACK CLASS	TEST SEGMENT		MEAN TGC GAGE				STANDARD DEVIATION TGC GAGE			
			Modeling Sample	Replicate 1	Replicate 2	Replicate 3	Standard Sample	Replicate 1	Replicate 2	Replicate 3
I	1	Curved	56.55	56.56	56.56	56.55	.158	.163	.167	.171
		Tangent	56.52	56.52	56.53	56.55	.156	.143	.138	.144
	2	Curved	----	----	----	----	----	----	----	----
		Tangent	56.63	56.65	56.65	56.63	.142	.161	.160	.161
II	3	Curved	56.60	56.60	56.62	56.61	.155	.157	.157	.158
		Tangent	56.47	56.46	56.46	56.45	.145	.143	.145	.138
	4	Curved	----	----	----	----	----	----	----	----
		Tangent	56.39	56.39	56.38	56.38	.155	.141	.164	.145
	5	Curved	56.66	56.66	56.65	65.64	.155	.152	.148	.162
		Tangent	56.50	56.51	56.51	56.50	.160	.138	.144	.131
	6	Curved	----	----	----	----	----	----	----	----
		Tangent	56.40	56.41	56.41	56.40	.145	.155	.151	.153
	7	Curved	56.28	56.27	56.27	56.28	.224	.228	.229	.223
		Tangent	56.28	56.28	56.30	56.27	.202	.194	.201	.189
	8	Curved	56.59	56.58	56.59	56.59	.174	.177	.190	.182
		Tangent	56.52	56.52	56.48	56.52	.185	.190	.181	.195
III	9	Curved	56.66	56.62	56.64	56.64	.194	.200	.203	.194
		Tangent	56.44	56.44	56.43	56.46	.142	.151	.148	.160
	10	Curved	----	----	----	----	----	----	----	----
		Tangent	56.46	56.46	56.46	56.46	.147	.165	.157	.173
	11	Curved	56.63	56.62	56.63	56.63	.155	.160	.160	.149
		Tangent	56.50	56.49	56.48	56.49	.172	.164	.186	.170
	12	Curved	56.82	56.84	56.84	56.83	.172	.169	.164	.166
		Tangent	56.74	56.76	56.76	56.73	.141	.135	.171	.159
	13	Curved	56.82	56.82	56.81	56.82	.142	.146	.144	.134
		Tangent	56.80	56.81	56.81	56.80	.113	.120	.118	.115
	14	Curved	56.95	56.93	56.92	56.93	.160	.163	.157	.160
		Tangent	**56.82**	56.82	56.80	56.82	.120	.119	.108	.113
	15	Curved	56.74	56.75	56.76	56.72	.147	.145	.149	.129
		Tangent	56.73	56.72	56.72	56.72	.109	.106	.110	.121
	16	Curved	56.73	56.73	56.72	56.73	.108	.104	.108	.113
		Tangent	56.66	56.65	56.67	56.65	.192	.185	.204	.192

TABLE 19

TGC X-LEVEL COMPARISON

TRACK CLASS	TEST SEGMENT		MEAN TGC X-LEVEL: Modeling Sample	MEAN TGC X-LEVEL: Replicate 1	MEAN TGC X-LEVEL: Replicate 2	MEAN TGC X-LEVEL: Replicate 3	STANDARD DEVIATION TGC X-LEVEL: Standard Sample	STANDARD DEVIATION TGC X-LEVEL: Replicate 1	STANDARD DEVIATION TGC X-LEVEL: Replicate 2	STANDARD DEVIATION TGC X-LEVEL: Replicate 3
I	1	Curved	1.66	1.51	1.57	1.68	1.939	1.915	1.833	1.97
		Tangent	-.25	-.31	-.18	-.03	1.360	1.392	1.448	1.496
	2	Curved	----	----	----	----	----	----	----	----
		Tangent	.50	.32	.31	.41	1.064	.976	1.000	1.132
II	3	Curved	-3.06	-3.02	-2.98	-3.07	.663	.716	.760	.642
		Tangent	-.16	-.22	-.23	-.22	.357	.369	.363	.341
	4	Curved	----	----	----	----	----	----	----	----
		Tangent	-.23	-.17	-.17	-.18	.425	.389	.418	.413
	5	Curved	-2.92	-2.93	-2.96	-2.92	.686	.665	.628	.684
		Tangent	-.15	-.21	-.19	-.17	.367	.375	.375	.384
	6	Curved	----	----	----	----	----	----	----	----
		Tangent	-.20	-.23	-.20	-.25	.495	.507	.525	.488
	7	Curved	-.41	-.45	-.43	-.37	.460	.454	.458	.446
		Tangent	-.24	-.18	-.25	-.21	.354	.372	.380	.407
	8	Curved	-1.46	-1.39	-1.39	-1.33	.874	.876	.888	.890
		Tangent	.13	.18	.09	.10	.482	.452	.463	.432
III	9	Curved	-1.77	-1.85	-1.86	-1.81	.637	.611	.588	.649
		Tangent	-.02	.02	-.00	-.03	.540	.565	.509	.549
	10	Curved	----	----	----	----	----	----	----	----
		Tangent	-.24	-.27	-.31	-.27	.394	.441	.418	.418
	11	Curved	-1.36	-1.34	-1.39	-1.33	.658	.654	.625	.660
		Tangent	-.39	-.18	-.32	-.28	.712	.578	.608	.641
	12	Curved	.38	.21	.52	.24	1.757	1.776	1.698	1.754
		Tangent	-.17	-.13	-.16	-.12	.398	.419	.444	.340
	13	Curved	.84	.47	.33	.66	3.789	3.737	3.798	3.826
		Tangent	.08	.11	.10	.11	.392	.370	.365	.380
	14	Curved	2.94	2.90	2.91	3.08	1.472	1.515	1.487	1.376
		Tangent	-.04	-.00	-.02	-.04	.235	.222	.265	.273
	15	Curved	-.77	-1.07	-.89	-.59	2.717	2.827	2.875	2.692
		Tangent	-.18	-.13	-.14	-.13	.260	.236	.232	.249
	16	Curved	-.72	-.95	-.86	-.61	3.074	2.949	2.925	2.983
		Tangent	-.19	-.20	-.19	-.19	.322	.340	.332	.340

TABLE 20

t-TEST VALUE OF THE STANDARD SAMPLE
WITH THE OTHER THREE REPLICATES

TRACK CLASS	TEST SEGMENT		TGC GAGE			TGC X-LEVEL		
			Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
I	1	Curved	0	0	0	0	0	0
		Tangent	0	0	X	0	0	0
	2	Curved						
		Tangent	0	0	0	0	0	0
II	3	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	X	0
	4	Curved						
		Tangent	0	0	0	0	0	0
	5	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0
	6	Curved						
		Tangent	0	0	0	0	0	0
	7	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0
	8	Curved	0	0	0	0	0	0
		Tangent	0	X	0	0	0	0
III	9	Curved	X	0	0	0	0	0
		Tangent	0	0	0	0	0	0
	10	Curved						
		Tangent	0	0	0	0	0	0
	11	Curved	0	0	0	0	0	0
		Tangent	0	0	0	X	0	0
	12	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0
	13	Curved						
		Tangent	0	0	0	0	0	0
	14	Curved	0	X	0	0	0	0
		Tangent	0	X	0	0	0	0
	15	Curved	0	0	0	0	0	0
		Tangent	0	0	0	X	0	X
	16	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0

0 = *t*-value less than 1.645

X = *t*-value greater than 1.645

TABLE 21

F-TEST VALUE OF THE STANDARD SAMPLE WITH THE OTHER THREE REPLICATES

TRACK CLASS	TEST SEGMENT		TGC GAGE			TGC X-LEVEL		
			Replicate 1	Replicate 2	Replicate 3	Replicate 1	Replicate 2	Replicate 3
I	1	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0
	2	Curved Tangent	0	0	0	0	0	0
II	3	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0
	4	Curved Tangent	0	0	0	0	0	0
	5	Curved	0	0	0	0	0	0
		Tangent	0	0	X	0	0	0
	6	Curved Tangent	0	0	0	0	0	0
	7	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0
	8	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0
III	9	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0
	10	Curved Tangent	0	0	0	0	0	0
	11	Curved	0	0	0	0	0	0
		Tangent	0	0	0	X	0	0
	12	Curved	0	0	0	0	0	0
		Tangent	0	X	0	0	0	0
	13	Curved Tangent	0	0	0	0	0	0
	14	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0
	15	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0
	16	Curved	0	0	0	0	0	0
		Tangent	0	0	0	0	0	0

DEVIATION MODELING

It appeared important to look for a different model for the paired measurements near the lower and upper ranges of the sample. Initially it was felt that a linear regression model would not place the importance to sample pairs in the deviation ranges and that separate models would be required.

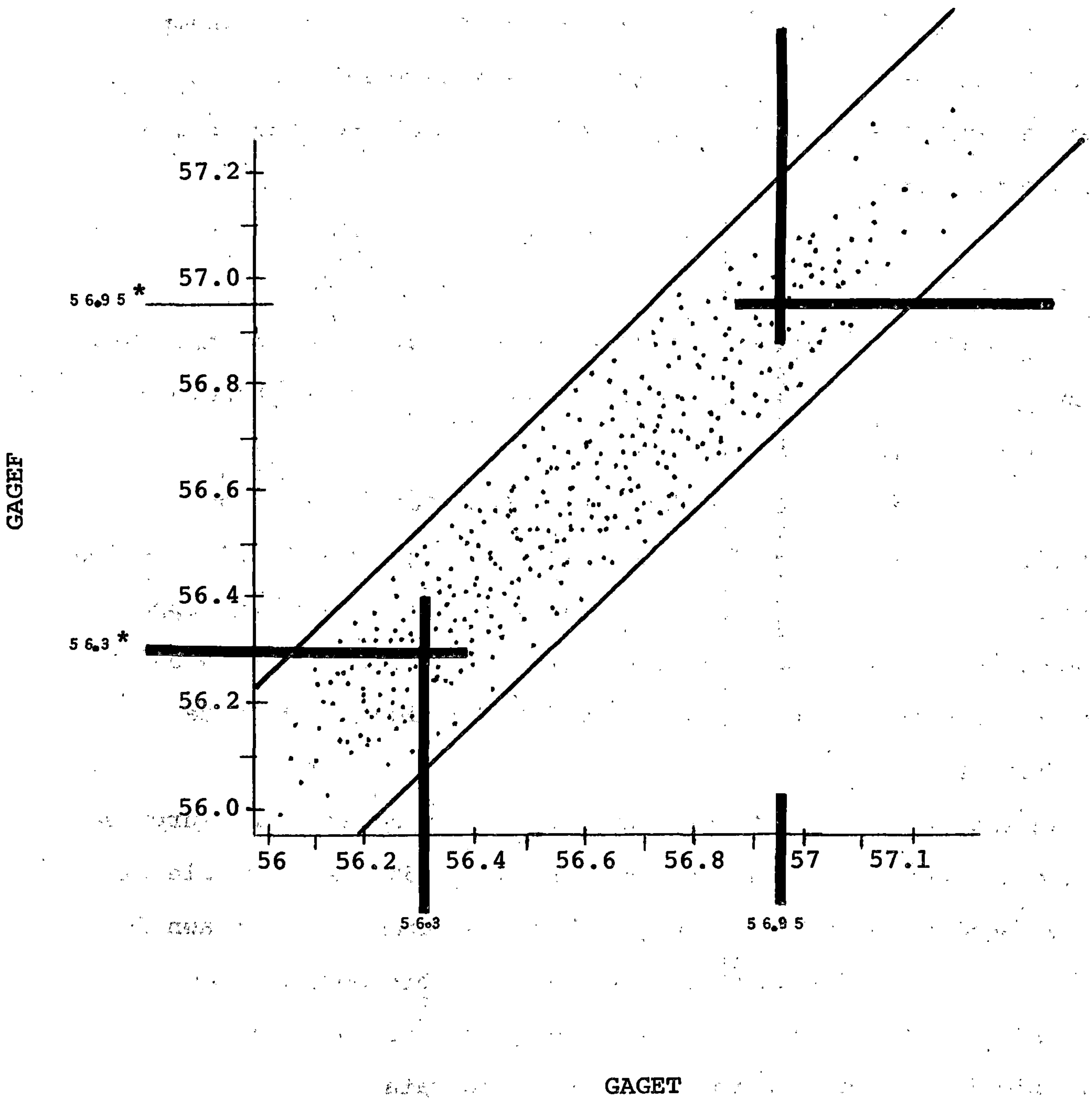
A close examination at the data plot of gage by the TGC and FRA measurements for a test run explains the modeling problem. All the data points lie along a wide linear band, with most of the data concentrated along the center line of the band. These phenomena are shown in Figure 7.

When the details of the data plot, (Figures 8 and 9) are studied, one observes that the data are no longer evenly distributed along the center line. Most of the data are crowded at the upper right corner or lower left corner of the diagrams, depending on whether the diagram is of low-valued data or high-valued data respectively.

Knowing the shape of the data plotted, it comes as no surprise to have a correlation coefficient less than 0.50 when a sample of the two hundred lowest or highest paired measurements is drawn for analysis. It was deemed unwise to try to create models from such information. The models previously based on all data is viable for the entire range of collected data.

FIGURE 7

GENERAL PLOT OF GAGET VS. GAGEF



* Two hundred lowest and highest paired measurements of GAGET are below 56.3 inches and above 56.95 inches repsectively for the Class III track surveyed.

FIGURE 8

THE PLOT OF LOWER EXTREME MEASUREMENTS

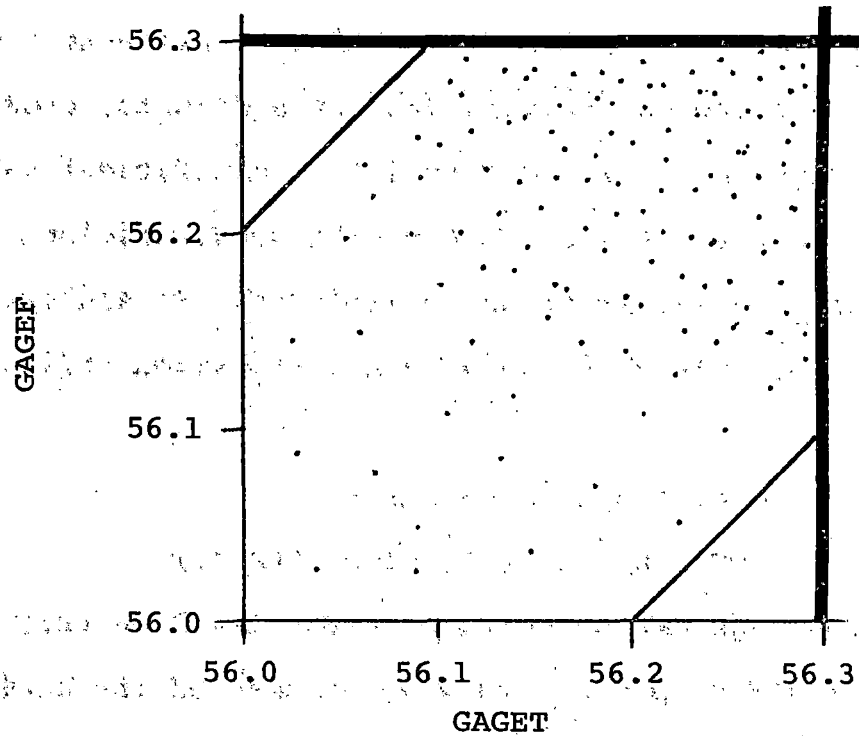
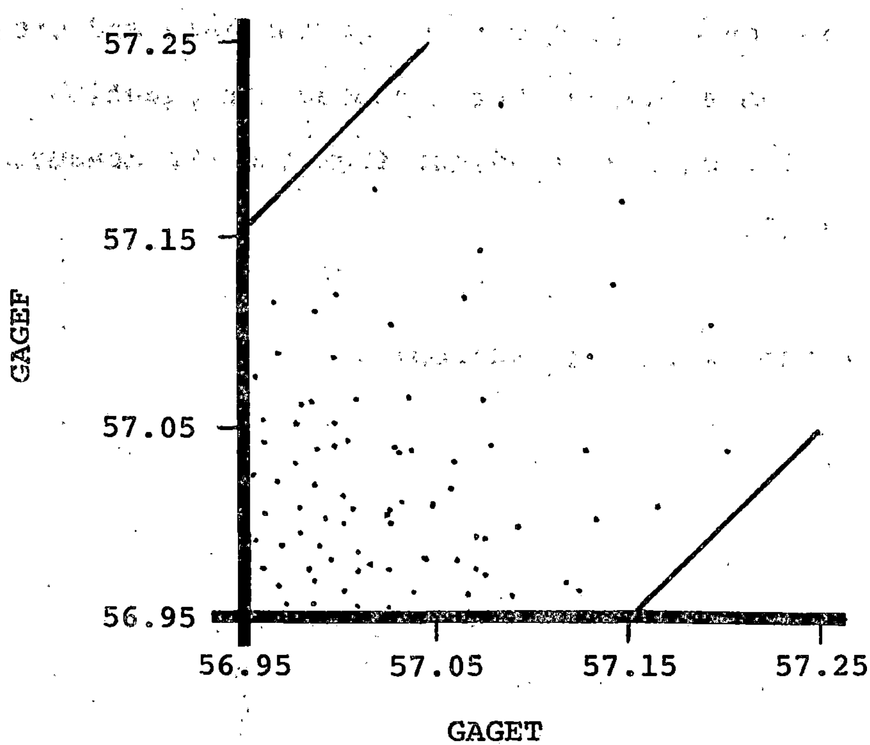


FIGURE 9

THE PLOT OF UPPER EXTREME VALUES



PROFILE DATA

The relationship, if any, between surface and cross level can be preliminarily determined by means of graphical representation* (i.e. plots of gage measurements vs. surface measurements, cross level data vs. the surface data) and correlation coefficient values (R-values) between these variables. A correlation coefficient matrix with different classes is shown in Table 22 . Regardless of track class, the only variables showing a correlation indicative of a relationship are:

1) gage by TGC and gage by FRA car; and

2) cross level by TGC and cross level by FRA car.

The plots of the gage measurements of cross level measurements against the measurements of profile show no pattern of any kind. As the graphs indicate, the points show a great deal of scatter in each instance.

No regression equation can be used to predict the FRA profile readings from a deviation of the TGC readings for gage and cross level. There is also no evidence that a regression equation could be used to predict surface readings from the FRA measurements for gage or cross level.

* FRA data on alignment were not available.

TABLE 22

CORRELATION COEFFICIENT MATRIX

Class I

	gagef	xlt	xlf	rpf	lpf
gaget	.92	.07	.03	.10	.07
gagef		.09	.04	.09	.03
xlt			.95	.17	-.00
xlf				.14	.02
rpf					.44

Class II

	gagef	xlt	xlf	rpf	lpf
gaget	.84	-.41	-.40	.04	.01
gagef		-.43	-.43	.07	.07
xlt			.99	.04	-.13
xlf				.04	-.12
rpf					.02

Class III

	gagef	xlt	xlf	rpf	lpf
gaget	.91	.17	.09	-.01	.04
gagef		.15	.06	.01	.05
xlt			.87	.05	-.06
xlf				.05	.01
rpf					-.22

gaget = gage measured by the TGC
gagef = gage measured by the FRA vehicle
xlt = cross level measured by the TGC
xlf = cross level measured by the FRA vehicle
rpf = right profile measured by the FRA vehicle
lpf = left profile measured by the FRA vehicle

PART V

APPLICATION OF MODELS TO DIFFERENT VEHICLES

Models presented in this report are valid only for the Iowa TGC. The trends established by these models and the magnitude of the corrections can be used to establish simple correction models for other high-rail vehicles having different weight and different measurement subsystems.

Models to correct gage measurements revealed that: 1) High-rail vehicle measurements for wide gage were not changed if one assumes a tolerance of $\pm$ 0.10 inch; and 2) Tight gage measurements taken by a high-rail vehicle are made wider by the model. The preceding observations can be used to establish two general models for all high-rail vehicles.

1) Any measurement of tight gage by a high-rail vehicle should be assumed to be a valid deviation; and

2) A measurement of wide gage by a high-rail vehicle should be considered a valid deviation for any measurement greater than the FRA standard minus 0.10 inch.

Models to correct cross level measurements by high-rail vehicles are more complex than those for gage. The three general models listed below could be used with any high-rail survey vehicle.

1) No adjustment of cross level measurements taken by a high-rail vehicle is required on Class II or III track;

2) The FRA standard minus 0.10 inch should be the minimum standard for cross levels on Class I jointed track;

3) No adjustment of cross level measurements taken by a high-rail vehicle are required on Class I welded track.

CHAPTER IV

TRACK SUFFICIENCY RATING SYSTEM AND REHABILITATION ESTIMATING METHODOLOGY

PART I

INTRODUCTION TO SUFFICIENCY RATINGS

Facility rating systems have been used for many years by highway administrators. Such systems provide comparative information concerning the adequacy of the physical components of a specific transportation mode. The ratings have been given various names such as needs ratings, sufficiency ratings, deficiency ratings, adequacy ratings and others.

One major use of such ratings is to provide information about the adequacy of a transportation system and its future funding requirements. A relatively simple, easily understood facility rating system serves well as a communication tool for providing information to legislatures. Another major use of facility ratings is for establishing priorities for the use of available funds. A rating system is particularly useful here because of its uniform, objective application.

The Iowa Department of Transportation considers facility ratings a prerequisite for meaningful transportation planning. It is necessary for administrators to have reliable information about the service characteristics and condition of existing facilities if one is to plan properly for the future. The Department believes that a facility rating is necessary for railroad planning. Such a rating should be useful to railroad companies for planning as well as other state agencies. This chapter contains the basic conceptual design of a "Sufficiency Rating System" and identifies how a rating system would tie into other aspects of rail planning.

SECTION I

HOW A RATING SYSTEM WOULD WORK

OUTPUT

The principle output from a sufficiency rating system is a numerical rating, usually based on a 100 point maximum. For highways, each segment of roadway is rated separately. The segments can range from a few hundredths to many miles in length. In rating airports, an overall rating is computed for each. Thus, the final numerical rating for each facility or segment puts it in proper perspective relative to all others rated. A listing of the ratings provides an excellent perspective of a mode in total from which administrators can develop effective long-range plans and improvement programs.

As mentioned previously, the output from the rating system is a numerical rating usually based on a 100 point maximum. Thus, a rating of 50 indicates 50% sufficient or 50% of fully adequate. In order to arrive at a rating, two basic questions must be answered. They are:

1. What are the features of a fully adequate facility?
2. What is the condition of an existing facility when compared to one considered fully adequate?

Another way to state the same questions is:

1. To what design standard should a given facility be constructed?, and
2. How well does the existing facility measure up to design standards?

The desired service levels referred to in Chapter II as a replacement for FRA safety standards would be equivalent to these design standards.

The three key components of a rating system as identified in the above questions are:

1. Design standards
2. Inventory of existing facilities
3. A rating procedure for comparing existing conditions to adequate design standards.

POINT ASSIGNMENT PLAN

The method proposed by Iowa for deriving a sufficiency rating involves the identification of pertinent rating features in three categories:

1. Structural Adequacy
2. Safety
3. Service

Once the individual rating features within each category are identified, each is assigned a weight or number of points such that the total point assignment to all three categories equals 100. The rating items tentatively selected for the proposed Iowa Railroad Sufficiency Rating System are shown along with their estimated weights in Table 23. The rating items under Structural Adequacy measure the physical condition of the facility. Items under Safety measure the geometric and other considerations which affect safety. Items under Service measure the capability of the facility to provide a reasonable level of service to transportation users.

TABLE 23

PROPOSED IOWA RAILROAD SUFFICIENCY RATING ITEMS

STRUCTURAL ADEQUACY		MAXIMUM POINTS
Track:		
Surface Defects	4	
Gage	8	
Ties	4	
Joints	4	
	20	
Ballast:		
Width	4	
Condition	6	
Track Cross Level	8	
	18	
Roadbed Drainage	12	
Subtotal		50
SAFETY		
Derailments	15	
Crossings	5	
Control	5	
Switches	5	
Subtotal		30
SERVICE		
Track Weight Capacity	10	
Speed Efficiency	10	
Subtotal		20
TOTAL POINTS		100

In the rating process, any rating item that meets or exceeds the design standard against which it is measured receives the maximum number of points. If a rating item on the existing facility is somewhere between fully adequate and fully inadequate, a lesser number of points will be assigned, with zero points indicating total inadequacy. When ratings are compiled systemwide, the facilities needing improvement most, from a sufficiency rating standpoint, will have the lowest ratings. This stratification not only identifies facilities most in need of improvement, but prioritizes then as well.

SECTION II

PROPOSED SUFFICIENCY SYSTEM

MAJOR EVENTS

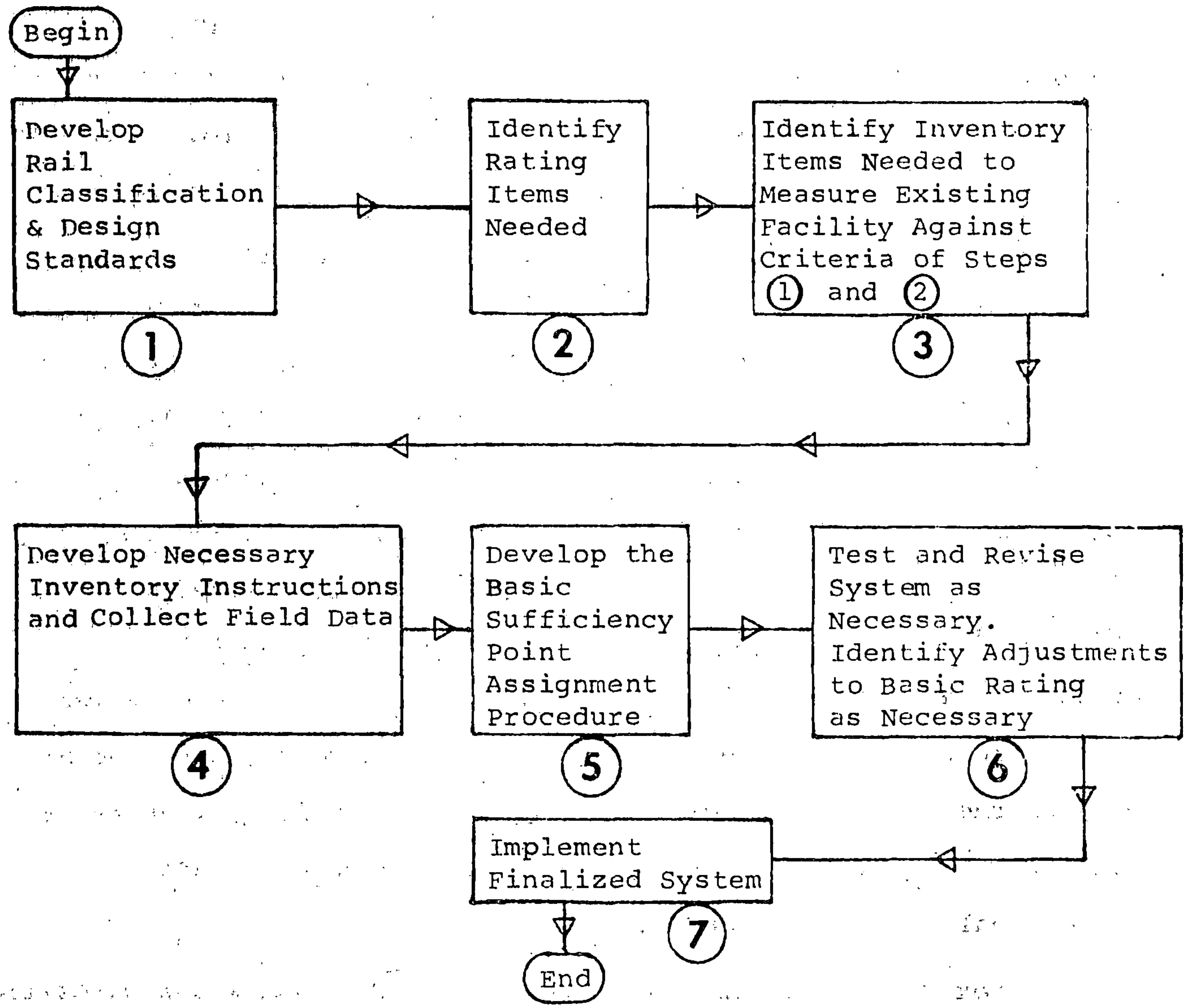
The proposed sufficiency rating system presented herein follows a logical procedure for development. Figure 10 shows, by major events, the procedural development steps that must take place in the establishment of a finalized rating system.

It should be noted at this point, however, that the proposed sufficiency rating system described does not include railroad bridges. A bridge or structure sufficiency rating system would have to be developed separately so that the importance of structures is not lost by absorption into the overall track rating system.

In the development of an actual rating system, a certain amount of overlap between activities would occur. A brief discussion on the major events and some explanation on foreseeable overlaps is included on the following pages.

FIGURE 10

SUFFICIENCY SYSTEM DEVELOPMENT



STEP 1: DEVELOP RAILROAD CLASSIFICATIONS AND DESIGN STANDARDS

The first and possibly most important step in developing a rating system, is the establishment of proper railroad classifications and design standards for sufficiency rating purposes. Because of the importance of this step, comprehensive discussion is warranted. It must be kept in mind at this point that the following analysis pertains particularly to Iowa, however, it should initiate a series of similar considerations in the minds of administrators in other states as well.

A Federal report entitled "Final Standards, Classification, and Designation of Lines of Class I Railroads in the United States" dated January 19, 1977, was analyzed to determine if it provided the necessary National guidelines for functionally classifying Iowa's mainline and branchline routes for sufficiency rating purposes. The four classifications derived in this study were "A" or "B" Mainlines and "A" or "B" Branchlines. The primary criterion used to determine the classification of a route segment in this report was use density (million gross tons annual per mile). Only in the "A" Mainline designation were two additional criteria utilized: 1) major transportation zone connectivity; and 2) national defense essentially.

Approximately 900 miles of Iowa's railroad system was classified as "A" Mainlines, leaving over 6000 miles classified by only the density criterion. This resulted in a system which did not adequately identify inter- or intra-state continuity nor the type of service each line is, or should be. The study also failed to specify any design requirements such as rail weights, signal controls, or design speeds which would be required as a minimum for each state to evaluate the relative condition of any interstate routes.

Iowa currently has a Rail System Plan which categorizes all rail lines in Iowa as either mainline or branchline. The resultant 3200 plus miles of mainline and 3800 plus miles of branchline were established through meetings with Citizen and Rail Advisory Committees. In addition, the Plan prioritizes all branchline segments based on a Benefit/Cost analysis. Thus, the objective of this plan was to determine where the state could best utilize branchline assistance monies for track upgrading and realize the greatest returns. Again the elements needed to rate railroads on a statewide system basis were not provided. All trackage was compared to FRA Class 2 standards. The different levels of service and length of hauls were not considered. In addition, no provision was made for overhead traffic as only tonnage originating or terminating in Iowa was considered.

Therefore, the Iowa Department of Transportation is now proceeding further in its rail planning and has developed a preliminary proposal for a Functional Classification of railroad routes that can be used in a sufficiency rating system. The preliminary functional classifications developed are as follows:

<u>National System</u> - Routes designated by the railroads and other agencies as their mainline system which are primarily important for interstate through movements of passengers or freight, and for national defense.

<u>State System</u> - Mainline and branchline routes important to the state or a large section of the state and large population centers for long distance intra-state or short distance interstate movements.

Area System - Mainline and branchline routes primarily for commodity movements within or between specified areas of the state and for providing regional connections to the National or State system.

Local System - Branchline routes that provide short distance service connecting small communities to the National, State or area system.

A comparison of Iowa's preliminary system and the FRA Class I study is shown in Table 24. As indicated, the various FRA "A" and "B" designations for Mainlines and branchline, are scattered throughout the four functional classes developed by Iowa. This shows how a classification system developed on limited criteria (use density) will not suffice as the basis for a comprehensive sufficiency rating system.

TABLE 24

CLASSIFICATION SYSTEMS COMPARISON

Proposed Iowa Functional Classification		FRA Classification	
National	2154 mi.	"A" Mainline	899 mi.
		"B" Mainline	1255 mi.
			2154
State	1587 mi.	"B" Mainline	805 mi.
		"A" Branchline	698 mi.
		"B" Branchline	84 mi.
			1587
Area	1428 mi.	"B" Mainline	169 mi.
		"A" Branchline	647 mi.
		"B" Branchline	612 mi.
			1428
Local	1860 mi.	"B" Mainline	14 mi.
		"A" Branchline	304 mi.
		"B" Branchline	1542 mi.
			1860

In order to obtain a further refinement required to adequately determine standards and rate railroad segments, each line must be placed into a design class. The design class is primarily dependent on the railroad's assigned functional class with further stratification based on usage density and a priority categorization based on a benefit/cost (B/C) analysis, (possibly other factors could be used). This facilitiates the differentiation of lines in the same functional class based on existing physical and operational conditions. For instance, a line with a high density and B/C ratio will receive a lower rating than a similar line with light density and a low B/C ratio. The density and B/C ratio would then be updated on an annual basis, as well as any changes that might affect the functional classification.

The preliminary proposal for design standards applicable for each design class are shown in Table 25.

TABLE 25

PRELIMINARY RAILROAD DESIGN STANDARDS

Functional Class	National		State		Area			Local		
FRA Track Class	4	4	4	3	3	2	1	2	2	1
Freight Density (MGT)	≥ 15	< 15	≥ 10	< 10	≥ 5	1 to 5	< 1	> 1	0.5 to 1	< 0.5
Design Class	1 *1	2	3	4	5	6	7	8	9	10
Speed-Passenger	80	80	80	60	60	30	15	30	30	15
Speed-Freight	60	60	60	40	40	25	10	25	25	10
Cross Ties:										
#Per 39 ft. Rail	24	24	24	24	24	24	21	24	21	21
Size (Ft.xIn.xIn.)	8.5-9-7	8.5-9-7	8.5-9-7	8.5-9-7	8.5-9-7	8-9-7	8-9-6	8-9-7	8-9-7	8-9-6
Spikes/Rail/Ties	4 *2	4 *2	4 *2	3 *2	3 *2	2 *2	2	2 *2	2	2
Joint Bars:										
Condition	Welded	FRA	FRA	FRA	FRA	FRA	FRA	FRA	FRA	FRA
Length(feet)		3	3	3	3	2	2	2	2	2
No. Bolts		6	6	6	6	4	4	4	4	4
Rail Weight	132/119 *3	119	119	115	115	112	80	90	80	70
Tie Plates:										
No. Per 39 Ft. Rail	48	48	48	48	48	48	42	48	42	42
Size (inches)	7 3/4x12/11 *4	7 3/4x11	7 3/4x11	7 3/4x11	7½x11	7½x10	6½x8 3/4	7½x10	6½x8 3/4	6½x8 3/4
Clearances:										
Horizontal (Ft.)	8	8	8	8	8	8	8	8	8	8
Vertical (Ft.)	22	22	22	22	22	22	22	22	22	22
Ballast:										
Type(top only)	Cr.Rock	Cr. Rock	Cr. Rock	Cr. Rock	Cr. Rock	Gravel	Gravel	Gravel	Gravel	Gravel
Top Surf. Width (Ft.)	9.5	9.5	9.5	9.5	9.5	9	9	9	9	9
Sub. Surf. Width (Ft.)	20'	20'	20'	16.5'	16.5'	15.5'	15.5'	15.5'	15.5'	
Min. Top/Sub Depth (In.)	8/8 *5	8/8	8/8	6/8	6/8	6/6	6/4	6/6	6/4	6/0
Roadbed Top Width (Ft.)	24 *6	24	24	20	20	18	17	18	17	16
Anchors Per 39' Rail	76	32	32	32	32	28	16	28	16	16
Note: Runoff rates; Profile & Cross level variances; Gage & Rail Condition by FRA Class										
Sidings:										
Track Weight	132/119	119	119	112	100	90	80	90	80	70
Ties/39 Ft.	24	24	24	24	21	21	21	21	21	21
Capacity (No. Cars)	88	88	88	78	68	58	48	58	48	—
Spacing (Miles)	40	60	60	60	100	150	150	150	300	—
Traffic Control	ATS/CTC	ACS/CTC	CTC	ABS	ABS	TO	Dark	TO	Dark	Dark

*1 Includes interstate passenger routes
*2 Add 1 spike/rail/tie for horizontal curves > 1°
*3 132# for single trackage, 119# for double
*4 12" for 132# rail and 11" for 119. Use double shoulder plates for all rail ≥ 112#
*5 Top ballast depth is from bottom of tie. Add tie depth - 2" for full depth of Top ballast at shoulders.
*6 Add 14 feet for double trackage.

STEP 2: IDENTIFY SUFFICIENCY RATING ITEMS

The proposed sufficiency rating items Iowa has tentatively selected were shown in Table 23. The items and their point weights were selected after research of available railroad literature, and consultation with knowledgeable people in the railroad field. The items selected are in no way to be construed as a complete list of all important railroad features.

For a realistic workable rating process, the number of features evaluated must be contained within practical limits. If this is not done, the individual ratings must be assigned such minimal point weightings that the significance of the final total segment rating is lost. Therefore, only items considered the most pertinent and best overall indicators in each major Category (Structural Adequacy, Safety, Service) were chosen.

There is, of course, a definite interrelationship between items included in one major Category and the remaining Categories. For example, the items included in the Structural Adequacy Category also influence the Safety and Service of the railroads. This interrelationship can be handled in the numerical rating procedure by a rating adjustment. For instance, a low rated Structural Adequacy element can trigger a proportionate downward adjustment in the overall rating for Safety.

The maximum points assigned to the items in Table 23 should be considered as very preliminary. It is impossible to make valid final point assignments in a Sufficiency Rating System until the entire detailed procedure is tested.

A more detailed discussion of each selected rating item is included in Appendix E.

STEP 3: IDENTIFY INVENTORY ITEMS NEEDED

Information about track structure and other features within the right-of-way as well as various operating characteristics of the railroad would be required for a sufficiency rating system. Part of the information would come from the railroads and part from a field inventory. Table 26 shows the items tentatively selected by Iowa for sufficiency rating purposes.

The items that would be obtained from the railroads could be gathered with little effort or expense. Many of the items would come from material already made available to the states. These sources would include timetables, track charts, density charts, and line clearance charts. Railroads would be requested to provide updated information periodically but most of the data would be readily available. No large expenditure of time or money would be required from the railroads.

The remaining items would be gathered by field crews employed and trained by the State. The data collection process is not covered in this report.

Companion to the problem of gathering information concerning a transportation mode is its processing and retention of data. Iowa's approach to this problem is the development of a computerized rail data base. This data base will be used in many rail planning studies, and will be available for a sufficiency rating analysis. The sufficiency rating analysis would be contained in a battery of computer programs. The first program in the series would select from the base data records the information for the rating analysis programs.

In brief, the base record system would contain a record for each segment of rail line. Segments could be from 0.01 miles to many miles in length. The record for each segment would contain unique identification data, pertinent measurements, condition ratings of various components, and many other items. Updating capabilities will be built into the system, since an up-to-date record is essential for analyses such as sufficiency ratings.

Appendix F of this document contains the list of items tentatively included in Iowa's proposed Rail Base Record System.

TABLE 26

SUFFICIENCY INVENTORY ITEMS
AND INFORMATION SOURCES

SOURCE	ITEM
RAILROADS	
Timetables	Railroad Division and Subdivision Speed Limits Siding Locations and Length Weight Capacity (Track and Bridge)
Track Charts	Station Identification Line ID (Main-Branch-Spur) Mile Post Rail Weight, year rolled, year laid
Density Charts	Gross Net Tons of Freight
Line Clearance Charts	Horizontal and Vertical Clearances
Other	FRA Track Class Train Control (Signal System) Derailments (Year, Location, cause)
FIELD INVENTORY	Tie size, Condition, No. in 39 ft. rail Ballast Width, Type and Condition Rail Condition No. of Rail Anchors & Tie Plates Joint Condition No. of Switches and Condition Drainage Condition Crossing Condition Cross Level and Gage (Track Geo. Car)

STEP 4: DEVELOPMENT OF INVENTORY INSTRUCTIONS AND COLLECTION OF FIELD DATA

The Inventory Items needed for a Railroad Sufficiency Rating system are identified in Appendix F.

STEP 5: DEVELOP THE BASIC SUFFICIENCY POINT ASSIGNMENT PROCEDURE

The development of the Sufficiency Point Rating procedure is essentially empirical in nature. In sufficiency rating systems, Iowa uses what is called "The Tolerable Standards Approach." A tolerable standard is defined as the minimum prudent condition, geometric or structural, which can exist without being in critical need of upgrading. The tolerable standard for any rating item is equal to one-half the maximum number of points allotted.

For example, Track Gage under Structural Adequacy (Table 23) is allotted a maximum of 8 points. The tolerable standard then would equal 4 points. Any rail segment receiving a gage rating of less than 4 points would be in critical condition.

Each rating item would have its own tolerable standard at which the tolerable level would equal one-half the total points allotted. It follows, then, that a segment of railroad on which all rating items were at the tolerable level would receive a basic rating of 50 points.

The relationship of an individual rating to its tolerable standard can then be used, in conjunction with mathematical formulas, to magnify ratings which are below the critical point thus lowering the overall segment rating artificially. By lowering the overall rating, the priority for improvement is higher than would be the case for a segment having an equal basic rating but no intolerable individual ratings. This procedure is called a Tolerability Adjustment and is beyond the scope of this preliminary proposal.

A brief explanation of how each item would be rated is included in Appendix E. It should be kept in mind that only preliminary examples are given. In a full-blown functional rating system, a great deal of judgment by knowledgeable persons would go into the development of each rating table or instructions for visual evaluations.

STEP 6: TEST AND REVISE SYSTEM AS NECESSARY - IDENTIFY ADJUSTMENTS TO BASIC RATING AS NECESSARY

Once a basic sufficiency rating system is developed, it must be tested and, if necessary, revised. Ratings would be calculated for sample railroad segments. These results would be compared with observations by persons knowledgeable about railroad conditions and operations. If the ratings are not consistent with the observations, it may be necessary to revise the basic methods. For example, the system might give better results if the relative weights of various rating items were altered. This fine-tuning process would be repeated until the system yields results that are consistent with the observed condition of the rated segments. This phase of the system development is very important. The ratings derive their validity from the empirical nature of the process.

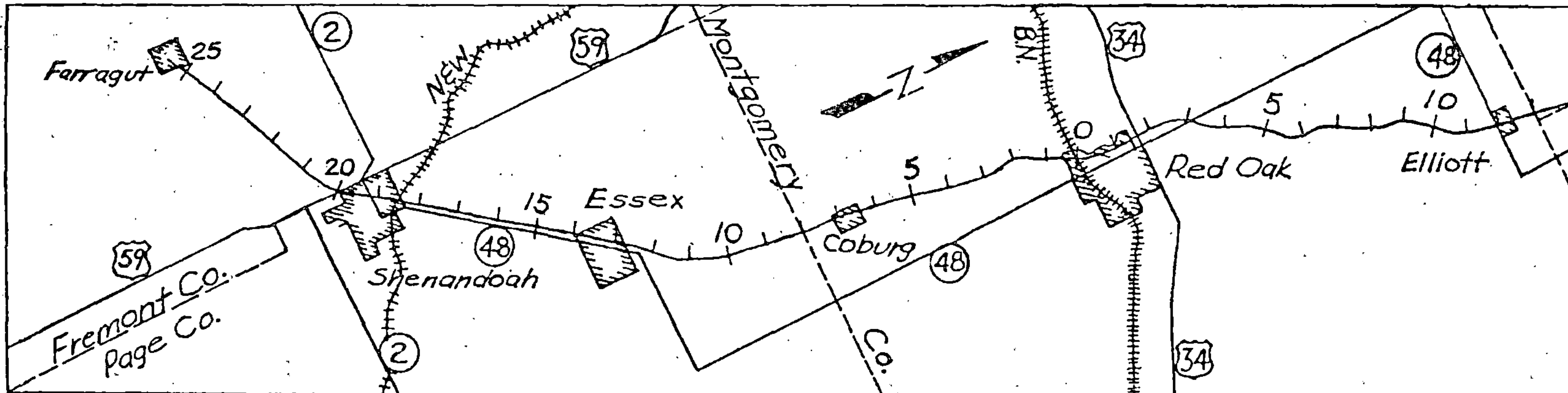
The basic rating would be adjusted at least once to arrive at a final rating. The first adjustment would be in the tolerability adjustment described previously. Items rated below the tolerable level would be given additional weight in order to emphasize their poor condition. Other adjustments may be made as the process is developed, such as adjustments for poor structures on the track segment and adjustment for system continuity.

STEP 7: IMPLEMENT FINALIZED SYSTEM

In this proposal it is envisioned that in the implementation of the sufficiency rating system described herein, a computerized sufficiency rating log report of a state's entire rail system would be published annually. A suggested format is shown in Figure 11. As mentioned previously, sufficiency ratings have many uses. So, in addition to the log format shown many additional summary tables could be included dependent upon individual state's needs.

FIGURE 11

SAMPLE RAILROAD SUFFICIENCY LOG FORMAT



Route Number	Railroad	Description	Structural Adequacy	Safety	Service	Total	Adjustment	Adjustment
7A	BN	End of track in Farragut (MP 25.9) to Fremont - Page Co. Line (MP 19.9)	37	24	13	74	72	72
7A	BN	Fremont - Page Co. Line to N & W crossing in Shenandoah (MP 18.5)	38	24	13	75	73	73
7B	BN	N & W crossing in Shenandoah to Essex (MP 13.3)	41	24	14	79	77	80
7B	BN	Essex to Page-Montgomery Co. Line (MP 8.1)	34	22	14	70	66	62
7B	BN	Page-Montgomery Co. Line to Coburg (MP 7.0)	36	23	15	74	71	71
7B	BN	Coburg to BN Crossing in Red Oak (MP 0.4)	36	23	13	72	70	69
7C	BN	BN Crossing in Red Oak (MP 0.2) to Elliot (MP 12.4)	35	22	15	72	69	67

SECTION III

WHAT MAKES SUFFICIENCY RATINGS VALUABLE

There are a number of valuable features of a sufficiency rating system in addition to its use as a communication tool. A short discussion on these features follows.

1) Objectivity

   Most sufficiency rating systems are computerized. Therefore, once design standards are developed, and an inventory is collected, the ratings are determined by computer analysis. This approach allows complete uniformity in assignment of points by eliminating human judgment in the rating process.

2) Identifies Specific Deficiencies

   The sufficiency rating can be used on a systematic basis to determine where emphasis in system upgrading should lie. Summaries of sufficiency ratings by categories will indicate whether emphasis should be placed on eliminating poor structural conditions, poor safety or service conditions, or all three equally.

3) Monitor Depreciation

   Sufficiency ratings provide an excellent monitoring system for year to year depreciation. For example, if 1000 miles of railroad rated below 50 points in 1 year and 1,200 miles rated below 50 points in the next year, a lack of adequate maintenance programming would be indicated. In conjunction with the identification of specific deficiencies the monitoring of depreciation can be used in the formulation of a rational improvement program aimed at correcting a deteriorating railroad situation.

SECTION IV
AUTOMATED INSPECTION DATA AS INPUT TO A SUFFICIENCY RATING

Planners and engineers responsible for the planning, construction and maintenance of railroads are often faced with a difficult problem. Inventories of railroad track condition, upon which administrators could base decisions, are not available. This is especially true for planners and engineers working for the governmental section of the industry.

Compiling railroad inventories by manual methods is a very expensive and time-consuming project. It is becoming increasingly obvious that automated track inspection is required for obtaining timely complete records of existing track conditions.

In the past the quality of a railroad track was assessed by having experienced personnel travel over the track to make a value judgment on track quality. This approach has two major weaknesses:

1) Ratings are subjective and may vary dramatically on the same track when analyzed by different personnel.
2) It is impractical to compile enough <u>nonvisual</u> information to study track behavior over an extended period of time.

The objectivity of an automated track inspection vehicle coupled with its inspection capacity produces an inexpensive approach towards obtaining a record of existing track conditions.

An automated track inspection vehicle, like the Iowa Track Geometry Car (Iowa TGC), can provide much of the input required to assign points to a facility rating. The proposed sufficiency rating presented in this report contains two items directly associated with the inspection vehicle; 1) gage, and 2) cross level. These two track parameters comprise 16 percent of the total rating.

The addition of a camera system to the track inspection car, see Chapter II greatly increases the application of the vehicle to sufficiency studies. Most of the items assigned points under the structural adequacy and safety categories require in-the-field inventory collection. This type of inventory could be collected by a process called photologging at a lower expense.

Photologging consists of mounting a camera system onboard the track inspection car. A series of single frame photographs is taken at a fixed interval as the car moves over the track. By viewing a cine projection of the photographs the condition of the track can be assessed. The exposed film or photofile is a permanent record of track conditions that can be viewed and analyzed by any engineer, planner or administrator whenever a need occurs.

Much of the engineering data required for a sufficiency study is obtainable from the photofile. Surface defects, tie condition, joint condition, ballast width, ballast conditions, drainage condition, crossing condition and switch conditions can be derived directly from the film with sufficient accuracy for most needs. Thus an automated inspection car equipped with a camera system could serve as the data source for 65 percent of the sufficiency rating point assignments.

PART II

INTRODUCTION TO A REHABILITATION COST ESTIMATING METHODOLOGY

A railroad rehabilitation cost estimating methodology could be developed to estimate track upgrading costs based upon data outputed by a high-rail survey vehicle, along with other non-geometric information. Such a methodology would provide a basis for evaluating cost estimates prepared by the railroads in connection with the programming of financial assistance to railroads for track rehabilitation.

In order for the methodology to be useful, it must:

1) Cost less in terms of time consumed and dollars expended than estimates prepared by consulting engineers; and
2) Be capable of providing estimates for track rehabilitation to within 10% of the estimates prepared by consulting engineers.

A preliminary design for a RCEM is presented in Appendix I.

CHAPTER V

IDENTIFY AND EVALUATE PROCEDURES FOR SELECTION OF TRACK SEGMENTS FOR MEASUREMENT, VEHICLE SCHEDULING PROCESSING OF DATA AND REPORTING IDENTIFIED DEVIATIONS.

PART I

INTRODUCTION

Track testing vehicles are usually owned by railroad companies or testing firms that contract their services to railroads. The Iowa TGC is the only state-owned, railroad track inspection vehicle. The operation of this vehicle at the direction of a public agency rather than by a proprietary company raises a number of new procedural questions for consideration. What should the relationship between private industry and a government agency be in regards to the efficient and appropriate use of an inspection vehicle by a public agency?

The elements noted in the Task title will have little if any historical record to draw upon. Each element will be influenced by the conditions prevailing at the time they are implemented. However, there may be some general principles for each element that may serve to guide the implementation of other inspection systems. It is the objective of the remaining sections to identify and evaluate factors that influence these elements and to provide an initial definition of a working procedure.

PART II

PRIORITY RANKING

STATEMENT OF RANKING SYSTEM PURPOSE

Design of a system to improve the selection of TGC inspection sites is undertaken in this section. The task is to develop a system for identifying track segments that need inspection by the TGC more than others.

The basic purpose of the TGC inspection program is to rapidly identify track segments containing geometric configurations associated with track structure problems which are in turn associated with causes of train derailment. The identification of such areas, for the railroads and for the Federal Railroad Administration (FRA) certified inspectors, is expected to result in the repair of the dangerous conditions. The detection of a track defect by the Iowa TGC does not require remedial action on the part of the railroad.

The basic purpose of the TGC inspection program is to rapidly identify track segments containing geometric configurations associated with track structure problems which are in turn associated with causes of train derailment. The identification of such areas, for the railroads and for the Federal Railroad Administration (FRA) certified inspectors, is expected to result in the repair of the dangerous conditions.

The development of this TGC priority ranking system is an effort to better focus the inspection effort on those areas most likely to incur track problems that lead to derailments and to reduce inspection efforts where track problems are less likely to be found.

The operation of any track geometry vehicle over a track segment will not gaurantee the identification of all defects. Geometry measurement addresses only a few of the defects that contribute to derailments. The fact that the Iowa TGC is able to inspect all the track in Iowa within one year reduces the need for a priority ranking system in comparison to a situation where vehicle operation would take place very infrequently. Therefore, the incremental improvement in TGC scheduling made possible by an inspection priority ranking system must be considered in the light of what benefits of that system will cost.

It is certainly possible to develop an elaborate ranking system, using numerous criteria. However, the magnitude of incremental improvement in the efficiency of TGC usage envisioned as resulting from a ranking system does not justify an elaborate system. Thus the alternative of a simplified ranking system was pursued and developed under this task.

CRITERIA CHARACTERISTICS

Inspection leading to identification of track defects, leading to notification of authorities, leading to repair of defects, eventually leading to prevention of derailment, is the flow of logic behind inspection efforts. Selecting the proper inspection sites is the key to setting this flow in motion.

Railroad experience has identified many indicators which are associated with track-caused derailments. These can be generally grouped. One group is measures of service life for components of track structure such as rail age, tie age, and the like. Another group is measures of service usage such as ton-miles, train frequency, etc. A third group may be environmental influences such as subsoil type, climate conditions, topography and so forth.

Other indicators of track-caused derailments have a basis less in engineering and more in empirical reasoning. Derailment history is one. If derailments have occurred, conditions must be present to have caused them. If so, more derailments can be expected in that area until those conditions are removed. Another is number of defects found on last inspection. These defects may or may not have been repaired after the last TGC inspection or measures close to defect tolerances may have exceeded them since last inspection, creating a dangerous condition. A third is the elapsed time since last inspection. The longer the time from last inspection, the greater the opportunity for undetected defects to develop.

The incorporation of this myriad of indicators into an inspection priority ranking system would undoubtedly improve Iowa's capability to direct inspection efforts to problem areas. However, the availability and acquisition costs for the data necessary to operate such a system is prohibitive.

Use of rail wear, subsoil type, hazardousness of cargo, tie age and a multitude of other influences on track condition is prohibited by data availability problems and acqusition costs are too great to justify their use in a quarterly ranking process. Where data is more accessable, and at a lower cost, some of these indicators could become part of a viable ranking system.

DESCRIPTIONS OF CRITERIA USED FOR RANKING

CRITERION 1 - Segment Derailment History

This criterion consists of the number of track-caused derailments reported for the segment for the most recent twelve month period prior to the ranking process for which derailment data is available.

A derailment is a demonstration of an unsafe condition. The labeling of its cause is done by the railroad and reported as discussed later. One might question the value of setting a higher inspection priority on a segment of track experiencing a derailment as being a case of locking the barn door after the horse has been stolen. Derailment history is, however, a useful indicator for needed inspection because it shows a safety problem did exist. Repairs made to the derailment site do not affect similar causative conditions that may exist elsewhere on that segment. Multiple derailments emphasize the likelihood that problems exist at several places on the segment.

A source of the derailment data is the derailment incident reports filed monthly by the railroads with the FRA. A copy is also required to be filed with the Iowa DOT. The report form is conducive to data processing. Parts of the form applicable to this criterion are the identification of location and cause of the derailment. This makes it possible to locate the derailment on a given segment and to select only derailments caused by track condition for consideration. There is no data adquisition cost for ranking purposes since derailment data is routinely submitted by the railroads.

The processing of the data for use in ranking segments requires inclusion of the applicable Iowa DOT track segment code on the derailment report by an Iowa DOT Railroad Division clerk. The reports are then key punched for entry on the railroad base records at the next update period.

CRITERION 2 - Segment Deviation from FRA Standards

This criterion is based upon the number of deviations from FRA track standards for gauge and superelevation identified by the TGC during its most recent inspection run on the segment. The criterion is the median number of deviations per mile over the segment with each measurement observation value outside FRA standards constituting one deviation. The median is employed as a better indicator of total segment condition by de-emphasizing the one or two extreme deviation per mile scores possible in a several mile long segment.

The use of deviation history is based upon the assumption that the greater the number of deviations, the greater the chances for derailment. No particular attention is given to the magnitude of the deviation since any deviation should be considered completely unacceptable. The frequency of deviations is used to indicate the need for re-inspection. A low frequency history would yield a longer interval between inspections.

The sources of the data for priority ranking purposes is the data file generated for each track segment after each TGC inspection run. Part of the routine analysis of the TGC data for reporting purposes to the railroads, DOT inspectors and others is the computation of the median number of deviations per mile on the segment. Because the source of data for this criterion is the base record computer file for railroads, no additional processing costs are required to make the data ready for use in the priority ranking system. Thus, there are no additional data collection costs for this criterion for the inspection priority ranking system.

CRITERION 3 - Elapsed Time from Last TGC Inspection

This criterion consists of the number of calendar months elapsed since the last TGC inspection run on the track segment. The thrust behind this criterion is the assumption that the greater the time since the last TGC inspection, the greater the likelihood of unidentified deviations have developed.

The criterion also balances the first two criteria in that repeat inspections do not follow too closely and that track in better condition is not totally ignored. Calendar months are used for ease of application. The timing "error" of scoring a May 1 inspection date the same as a May 31 date is accepted. Each is scored as being inspected in May or as three elapsed months for the fourth quarter ranking.

The source of the date is in the data file generated for each track segment at the completion of each TGC inspection run. Use of the date of inspection in the ranking system requires no additional data collection or costs. Likewise, the inspection date's place as part of the routine data on file requires no additional processing or costs to make it useable for the ranking system.

CRITERION 4 - Elapsed Time from Last Visual Inspection

This criterion consists of the number of calendar months elapsed since the most recent visual inspection of the segment by one of Iowa's FRA certified track inspectors. As with the TGC inspections, the longer the time interval since last inspection, the greater the presumption of deviation presence. Tracks not inspected by either FRA or State inspectors would receive the maximum rating contributed to this criterion.

The data source is the reports prepared by the inspectors. Thus no additional cost are incurred for data collection. Processing the data for inclusion on the base record requires a railroad division clerk to enter the segment code used by Iowa DOT on the report and forward it for key punching and inclusion on the base records in EDP form. If a priority ranking is implemented, the processing of the visual inspection data by the railroad division clerk would require the segment code and the inspection date to be provided to the office of data processing for inclusion on the base record at the next update.

The creation of a visual inspection report file is not required for the ranking system but could be of value to the railroad division. The cost of placing date and segment code on the base record file for purpose of ranking is minimal.

PROBLEMS WITH DATA COLLECTION

Criterion 2 is based on a per mile factor. For convenience of computations from data on magnetic tape, it would be best to compute on the basis of whole miles as labeled by railroad mile posts. However, track segments do not necessarily begin and end at a mile post. Also, changes in route over the years have made some "miles," as defined by mile posts, more or less than one mile long. Therefore, the defects per mile as calculated under routine data processing will be over a measured mile not necessarily the mile post mile. Statistics such as the median will be computed on the basis of any partial measured mile under 0.5 mile being dropped and above 0.5 mile being increased to one mile on a ratio of defects in partial mile to length of partial mile. It is expected that the length of segments will be substantial enough so that partial mile data will be of very little influence in the ranking system.

Criteria 3 and 4 both involve inspection of a given track segment over a given time period. It is likely that a segment at some time or another will not be completed. The TGC may break down and not complete the segment. A visual inspector may only cover a part of a segment before moving elsewhere. Since a single inspection date is to be applied to a segment it is necessary to establish a convention to handle the circumstance described. First, inspection segments for the TGC and the visual inspectors should be the same. Naturally it will take the visual inspector longer to cover the segment miles than it will take the TGC. This is immaterial as long as the visual inspector includes all the miles of the segment in one report of his inspection even if the work requires four days to the TGC's one day. If the TGC segment is from point A to point D, the visual inspectors inspection and report should cover points A to D even if a day is devoted to each segment A to B, B to C, and C to D. The visual inspector should not end his inspection at B or C.

Yet, due to breakdown, illness, or other duties the full segment may not be completed. If the segment is not completed by the visual inspector, the date of his report on the partial segment is not included on the base record. The previous date of the last full segment inspection is retained and used in the ranking system.

If the segment is not completed by the TGC, no information is changed on the base record. If the TGC can return within 30 days to complete the segment by starting where it previously ended, the deviation data from both partial segments is to be considered as being collected at the same time. That time being the later date. If return is not possible within 30 days, the whole segment should be rerun with no use of the earlier partial segment data being made. If on the basis of previous experience, should more than 75% of the segment be run before breakdown, a decision may be made to extrapolate from that 75% to the full segment. This will be a case by case decision as part of continued data processing. The result of that decision will be used in the ranking system.

REVIEW OF OTHER POSSIBLE CRITERIA

As noted earlier, several other criteria would suggest themselves as reasonable indicators for inspection priority. Density measures are such criteria. In order to give some consideration to density without incurring the difficulty of obtaining the data and the cost of doing so, a weighting factor is applied according to track class. On the assumption that track segments carrying higher densities are more subject to wear and that high density traffic is routed over higher classes of track, the weighting of the segments score on the basis of track class is a surrogate for employing a density criterion. The weighting formula is provided later. The impact of density upon inspection priority ranking is diminished by the railroad's tendancy to inspect and maintain its higher class mileage and higher density mileage to a greater degree than lesser class trackage.

The value of freight or the transport of hazardous materials could be part of the ranking system criteria on the premis that a derailment would cause more dollar value damage or more injury damage on these routes than on routes which do not carry valuable or hazardous cargo. The accessability and cost of obtaining such data prevents its use.

Inspection practices by the railroad could also influence inspection priority by the TGC. The quality of such is undependable and has resulted in government inspection programs. Thus, the only inspection practice that should influence TGC inspection priority is the regular operation of a geometry test car over the lines by the railroad itself.

PART III

WEIGHING THE RANKING CRITERIA

Assigning weights to criteria scores in a ranking system is a method of indicating the influence of a given criterion in relationship to the other criteria employed in the system. The establishment of a weighting value is essentially a result of judgement. Given the goal, in this case, of selecting track segments most in need of TGC inspection as a deterrent to derailments and given the four criteria to work with, as described in Part II, the importance of the criteria from greatest to least is, in the judgement of the author, derailments, deviation frequency, elapsed time from last TGC inspection, and elapsed time from last visual inspection.

While this is the rank order of the criteria, a measure of how much more important is one compared to the next is needed. Again, judgement is used to establish this relationship. Given the modest level of precision required from the TGC inspection priority ranking system, the relative importance of each criterion to the goal was established by the use of a review panel. Utilizing the concept of 100% as the maximum weight for all criteria, the weight is apportioned to the criteria as follows:

Derailment history - 40%

Deviation frequency - 25%

Elapsed time from last TGC inspection - 20%

Elapsed time from last visual inspection - 15%

These weights are applied to the criteria scores described in Part IV during the calculation of ranking priority. The weighting assignments emphasize the indicators based upon demonstrated problems in track structure over the indicators related to time between inspections. The last adjustment to be applied to criteria scores is a factor related to track class as defined by FRA track safety standards.

Earlier, the possibility of including criteria based upon traffic density, freight value, transport of hazardous materials and the like was reviewed. These items are not included in this ranking system due to the cost such inclusion would incurr. However, operating on the assumption that track class is positively correlated with traffic volume and freight value, a weighting factor applied on the basis of track class could be used as a surrogate for these costly potential criteria.

With this weighting it is possible for a higher class track which may have a lower score on derailment or deviation criteria to be ranked for inspection ahead of a lower class track with higher scores. In this way traffic density is allowed some influence on inspection priorities. This adjustment factor considers the opportunity frequency for and cost of a mainline derailment as compared to one on a branch line.

The track class weights are applied to the derailment and deviation frequency criteria by multiplying the sum of the weighted scores on each criterion by 1.0 for Class I track, 1.2 for Class II track, 1.5 for Class III track and 1.9 for Class IV track. Additional weights are not required in Iowa because no railroad in Iowa operates on Class V or VI speeds.

PART IV

COMPUTATION OF EACH CRITERION'S SCORE

GENERAL - Each criterion is evaluated on a point scale of 1 to 25 which is weighted as described in PART III. The greater the score, the higher the inspection priority.

THE DERAILMENT CRITERIA - Each track caused derailment on the segment over the preceding twelve months is assigned five points. Therefore, five or more reportable track caused derailments will score the maximum 25 points. The score for this criterion is computed by multiplying the number of track caused derailments on the segment in the last twelve months by five.

THE DEVIATION FRQUENCY CRITERION - The number of gauge and crosslevel deviations from FRA standards are totaled for each measured mile in the segment. Data for fractions of miles less than 50% are ignored. Data for fractions above 50% is extrapolated for the full mile. This procedure introduces less error as the number of miles in the segment increases. It has little effect on the overall ranking. The defect totals for each segment mile are ranked in ascending order. The median per mile deviation frequency is computed and divided by 100. The quotient becomes the segment score on this criterion. The maximum allowable score is 25 regardless of a possibly larger quotient.

THE ELAPSED TIME FROM LAST TGC INSPECTION CRITERION - The influence of this criterion is not applied in strictly linear fashion. Each of the first three months following a TGC inspection are awarded zero points. Beginning with the fourth month after a TGC inspection, a point is awarded and three accumulated points are computed. Thus, if the ranking occures 4 months after a TGC run, the criterion's score is 4, if it were the eighth month, the score would be 8. The single point per month is applied to months 4 through 12. Beginning with the 13th month, the awarded points per month is raised to 1.5 points. Thus the score thirteen months from the last inspection is 12 + 1.5, for the fourteenth month it is 12 + 3, for the twentieth month it is 12 + 12, beyond the twentieth month the maximum score of 25 points is used. The score for this criterion is calculated as $S = 0.5(M-12) + M$, where M equals the number of months after TGC inspection and all products or results less than 4 are given the value zero.

THE ELAPSED TIME FROM LAST VISUAL INSPECTION CRITERION - The influence of this criterion is not linear either. There are four elements representing different periods of time since the last visual inspection. If the time is less than two months the score for this criterion is zero. If the time is three, four or five months, the score is 10. If the time is six to eighteen months, the score is computed as, $(M - 5) + 10$, where M is the number of months since last inspection. For a period exceeding 18 months the score is computed as $2(M - 18) + 13$, up to a maximum of 25.

TGC INSPECTION PRIORITY RANKING FORMULA

The four criteria are limited to the maximum of 25 points as described above. These scores are weighted on relative importance and for track class as described in Part III. The formula for computing track segment ranking is shown below.

$$\frac{Y_t\ (200\ (D)) \doteq Y_t\ \left(\frac{25(X)}{100}\right) + 20\ \left(\frac{(M-12)}{2} + M\right) + 15\ E_z}{100} = S$$

WHERE:

Y_t = The weighting factors for each track class.

track class	Y_t
I	1.0
II	1.2
III	1.5
IV	1.9

D = The number of track caused derailments during the most recent twelve months.

X = The median number of deviations per mile on the segment.

M = The number of elapsed months from last TGC inspection.

E_z = A parameter based upon elapsed months from last visual inspection of the segment.

S = Segment ranking.

elapsed time	E_z
0 - 2 Mos.	0
3 - 5 Mos.	10
6 - 18 Mos.	(1 pt. per mo.) - 5 + 10
19+ Mos.	2(number of mos. - 18) + 13

E_z Maximum Value = 25

DATA PROCESSING

The development of a ranking of track segments for inspection according to the previously described criteria will be accomplished by the office of data processing of the Iowa DOT. The key item in being able to generate a track segment ranking is the creation of a railroad base record. The essential aspects of this record are the assigning of a unique identifying code to each segment of track in the state and the collection of data for each of those segments.

This author envisions the development of a priority ranking system to be made once per quarter. The base record types would be read, a ranking value computed, and a list of track segments printed in order from highest to lowest priority. A general flow chart of necessary programming and an example for a sample rail system ranking are shown in Figures 12 and 13.

USAGE OF THE RANKING SYSTEM

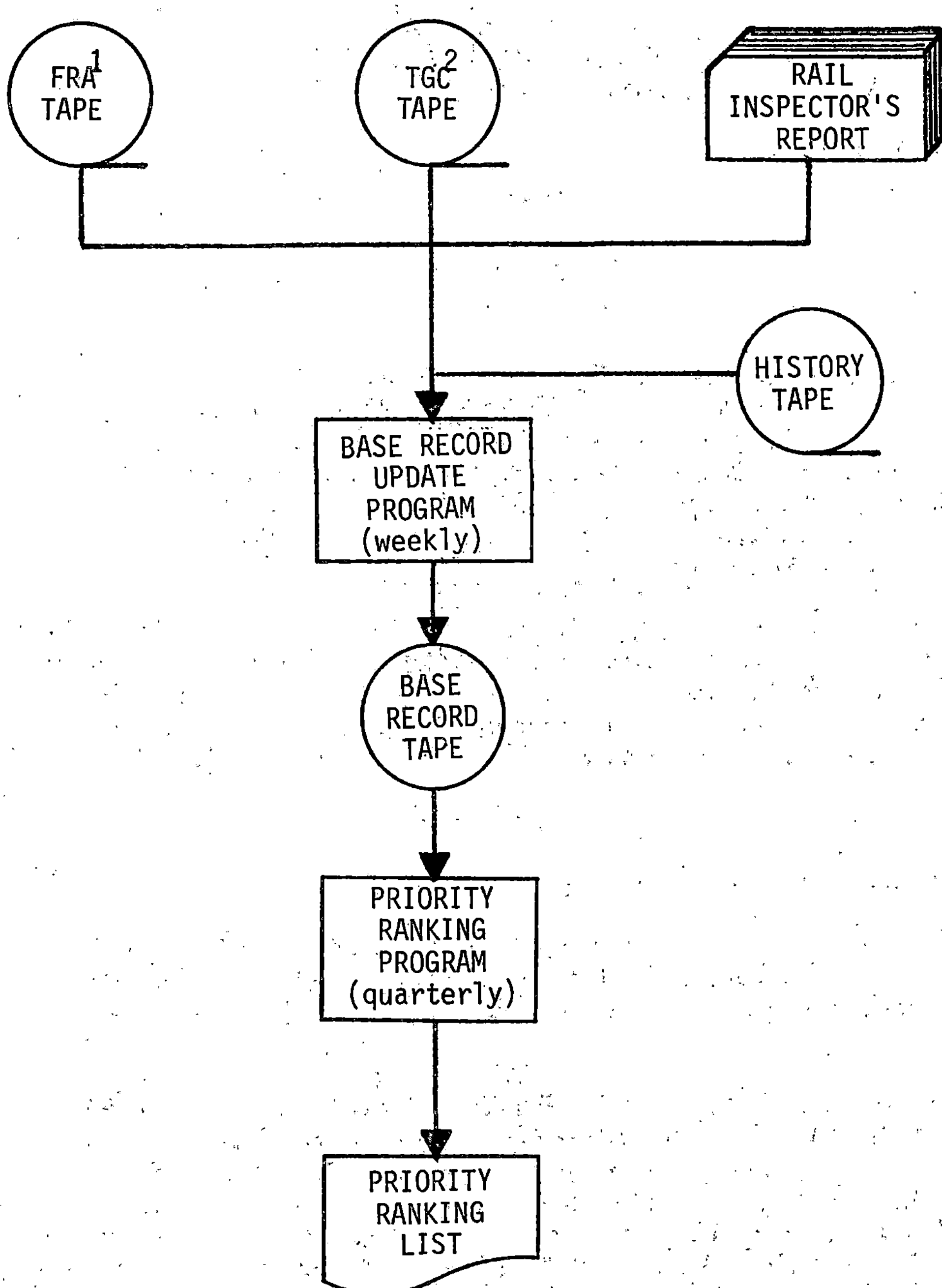
The ranked list of track segments resulting from the ranking system will be used by the Iowa DOT Railroad Division as a guide for scheduling the TGC. The ranking of all track segments in Iowa would be accomplished once each calendar quarter.

It is quite likely that the segments ranked of highest priority for TGC inspection will not exhibit convenient closeness. The effecient usage of the TGC includes minimizing non-measurement travel time between sites and minimum disturbance to railroad personnel's normal duties. Therefore, the segment ranking priority may be set aside by special project operations. These operations could include coverage of track segments which are part of the Iowa Brachline Rehabilitation Program or data collection runs for transportation planning purposes. The priority ranking guides, but does not dictate the location of TGC inspections.

The thrust of the TGC inspection priority ranking system is to provide a guide to the Railroad Division in the routine scheduling of the TGC so that inspections are directed toward segments requiring track repair work. The Railroad Division receives the list of segments ranked by this system

FIGURE 12

GENERAL FLOW CHART



[1]FRA derailment tapes are available monthly--data is 3 months old when reported.
[2]TGC tapes are available weekly for the past week.

FIGURE 13

SAMPLE RAIL SYSTEM RANKING

RANKING BY PRIORITY FOR TGC INSPECTION PAGE 1

CTY NO	PR	RTE NO	DIV	SUB	SEG NO	MILE POST ID	SEG LENG	FRA CLASS	LINE ID	DATE TGC RUN	GA.DEV. PER MI.	SUM GA. DEV/MI.	X-LEV DEV/MI.	SUM XL DEV/MI.	DE RL	VISUAL INSP.DATE	PRIORITY SCORE
12	NW	0712	9	12	127	12.11	0.12	IV	SPUR	12/ 1/75	125	70.	80	300.	10	11/15/76	29.930
8	DRI	0076	13	8	83	8.07	0.08	IV	BRCH	8/ 1/76	40	30.	25	75.	6	7/ 1/76	23.799
11	ITR	0711	10	11	113	11.10	0.11	III	BRCH	2/ 1/76	100	60.	60	200.	9	10/ 1/76	20.640
7	RI	0777	14	7	70	7.76	0.77	III	MAIN	9/ 1/76	30	20.	15	50.	5	6/ 1/76	18.639
13	UP	0713	8	13	130	13.12	0.13	I	MAIN	6/ 1/75	150	100.	100	500.	11	12/15/76	17.125
14	WLO	0314	7	14	140	14.13	0.14	II	BRCH	1/ 1/72	200	200.	200	700.	12	1/ 1/77	16.440
10	ICG	0010	11	10	100	10.09	0.10	II	MAIN	6/ 1/76	75	50.	50	150.	8	9/ 1/76	15.331
9	DCI	0779	12	9	90	9.78	0.79	I	SPUR	7/ 1/76	50	40.	35	100.	7	8/ 1/76	12.626
6	CNW	0076	15	6	60	6.05	0.06	II	SPUR	10/ 1/76	25	10.	10	40.	4	4/ 1/76	12.621
4	CITC	6235	17	4	40	4.03	0.04	IV	MAIN	12/ 1/76	15	5.	4	20.	2	2/ 1/76	12.086
5	MILW	0005	16	5	50	5.04	0.05	I	BRCH	11/ 1/76	20	4.	5	30.	3	3/ 1/76	8.426
3	CIC	A2A	18	3	30	3.02	0.03	III	SPUR	1/ 1/77	10	2.	3	10.	1	1/ 1/76	5.404
2	BN	1A	19	2	20	2.01	0.02	II	BRCH	2/ 1/77	5	1.	2	5.	0	6/ 1/75	3.969
1	ATSF	1	20	1	10	1.00	0.01	I	MAIN	2/31/77	0	0.	1	3.	0	1/ 1/75	3.752

END OF JOB- PRIORITY RANKING.

and Division personnel incorporate as many of the high ranking segments into the next quarter's operating schedule as is consistent with geographical locations, climate, special order runs and other influences that may impinge on schedule considerations.

PART V

ACCESS

STATEMENT ON HIGH-RAIL ACCESS

Before beginning a discussion on access it is important to clearly understand the ramifications of operating a high-rail inspection vehicle. The Iowa TGC does not encounter the same problems in obtaining access as the typical train concept inspection car. The main advantage of the high-rail vehicle is its ability to clear the track without interferring with normal train operations. By setting on and off track the high-rail vehicle can survey track condition without rescheduling established train traffic.

A high-rail vehicle eliminates many of the operational problems that make it difficult to obtain access for train type inspection cars. The high-rail vehicle frees railroad tracks for normal traffic during non-inspection travel. It does not tie up yard space and support services during non-testing periods. Nor does it require complete train crews and seldom does it require extensive scheduling. These advantages create a more receptive atmosphere for obtaining access than the demanding labor intensive, train concept inspection cars.

RIGHT TO INSPECT IN ACCORDANCE TO FEDERAL RAILROAD SAFETY ACT OF 1970

A provision of the Federal Railroad Safety Act of 1970 authorized the Federal Railroad Administration to enter upon, inspect and examine rail facilities. A House Report on the Act reveals Congress's concern over accidents involving volatile and explosive substances. The prevention of such accidents was deemed possible through the implementation of an inspection program aimed at advance detection of potential track hazards.

Both the public and general public benefit from the FRA's inspection program. The inspected railroad, in deriving considerable benefits from the inspection, improved ride quality, increased safety and more efficient maintenance practices, is not subjected to covering operating costs of the inspection vehicle. The FRA pays for: 1. Salary of train and engine crews; 2. Supplies such as fuel, water, etc.; 3. Cost arising from carrier actions to service or repair to equipment; 4. Cost relating to security necessary to protect the equipment ; and 5. Cost relating to the non-operational movement of the inspection vehicle.

The United States Court of Appeals held that the Federal Railroad Administration could require railroads to bear the responsibility for accidents arising out of negligence of railroad crews during the course of an inspection trip (553 F 2nd 1156 (8th Cir 1977)). Requiring railroads to assume responsibility for their own negligence in the course of a safety inspection will hopefully insure a safe performance of the inspection trip. This risk of loss is intended to ensure the proper supervision and selection of crew members by the inspected railroad.

PART VI

RIGHT TO INSPECT IN ACCORDANCE TO IOWA CODE

The Iowa Department of Transportation is also responsible for conducting railroad track safety inspections. Iowa Code requires the inspection of each railroad in regards to public safety and conveniece. Thus under legislative mandate the inspection of railroad property is a right of the State and not a privilege to be granted or denied by railroad companies. The sections in the Code granting this authority are presented below:

> 424.10 GENERAL JURISDICTION OF TRANSPORTATION DEPARTMENT. The State Department of Transportation shall have general supervision of all railroads in the state....
>
> 474.12 INSPECTION--NOTICE TO REPAIR. It (Iowa DOT) shall from time to time carefully examine into and inspect the condition of each railroad, its tracks, bridges and equipment, and the manner of its conduct, operation, and management with regard to the public safety and convenience in the state. If found by it unsafe, it shall immediately notify the railroad company whose duty it is to put the same in repair, which shall be done by it within such time as the department shall fix. If any corporation fails to perform this duty the Department may forbid and prevent it from running trains over the defective portion while unsafe.

Iowa Administrative Code paved the way for TGC operations on railroad property by allowing the use of whatever equipment the Iowa Department of Transportation deems as necessary for inspection. The appropriate sections of the Iowa Administrative Code pertaining to railroad inspection are shown below:

> 820--(10,E) 2.2 (474) ACCESS FOR INSPECTION.
>
> 2.2(1) Individuals certified by the division with proper credentials issued by the Department on their person shall be admitted on the property of any railroad company for the purpose of inspecting the saftey of track and track structures of that railroad.

2.2(2) Certified inspectors shall be permitted by the railroad company to utilize such measurement tools and vehicles as deemed necessary by the division for the conduct of inspection duties. Use of measurement vehicles shall be in a prudent manner and shall take cognizance of safe operation procedures with relation to train operation on the segment of track being inspected. The railroad company shall provide the inspector with such information and assistance necessary for safe operation of the inspection vehicle on the tracks.

PART VII

A BALANCE BETWEEN LEGAL RIGHT AND COOPERATION

Obtaining access under a track inspection program should not have its basis in legal statute. This narrow justification may block the effectiveness of the inspection program and could place unnecessary obstacles in the path of other programs involving a private railroad company and a state agency.

Inspection programs can and should be sold on the benefits incurred to the participating railroad firms. The benefits which can accrue due to prevention (reduction) of railroad accidents are reduction of damage costs and a reduction of financial losses due to injuries, death or customer disatisfaction. The benefits to the railroad company can be assigned a dollar value. Those benefits which are relatable to the measurement capabilities of the inspection vehicle represent an anticipated savings derived from the inspection. This benefit-cost approach is discussed in length in Chapter II.

Efficiency, safety, courtesy and good will point to cooperation in track safety inspection programs between a railroad and the Iowa DOT. While the State retains the right to inspect with or without railroad permission it will not conduct an independent inspection until all avenues of compromise are closed. The Iowa DOT attempts to first resolve differences and misunderstandings of the inspection program by mutual understanding and education between railroad companies and itself and not by legal dictate.

PART VIII

LIABILITY CONSIDERATION AND OPERATOR ISSUE

Concern over limiting the liability arising out of an accident was the principle obstacle encountered in obtaining access to inspect railroad property for the Iowa TGC. As noted earlier, the railroad must bear responsibility for accidents involving the federal inspection train which arise out of negligence of railroad crew members. This was carried over to the Iowa hy-rail inspection program with some slight changes.

To increase the safety and quality of the inspections the Iowa DOT wants the railroad's on-board representative to drive the TGC while on rail. To facilitate this procedure, the Iowa DOT purchased liability insurance coverage for the railroad representative. This coverages reduces the liability exposure of the railroads under these circumstances. The State carries at State expense a policy which names the railroads as the insured with limits of $500,000/$1,000,000 for bodily injury coverage and property or physical damage resulting from the operation of the TGC.

The Iowa DOT has also agreed to release, indemnify, and hold harmless the railroad companies from all liabilities caused or resulting from the operation of the TGC excepting acts of willful or wanton negligence of the railroad, its agents or employees.

Damage to railroad property in excess of the liability policy is the responsibility of the railroad. It is unlikely that excessive property damage could occur due to the limited size and operating speed possessed by the Iowa TGC.

Another issue that had to be resolved before the Iowa TGC could obtain access to railroad property was the railroad's refusal to allow its employees to drive the TGC while on track. The arguements included in the Iowa DOT's response in resolving this issue are presented below:

- TGC is a vehicle similar to those already operated by railroad personnel.

- Where else but at the controls of this vehicle could the railroad place a representative which would afford more direct and efficient adherence to operating rules and other safety considerations.

- Railroad personnel driving the TGC on track permits the full attention of the State operator to tape annotation, which yields better data collection.

- The Iowa DOT is paying for insurance to cover the railroad employee liability as vehicle driver.

To date the Iowa DOT has not attempted to have its employees drive the vehicle while on track. The Iowa DOT has negotiated with the railroad companies to remove obstacles which were preventing railroad employees from driving the vehicle.

PART IX

VEHICLE SCHEDULING

INTRODUCTION

The objective of this section is to identify the practices used by the Iowa Department of Transportation (Iowa DOT) in scheduling the operations of the Iowa Track Geometry Measurement Car (TGC) and to discuss the foundations for these practices as a basic reference for scheduling considerations involving possible use of federal vehicles of this general type in the future.

The practices adopted by the agency responsible for vehicle scheduling, in Iowa's case the Railroad Division of the Iowa DOT, will materially affect the overall efficiency of the vehicle operation and the relationship between the operating agency and the private railroad company.

The effects of poor scheduling practices include frequent trip cancellations, an improper ratio of non-testing to testing time, substantial deadheading and failure to meet production goals. Poor scheduling can also lead to a disproportionate involvement of certain railroad personnel and the generation of an attitude on the part of railroad officials that the vehicle causes more problems and time loss than its benefits warrant. Poor scheduling can also affect the attitudes and work efficiency of the vehicle's crew if the production targets and time away from home are perceived as excessive.

CURRENT IOWA PRACTICES

The primary production objective for the Iowa TGC is to record measurements of all the main and branchline track miles within the state at least once per year. This objective is to be attained on the basis of a five-day work week containing eight-hour work days. Allowing for non-measurement days due to cancellations requested by the railroads, from vehicle malfunctions, and severe weather conditions -- along with non-measurement days for maintenance, and part days for intersite travel -- the average daily coverage needed to accomplish this objective is 60 to 70 miles.

Work days in excess of eight hours are allowed only at the request of the railroad and only under circumstances that require a short extension of work time. This is most often found when only a few miles of measurement territory remain after the usual eight hour work day.

Although equipped for night work, the TGC is scheduled for on-track operation only in daylight hours. Starting and finishing times are set according to the preference of the railroad within the workday parameters identified above.

The process of selecting segments of track for TGC coverage begins with the identification of segments cancelled during the past scheduling period. These are to be included if possible in the next period. Additional criteria employed in the selection of segments to be incorporated into the next scheduling period include:

- the date of the last TGC trip over the segment.
- the roadmaster's territorial limits.
- the minimization of off-track travel time between segments.
- the minimization of off-track travel time between the TGC base and segment site.
- the date of the last visual inspection of the segment by the state.
- the possible impact of unfavorable climate conditions.
- the applicability of any special railroad operating practice.
- special request trips.

On the basis of these criteria a tentative schedule is drawn up in draft form. The division engineer of each railroad division over which the TGC is to operate during the schedule period is contacted by telephone and informed of the date and site of the tentative TGC run on his division. At this time he is asked to agree to the schedule or indicate that it is not possible for him to schedule the TGC at the date and place requested. When a full month's schedule is established it is sent in written form to those division engineers affected by it during the period covered, see Figure 14.

If the schedule requires modification due to cancellation by the railroad or cancellation by the Iowa DOT, the change is communicated by telephone. Depending upon the amount of advance notice of a cancellation, the Iowa DOT will attempt to schedule a substitute segment on the same or on another railroad by telephone. The propinquity of rail lines in Iowa often makes this possible.

T. G. C.

WEEKLY WORK SCHEDULE

INSPECTION ACTIVITIES

(1) INSPECTOR	ID NO.	(2) STATE	(3) REPORT DATE YEAR	MONTH	TYPE OF INSPECTION
	TGC	IOWA	1977	Nov	[X] TRACK [ ] EQUIPMENT [ ] OTHER

(4) WEEK OF INSPECTION	(5) RAILROAD CODE OR OTHER ACTIVITY	(6) RAILROAD DIVISION	(7) LOCATION FROM CITY NAME & CODE	MILE-POST	(8) LOCATION TO CITY NAME & CODE	MILE-POST	(9) NO. OF UNITS	(10) REASON FOR INSPECTION CODE	(11) DATE OF LAST INSPECTION	(12) REMARKS
Mon 11/15	C. & N.W.	Iowa	Boone	200	Watkins	100.8	100.8	512	10/2/76	Confirmed 10/20/77
Tue 11/16	I.C.G.	Iowa	Alden	330.6	Waterloo	276.3	56.3	512	5/22/76	Confirmed 10/16/77
Wed 11/17	I.C.G.	Iowa	Mona Jct.	0.0	Lyle	75.7	75.7	512	5/23/76	Confirmed 10/16/77
Thu 11/18	C. & N.W.	Central	Oelwein	245.5	Allison	295.4	49.9	512	8/4/76	Confirmed 9/27/77
Fri 11/19	C. & N.W.	Central	Allison	295.4	Clarion	344.6	49.2	512	8/5/76	Confirmed 9/27/77
					TOTAL-----------		331.9			

FIGURE 14

EXAMPLE WORK SCHEDULE

DISCUSSION OF INDIVIDUAL SCHEDULING PRACTICES

In this section, the basis for, and reaction to, a number of scheduling practices will be discussed. The information related herein is collected through personal interview by the researcher with the Iowa DOT personnel associated with scheduling the TGC and with railroad division office officials of division engineer rank or higher for the divisions of the five railroads operating the most mileage in Iowa.

Production Goals: Within the general estimate of 60 to 70 measured miles per day required to accomplish the yearly coverage of all Iowa main and branchline track, the weekly and daily target miles are based upon several factors.

For reasons of personal and equipment safety, the TGC is not operated at more than 20 miles per hour and is slowed below that on the poorer track segments. The average speed used for estimating the purposes is 10 mph. on Class I track and 20 mph. on all other classes. Required highway travel from one measurement site to another is estimated at 40 mph.

The second factor in daily production estimating is the size of the roadmaster's territory. It is the policy of the Iowa DOT not to use more than three days of a given roadmaster's time during any calendar quarter, if possible. It has proven through experience that three days or less at the estimated speeds will allow coverage of a roadmaster's territory.

At times scheduling estimates do not match actual experience on a given trip. The roadmaster territory occasionally leads to a work day slightly longer than eight hours when the roadmaster wants to finish up his territory and not have to come back the next day for just a few miles. It can cause a shorter than eight hour day if the trip goes particularly well and the territory is completed early. It is also possible that a roadmaster's territory doesn't require a set of full days to complete. At these times light maintenance is performed or data analysis is begun.

Early in the Iowa Track Inspection Program consideration was given to night and weekend operation of the Iowa TGC. This was abandoned when it became apparent that the production increase would not justify the cost in dollars and in railroad cooperation.

Vehicle and equipment maintenance is scheduled at the TGC base in the Iowa DOT complex in Ames. Maintenance is performed on weekends. The overtime cost associated with this practice is deemed acceptable in view of the production goals and the down-time costs of personnel.

THE SCHEDULING WINDOW

The optimum scheduling window would be of a duration which gives the most advance notice with the minimum amount of change. Originally the Iowa DOT prepared and distributed a quarterly schedule to the railroads. The frequency of modifications requested by both the Iowa DOT and the railroads demonstrated that neither mechanical reliability of the TGC nor the demands on roadmaster's time could be predicted over that span of time.

The schedule window has been reduced to one month. There does appear to be a difference in definition of the term month. The Iowa DOT has been issuing schedules for the calendar months. However, the railroads prefer a month's notice of a schedule trip. Therefore, a railroad should be notified of a scheduled trip during the corresponding week of the month preceeding the trip. For example, December's schedule should be issued the first week of November so the railroad scheduled for the first week of December has a month's notice.

The effect of this preference upon the schedule drafters is to require a tentative schedule period of at least two months with the fixed schedule possible for just one month. While there is support among some railroads for a scheduling window of as much as six months, the major emphasis is upon notice prior to a measurement trip of at least 30 days so that adjustments can be made.

ADJUSTMENTS TO THE TENTATIVE SCHEDULE

The tentative schedule is drawn up to meet the objectives of the Iowa DOT. The resulting schedule does not always mesh with the plans and scheduling of the railroads. The major reason for a railroad not being able to agree to a tentative schedule is the availability of manpower. The railroads will usually accommodate a TGC trip in the routine work load. However, vacations, special inspections or trips by corporate officers, or planned use of special maintenance of way equipment will not be rescheduled to accommodate a TGC inspection.

Some railroads will permit the assistant roadmaster or another employee to accompany the TGC when the roadmaster is committed to other duties. Some railroads insist the roadmaster only is permitted to accompany the vehicle. Clearly more flexibility in scheduling is available to the former and the need for a longer advance notice apparent for the latter.

The use of the TGC by Iowa is reported by the railroads to have no effect on normal train operations. Certain maintenance of way operations will cause a trip to be refused or one to be cancelled if previously accepted. These have been noted before.

The tentative schedule is influenced if not actually adjusted by the Iowa climate. Rain, cold, or heat do not impare TGC operation, but ice and snow conditions can. During the period of the year most likely to experience ice and snow conditions the TGC is scheduled primarily on main lines or frequently used branch lines. In this way normal train operations clear the track sufficiently for the TGC operations. Infrequently used branch lines are not scheduled at this time.

INTERRUPTIONS TO THE FIXED SCHEDULE

Once the tentative schedule becomes fixed, interruptions to it may be requested by the Iowa DOT due to some type of equipment or vehicle malfunction. The fixed schedule is not interrupted for special trips. Visiting dignataries are accommodated on the vehicle only if they can join it in its scheduled operation and have received permission from the Iowa DOT.

Cancellations may also be requested by the railroads. Causes normally relate to an emergency (derailment) or a requirement issued by corporate headquarters on short notice. Trips cancelled by the railroad have averaged about one per month.

The response by the Iowa DOT to fixed schedule interruptions as well as to refusals to accept a tentatively scheduled trip is to accommodate the request and reschedule the segment as soon as possible. This courtesy is returned by the railroads when the Iowa DOT requests a trip on very short notice due to a cancellation by another railroad.

ESTABLISHING THE FIXED SCHEDULE

The chief operator of the TGC is responsible for establishing the tentative schedule and contacting the railroad for agreement. The contact is made with the division engineer or any higher ranking division officer specified by a given railroad. As supervisor of the division's roadmaster or other track maintenance individuals, he prefers to be the contact for requests involving his men. Any relaying of information up or down the organizational structure regarding the schedule is his responsibility. This system is overwhelmingly preferred by the railroads in Iowa.

The geographical limits to TGC operation (only in Iowa) and the limited daily coverage (roadmaster territory) places the appropriate contact level for scheduling at the division management level.

The method of railroad contact currently used by the Iowa DOT is for the chief operator to telephone the division engineer and relay the elements of the tentative schedule to him. At this time the division engineer is expected to indicate if he is able to assign his people to accompany the TGC and that the selected track segment will be available for a TGC trip. If there is a conflict in the schedule an attempt is made to work it out at the time. If that can't be done the segment is dropped from the schedule and another segment from either another roadmaster's territory or another railroad is selected. This procedure is followed until a complete month is scheduled. It is possible that some days will be lost due to total unavailability of an appropriate track segment for measurement. The completed fixed schedule is set out in writing and sent to the division engineers affected by it.

The problem of short notice for the first weeks of a schedule window was discussed earlier. The difficulty expressed by division engineers over this system of schedule fixing is that the workloads and schedules of their men or the details of a maintenance program are not always immediately available at the time of the phone call. Thus a trip may be refused over the phone when, if given some time, a suitable adjustment could be made to allow the TGC to make the requested trip. A preference was expressed by some for receipt of a written tentative schedule well in advance of actual trip days and an opportunity to review it in order to adjust the railroad's work program and manpower assignments to accommodate it. All of the engineers contacted expressed a preference for schedule confirmation in writing.

GENERAL OBSERVATIONS

Scheduling practices for a TGC type vehicle are influenced by many factors. The objectives of the operating agency influences the operational technique which in turn impacts scheduling. Using a high-rail vehicle as an inspection platform for citing track safety standards violations will slow it down much more than using it as a screening device. Concentrating its work on a single railroad system as compared to all systems in a geographical area will result in different scheduling problems and solutions.

Iowa's experience with its track geometry measurement car has, however, identified several scheduling principles that should have broad application. Perhaps the foremost principle is to MAKE THE TRIP AS UNOBTRUSIVE TO NORMAL RAILROAD OPERATIONS AS POSSIBLE. This is closely followed by PROVIDING A SUFFICIENT ADVANCE NOTICE TO THE RAILROAD OF A TRIP REQUEST. In observing these two principles, the remaining scheduling practices, developed upon the ag ncy's objectives for vehicle use, should fall out as matters of common sense verified or modified by experience.

PART X

PROCESSING DATA

INTRODUCTION

The objective of the initial portion of the research contract is to produce a hardware/software system that will collect and log data in real time as received from the data sensors on-board the Iowa Track Geometry Car (TGC). This system must also monitor all of the data and print out in real time any FRA violations that are observed from the gauge and cross-level measurements. The proposed system had size and cost limitations. To meet the above requirements Hewlett-Packards newest and most advanced programmable calculator, the 9825A, was chosen. This calculator was designed principally for use in engineering, research and real time control applications.

In order to drive the Hewlett-Packard equipment and to meet the requirements of the system, three software programs were written:

1. Geodata Test Program
2. Geodata Header Program
3. Geodata Calibration Program

The Geodata Test program is the heart of the TGC Data Processing System while the Header and Calibration programs act as auxillary units to obtain pre and post data. The total hardware/software data recording/processing system has been named the GEODATA PROCESSING SYSTEM. This hardware/software system is described in detail in the text of this section.

SYSTEM REQUIREMENTS

In order to design a complete hardware/software system which would satisfy the contractual requirements, the following system requirements were set forth to establish a base for system design.

1. INPUTS:

   a. Gauge measurements
   b. Cross-level measurements
   c. Distance measurements
   d. Clock time
   e. Observer event switches
      -milepost
      -bridge
      -road crossing

-switch
-observer comment
-right curve
-left curve
-spare

f. FRA track class
g. Header data
h. Calibration data

2. OUTPUTS:

   a. All of the above inputs on an IBM compatable magnetic tape
   b. Hard copy real time printout of gauge and cross-level FRA defects.

3. DATA RECORDING:

   a. Iowa track geometry car maximum speed of 20 mph
   b. Data sampling interval between 1.5 feet and 6.5 feet
   c. No input data loss while processing or printing
   d. Maximum system durability with minimum maintenance
   e. Data sensor calibration capabilities

4. INTERNAL COMPUTATIONS:

   a. Analog to digital conversion of inputs
   b. Scaling to required engineering units
   c. Cross-level variation between the current cross-level measurement and the previous 12 measurements
   d. Frame counter
   e. Accumulation and printout of gauge and cross-level FRA defects.
   f. Test distance using $\pm$ mileposts and discontinuous test

5. OPERATOR INTERVENTION FOR:

   a. Header input
   b. Calibration input
   c. Test termination input
   d. Test stop and continue
   e. Magnetic tape down input
   f. Event notation

<u>GEODATA PROCESSING SYSTEM STRUCTURE</u>

The GEODATA PROCESSING SYSTEM is composed of a combination of hardware/software components. The major components in this system are listed below:

HARDWARE

1. TGC gauge sensor
2. TGC cross-level sensor
3. TGC distance sensor
4. TGC event switches
5. HP digital clock
6. Multi-programmer
7. GPIO interface
8. HP 9825A programmable calculator
9. HP-IB interface
10. Magnetic tape system

SOFTWARE (GEODATA TEST PROGRAM)

1. Subroutine INPUT
2. Subroutine CONTROL
3. Subroutine EDRBUILD
4. Subroutine PRINT
5. Subroutine OUTPUT
6. Input buffer "IN"
7. Print buffer "PRINT"
8. Output buffers "OUT 1" and "OUT 2"

The total GEODATA SYSTEM STRUCTURE and inter-relation between these hardware/software components is shown in Figure 15. This figure is a visual representation of the system design and structural components.

The software programs HEADER and CALIBRATION are not shown in Figure 15. because they are used as auxillary programs to obtain pre and post test data. The functions of these programs are described in Appendix H.

SYSTEM DESIGN CRITERIA AND SPECIFICATIONS

In addition to meeting the system requirements the following criteria and specifications were formulated as a base for the GEODATA PROCESSING SYSTEM design.

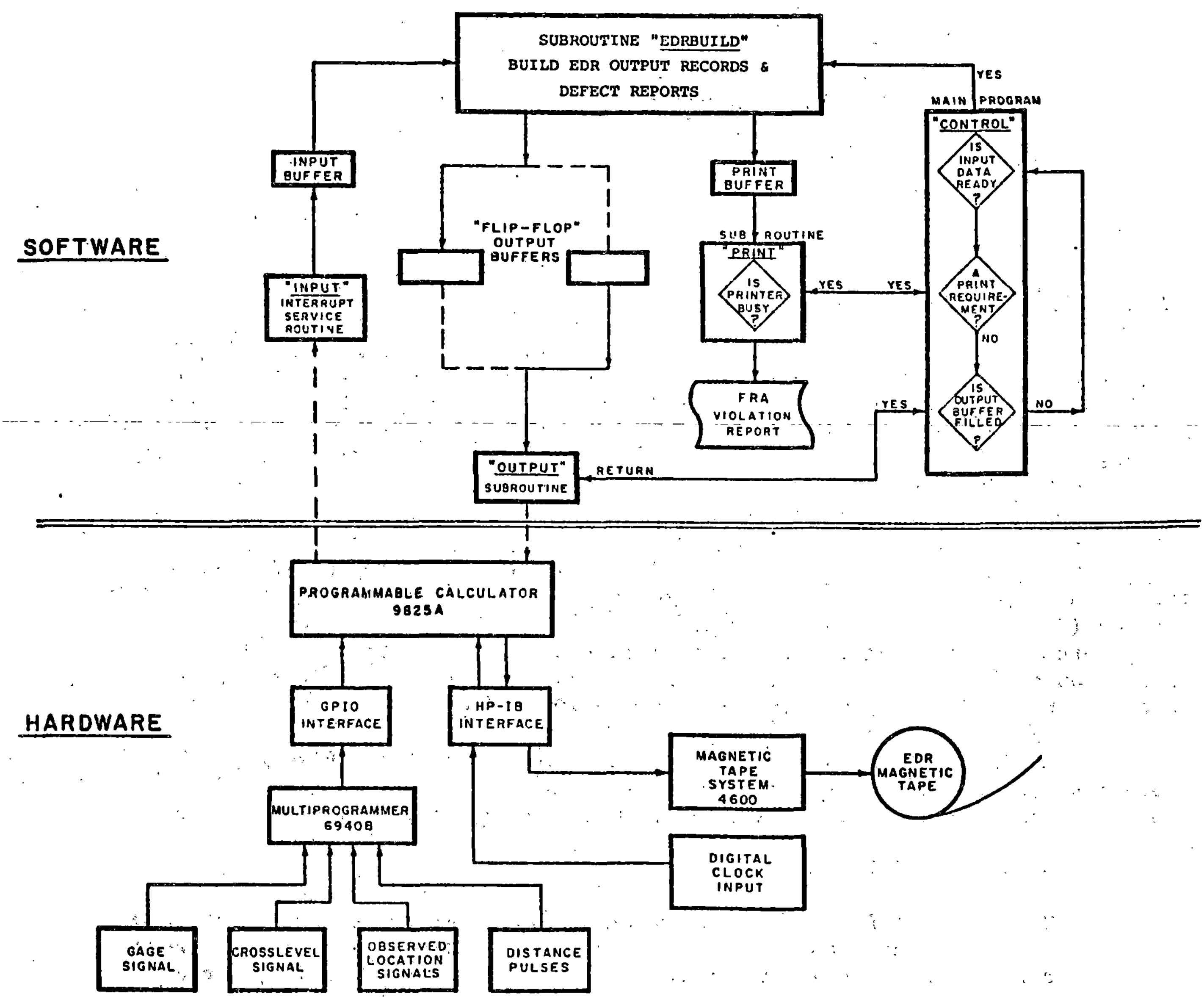
DESIGN CRITERIA

1. Automatic interrupt buffered input with the highest system priority
2. Print buffers for semi-real time print of FRA violations
3. "Flip-Flop" buffered output design
4. Two output magnetic tape files per test

    a. File #1 - Test data
    b. File #2 - Header data

FIGURE 15

HARDWARE/SOFTWARE COMPONENTS



5. Geodata Software System to have 3 separate programs with each to reside in the 9825A memory separately:

   a. pre test - GEODATA CALIBRATION PROGRAM
   b. during test - GEODATA TEST PROGRAM
   c. post test - GEODATA HEADER PROGRAM

6. FRA Defect Criteria - shown in Figure 16.

SYSTEM SPECIFICATIONS - SOFTWARE

1.	Data sample distance	- 4.593 feet
2.	Output volume	- Magnetic Tape
3.	Number of tracks on magnetic tape	- 9
4.	Density of magnetic tape	- 800 BPI
5.	Output frame (record) size	- 50 Bytes
6.	Output block size	- 2000 Bytes
7.	Output frame format	- Figure 17
8.	Number of files per test	- 2

   a. Test
   b. Header

GEODATA TEST PROGRAM

The main objective of the GEODATA TEST PROGRAM is to receive input data, monitor this data, log it on magnetic tape and printout in real time any FRA violations in gauge and cross-level readings. In order to perform this task and not lose any input data, the GEODATA TEST PROGRAM was designed utilizing an extensive buffering system. Figure 14 shows the GEODATA TEST PROGRAM logic flows and the corresponding buffers. The input buffer "IN" has the highest priority which assures there will be no data loss. The input and print buffers are automatic interrupt buffers and are filled and emptied as required. The output buffers "OUT 1" and "OUT 2" are programmed interrupts only in that one of them begins to empty out when it has been filled with 40 Engineering Data Records (EDR) or 2000 bytes. This transfering out takes quite a while and is interrupted for data input and some data processing. Two output buffers are used because there becomes a requirement to begin to fill the output buffer before it has finished emptying the previous 2000 bytes.

The GEODATA TEST PROGRAM has a main program (CONTROL) and five labeled subroutines. The hierachal structure of this program is shown in Figure 18. The functions of each GEODATA TEST PROGRAM subroutine is described as follows:

SUBROUTINE INPUT:

Subroutine INPUT sets up a buffered array "IN" to receive input from five different input sources. These inputs are placed in a six word array to be received by subroutine EDRBUILD. The five inputs are as follows:

FIGURE 16

GEODATA PROGRAM

FRA DEFECT CRITERIA

	TRACK CLASS 1	2	3	4
1. GAUGE (+) (OPEN) *	+1.25	+1.0	+1.0	+ .75
2. GAUGE (-) (TIGHT) *	- .5	- .5	- .5	- .5
3. X-LEVEL (+) (VARIATION) TANGENT ONLY	3.0	2.0	1.75	1.25

* Standard Gauge = 56.5 inches

FIGURE 17

OUTPUT FRAME FORMAT

ENGINEERING DATA RECORD (EDR) FORMAT

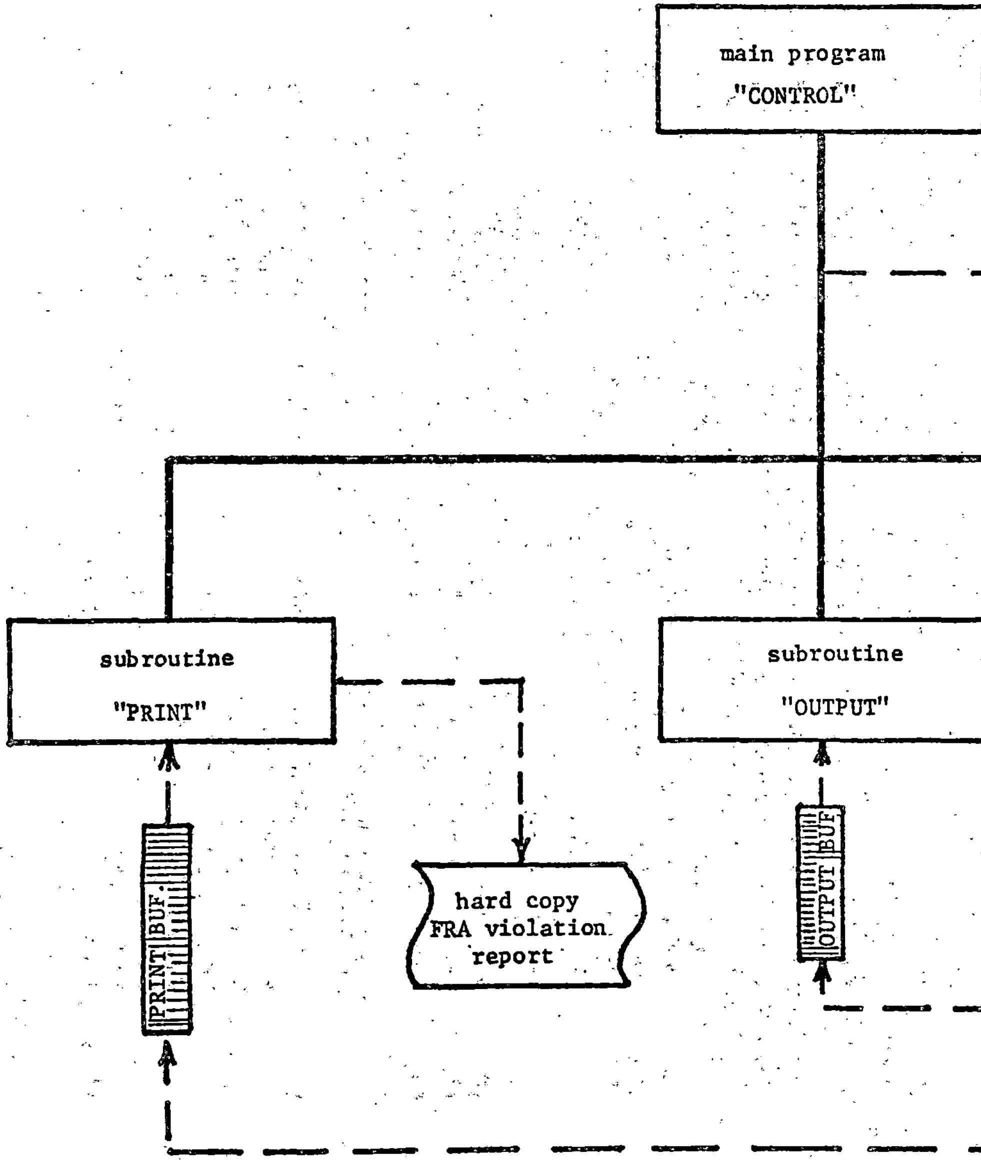
WORD NO.	DATA DESCRIPTION	PROGRAM VARIABLE NAME	FORMAT	UNITS	TYPE	NO. BYTES
(1)	Record (Frame) No.	M(1)	F6.0	Numeric	EBCDIC	6
(2)	Gage Measurement	M(2)	F6.2	Inches	EBCDIC	6
(3)	Cross Level Measure	M(3)	F6.2	Inches	EBCDIC	6
(4)	Mile Post No.	M(4)	F6.0	Miles	EBCDIC	6
(5)	Distance Past M.P.	M(5)	F6.0	Feet	EBCDIC	6
(6)	Clock Time from Test	M(6)	F6.2	Sec.	EBCDIC	6
(7)	Spare	M(7)	F4.0	———	EBCDIC	4
	CALCULATED DATA					
(8)	X Level Variation	C(1)	F6.2	Inches	EBCDIC	6
(9)	FRA X Level Violat	C(2)	1 b	On/Off	BINARY	1
(10)	FRA Gage Violation	C(3)	1 b	On/Off	BINARY	1
	OBSERVATION DATA					
(11)	Mile Post Event Mark	Ø(1)	(LSB)	On/Off	BINARY	↑
	Bridge Event Mark	↓		On/Off	↓	
	Road X Event Mark			On/Off		1
	Switch Event Mark			On/Off		
	Observer Comment*			On/Off		
	Right Curve			On/Off		
	Left Curve	↓	(MSB)	On/Off	↓	↓
(12)	Spare	Ø(2)		Off	BINARY	1
						50

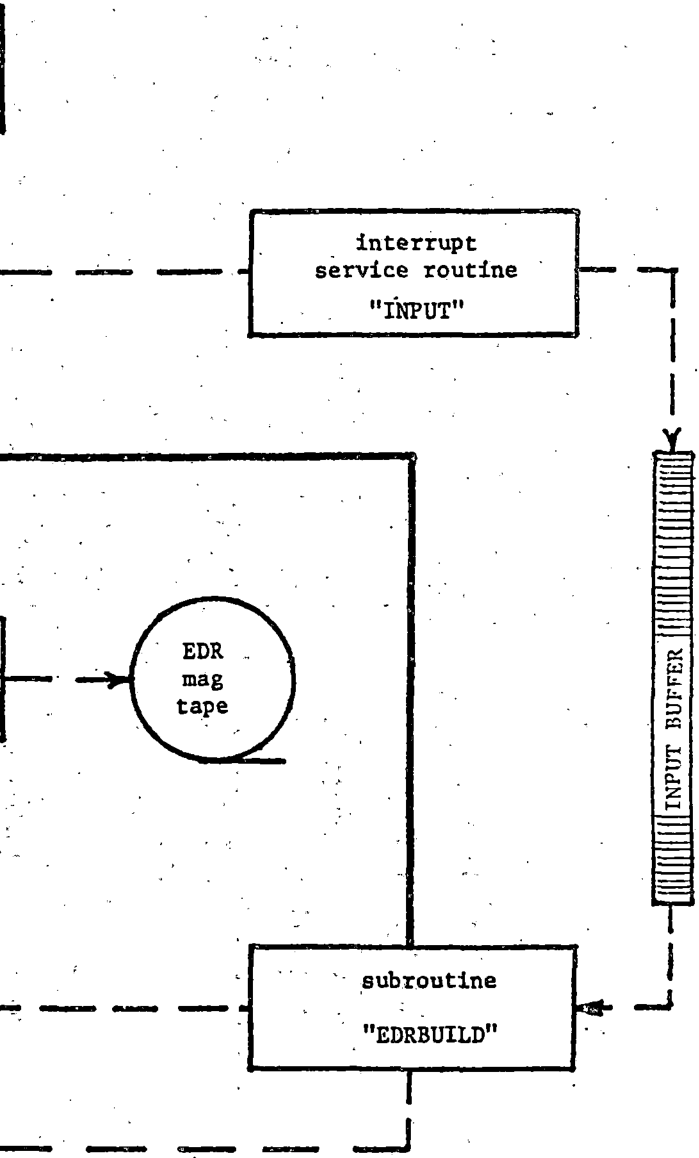
END OF RECORD

Block size is 2000 (40 Records)

FIGURE 18

HIERACHAL STRUCTURE




interrupt
service routine
"INPUT"
INPUT BUFFER
EDR
mag
tape
subroutine
"EDRBUILD"

1. Distance - words one and two
2. X-level - word three
3. Gauge - word four
4. Observations - word five
5. Clock time - word six

SUBROUTINE EDRBUILD

Subroutine EDRBUILD builds the Engineering Data Record (EDR) to be output to magnetic tape and determines the FRA defects in gauge and cross-level and places them in a print buffer. The main function of this subroutine are as follows:

1. Analog to digital conversion of all inputs to decimal engineering units
2. Constructs Words in EDR format for magnetic tape output
3. Distance/milepost calculation
4. Gauge and X-level value calculations
5. X-level variation calculation
6. FRA gauge and X-level violation logic
7. Fills output buffer

SUBROUTINE PRINT

Subroutine PRINT prints out in real time the FRA violations for the TGC operator to observe. These prints are buffered in a manner that allows all other program inputs and calculations to continue during this period. Subroutine PRINT continues to check the status of the printer and when the printer is not busy, the next print frame in the buffer will be printed.

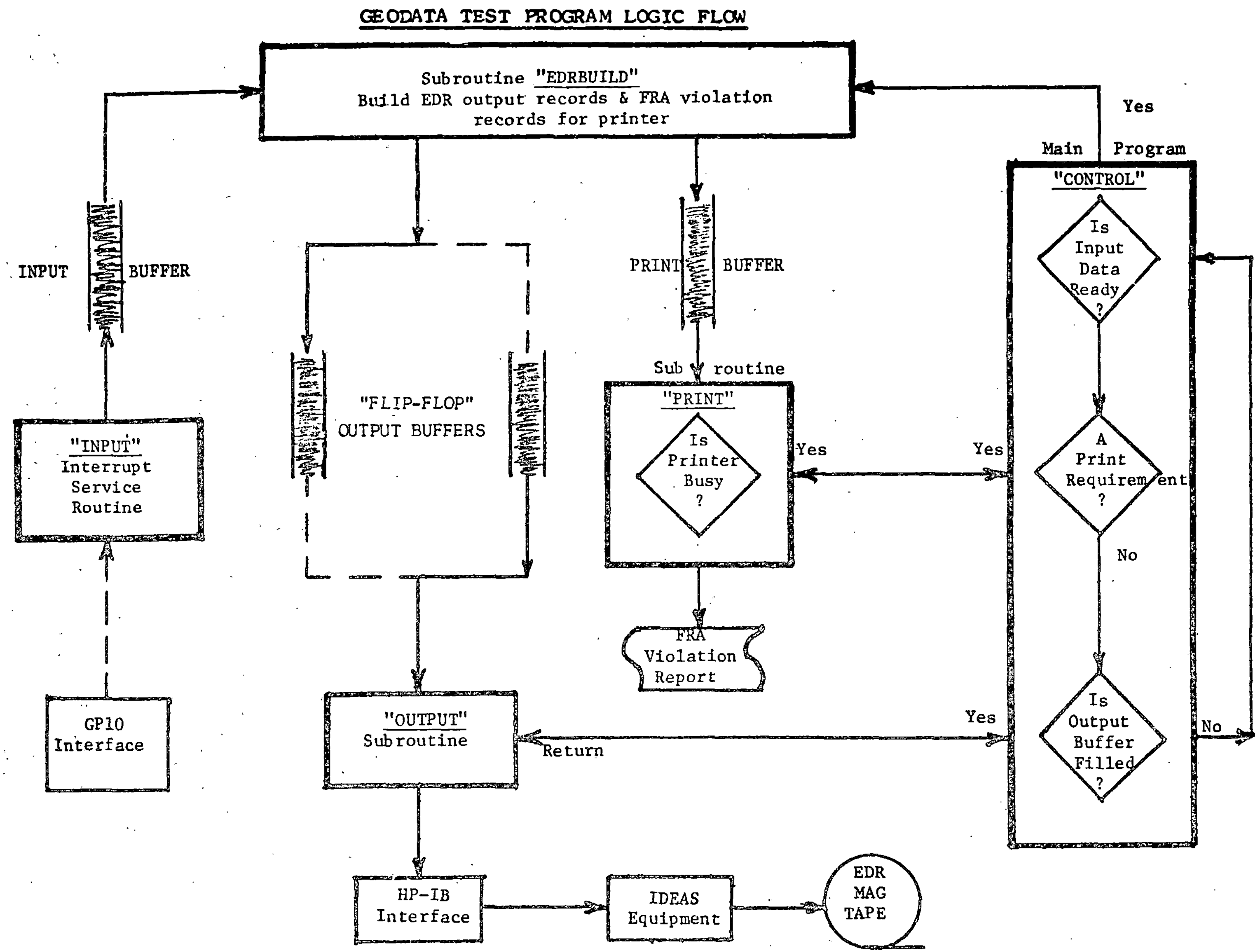
SUBROUTINE OUTPUT

Subroutine OUTPUT places the fixed length 50 byte EDR record in a 2000 byte buffered array to be received by the magnetic tape equipment via the HP-IB interface. Since the data transfer of 2000 bytes out to the magnetic tape equipment takes longer than the data input cycle time, the output transfer must be interrupted to allow inputs and data processing. This situation requires a "flip-flop" output buffer scheme as shown in Figure 19. One buffer is being filled while the other is being emptied. Subroutine OUTPUT also conducts test termination procedures such as setting control words, writing end of file on the magnetic tape, etc.

SUBROUTINE PRINTEST

Subroutine PRINTEST may be executed upon the option of the TGC operator at the completion of a test. The sole purpose of Subroutine PRINTEST is to print post test data that has been accumulated during the test. These data items are shown here; the first ten are used by

GEODATA TEST PROGRAM LOGIC FLOW



the TGC operator as Inputs to the Header program; the last five data items along with the first ten may be used by an analyst to trouble shoot in the event problems occur and the test is prematurely aborted.

TEST RESULTS
DATE (mdy)
TIME (hms)
SAMPLES
START MP
END MP
TEST DIST.
TIME TOTAL
TRACK CLASS
GAUGE DEFECTS
XLEV DEFECTS

PART XI

DEVIATION REPORT DISTRIBUTION

STATEMENT ON DEVIATIONS

A deviation report is assembled on each segment of railroad track inspected by the Iowa Track Geometry Car. The objectives of this chapter are to identify recipients of the deviation reports and to establish a deviation report format appropriate to each report recepient.

Data collected by the TGC is recorded on an analog strip chart on a paper tape and on magnetic tape. Reports prepared by each of the recording mechanisms are processed separately and have different distribution channels.

ANALOG STRIP CHARTS

The primary purpose of the Iowa TGC program is to assist roadmasters and division engineers in maintaining and improving Iowa's rail lines. An inexpensive and relatively easily understood format for presenting track deviation to these individuals is the analog strip chart. The expanse of the strip chart coupled to its unsummarized nature limits any widespread dispersion. Most of the work in developing a format and distribution process for analog charts has been directed towards use by roadmasters employed by Iowa's railroads. The ease with which a roadmaster can relate the actual measurements produced on the chart to track conditions along with the small amount of track he is directly responsible for makes him a prime recipient of analog charts.

At the completion of a days testing the analog strip charts are not turned over to the on-board railroad representative. Instead, the Iowa TGC operator brings the original charts back to the Ames Office of the Iowa DOT. Copies of the strip charts are made and forwarded on to the division engineering office of the appropriate railroad.

The Iowa DOT representative and the railroad representative review the analog chart while it is on the survey vehicle. The roadmaster is notified of hazards as they are measured and occasionally the survey vehicle is stopped for hand verification of measurements. Due to the repetive nature of the Iowa TGC survey operation most roadmasters are familiar with the analog charts and do not question the recorded measurements.

The individual railroads are responsible for the distribution of the strip charts to their own personnel. District engineers normally forward the strip charts to the roadmasters directly responsible for the segments of tested track. One railroad has used the analog charts in determining a speed ordinance before the Transportation Regulation Board.

Private individuals can also purchase a copy of any analog chart from the Iowa DOT for the cost of reproduction. Recipients of this nature are infrequent and cannot be reached by a formalized distribution process.

The original analog strip charts are retained within the Iowa DOT at the Railroad Division. Before a computer assessment of geometry data was available, a manual assignment of point values for a track quality rating was made on the original strip charts. A copy of the charts was then sent to the Planning and Research Division of the Iowa DOT. With the computerized system the more quantitative statements from the computer are preferred over the manually assigned strip charts.

Other state employees having a use for the TGC analog strip charts are the state rail inspectors and the TGC operator. State rail inspectors use the strip charts as an aide in determining visual inspection schedules. The TGC operator uses the strip charts while on the vehicle to insure the reliability and presence of data going onto the magnetic tape. If the analog trace is lost, the test is immediately haulted and equipment adjustments are made.

Chart recording on the Iowa TGC displays measurements for gauge and cross levels. Each segment of test track has a chart identified by a label. This label, as shown in Figure 20 is stamped onto the chart paper at the beginning of a test run and is filled out by the TGC operator.

An annotated strip chart is shown in Figure 21. The Iowa TGC analog strip chart has two traces for measurement data and three traces for marked events. To determine measurement speed it is necessary to divide the number of speed marks per mile into 600.

While a test is underway the TGC operator records on-the-ground location markers and makes general operating observations on the strip chart. If the chart indicates a problem area the TGC operator verbally informs the railroad representative of the problem. The railroad representative is encouraged to record such verbal communications in a field log. This log allows problem areas to be identified and corrected without waiting for a copy of the strip chart.

<u>DEVIATION PRINTOUT--Real Time Processing</u>

On-board analysis of track geometry data is performed on a programmable calculator. Each reading collected by the measurement sub-systems is examined in real time for deviations exceeding FRA track safety standards. Upon detection of a reading greater than standards the violation and its location is identified on the calculator output tape. The acronyms used for the data on the print-out are show below.

G = gauge in inches
X = cross-level variation from 0 in inches
M = milepost location in miles

A sample printout would appear as follows:

G = -1.27	M = 137.48
X = 3.16	M = 137.61
X = 3.23	M = 137.62

FIGURE 20

STRIP CHART LABEL

IOWA DEPARTMENT OF TRANSPORTATION
RAILROAD DIVISION

Date 5-18-77

RAILROAD I.C.G. CLASS III

DIVISION IOWA SUBDIV. ALBERTLEA SUB

LOCATION M.P. 75.5 TO M.P. 0

FROM IA. LINE TO WATERLOO

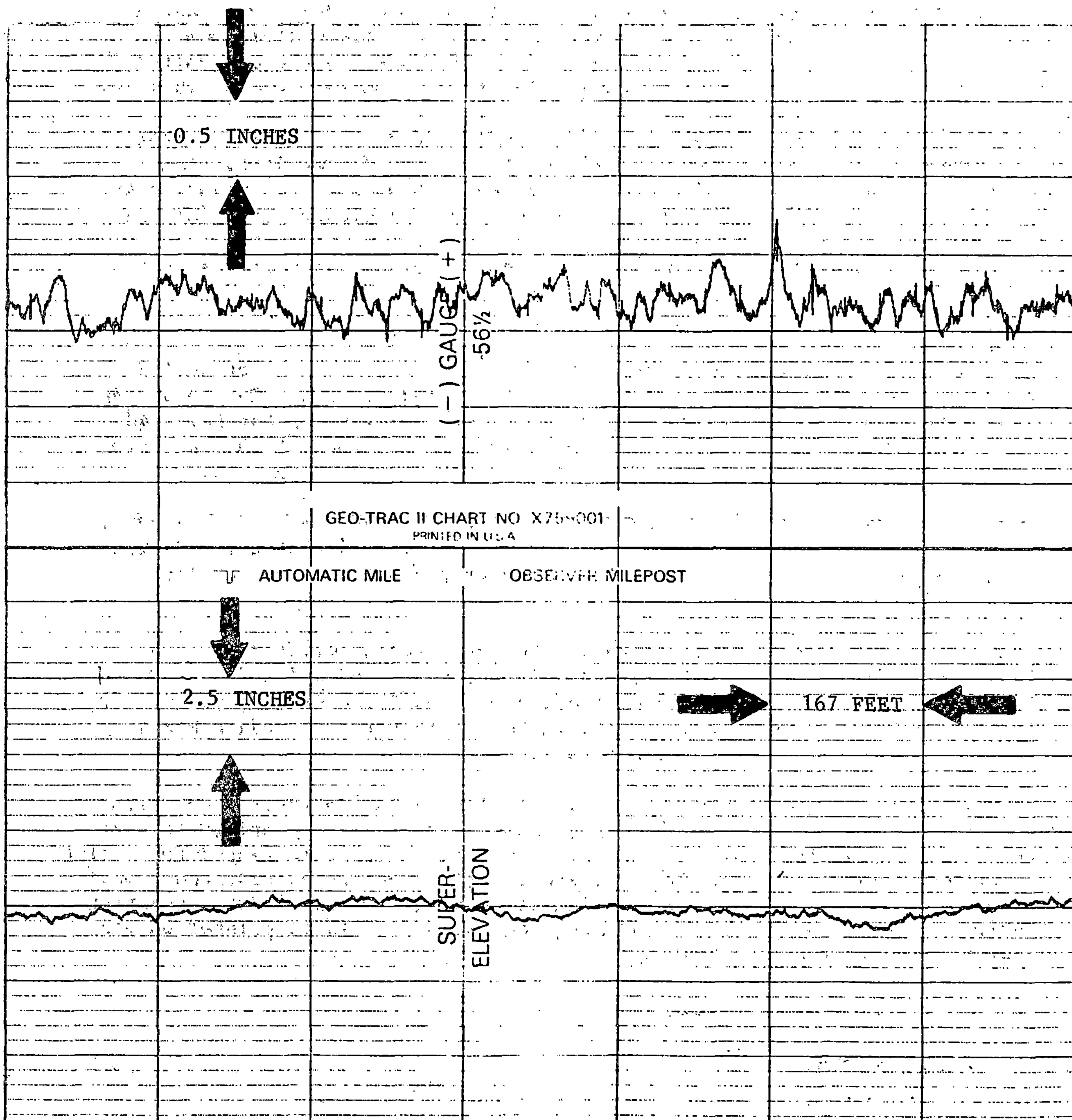
R. R. REP. V. BATEMAN TITLE TRACK SUP.

MARK ON TAPE INDICATES VERBAL NOTIFICATION
OF DEFECT TO CARRIER REPRESENTATIVE

T.G.C. OPERATOR CHRIS

FIGURE 21

ANNOTATED STRIP CHART



The printout tape is intended to be handed over to the railroad representative at the end of the test run. It represents a short but concise listing of all measurable deviations. A roadmaster can use the listing to organize his maintenance effort. Since the same roadmaster rides up to 3 days on the TGC, a short header and a summary are put on the tape for future identification.

This type of deviation report has been well received by the railroad representative. It reduces turnaround time between detection of a deviation and the written notification of the detection to the roadmaster. One change in the current test program that will be made because of roadmaster comments is to represent milepost locations in terms of feet distance instead of hundredths of a mile. For example, milepost recording 10.11 would be recorded as 10 + 591.

While the test is in process the calculator's LED display shows in real time the gauge, cross-level and milepost locations for all readings. This visual presentation of all readings in used by the TGC operator to insure that data is being received by the system. A blank display indicates that data is not being received. A display showing values in deviation ranges when the printer is not recording deviations would indicate a malfunction in the system.

DEVIATION PRINTOUT--Off Line Exception Program

Off line exception programs which use the track geometry data collected and stored by the Iowa TGC on magnetic tape have been developed. The resulting deviation reports are used by State track inspectors working for the Railroad Division of the Iowa Department of Transportation. The format of the deviation report has been tailored to the specifications of the track inspectors.

The first generation off-line deviation report for the Iowa TGC is shown in Figure 22. Note that the event switchs are all displayed and that the location of the visual milepost is compared to the measured milepost so that on-the-ground location is maintained.

A deviation is designated by a ← located next to the digital printout. To date, no adjustment to cross-level deviations encountered while in a curve have been attempted. Once the degree of curvature and the operating speed have been entered into a base record file it will be possible to make adjustments for elevation of the outer rail while in a curve.

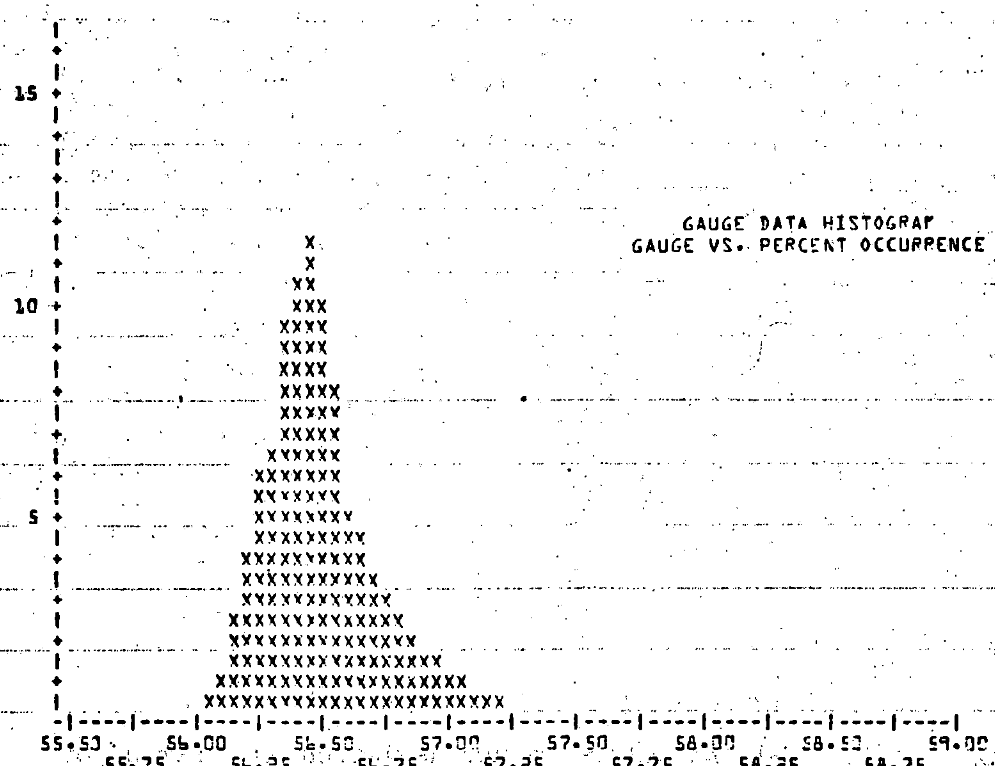
As noted earlier, the programming for off-line deviation reports has been directed towards the development of user originated data. Fancy printouts that lump data into groups are desirable, however the rail inspectors wanted to receive all deviations uncovered by the TGC. Hopefully after the inspectors become more comfortable with computer printouts it will be possible to consolidate deviation information. For example, a string of gauge deviations could be printed on one line instead of printing each reading:

FIGURE 22

OFF LINE DEVIATION REPORT

TGC TRACK EXCEPTION REPORT
83302 RI ILL 75. 64. ALTOONA TO ELDON OTTUMWA TO ELDON TAPE #2

	MILEPOST	DISTANCE	GAUGE	CROSS LEVEL	X-LEVEL VAR
**ROAD	74.83	4384	56.75	-1.06	1.14
	74.82	4214	57.79 ←	2.58	1.32
	74.80	4210	57.75 ←	2.86	1.60
	74.73	3870	57.21	-1.50	3.08 ←
	74.61	3195	57.77 ←	-1.72	0.82
	74.53	2795	57.81 ←	0.20	0.93
	74.53	2791	57.89 ←	0.22	0.66
**SWITCH	74.52	2768	56.61	0.62	0.44
	74.48	2516	57.77 ←	2.53	0.26
	74.48	2511	57.76 ←	2.46	0.28
**ROAD	74.32	1797	57.32	2.34	0.74
	74.27	1436	57.77 ←	0.97	1.04
	74.26	1371	57.86 ←	-0.72	0.48
	74.26	1367	57.77 ←	-0.10	0.40
	73.98	5197	57.87 ←	-3.08	0.88
	73.98	5193	57.85 ←	-3.28	0.68
	73.98	5186	57.80 ←	-3.50	0.46
	73.97	5175	57.86 ←	-3.78	0.34
	73.97	5171	57.85 ←	-4.76	0.62
**ROAD	73.96	5064	57.35	-2.44	2.36
**BRIDGE	73.69	3631	56.84	0.36	0.40
**ROAD	73.61	3222	56.67	0.10	0.26
	73.39	2761	57.75 ←	-1.76	0.60



this:

Milepost to	Milepost	Maximum Gauge	Leading* Gauge
10.11	10.13	57.61	57.57

replaces:

Milepost	Gauge
10.11	57.57
10.11	57.58
10.12	57.61
10.12	57.55
10.13	57.51

State track inspectors are still acquiring experience with data collected by the Iowa TGC, however, some preliminary attempts at data consolidation have gained acceptance. Figure 22 shows a pictorial representation of gauge data collected on a test segment. This histrogram and more importantly an interpretation of similar histograms are being used by the track inspectors. The histrogram in Figure 22 has gauge measurements in inches on the X-axis and the percentage of gauge data points on the Y-axis.

The off-line deviation report is prepared weekly in conjunction to the transfer of field tapes to the master file at the data processing center. In its present form the report is bulky and is not readily available for reproduction. As consolidation is accepted by the State track inspectors it will become possible to reduce the material to a simple summary report on track condition that could be produced annually.

*Leading Gauge = First encountered gauge deviation in a string of deviations.

CHAPTER VI

IDENTIFY PERSONNEL REQUIREMENTS FOR ALTERNATIVE HIGH-RAIL TGC OPERATION MODES

PART I

PERSONNEL REQUIREMENTS

STATEMENT OF PURPOSE

The Federal Railroad Administration (FRA) monitors the inspection of railroad tracks to promote compliance with Federal Track Safety Standards. Visual inspections made by walking a rail line or by riding a slow moving vehicle can only permit a relatively small amount of inspection. However, track geometry and important inspection parameters, may be detected at relatively high speeds with automatic equipment mounted on track geometry measurement vehicles.

A fleet of track geometry vehicles have been developed by the FRA. The first generation of test cars T-1, T-2, T-3 and T-4 were designed to measure track geometry under loaded conditions. Each car has a total length of 85 feet, a total weight of 55 tons with a load of 13.75 tons per axle.

Another type of inspection vehicle, the light weight highway-railroad (high-rail) car, may provide an acceptable inspection record for branch line and lower class trackage. However, it does not have the capacity to do so in a loaded environment. The FRA is interested in supplementing the national track inspection program with a fleet of high-rail vehicles. The purpose of this task is to identify personnel requirements for the operation of high-rail Track Geometry Cars (TGC's).

This report proposes an operational mode for high-rail TGC activities under State direction and Federal regional direction. Staffing considerations for high-rail car operation will involve the areas of vehicle operation, maintenance, scheduling, data processing and general support.

ADVANTAGES OF HIGH-RAIL VEHICLES

The basic personnel requirements to perform testing on a rail bound passenger car type inspection vehicle consists of a test crew of six people, a train crew, a Federal Track Inspector and a railroad representative. A minimum of eleven people and several support personnel are needed to keep the rail inspection vehicle functioning. It is labor intensive to perform inspections of this type on branch lines, particularly on Class I tracks where operating speeds of 10 miles-per-hour occur.

In addition to labor savings, high-rail vehicles cost less to procure and operate. Train concept inspection vehicles are expensive. A diesel locomotive with two coaches similar to those used on the federal inspection cars would have a replacement cost in excess of 1.5-million dollars. On-board computer equipment and measurement devices would increase the total investment to a point where operation on a branch line becomes cost prohibitive when compared to the alternatives. A fleet of high-rail cars would cost less, would retain some limited inspection capability should a breakdown occur and probably operate with less fuel consumption than a single train concept inspection vehicle.

A major advantage of the high-rail cars over the train type vehicle is the increased mobility offered by highway travel. Testing units confined to just rail travel, at times experience some back tracking when testing on dead-end branch lines. Backing over track already tested at 10 miles-per-hour to reposition the vehicle for continued testing decreases fuel economy, labor productivity and the testing potential during a test day. A high-rail vehicle after completing a survey simply sets off the track at the nearest road crossing and then operates over the highway to the next survey site.

With regards to safety there is insufficient data to draw any direct comparisons between high-rail and train concept measurement vehicles.

PART II

OPERATIONAL MODES

BACKGROUND FOR OPERATIONAL MODES

The operational mode of a high-rail track geometry car depends upon the objective of the inspection. Such objectives can include measureing track geometry to determine whether it complies with federal standards, inspecting track to determine whether it is being maintained adequately, or simply collecting a reference inventory of track geometry data.

This report will discuss two modes for a high-rail TGC program. The first mode is one under State direction based on the objectives that; 1) All rail lines within the State are inspected annually; and 2) Inspections will be used to collect rail data for planning purposes and to assist railroads in maintenance planning. A mode of operation under the regional offices of the FRA was asssumed to have one objective: 1) The periodic inspection of all rail lines within the region for the identification of deviations from Track Safety Standards in connection with the Federal compliance and enforcement program.

IOWA MODE OF OPERATION

Iowa shares the responsibility of enforcing track safety standards with the Federal Railroad Administration. The Iowa TGC inspection program is used to assist in identifying track segments containing geometric configurations which may pose train derailment risks. As Iowa perceives it, satisfactory fulfillment of this purpose requires at least an annual inspection of all rail lines in Iowa, therefore it is the Iowa DOT policy to inspect branch lines once a year and main lines twice a year.

Iowa's rail system includes approximately 7,400 miles of roadway. Annual inspection of this system would require about 9,100 miles of on-the- rail inspection per year. While the Iowa TGC is currently operating at this rate it would be possible to inspect a larger system with one TGC. Assuming an average inspection speed of 17.5 miles-per-hour, 200 work days per year, and five hours on-the-rail operation per day a TGC could inspect 17,500 miles per year. However, the expense for these additional inspections is currently unjustified given the limited applications the State has for the rail inspection data.

High-rail track geometry car allows Iowa the opportunity to acquire the data needed for railroad planning on a statewide basis. Prior to the TGC inspection program there was no source of information on railroad conditions that was reliable, uniform and sufficiently detailed for rail planning. Chapters IV and V of this report identify examples of the analytical techniques that Iowa planners can use with the information supplied from the TGC inspection program.

The identification of deviations is expected to result in remedial actions by the appropriate railroad companies. The TGC program is also designed to assist railroad companies in developing maintenance-of-way programs that have the objective of maximizing the limited amounts of railroad funding.

MODE OF OPERATION UNDER FEDERAL DIRECTION

Operation of a TGC in an enforcement role requires that inspected tracks containing deviations be subject to the same on-site enforcement actions as those inspections which are provided by the more conventional methods (track walking or train type inspection vehicles). Companies are required to bring the track to comply with federal track safety standards, including the associated penalties for non-compliance, or to halt operation over the track. (Reference: 49 Code of Federal Regulations, Section 213.5). The subsequent TGC or follow-up routine inspections should then determine if the remedial work was performed. If the deviations have not been corrected, additional enforcement actions would result. Follow-up inspections are vital to the documentation of the effectiveness value of the safety effort.

Assuming that a federally directed TGC inspection program requires follow-ups, the potential miles inspected per year would be lower than in the State program. Using the assumptions of the Iowa operational mode as a baseline estimate of inspection mileage, plus a 10% follow-up use of the high-rail vehicle the TGC under federal operation could have the potential to inspect about 15,900 miles per year. (17,500 miles/year - 10% ≈ 15,900 miles/year).

A federal operational mode would employ certified track inspectors thereby creating vehicle stops for non-geometric deviation cause as well as additional stops for inspection and measurement which may be necessary for complete documentation. These stops would further reduce the utilization of the TGC. From the experience matrix presented in the Chapter II visual inspection on non-geometric deviations such as broken joint bars and other deviations would reduce utilization of a federally operated TGC to 8,500 miles per year. However, it should not be overlooked that the inspection effort would be more comprehensive.

The focus of the operational mode for a federally directed TGC inspection program is strictly in connection with the track standards compliance and enforcement program.

PART III

STAFFING PLANS

PERSONNEL REQUIREMENTS OF THE IOWA OPERATION

The Iowa TGC is currently staffed by a two-man crew. One man is needed to control the operation of the vehicle while the other man handles the instrumentation. Under the operating procedure used by the Iowa DOT a railroad representative and a State TGC operator make up the operating staff.

A railroad representative drives the vehicles while it is on track. This provides for safer on-track operation of the vehicle since the on-board rail representative is an authorized and qualified operator of the carrier.

The State TGC operator drives the TGC to and from the inspection sites. Freeing the State operator from driving the vehicle while on track allows him to maintain proper testing procedures and to annotate the measurement recordings. However, when the unit is being used in the federal track inspection activity, the FRA requires that a federally authorized State track inspector be on board. Light maintenance of the vehicle and equipment is also performed by the State TGC operator. Operation of the instrumentation and minor in-the-field maintenance duties require that the State operator is well versed in the technical components of the Iowa TGC.

Normal preventative and minor corrective maintenance of the Iowa TGC is done on weekends at the central motorpool. During normal operations the Iowa TGC does not return to the central motorpool on a weekly basis. Usually the operator parks the car in a district office and uses a loaner vehicle to return to the central office at the end of a testing week. For this reason the Iowa TGC receives only preventive and minor corrective maintenance once a month.

The routine light maintenance provided by the State operator of the vehicle, while the less routine maintenance is accomplished in the district shops. Since the vehicle carries an extensive set of replacement circuitry boards the manpower for light routine maintenance becomes part of the normal workload of the State operator.

The schedule for operating the TGC is developed by the alternate TGC operator. To reduce the amount of field work associated with the TGC operation, the Iowa DOT employs two TGC operators. While one operator is in the field, the second operation prepares schedules, requests and reviews computer listings of TGC data, and is assigned other duties by the Railroad Division.

Once the computer programs to analyze track geometry data are written, the manpower requirements for data processing are reduced substantially. Someone must take the submitted jobs and load them on the next computer run and someone must operate the computer. The amount of time these individuals are actually working on the TGC data processing is almost negligible.

A limited amount of personnel for general support is needed to keep the TGC in the field. Supervision of the State operators involves managers from within the Railroad Division. Proposed schedules, inspection accomplishments and operational problems are all reviewed. General accounting, clerical and facilities management personnel are needed to provide support staff for the effort.

The estimated manhours to keep the Iowa TGC operating per week and per month are shown in Table 27. This table also identifies the category of personnel. Estimates were based on three years of experience with a high-rail inspection program. Abnormal personnel start-up difficulties experienced in setting up the program have been excluded from this estimate.

TABLE 27

ESTIMATED MANHOURS
IOWA MODE OF OPERATION

CATEGORY OF PERSONNEL	PER WEEK	PER MONTH
High-Rail Vehicle Operator	40.0	173
Maintenance Workers[2]	4.0	17
Alternate TGC Operator[3]	20.0	87
Data Processing	0.5	2
Other General Support	4.0	12
Totals:	68.5	296

NOTES:

1. 4.33 weeks per month.
2. Averages slightly over two (2) men working one (1) full day per month.
3. Performs scheduling, data assembly and data reporting.

PERSONNEL REQUIREMENTS FOR A POTENTIAL MODE OF OPERATION OF HIGH-RAIL VEHICLE

The basic manpower needs for a single car inspection program were outlined in Table 28. Any program that attempts to use the inspection vehicle five (5) days per week on-the-rail will encounter the same personnel requirements. An inspection program with only four (4) days of on-the-rail work has been estimated in Table 28.

TABLE 28

ESTIMATED MANHOURS
FOUR DAY INSPECTION WEEK - ONE VEHICLE

CATEGORY OF PERSONNEL	HOURS PER WEEK	HOURS PER MONTH
High-Rail Vehicle Operator	40.0[1]	173
Maintenance Workers	4.0	17
General Support	4.0	17
Totals:	48.0	207
Estimated Miles Inspected Per Year:	5440	

NOTE:

1. Eight hours per week are spent on scheduling and reporting.

Manpower requirements for a five vehicle fleet of track geometry cars will depend on the objectives and conditions of the inspections. A staffing plan designed to use personnel only for high-rail inspection work would be considerably different from one in which additional duties and functions are assigned to the inspection personnel.

Staffing requirements presented in the remaining portion of this report are based on the operational mode developed in Part II and the following assumptions:

1. Inspection vehicle is used on-the-rail four (4) days per week under Scenarios 1 and 2 In Scenario 3 the vehicle is used five (5) days per week with maintenance being performed on weekends.

2. Vehicle operators are certified railroad track inspectors. Operators are able to fulfill the light maintenance requirements associated with the operation of the inspection equipment.

3. Supportive staff have additional responsibilities and are not required to work solely on the high-rail inspection program.

Manpower estimates for the various operating scenarios are presented in Table 29.

TABLE 29

ESTIMATED MANHOURS
FIVE VEHICLE FLEET

CATEGORY OF PERSONNEL	SCENARIO 1 FOUR DAY OPERATION		SCENARIO 2 FOUR DAY OPERATION		SCENARIO 3 FIVE DAY OPERATION	
	HOURS PER WEEK	HOURS PER MONTH	HOURS PER WEEK	HOURS PER MONTH	HOURS PER WEEK	HOURS PER MONTH
High-Rail Vehicle Operator	200	865	200	865	200	865
Maintenance Workers	20	87	20	87	20	87
Support Operator	0		40	173	40	173
Other General Support	20	87	20	87	20	87
Totals:	240	1,039	280	1,212	280	1,212
Estimated Miles Inspected Per Year:	27,200		34,000		34,000	

The paperwork and report writing expected from the vehicle operators may require one full day per week. This would indicate that Scenario 2 or 3 would be the most suitable staffing plan under the given assumptions. A side benefit of this plan is that it provides the personnel to cover during vacations so that the expensive inspection equipment does not remain idle.

CHAPTER VII

Iowa Track Geometry Car Operators Safety Manual

PART I

GENERAL STATEMENT OF SAFETY

It is the policy of the Iowa Department of Transportation to exercise its responsibilities for the inspection of railroad track in the State of Iowa, in a manner which provides for a high degree of safety. Safety rules and regulations which are consistant with the proper fulfillment of this responsibility are intended to maximize safety of agency and railroad personnel as well as the general public. The safety rules contained herein are to be observed by all personnel who work on or visit the Iowa Track Geometry Car.

Safety is of the first importance in the discharge of the track inspection work. It is impractical to include rules and instructions for safe practices to meet all contingencies. Therefore, it is the responsibility of each person on the Iowa TGC to be constantly alert for dangerous situations. When confronted by a situation not provided for herein, employees shall act as directed by the supervisor, or if not directly supervised, act as their own best judgement dictates.

PART II

THE ROLE OF THE RAILROAD REPRESENTATIVE

The Iowa TGC is staffed by an operator, designated by the State, and one railroad employee. While on the track, the railroad representative drives the vehicle. This provides for a safer operation since the railroad employee will be familiar with the track being inspected and has himself been tested over the operating rules for High-rail vehicles. Placing the railroad representative in the driver's seat puts him in a position to insure that the operating rules of the railroad being inspected are followed.

Safety rules for High-rail vehicles published by the appropriate railroad shall be followed whenever the Iowa TGC is on-track. Final authority regarding interpretation and application of High-rail operating rules shall rest with the railroad representative. The safety rules contained herein are only intended to supplement the operating rules issued by the railroads.

PART III

GENERAL RULES

Rules Pertaining to Operator Safety

The following general rules for operator safety must be observed at all times to minimize the possibility of accidents and personal injury while on railroad property.

Look in both directions before stepping onto or crossing tracks.

Keep a safe distance, (15 - 20 feet) from ends of cars or locomotives when crossing tracks.

Do not walk or step on rail, frog, switch, guard rail, interlocking machinery, or other similar track structures.

Keep a careful lookout for obstructions, holes and openings to prevent tripping, slipping, falling or turning an ankle.

Do not walk where there is steam, dense smoke or other visual obstructions.

Do not lie down or cross under cars or cross between coupled equipment.

Do not stand on a track while trains are passing on the adjacent track.

Do not lean against standing cars or locomotives.

When it is unavoidable to be off of the track area when a train is passing, walk against the current of traffic watching the approaching train.

Scuffling, horseplay, practical jokes and all conduct of a similar nature is forbidden.

Rules Pertaining to Vehicle Safety

The following general rules apply to the operation of the Iowa TGC while in use on railroad property.

Exercise caution and sound warnings when passing doorways, rounding corners, and passing congested areas.

Do not run over hose lines or electrical cables with the Iowa TGC.

Do not leave the Iowa TGC where it may foul tracks or highways.

Unshielded glass containers and firearms shall not be carried on board the Iowa TGC.

Do not carry unauthorized persons in the Iowa TGC.

The Iowa TGC must be operated in a safe manner regardless of the urgency or importance of the mission.

The following precautions must be taken before leaving the TGC unattended:

(a) Engine and all other equipment turned off.

(b) Hand brake set.

(c) Wheels turned towards curb and gear lever placed in park.

PART IV

RULES PERTAINING TO OFF-TRACK OPERATION

Vehicle Operation While Off-Track

The driver of the Iowa TGC must have a valid driver's license.

Compliance with traffic laws is required and ordinary courtesy should be practiced.

Be sure all passengers are seated and all tools and equipment are secured before operating the Iowa TGC.

Do not operate the Iowa TGC down grade with the transmission in neutral.

Shut off the engine and permit no smoking when refueling.

The TGC shall not be used to tow or push another vehicle. It may be placed in a position where the beacon can be used to warn on-coming traffic of a disabled vehicle.

During all times of non-rail travel, the guage measurement carriage and the High-rail equipment must be in the retracted position and secured by the means provided for each.

Ice and frost must be removed from all windows before operation, and should be removed from the boarding steps.

Vehicle Maintenance Practices

The designated state operator is responsible for vehicle maintenance, appearance and cleanliness. Grease, dirt or debris must not be allowed to accumulate in the cab or equipment cabinets. Any unsafe condition or maintenance need must be brought to the attention of the central maintenance office in Ames.

Only authorized persons are permitted to perform work on the electrical and hydraulic equipment on board the Iowa TGC.

All conductors, wires and electrical

equipment shall be considered energized unless positively known to be deenergized and grounded. If not grounded they are not considered deenergized.

Safe practices common to work on all electrically powered equipment shall be employed.

When using the auxiliary power cable with a stationary source, be sure to properly connect the grounding cable.

Sitting or lying underneath the Iowa TGC is prohibited, except to make repairs or inspections, and then only if the brakes are set and wheels blocked.

Keep the interior of the cab and instruments clean and orderly. Keep all tools and supplies in the designated places. Do not leave tools or other material on sills, ledges and the like where they may fall or be jarred from place.

Equipment Safety Checks

Before the Iowa TGC begins an inspection run, the operator shall: check for loose bolts, missing cotter keys, fuel leaks, worn guide wheels, condition of locking pins, proper tire inflation, proper operation of lights and beacon and the condition of other wearing parts.

A running test of the Iowa TGC brakes shall be made prior to taking track measurements or within ¼ mile of the setting on point.

At least once per week or immediately after any derailment of the Iowa TGC, the designated state operator should observe that there is clearance between guide wheels flange and rail and that the flanges do not ride or bind the rail while on unelevated tangent track. A check of gauge should be made according to manufactures specification.

Check the Iowa TGC's safety devices (horn, lights, wipers, tires, beacon, etc.) and repair if necessary before operating.

When turning the vehicle over for maintenance at the completion of an inspection week, the designated TGC operator will use a safety check list for equipment inspection. Needed repairs are to be made and the check list signed and dated by maintenance personnel before the Iowa TGC can leave the maintenance garage.

PART V

RULES PERTAINING TO PREPARATIONS FOR ON-TRACK OPERATIONS

Meeting the On-Board Railroad Representative

Exercise care not to foul tracks, walks, drives or roadways when parking TGC prior to entering a facility to meet the railroad representative.

Ensure that the railroad representative has secured written confirmation of the train line-up for the day and segment for inspection. The written authority must be read and understood by all involved personnel.

Prior to the start of mearsurement work, all occupants of the Iowa TGC shall be informed and have a thorough understanding of the procedures to be followed should an emergency arise.

Prior to the start of measurement work, the designated TGC operator shall explain any duties and activities assigned to the railroad representative and/or other TGC occupants to be performed by them during inspection operations.

Setting the Iowa TGC On or Off Track

The designated state operator shall endeavor to select a road crossing with little traffic for use in setting the Iowa TGC on and off track, even if it is some distance from the inspection starting point.

When weather conditions or line of sight distance along the highway is obscured, the setting on and off track of the Iowa TGC shall be protected by flagging.

When placing the Iowa TGC on or off track keep feet clear of rail and wheels, prevent movement of the Iowa TGC until the person operating the hydraulic Hy-rail signals is clear, and exercise care not to catch hands or clothing on the Hy-rail controls or locking mechanisms.

The Iowa TGC beacon light and headlights shall be turned on while setting on and while operating on track.

When the Iowa TGC is on-track the steering wheel shall be locked in place.

The designated state operator shall operate the Iowa TGC on the highway and when placing the Iowa TGC on-track.

The designated state operator shall operate the hydraulic High-rail system.

Select for calibration purposes a segment of track offering a satisfactory sight distance in both directions and is as free of ground clutter, such as vegetation, waste material, and track appurtenances as possible.

When calibrating on double track work from the side away from the second track if possible.

Fasten calibration tools and other loose material securely before beginning the inspection run.

If it is necessary to hand start the auxiliary generator, keep fingers and thumb on the same side of crank handle and pull towards you, do not push away.

Insure that the drivers seat is locked into the proper position before beginning an inspection run.

Radio Practices and Procedures.

Instruct the railroad representative in the use of the Iowa TGC radio and perform a radio check on railroad's frequency.

Notify appropriate railroad officials by radio when the Iowa TGC begins an inspection run.

The radio operator should clearly identify the transmitting station as the Iowa Track Geometry Car along with his name.

Before transmitting, the radio operator shall listen a sufficient interval to ensure the frequency is not in use, especially for an emergency transmission. Unacknowledged transmissions must be repeated and not assumed as received.

A distress call shall be preceeded by the word "emergency" repeated three times. The call should be repeated until answered.

PART VI

RULES FOR ON-TRACK OPERATION

Vehicle Operation While On-Track

Operating rules of the railroad being inspected take precedence over any rules in this section. The railroad representative should be so informed by the designated state operator so that the Iowa TGC can adhere to the railroad's operating rules.

When the Iowa TGC is on-track the steering wheel shall be locked in place.

Unless otherwise restricted by railroad operating rules the maximum on-track speed of the Iowa TGC shall not exceed 30 mph at any time or 20 mph when taking measurements. Passage through highway grade crossings, frogs and interlocking plants shall not be made at more than 5 mph.

The maximum on-track speed of the Iowa TGC shall not exceed 30 mph at any time or 20 mph when taking measurements. Passage through highway grade crossings, frogs and interlocking plants shall not be made at more than 5 mph.

Extreme caution should be exercised when approaching highway grade crossings and the right-of-way shall be yielded to the highway traffic.

The Iowa TGC must be operated with special caution while passing work gangs on or near the track.

Persons mounting and dismounting from the Iowa TGC shall do so only when the vehicle is not moving, and shall face the vehicle using the grab irons provided.

Persons exiting from the Iowa TGC shall exercise care to check for a passing train on an adjacent track, if any, and for insecure footing or obstacles before leaving the vehicle. Do not leave the vehicle on the side next to an approaching train.

The occupants of the Iowa TGC shall not extend limbs or head outside the vehicle when it is in motion.

The operator shall request the railroad representative once in every four hours of on rail operations to check for changes in the train lin up sheet.

The operator shall instruct the railroad representative to be alert, as well as remaining so himself, for high ballast, debris or snow conditions which could damage the gauge sensors on cause the rear dual wheels to lift enough to derail the guide wheels.

The Iowa TGC shall not pass under or across a bridge of a railroad while the bridge is occupied by a moving train.

When meeting or being overtaken by a train on an adjacent track the occupants of the Iowa TGC shall:

(a) Exit from the Iowa TGC well in advance of the approaching train's passage.

(b) Position themselves well away from and on either side of the track being used by the train.

(c) Observe the train for problems such as dragging equipment, hot boxes, sticking brakes, shifted lading and the like and if seen, report it to the railroad representative immediately.

PART VII

ACCIDENT PREVENTION AND EMERGENCY PROCEDURES

The Iowa TGC is equipped with an approved first aid kit which includes a Red Cross Standard First Aid and Personal Safety manual. This equipment is located in a convenient and conspicuous place.

If an injury should occur consult the first aid manual immediately. When required, competent medical aid should be summoned. The following are basic rules and guidelines for preventing accidents and injury.

Safety Equipment

Two red flags, five 10-minute fusees and a warning triangle flare kit shall be carried aboard the Iowa TGC at all times. The TGC shall also carry any additional equipment required by the railroad rules for the track being surveyed. Any damaged or old materials will be disposed of keeping aboard only enough equipment as may be reasonably expected to be used during one incident.

Two red flags, five 10-minute fusees and a warning triangle flare kit shall be carried aboard the Iowa TGC. Any damaged or old materials will be disposed of keeping aboard only enough equipment as may be reasonably expected to be used during one incident.

Warning devices will be used at the direction and in the manner prescribed by the on-board railroad representative.

An operable 2½ lb. dry-chemical B C fire extinguisher shall be on-board the Iowa TGC every time it is operated on track.

The designated state operator will ensure that sufficient supplies and a first aid manual are contained in the first aid kit.

Hard hats and gloves should be worn during equipment calibration and other work under the TGC to protect against head injury from raising up, or hand injury from scratches from equipment or track appurtenances.

Safety Practices for Avoiding and Handling Accidents

Thin soled, open toe, cloth shoes or unbuckled overshoes must not be worn by TGC operators. Similarly they should avoid wearing loose or baggy clothing which could catch or snag on TGC equipment and cause an injury.

The designated state operator will inform all TGC occupants of the location of the on-board fire extinguisher(s). Every six months the operator shall check to assure that the extinguishers are in serviceable condition and charged.

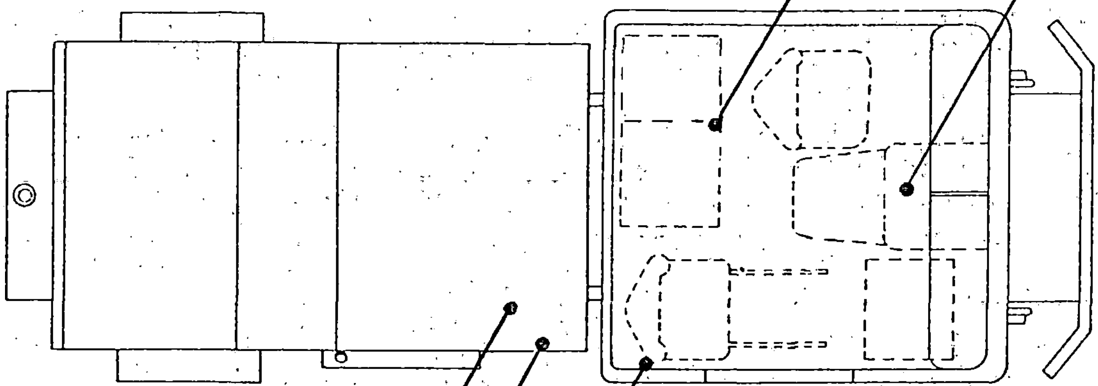


FIGURE 23

LOCATION OF SAFETY EQUIPMENT

Extinguishing fires aboard the Iowa TGC should be attempted only to the degree consistent with the safety of personnel.

Derailment or other accident involving the Iowa TGC severe enough to cause obstruction of the track or immobility of the TGC shall be reported to the railroad by the quickest available means of communication. Notification of the Iowa DOT headquarters shall be made as soon thereafter as possible.

Injury of any kind, however minor, must be promptly treated and properly reported to avoid complications.

When employees or others are injured, proper first aid procedures are to be applied. All injuries should be treated by a physician as soon as practical.

Reporting of injuries by the operator includes completion of forms requested by the railroad and by the Iowa DOT as specified in the general Iowa DOT safety manual.

PART VIII

ADDENDUM

The loss of the Iowa Track Geometry Car to a engine compartment fire identified two additional items of safety equipment that should be incorporated into future high-rail inspection vehicles. These items are:

1. The engine oil pressure should be measured by an electronic gauge system. A rupture in the oil line between the engine and the pressure gauge caused the fire on the original TGC. Excessive vibrations encountered with vehicle operation while on rail probably led to the rupture. A electronic oil pressure gauge would not require an oil line thereby eliminating a fire hazard.

2. The oil emitted from the ruptured oil line fed a fire which could not be extinguished with hand equipment. Future high-rail track geometry cars should be quipped with automatic fire extinguisher systems in the engine and generator compartments. It is also advisable to use a non-corrosive gas system in the computer area to put out small electrical fires without damaging equipment.

APPENDIX A

SUBCONTRACT WITH GEO-TRAC, INC.

3.3 The contractor shall assess the benefits and costs of adding to the TGC the ability to measure each of the track geometry parameters of surface/profile or curvature or alignment. For any of these additional parameters found to produce greater benefits than costs, the contractor shall, upon authorization by the project manager, provide a general discussion of the basic sensors, method of data acquisition and compatability with current TGC equipment, instrumentation, and operating procedures of the system required to measure the parameter. The assessment of benefits and costs shall address but not be limited to the following considerations:

3.3.1 Study work plan - The contractor shall prepare, for project manager review and approval, a work plan for the conduct of assessment activities which shall include a detailed description of the work to be performed and a diagramatic display of the work performance schedule.

3.3.2 Study content

a) The evaluation of benefits shall include a delination of the incremental improvement in the capability of the TGC to detect deviations from FRA track standards provided by the additional measurement system over those currently on-board the TGC. Furthermore, the incremental improvement in deviation detection, if any, provided by an additional measurement system shall be evaluated in terms of the impact such deviation detection could have upon the frequency of train derailment incidents and upon the ability to utilize TGC data in the estimating of track and roadbed rehabilitation costs.

b) The evaluation of costs shall include a delineation of estimated gross dollar costs to buy or construct and install the equipment required by the additional system on the TGC. This deliniation shall indicate the feasibility of installing the system on the current TGC vehicle or the necessity to provide the system on a new or trailer vehicle.

c) The evaluation of costs shall also include delineation of estimated maintenance requirements, facilities and skills associated with the system. In addition the cost evaluation shall provide estimates of crew skill levels and size requirements and any other operating limitations imposed by the system, such as operating speed or weather.

d) The results of the assessment of benefits and costs shall be provided to the project manager who, after review of the results, shall determine if the contractor shall proceed with the discussion of the system's sensors, data acquisition method, and compatibility with the existing TGC systems.

APPENDIX B

TRACK SAFETY STANDARDS

F.R.A. TRACK STANDARDS

CLASS	1	2	3	4	5
SPEED PASSENGER	15 MPH	30 MPH	60 MPH	80 MPH	90 MPH
SPEED FREIGHT	10 MPH	25 MPH	40 MPH	60 MPH	80 MPH
ALINEMENT - TANGENTS	5"	3"	1 3/4"	1 1/2"	3/4"
ALINEMENT - CURVES	5"	3"	1 3/4"	1 1/2"	5/8"

NOTE: THE MID-ORDINATE FOR A 62' CHORD IN INCHES = DEGREE OF CURVE

CLASS	1	2	3	4	5
TRACK SURFACE					
RUNOFF IN 31 FEET	3 1/2"	3"	2"	1 1/2"	1"
DEVIATION FROM PROFILE	3"	2 3/4"	2 1/4"	2"	1 1/4"
DEVIATION ON SPIRALS	1 3/4"	1 1/2"	1 1/4"	1"	3/4"
CROSS LEVEL ON SPIRALS	2"	1 3/4"	1 1/4"	1"	3/4"
OTHER CROSS LEVEL	3"	2"	1 3/4"	1 1/4"	1"
DIF. IN CROSS LEVEL IN 62'	3"	2"	1 3/4"	1 1/4"	1"
CROSS TIES					
MIN. GOOD TIES PER 39'	5	8	8	12	12
MIN. GOOD TIES PER JOINT	1	1	1	2	2
MAX.DIST.BETWEEN GOOD TIES	8'-4"	5'-10"	5'-10"	4'-0"	4'-0"
RAIL END MISMATCH					
ON TREAD	1/4"	1/4"	3/16"	1/8"	1/8"
ON GAGE SIDE	1/4"	3/16"	3/16"	1/8"	1/8"
RAIL END BATTER	1/2"	3/8"	3/8"	1/4"	1/8"
JOINT BARS					
CRACKED OR BROKEN	OK	OK	R E P	L A C	E
CRACKED OR BROKEN CENTER	R E	P L	A C	E	
BOLTS PER RAIL-EACH JOINT	1	2	2	2	2
BOLTS PER RAIL-C.W. RAIL	2	2	2	2	2
TORCH CUT OR BURNT HOLES	OK	OK	DO	NOT	USE
TIE PLATES					
PLATES PER TEN TIES	—	—	8	8	8
TRACK SPIKES - MINIMUM PER RAIL PER TIE					
TANGENT TO 2° CURVE	2	2	2	2	2
2° CURVE TO 4° CURVE	2	2	2	2	3
4° CURVE TO 6° CURVE	2	2	2	3	—
CURVES SHARPER THAN 6°	2	3	3	—	—
GAGE AT GUARD RAILS					
GUARD CHECK GAGE-MIN.	54 1/8"	54 1/4"	54 3/8"	54 3/8"	54 1/2"
GUARD FACE GAGE-MAX.	53 1/4"	53 1/8"	53 1/8"	53 1/8"	53
GUAGE - TANGENTS	56" to 57 3/4"	56" to 57 1/2"	56" to 57 1/2"	56" to 57 1/2"	56" to 57"
GUAGE CURVES	56" to 57 3/4"	56" to 57 3/4"	56" to 57 3/4"	56" to 57 1/2"	56" to 57"

APPENDIX C

RECOMMENDATION FOR A NEW VEHICLE

Factors supporting the acquisition of a new vehicle are presented below:

1. The addition of a calculator printer and magnetic tape storage system has reduced the cab space on the current TGC drastically.

2. The addition of a camera system, an alignment unit, and surface measurement equipment would create chaos in the present cab operating conditions.

3. Operating limitations in the calculating ability of the existing TGC are being pushed to a maximum. New measurement systems could not be added on without expanding the existing sampling rate.

4. Acceptance of the current equipment by the railroads and roadmasters has opened the door to more sophistication in automated track inspection in Iowa.

The Iowa Department of Transportation decided in January of 1978 to purchase a replacement track geometry vehicle based on the above factors and on the favorable performance of the high-rail vehicle compared to the rail bound vehicle as outlined in Chapter III.

APPENDIX D

DEVIATION DETECTED DURING THE COMPARISON TEST

The actual deviations in gage and cross level measurements detected by the FRA test car are so few that it is impossible to come up with a statistical analysis of deviations. The FRA test car detected one gage deviation and 236 cross level deviations within the 32 miles of test track surveyed during the comparison tests with the Iowa Track Geometry Car. The operational plan for this survey can be found in Appendix J.

A summary of the deviation detection capability of the Iowa TGC is shown in Table 31. This table assumes the deviations detected by the FRA test car to be 100% accurate. By using the models developed in this report the accuracy or false reporting of deviations by the Iowa TGC can be reduced by 32%.

The data in Table 31 implies that the Iowa TGC could detect only 49% of the cross level defects. This is somewhat misleading since the TGC found a cross level defect within every group of cross level defect located by the FRA car. Correction of cross level defects located by the Iowa TGC would also cause a correction of the cross level defects located only by the FRA car.

The Iowa TGC did not detect the gage deviatioms located by the FRA test car. This reading is shown in Table 32 along with the upper and lower 95% confidence interval for the modeled TGC measurement value.

TABLE 30

DETECTED GAGE DEFECT

GAGEF	P_GAGE	L_LEVEL	U_LEVEL
55.9712	56.1191	55.97	56.27

GageF = Gage measured by FRA vehicle
P_GAGE = Predicted gage from TGC measurement
L_LEVEL = Lower 95% confidence level
U_LEVEL = Upper 95% confidence level

By using a 95% confidence interval on the modeled TGC data the detected gage defect would be recorded as a defect. The 95% confidence interval also creates ten modeled deviations which are not deviations as measured by the FRA vehicle.

TABLE 31

DEVIATION DETECTION CAPABILITIES

Track Class	Variable	1 Deviations Found By The FRA Car	2 Deviations Reported By The TGC	3 Deviations Predicted By Modele TGC Data	4 Deviation In Colume 3 Common To Column 1	5 Deviations Not Predicted (Col.1 - Col.4)	6 Deviations Erroneously Predicted (Col.3 - Col.4)
I	X-level	109	49	54	41	68	13
II	Gage(W)	0	128	0	0	0	0
	Gage(J)	1	11	0	0	1	0
	Gage (C)	0	26	0	0	0	0
	X-level (J)	6	0	1	1	5	0
III	Gage(C)	0	0	0	0	0	0
	X-level (J)	121	44	74	74	47	0
		237	258	129	116	121	13

W = Welded

J = Jointed

C = Curved

APPENDIX E

RAILROAD SUFFICIENCY ITEM RATINGS

I. Structural Adequacy Category

The evaluation of a railroad section for structural adequacy would include ratings for some of the major items included in the three components of a track structure (i.e.: track, ballast, and roadbed.)

A. Track

Items rated in the Track sub-heading of structural adequacy include track defects, gage, joints, and ties.

1. Defects: Defective rail can break, and if undetected, may cause a serious train derailment. Defects may be either minor surface defects such as shelly spots and engine burns or major defects such as engine burn fractures and head-web separations. Defects which may be located by surface inspection would be compiled by inventory crews. Defects which require the use of a rail flaw detection car would be acquired elsewhere if available The rating can be determined by computing an equivalent weighted defects/mile and developing a rating table. An example of this procedure follows:

$$\text{Defects/Mile} = \frac{\text{Major Defects} + 0.5\ \text{Minor Defects}}{\text{Section Length (Miles)}}$$

Track Defects Rating						
	Design Class					
D/M	1	2,3	4,5	6	7,8	9,10
0 to 0.5	8	8	8	8	8	8
0.5 to 1.0	6	6	7	7	8	8
1.0 to 1.7	4	4	5	6	7	8
1.7 to 2.3	0	1	3	4	5	7
2.3 to 3.0	0	0	1	2	3	5
3.0 to 3.6	0	0	0	0	1	3
>3.6	0	0	0	0	0	0

2. Gage: Rail must be installed and maintained at the proper gage to limit amounts of wheel-rail head wear and to prevent derailments. Narrow gage is the primary cause of excessive wheel wear. The standard gage is 4'8½" with allowable deviations specified by the FRA. The rating for Iowa would be determined by using inventoried information from Iowa's Track Geometry Car (TGC) and the formulized rating process currently included in the publication entitled "Iowa Railroad Track Geometry Ratings".

States without access to TGC data could use trained field-inventory crews to acquire the necessary measurements. The measurements would only have to be determined at the most restrictive condition existing in a track segment of a predetermined length. This segment length could be fairly long for low-speed track and become fairly short at higher operating speeds.

3. Ties: Some important properties of cross ties are the distribution of rail loads to the ballast and the prevention of lateral or longitudinal rail movements. Ties that are spike killed, broken, or deteriorated to the point that they no longer perform the required functions are defective. The cross-tie rating would be determined by inventoring a rail segment's typical number of good ties per 39 ft. of rail and developing a Rating Table similar to that illustrated in the Rail Defects example.

4. Joints: Rail joints must smoothly transmit the wheel loadings from one rail to the next. They must also maintain the rail's horizontal alignment and provide a relief valve for rail expansive or contractive forces. The condition of the joints would be determined by on-site inspection of joint bars rail ends and joint ties. The rating would then be determined by the inventory crew following written guidelines. An example of this rating procedure follows:

Rating Description	Point Rating
Excellent	3.0 - 4.0

All joints are in excellent condition with no cracked or broken joint bars and negligible rail-end batter or mismatch. The joint ties are predominantly in excellent condition with only a few joint locations which just meet minimum FRA requirements.

B. Ballast

Some of the important functions of Ballast are to provide the mass and aggregate interlock necessary to prevent longitudinal and lateral tie movements; to uniformly support the ties for even weight distribution on the rails; distribute the tie imposed loads to the subgrade within acceptable soil limits; and provide adequate track drainage. Items which will be evaluated to determine the ballast rating include ballast width, ballast condition, and track cross-level.

1. Width: Ballast, in addition to filling the cribs between the rails, should extend outwardly onto the rail shoulders a minimum of six inches beyond the tie ends. This is needed to provide the required lateral restraint. The width of ballast is also a good indicator of the existing ballast depth. The typical width could be determined by inventory crews and the rating determined by a Table similar to the Track Defects example.
2. Condition: Ballast that is filled with impurities will not provide adequate drainage. In addition, if there is not a sufficient quantity or quality of ballast material, lateral and longitudinal tie movement may occur. The ballast condition would be a field rating determined as previously illustrated for the Track Joint rating.
3. Cross Level: Ballast which is adequately providing for proper drainage and evenly supporing the ties will maintain the rail surfaces at the required elevation. When the ballast is not functioning as required, the ties will not evenly support the rails and deviations in the rail cross-level may result. This rating for Iowa would be determined using

the aforementioned Iowa Track Geometry Car inventory information and the rating process developed in the publication "Iowa Railroad Track Geometry Ratings".

States without access to TGC data could follow the procedure previously discussed for the gage rating item. The only difference would be the equipment required.

C. Roadbed Drainage

Water which has been sufficiently drained from the subgrade surface and allowed to pond along the roadbed can cause unstable soil conditions leading to subgrade support failure.

To provide for adequate removal of this runoff, ditches of sufficient depth and gradient must be provided with adequately designed and structurally sound drainage structures. Inventory crews would evaluate and rate the drainage adequacy of a route segment following written guidelines similar to the previous rating example for joints.

II. Safety Category

Items rated in the safety category include some of the items which have in the past been shown to be major factors in train derailments such as crossings and switches. The type of train control and actual number of train derailments would also be evaluated.

A. Derailments

The derailment record of a track segment is an excellent indicator of its overall safety adequacy. Segments which have a higher derailment record than the state average for trackage providing the same types of service and with similar usage densities are indicative of an unsafe operating condition. The rating would be determined for each inventory segment by compiling the derailment history for the last five years, obtaining the current traffic density, and developing a rating formula. An example of this possible formulized rating process follows:

$$R = (X/M)\ 15$$

Where X = segment derailments per million train miles (MTM)

M = mean derailments per MTM for segments functional class

R = derailment rating

B. Crossings

The track structure at locations of at-grade intersections with roadways must withstand not only train induced loads but crossing motor vehicle impacts as well. Because of this duality of traffic stress, the probability of a crossing component such as rail or ties becoming defective is higher than for normal tangent trackage. The evaluation and rating of crossing adequacy will be determined by inventory crews following written guidelines. An example of this procedure has previously been shown for the Joints rating item.

C. Switches

Switches are one of the weakest parts of the track structure because of their importance in transferring traffic from one rail to another they are one of the most critical parts of the track structure. Switches with defective lights or reflectorized targets, unsound ties, or cracked or broken connecting rods can cause serious problems. Field crews will inventory a segment's total number of switches and the number which are defective. The switch rating will then be determined by weighting the total number of switches and the number of defective switches in a given segment with a formula and using a rating table similar to the one previously shown for the Defects rating item.

D. Control

Trains travel on a fixed route and require very long stopping distances. The engineers must therefore have ample time to stop or switch to a siding track when meeting another train. This advance notice is provided by train control systems. As the operating speed and the density on the route increase, the need for higher control system sophistication increases. This is especially true if the route is also for high speed passenger service. The control rating would be based on a track's existing control system and use compared to the use and control system desired if this track was in perfect structural condition. The final rating would be determined by developing a rating table similar to the previous Defect rating item example.

III. Service Category

To provide a viable state transportation mode, a railroad route must be able to provide adequate services. Two of the important indicators of the service provided are the speed efficiency and the weight capacity.

A. Speed Efficiency

To be competitive with other transportation modes and provide proper services, a railroad route must provide fast and efficient deliveries of goods. Routes with frequent segments operating under a slow order are severely restricted in their service capabilities. The rating would be determined by considering the desired speed on a route, the average weighted speed existing on the route now, and the speed allowed on the segment being evaluated. A formula similar to that shown for the Derailments rating item would then be developed to determine the final point assignment.

B. Track Weight Capacity

In addition to speed, the service efficiency of a railroad route is dependent on each track segment's ability to support modern railroad equipment needed to efficiently transport the major cargoes. In Iowa the primary cargo is grain and coal, therefore, all track segments will be evaluated on the abilities to support the 263,000 lb. jumbo hopper cars. Track charts and railroad capacity limitations on grades and structures will be used to determine the maximum permitted equipment. The rating will then be determined by developing a table similar to that previously shown for rating the Defects item.

APPENDIX F

PART I: RAILROAD BASE RECORD FORMAT SUMMARY

The following 68 items represent the inventory items identified as necessary for the formation of a railroad base record. Part 2 contains information on how the items would be positioned on a data tape.

	Item	Purpose
1.	County Number	Control Identification
2.	Rail Company Code	Control Identification
3.	Route Number	Control Identification
4.	Segment Number	Control Identification
5.	Update Card Letter	Data Processing Use
6.	Segment Length	Mileage Summation
7.	Milepoint Identification	Mileage Summation & Locator
8.	County Sequence	Order Counties in Sequence of Entry
9.	Township Number	Locator - Inventory
10.	Range Number	Locator - Inventory
11.	Section Number	Locator - Inventory
12.	FRA Track Class	Identifies Track Condition
13.	Analysis Code	Identifies Segments for Analysis
14.	R/M Status	Locates Segments as Rural or Munic.
15.	R/U Status	Locates Segments as Rural or Urban
16.	RR Division, Region, or District	Places Segment in a Rail Co. Ident.
17.	RR Subdivision or District	Further Identification in a Rail Co. Identification
18.	US DOT Category Title	Self Explanatory
19.	Line Identification Code	Differentiates Types of Lines
20.	Iowa Functional Classification	Functionally Classifies (Not Administrative.)
21.	Rail Plan District	Identifies Iowa Rail Plan District
22.	Analysis Section Number	Groups Like Segments for Analysis
23.	Analysis Section Typical Segment	Selected Segment Typical of All in Section
24.	FRA Zone Code	Ties Our Data to FRA Data
25.	Duplicate Route Identification	Identifies other RR Using Same Tracks
26.	US DOT - AAR Crossing Numbers	Ties Base Record to Crossing File
27.	Rail Traffic Density	Identifies Density in Millions of Tons
28.	Abandonment Status	Status of the Segment as Known
29.	Date of Abandonment Application	Date Abandonment Application Filed
30.	Date Abandonment Approved	Date Abandonment Application Approved
31.	Gross Net Tons of Freight	Thousands of Tons on Typical Only
32.	Trains Per Week	Number of Trains on Segment
33.	Seasonal Identifier Code	Identifies Season With Maximum Use
34.	Station Identification Number	Station Number Assigned by Railroad
35.	Station Milepoint	Station Milepoint from Track Charts
36.	Type of Siding	Type of Siding on Segment
37.	Siding Footage Capacity	Siding Capacity in Feet
38.	Track Direction	Sets of Rails & Direction of Travel

39.	Type of Rail	Inventory - Needs
40.	Rail Weight	Inventory - Needs
41.	Track Weight Restrictions	Restrictions as Applied by Company
42.	Year Rail Rolled	Year Rail Was Manufactured
43.	Year Rail Laid	Year Rail Was Enplaced
44.	Maximum Train Speed	Speed Limit as Assigned by Company
45.	Number of Grain Elevators	Shipping and Receiving Points
46.	Number of Shipping Points	Other than Elevators
47.	Number of Receiving Points	Other than Elevators
48.	General Commodities Term.	Type of Products
49.	General Commodities Orig.	Type of Products
50.	Ruling Grade	Inventory - Needs
51.	Ballast Type	Inventory - Needs
52.	Visual Inventory Year	Inventory - Needs
53.	TGC Inspection	Inventory - Needs
54.	FRA Visual Track Inspection	Inventory - Needs
55.	Condition of Joints	Inventory - Needs
56.	Condition of Ties	Inventory - Needs
57.	Condition of Tie Plates	Inventory - Needs
58.	Condition of Rail Anchors	Inventory - Needs
59.	Condition of Ballast	Inventory - Needs
60.	Condition of Rail	Inventory - Needs
61.	Condition of Switches	Inventory - Needs
62.	Condition of Drainage	Inventory - Needs
63.	Grade Crossing Condition	Inventory - Needs
64.	Signal Type and Condition	Inventory - Needs
65.	Minimum Horizontal Clearance	Inventory - Needs
66.	Minimum Vertical Clearance	Inventory - Needs
67.	Track Geometry Condition Rating	Inventory - Needs
68.	Node Identification Numbers	Advance Planning Purposes

PART 2: RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
1. County Number	2	1-2	Present two-digit numbering system		Control Identification
2. Rail Company Code	4	3-6	Each Rail Company is assigned an Alpha Identification Code. These codes will be right justifies: Atchison, Topeka, and Santa Fe — ATSF Burlington Northern — BN Cedar Rapids and Iowa City — CIC Central Iowa — CIRC Chicago, Milwaukee, St. Paul and Pacific — MILW Chicago and Northwestern — CNW Chicago, Rock Island and Pacific — RI Davenport, Rock Island and Northwestern — DRI Des Moines and Central Iowa — DCI Fort Dodge, Des Moines and Southern — FDDM Illinois Central Gulf — ICG Iowa Terminal — IAT Norfolk and Western — NW Union Pacific — UP Waterloo — WLO	This sheet is the Data Source	Control Identification
3. Route Number	4	7-10	This is an assigned four digit identification system that uniquely identifies route termini. Duplication of route numbers on the same railroad are not allowed.	Transportation Inventory & Advance Planning	Control Identification Should be Numeric Only
4. Segment Number	4	11-14	Individual Segments of rail will be numbered in ascending order by tens in the direction of mileposting (which will be the direction of inventory) by route within a county. The first segment of a route in a county will be numbered 0010, the next segment will be 0020, etc. Segment Numbers will begin over when entering another county.	Transportation Inventory & Track Charts	Control Identifica- Segments have been assigned using established criteria

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
5. Update Card Letter	1	15	A = Delete a Record B = Change Control I.D. of a Record C = Add a New Record D = Update T.P. E = Update T.P. F = Update T.P. G = Update T.P. H = Update T.P.	Transportation Inventory	Control Identification
6. Segment Length	4	16-19	The length in hundredths of a mile as determined by data available. The length is determined by the segment breaks.	Track Chars Inventory	
7. Milepoint Identification	7	20-26	The beginning milepoint of each segment will be recorded. Assume a decimal point between t.p. 24 and 25.	Track Charts Time Table Inventory	
8. County Sequence	2	27-28	This code is used to order the route sequentialy by county. The first county the route is in will be 01, the second county 02, the third county 03, etc. If the route exits a county and then reenters, the sequence must be advanced two numbers to keep segments ordered properly.	Transportation Inventory Present Methods	
9. Township Number	3	29-31	These positions locate a segment in a township	Transportation Inventory	
10. Range Number	2	32-33	These positions locate a segment in a range.	Transportation Inventory	
11. Section Number	2	34-35	These positions locate a segment in a section.	Transportation Inventory	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
12. Federal Railroad Administration Track Class	1	36	Six class codes have been designated by the FRA. Each segment will be assigned a class between 1 and 6.	Advance Planning	
13. Analysis Code	1	37	If the segment is to be analyzed, code 0 in this position. If the segment is not to be analyzed, code 1.	Advance Planning	
14. Rural/Municipal Status	1	38	Code 1 = Rural Rail Segment Code 2 = Municipal Rail Segment	Track Charts, Maps,etc.	
15. Rural/Urban Status	1	39	Code 1 = Segment Not in Urban Area Code 2 = Segment is in Urban Area	Track Charts, Maps,etc.	
16 Railroad Division, Region or District Code	2	40-41	This is the Division or other named area code to be assigned to the area.	Advance Planning	
17. Railroad Subdivision or District	2	42-43	This is the Subdivision or similar named area code to be assigned to the area.	Advance Planning	
18. US DOT Category Title	1	44	This category was devised to categorize rail lines. Code 1 = A Mainline Code 2 = Potential A Mainline Code 3 = B Mainline Code 4 = A Branch Code 5 = B Branch Code 6 = Defense Essential Branch	Advance Planning	
19. Line Identification Code	1	45	This code differentiates the types of lines Code 1 = Mainline Code 2 = Branch Line Code 3 = Spur Line	Advance Planning	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
20. Iowa Rail Functional Classification	1	46	This is the state functional classification identification. Code 1 = Interstate Code 2 = Intrastate Code 3 = Arterial Connector Code 4 = Arterial Collector Code 5 = Local	Advance Planning	
21. Iowa Rail Plan District	1	47	The state has been divided into 8 rail plan districts. The data is on an Iowa outline map and the limits are not clearly defined.	Advance Planning Iowa Outline Map	
22. Analysis section Number	3	48-50	This number is used to group consecutive like rail segments into one section for analysis purposes. The sections are numbered in ascending order by tens in the direction of inventory. The same section number is assigned to each consecutive like segment. One segment may make up a section or perhaps 25 segments may be involved. The analysis section begins over when a segment is different from the previous segment. Number 010, 020, 030, etc.	Transportation Inventory Present Data Available	
23. Analysis Section Typical Segment	1	51	The typical segment is assigned to the rail segment within an analysis section which best typifies all other segments in the section. The typical segment will be code 1. All other segments in the analysis section will be code 0.	Transportation Inventory Present Data Available	
24. FRA Zone Code	3	52-54	This code identifies the FRA zone in which the segment is located.	Transportation Inventory FRA Zone Maps	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
25. Duplicate Route Identification	36	1st: 55-68 2nd: 69-82 3rd: 83-96	These spaces are used to identify rail companies using the same tracks as the controlling railroad. Space is provided for three duplications. T.P. 55-58 2nd Rail Comapny Code (t.p. 3-6) T.P. 69-72 3rd Rail Company Code (t.p. 3-6) T.P. 83-86 4th Rail Company Code (t.p. 3-6) T.P. 59-62 2nd Rail Co Route No (t.p. 7-10) T.P. 73-76 3rd Rail Co Route No (t.p. 7-10) T.P. 87-90 4th Rial Co Route No (t.p. 7-10) T.P. 63-66 2nd Rail Co Segment No (t.p. 11-14) T.P. 77-80 3rd Rail Co Segment No (t.p. 11-14) T.P. 91-94 4th Rail Co Segment No (t.p. 11-14) T.P. 67-68 2nd Rail Co County Segment (t.p. 27-28) T.P. 81-82 3rd Rail Co County Segment (t.p. 27-28) T.P. 95-96 4th Rail Co County Segment (t.p. 27-28)	Transportation Inventory Present Methods	
26. US DOT - AAR Crossing Numbers	24	97-120	Space is allowed for three crossing numbers per segment. Record the numbers as they appear on the crossing form. The last digit identifies the crossing as P = Public or N = Private. No crossing = 00000000. 123614 J = 123614 JP 116283 R = 116283 RN	Transportation Inventory DOT - AAR Crossing File	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
27. Rail Traffic Density	4	121-124	These spaces are used to identify the rail traffic density in millions of gross ton miles per mile. Assume a decimal point between T.P. 122 and 123.	Advance Planning	
28. Abandonment Status Code	1	125	This position indicates the abandonment status of the segment. Code 0 = No known action pending Code 1 = Rail Company proposes to abandon Code 2 = Application filed for abandonment Code 3 = No official abandonment action but travel is impossible.	Rail Division Transportation Inventory Advance Planning Development Support DOT - AAR Crosssing Data	
29. Date of Abandonment Application	6	126-131	The date that the abandonment application is filed is coded in these spaces. August 2, 1977 = 080277	Rail Division Transportation Inventory DOT - AAR Crossing Data	
30. Date Abandonment Approved	6	132-137	The date that the abandonment is approved is coded in these spaces. August 2, 1977 = 080277	Rail Division Transportation Inventory DOT - AAR Crossing	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
31. Gross Net Tons of Freight	9	137-145	The gross net tons of freight is taken from density charts. Data is recorded in thousands of tons on segments that are typical (t.p. 51). All other segments will be zeros. Thousands of Tons — Code 1,263,797 — 000001264 63,297,419 — 000063297 129,328,500 — 000129329 1,264,628,941 — 001264629 11,295,698,499 — 011295698	Advance Planning	
32. Trains Per Week	4	146-149	This identifies the number of trains per week on the typical segment only. Assume a decimal point between t.p. 148 and 149. If there is less than one train per week code a digit to the right of the decimal point. All segments not typical will be coded 0000. Less than 1 train per week 000.5 1 train per week 001.0 15 trains per week 015.0 120 trains per week 120.0	Rail Division Advance Planning Development Support	
33. Seasonal Identifier Code	1	150	This code designates the season of the year when rail use is at a maximum. Code 1 = Winter (December, January, February) Code 2 = Spring (March, April, May) Code 3 = Summer (June, July, August) Code 4 = Fall (September, October, November)	Rail Division Advance Planning	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
34. Station Identification Number	5	151-155	The station number as assigned by the rail company. Ankeny = 07820 Boone = 07813 This code will be assigned to the segment on which it falls. All other segments will be coded 0000.	Transportation Inventory Advance Planning Time Tables	Stations without Identification Numbers will be assigned a number by Advance Planning. Listing program must print name of station.
35. Station Milepoint	7	156-162	The milepoint will be recorded on the segment on which it falls. If T.P. 151-155 is coded, then this item must be coded. A decimal point is assumed between t.p. 160 and 161. No Station = 0000000 Station mp 1.63 = 0000163 Station mp 75.98 = 0007598 Station mp 423.99 = 0042399	Transportation Inventory Track Charts and/or Time Tables	
36. Type of Siding	1	163	The type of siding will be recorded on the segment on which it falls. Code 1 = Passing Code 2 = Industrial Code 3 = Multiple Use	Transportation Inventory	
37. Siding Footage Capacity	7	164-170	The capacity of the siding in feet will be recorded on the segment where the siding begins or terminates. No Siding = 0000000 63,295 Feet = 0063295 104,263 Feet = 0104263 If more than one siding is present, record all footage.	Transportation Inventory	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
			The following data is for Rail Inventory. Spaces are provided for two sets of tracks.		
38. Track Direction	1	1. 171 2. 302	This is the set of rails and the direction of travel as determined by the mileposting. Code 1 = 1 set of tracks Eastbound Code 2 = 1 set of tracks Westbound Code 3 = 1 set of tracks Northbound Code 4 = 1 set of tracks Southbound Code 5 = 2 sets of tracks East and Westbound Code 6 = 2 sets of tracks North and Southbound	Transportation Inventory Track Charts	
39. Type of Rail	1	1. 172 2. 303	The type of rail as taken from the track charts. Code 1 = Standard Code 2 = Welded	Transportation Inventory Track Charts	
40. Rail Weight	3	1. 173-175 2. 304-306	This is the weight of a 3-foot section of rail. 80 lbs. 080 120 lbs. 120	Transportation Inventory Track Charts	
41. Track Weight Restrictions	3	1. 176-178 2. 307-309	The weight restrictions placed on tracks by rail companies. Record the weight in thousands of pounds. 220,000 lbs. = 220	Rail Division Track Charts Time Tables	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
42. Year Rail Rolled	4	1. 179-182 2. 310-313	The year of manufacture. 1895 = 1895 1934 = 1934	Transportation Inventory Track Charts	
43. Year Rail Laid	4	1. 183-186 2. 314-317	The year the rail was enplaced. 1918 = 1918 1953 = 1953	Transportation Inventory Track Charts	
44. Maximum Train Speed	3	1. 187-189 2. 318-320	Maximum train speed in miles per hour allowed on the track segment. 5 mph = 005 35 mph = 035 100 mph = 100	Transportation Inventory Track Charts Time Tables	
45. Number of Grain Elevators	1	1. 190	Record the number of grain elevators on the segment. 1 = 1 9 = 9	Advance Planning	
46. Number of Other Shipping Points	1	1. 191	Record the number of shipping points (other than elevators) on the segment. 1 = 1 9 = 9	Advance Planning	
47. Number of Receiving Points	1	1. 192	Record the number of receiving points (other than elevators) on the segment. 1 = 1 9 = 9	Advance Planning	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
48. General Commodities Terminating	6	1. 193-198 2. 321-326	Identify the general commodities terminating on the segment as supplied by the railroad company.	Advance Planning 1% Waybill Sample	
49. General Commodities Originating	6	1. 199-204 2. 327-332	Identify the general commodities originating on the segment as supplied by the railroad company.	Advance Planning 1% Waybill Sample	
50. Ruling Grade	3	1. 205-207 2. 333-335	Record the ruling grade on the typical section only to the nearest 0.01%. A Decimal point is assumed between T.P. 195 and 196. 1.39% = 139 2.13% = 213 .63% = 063	Transportation Inventory Track Charts	
51. Ballast Type	1	1. 208 2. 336	Record the ballast type as: Code 1 = Gravel Code 2 = Cinder Code 3 = Crushed Rock Code 4 = Crushed Slag Code 5 = Other	Transportation Inventory Track Charts	
52. Inventory Year Visual	2	1. 209-210 2. 337-338	Record the year of inventory as: No Visual Inventory = 00 1978 = 78	Transportation Inventory	
53. Track Geometric Car Inspection	4	1. 211-214 2. 339-342	Record the month and year of the latest TGC inspection. No Inspection = 0000 June 1977 = 0677 August 1978 = 0878	Rail Division	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
54. FRA Track Inspection Visual	4	1. 215-218 2. 343-346	Record the month and year of the latest Track inspection. February 1976 = 0276 April 1977 = 0477	Rail Division	
55. Condition of Joints	2	1. 219-220 2. 347-348		Transportation Inventory Rail Division Visual	
56. Condition of Ties	2	1. 221-222 2. 349-350		Transportation Inventory Rail Division Visual	Possible use of a photo-file.
57. Condition of Tie Plates	2	1. 223-224 2. 351-352		Transportation Inventory Rail Division Visual	
58. Condition of Rail Anchors	2	1. 225-226 2. 353-354		Transportation Inventory Rail Division Visual	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
59. Condition of Ballast	2	1. 227-228 2. 355-356		Transportation Inventory Rail Division Visual	
60. Condition of Rail	2	1. 229-230 2. 357-358		Transportation Inventory Rail Division Visual	
61. Condition of Switches	2	1. 231-232 2. 359-360		Transportation Inventory Rail Division Visual	
62. Condition of Drainage	2	1. 233-234 2. 361-362		Transportation Inventory Rail Division Visual	

RAIL BASE RECORD PROPOSAL
TAPE FORMAT

Item	Position Required	Position Assigned	Recording Possibilities	Data Source	Remarks
63. Grade Crossing Condition	9	1. 235-243 2. 363-371	Record the grade crossing condition from railroad view. There are 3 spaces each for three crossings per segment.	Transportation Inventory Rail Division Development Support	
64. Signal Type and Condition	6	1. 244-249 2. 372-377	Record the signal type in T.P. 244-245 and the signal condition from railroad view in T.P. 246-247 and 248-249. Spaces are allotted for two signals per segment.	Transportation Inventory Rail Division	
65. Mimimum Horizontal Clearance	4	1. 250-253 2. 378-381	Record the minimum horizontal clearance from center line of track. Measurement can be left or right. T.P. 250-251 = feet, and T.P. 252-253 = inches.	Transportation Inventory	
66. Mimimum Vertical Clearance	4	1. 254-257 2. 382-385	Record the minimum vertical clearance from each rail to object from two different points on each rail. T.P. 254-255 = feet, and T.P. 256-257 = inches.	Transportation Inventory	
67. Track Geometry Condition Ratings	30	1. 258-287 2. 386-415	To Be Developed; will include Track Geometry Rating and Track Sufficiency Rating.	Advance Planning	
68. Node Identification	14	1. 288-301 2. 416-429	Allows 7 spaces for each Node Link.	Advance Planning	
Reserved for Future Requirements		430-500			

APPENDIX G

IOWA TRACK GEOMETRY RATING SYSTEM

Purpose

A wide variety of techniques, models and simulations exist for transportation planning, however, few of them have been adapted to statewide rail planning. This analytical void has resulted from the absence of rail data needed for planning purposes. The Iowa DOT has been able to adapt these techniques to railroad planning by using the data collected by the Iowa TGC.

Information collected by the Iowa TGC has been used to develop a numerical rating which represents track conditions for each mile of rail trackage in Iowa. The purpose behind this track geometry ratings is to provide administrators with a guide for programming construction funds so as to maximize benefits from project investments. A year to year comparison of ratings will indicate the rate of progress, or lack of progress, being made in railroad maintenance.

The Rating Process

The ratings are computed on a 30 point base, 15 points each for gauge and crosslevels in relationship to a predetermined set standard indicating overall track condition. A rating of 30 points indicates trackage where gauge and crosslevels are well within FRA standards for a particular class of track.

The track geometry ratings are summarized on colored maps and in a track geometry log. Colors used on the maps indicate whether the track geomtery is good, fair, or critical. Rating distribution for each track class is shown in Table 33. Detailed descriptions of track geometry conditions are as follows:

Good: Gauge and cross levels are typically well within FRA limits; occasional deviations may be found.

Fair: Gauge and cross levels frequently approach FRA limits; temporary slow orders may be common.

Critical: Deviations in FRA standards for gauge and cross levels are likely to be so frequent that significant maintenance effort may be required to maintain the present FRA track class; slow orders are likely to be in effect for extended periods of time.

TABLE 32

RATING DISTRIBUTION

	CONDITION		
FRA TRACK CLASS	GOOD	FAIR	CRITICAL
IV (High Speed)	28.0-30.0	23.0-27.9	0.0-22.9
III	27.0-30.0	20.0-26.9	0.0-19.9
II	25.0-30.0	18.0-24.9	0.0-17.9
I (Low Speed)	21.0-30.0	15.0-20.9	0.0-14.9

Figure 11 is a page from the track geometry log. Entries in the log include locational information, a partial rating for gauge and cross level, a total rating for each one-mile track segment and weighted rating for longer segments.

The results of the track geometry ratings are summarized in Table 34. Almost 900 miles of track have not been rated. The critical mileage in Table 34 includes 222.1 miles of track that could not be rated because the track was either out of service or in such bad condition that the Iowa TGC was unable to operate.

A track geometry rating system must not be considered as an overall sufficiency rating. Other factors such as rail, tie and roadbed condition, ton miles, service frequency, access to alternate modes and energy usage must eventually be worked into a final rating. The conceptual design for such a rating system capable for comparing a given segment of track to other segments being developed as part of the FRA sponsored research contract with the Iowa DOT. When completed this objective rating would be of great assistance in planning the programming of public funds going into track rehabilitation.

TABLE 33

SUMMARY OF IOWA TRACK GEOMETRY RATINGS

JULY 1978

FRA TRACK CLASS	CONDITION						TOTAL	
	GOOD		FAIR		CRITICAL			
	MILES	%	MILES	%	MILES	%	MILES	%
IV	338.0	46.9	439.8	53.1	0.0	0.0	827.8	100.0
III	1656.1	54.9	1355.2	45.0	3.0	0.1	3014.3	100.0
II	371.3	79.5	91.9	20.0	4.0	0.1	467.2	100.0
I	1018.7	84.3	185.3	15.4	4.0	0.3	1208.0	100.0
TOTAL	3434.1	62.2	2072.2	37.6	11.0	0.2	5517.3	100.0

APPENDIX H

HEADER AND CALIBRATION PROGRAMS

GEODATA HEADER PROGRAM

The objective of this program is to provide the capability for the TGC to add supplemental "Header" type information to the test Engineering Data Records (EDR) log tape. The Geodata Header file consists of an unformatted series of EBCDIC characters. There will be 39 data entries on the file. Each entry will have a set of delimiter characters which terminate that entry. These delimiters are the carriage return and line feed characters (&). Therefore if a requested data entry is unknown to the TGC operator he may either type in "unknown" or he may just press "continue." In either case the entry will be bracketed by the delimiters; therefore no entry can be lost. This allows the monitor of the header file to keep track of which entry he is reading in this unformatted file, i.e., there will always be 39 sets of delimiters.

The Geodata Header file will actually be a trailer file following the series of Geodata EDR measurements. The Header file will be blocked at 800 bytes. After completion of the TGC test, the following Header data may be obtained from the Geodata Test program.

1. DATE (month, day, year)
2. START TIME (hour, minute, second)
3. NUMBER OF DATA SAMPLES
4. START MILEPOST (miles)
5. ENDING MILEPOST (miles)
6. TEST DISTANCE (miles)
7. TEST TIME DURATION (hour, minute, second)
8. FRA TRACK CLASS
9. NUMBER OF GAUGE VIOLATIONS
10. NUMBER OF CROSS-LEVEL VIOLATIONS

GEODATA CALIBRATION PROGRAM

The objective of this program is to provide the capability for the TGC operator to verify proper operation and to calibrate the Cross-level system, Gauge system, Mileage system and Event (Observer Input) system. A hard copy print from the calculator's internal printer of the data is obtained from the calibration test.

IN HOUSE DATA PROCESSING

The daily tapes from the Iowa TGC operation are submitted to the Data Processing Center at the Iowa DOT at the beginning of each work week. A master tape having a higher density of information and consolidating several of the daily tapes is developed and retained in the Data Processing tape library. Section VI of the Task 11.0 report describes the analysis program used in Data Processing for weekly programming from the master tape file.

APPENDIX I

DESIGN FOR A RAILROAD TRACK REHABILITATION COST ESTIMATION METHODOLOGY

GENERAL MODEL REQUIREMENTS

In terms of its input requirements any proposed RCEM should rely heavily on Iowa TGC generated data. Such an alliance would minimize the cost and provide objective consistency of input data. Extensive collection of additional non-TGC generated data would defeat the purpose behind exploiting the development of a RCEM.

The methodology should be no more complicated than necessary to achieve the desired results. Marginal improvement of the model by inclusion of additional variables would not be worth the additional complexity.

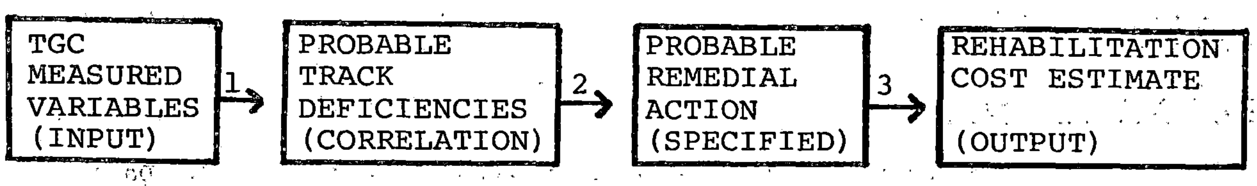
A working methodology would be able to estimate remedial actions necessary to correct track deficiencies. This feature of the model would be h ighly dependent on its ability to synthesize probable track deficiencies from input data. The model should also recognize that some required rehabilitation actions may be determined solely by comparison of certain track components to predetermined standards -- for example, the replacement of 60 pound rail with 100 pound rail.

BASIC MODEL DESIGN

A model which uses the track parameters generated by the Iowa TGC, or subsequently derived from those parameters, would have the basic structure depicted in Figure 24. This structure indicates the necessary links between data collected by the Iowa TGC and the predicted rehabilitation costs. Links two and three of the model would be established through engineering experience and a review of the costs associated with the recent rehabilitation projects.

FIGURE 24

BASIC MODEL STRUCTURE



LINK:

1 - Synthesize Empirical Relationships
2 - Apply Railroad Engineering Practices
3 - Utilize Historical Costs Information

The analysis to establish link one is the key to developing a RCEM. Unfortunately the ability of the TGC to correlate measured variables to track deficiencies can no longer be tested.

A correlation of the type necessary to establish link one was proven using historic data. Unfortunately the loss of the Iowa TGC to a fire prevents any testing of the correlation on tracks other than those used to establish the correlations. Therefore, without a replacement TGC, it is impossible to verify the correlations.

Various physical or empirical relationships presumed to constitute link one should by hypothesized and examined after a replacement vehicle is made available. It would also be prudent to take advantage of any new track parameters that a replacement TGC would provide.

A subcontracted study regarding the development of a RCEM is presented in Appendix L in its entirety.

APPENDIX J

OPERATIONS PLAN FOR TRACK SURVEY

The comparison survey of the Iowa Track Geometry Car (TGC) and the Federal Railroad Administration's T-2/T-4 consist places several constraints upon the method and form in which data is collected. These are identified below.

1) Measurements were sampled at one foot intervals on the FRA vehicle and at 4.6 foot intervals on the Iowa TGC. All measurement data was recorded on magnetic tape.

2) Collection sites contained curved track and were two miles in length. Grade crossing within the test segments were avoided to the extent possible.

3) Both vehicles had to operate on Class I, Class II, and Class III track. The FRA expressed some concern about operating the T-2/T-4 consist on Class I trackage fearing equipment damage or a derailment. To reduce exposure to a derailment situation the Class I trackage tested was on a line which had recently been improved.

The detail of the Operations Plan for the survey is attached hereinafter along with the operation schedule.

Contract Number DOT-FR-64113

10 October 1977

OPERATIONS PLAN
FOR TRACK SURVEY
ON
CHICAGO ROCK ISLAND AND PACIFIC RAILROAD (CRIP)
RI-292
VICINITIES OF DES MOINES, IA AND IOWA FALLS, IA

Submitted by: Robert P. Taylor
ENSCO, INC.
10/10/77
Date

Concurrence by: Ray T. Liang
FRA Program Manager
Oct. 11, 1977
Date

Approved by: James B. Wirin
FRA
Oct 11, 1977
Date

Appendices A - C Attached

Distribution:

FRA
J.C. Mould
R. Liang

ENSCO
E. Guinn
W. Szabo
J. Thomas
S. Szadokierski (2)
C. Thomas (4)

CRIP
H.E. Strate
M.C. Durkart

Iowa DOT
M.A. Sherfy

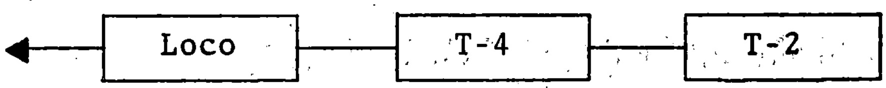
I. PURPOSE

The purpose of this survey is to collect track geometry data for comparing measurements taken by the Iowa track geometry car (TGC) with data taken by FRA T-2/T-4 consist.

ZONE

The zone for this test is collection sites on the CRIP in the vicinity of Des Moines, IA Winterset, IA and Iowa Falls, IA. Detailed test sections are set forth in the Task Design, dated October 7, 1977, prepared by the Iowa Department of Transportation.

III. CONSIST



IV. SCHEDULE

Normal operating procedures will call for ENSCO crew call at 0600, with departure at 0730. An instrumentation verification (IV) will be performed after departing the yard. No further routine tangent or left and right curve IV's will be performed. The track geometry survey should be completed at about 1630, post-run calibration checks will require about one (1) hour.

A. Special Instructions

1. The CRIP tracks to be surveyed are both north-south and east-west sections. Track numbers will be as indicated by the class and speed information of the CRIP.

2. Track geometry data recorded on digital magnetic tape and analog strip charts will be reproduced using the computer system onboard T-2/T-4 at the conclusion of each test day. This reproduced data will be transferred directly to the Iowa DOT representative present during testing.

B. Daily Schedule for RI-292

Date	Start Survey	End Survey	Miles
Mon. 17 Oct.	Received cars over weekend. Prepare cars for survey.		
Tues. 18 Oct.	Des Moines, IA (via Winterset and Stuart)	Des Moines, IA	110
Wed. 19 Oct.	Des Moines, IA	Iowa Falls, IA	80
Thurs. 20 Oct.	Iowa Falls, IA (via Galt)	Des Moines, IA	120
Fri. 21 Oct.	Ship cars to North Bessemer, PA for B&LE Survey T2-287.		

The Iowa Department of Transportation Task Design, Comparison of Track Geometry Measurement Vehicles, October 7, 1977 Schedule, describes in detail, the locations and activities for collecting the data required.

V. INSTRUMENTATION

A. Track Geometry Data Measurement System

1. The on-board Data Measurement System will be used to develop, record, and display the following parameters:

- Gage
- Curvature
- Crosslevel
- Profile, Left and Right Rail (62 Ft. Chord)

In addition, the following will be recorded and displayed:

- ALD events, such as Mileposts, Crossing, Turnouts, etc.
- System control events such as Sensor Activate, Track Change, Data Message, etc.
- Time in seconds.

2. Parameters and events will be stored on digital magnetic tape and will be displayed in analog form on chart recorders.

3. The recorder will be distance driven with a scale of 17.2 inches per mile. Channel assignments for the 8- and 6-channel recorders are listed in Appendix B. The recorders are as follows:

- One 8-channel, Brush Model 200 recorder.
- Two 6-channel, Brush Model 260 recorders. One located in the rear vestibule and one located on the maintenance table.

B. Manual Instrumentation

Manual gage and crosslevel instrumentation will be available for off-train gage and crosslevel measurements. These measurements will be recorded for each Instrument Verification (IV) and the completed IV sheets included in the Operating Log.

C. Calibration Requirements

All instrumentation will be calibrated at the start of each day, and checked at the end of the day, in accordance with standard operating procedures and individual subsystem manuals. These calibrations will be documented on the standard format. The completed forms will be made part of the Operating Log.

VI. DOCUMENTATION

A. Operating Log

The Operating Log will consist of the following:

- A handwritten Chronological Events Log.
- The Magnetic Tape Log showing the digital tape numbers, data recorded, and applicable remarks.
- Instrumentation Verification sheets (IV's) showing manual measurements, system parameters, and any recalibrations.
- Calibration Check-off Lists showing "Pre" and "Post" run calibration data and system parameters.

B. Passenger Log

A Passenger Log will be kept for each survey day.

VII. STANDARD SURVEY OPERATIONS

A. The locomotive should be equipped with radio frequencies that are usable on all the railroads being surveyed per this document. The conductor shall have a radio with appropriate frequencies to maintain communication with the train engineer and/or railroad facilities.

B. The maximum train speed will be set by the applicable railroad. The measurement cars are capable of operating at passenger train speeds.

C. When requested by the FRA, railroads will provide, at FRA cost, the following:

- Locomotive power.
- Operating crews
- Security for measurements cars during extended stops, overnight and weekends
- Number 2 diesel fuel for generators (estimated 100 gallons daily)
- Potable water (estimated 100 gallons daily)

D. It is necessary that precise locations of certain equipment such as flange detectors, spring switches and spring frogs, high-guard rails, etc., be provided during the survey. Past experience has indicated that a knowledgeable railroad employee is beneficial to provide this information to the ENSCO Forward Observer during the survey run.

E. Track speed and class information by milepost should be supplied to ENSCO by the CRIP one week prior to running this survey.

F. Instrumentation failures or other damaging faults require the train to stop as soon as practical for appropriate repairs. Sections of track where valid data was not recorded may be rescheduled for coverage at the discretion of the Survey Director in coordination with the FRA Track Inspector and the Senior Railroad Official onboard. Sections of invalidly recorded track data may be deleted when it is in the best interest of the overall objective.

G. Milepost locations for track switches, railroad changes, and state line locations shall be recorded in the Chronological Events Log.

H. During this survey, a copy of the applicable Operations Plan will be posted in the instrumented car near the control console.

VIII. SAFETY RULES/REGULATIONS

The Survey Director is designated as Safety Officer for this survey and as such is responsible for ensuring all survey activities are performed in accordance with the safety rules of the operating railroad, ENSCO Safety Policies and Directives, and the safety rules and regulations detailed in the "Safety Manual, FRA Test Cars," dated February 1977. In the event that the Survey Director is not on site, the Senior ENSCO representative will assume these responsibilities. Additionally, each survey crew member is responsible for ensuring adherence to all safety rules. On the spot corrective action will be taken on any violation or known safety hazards. Safety violations will be reported to the proper authority in order that action can be taken to prevent a recurrence.

IX. INFORMATION SOURCES

General Procedures	J.C. Mould, FRA (202) 426-1682
Survey Coordination/Movement	C. Thomas, ENSCO (703) 370-0000
FRA, Office of Rail Safety Research	R. Liang (202) 426-1682
Iowa DOT	M. Sherfy (515) 296-1140
CRIP	H.E. Strate (515) 284-7158

X. PERSONNEL ASSIGNMENTS

Survey Director	H. Stintz
Assistant Survey Director	G. Burke
Support Engineer	M. Dolinger
Forward Observer	J. Wichser
Data Specialist	D. Sanderson

A. The duties of assigned personnel are set forth in Appendix A.

B. Pursuant to its authority under Section 208C of the Federal Railroad Safety Act of 1970 (45 U.S.C. 437), the Office of Safety, Federal Railroad Administration has authorized ENSCO, Inc., Springfield, VA, and their above-named employees to act as agents of FRA while performing certain functions in connection with Survey RI-292 as detailed in this Operations Plan.

C. Designated representatives from ENSCO, FRA, Iowa DOT and CRIP are authorized to be onboard the measurement cars during this survey.

DUTIES

Personnel assigned to duty stations listed in this document shall have the responsibilities listed below:

Survey Director	He has complete responsibility for measurement train operations and data collection processes including approval of measurement car operations and movements. In coordination with the FRA Track Inspector and senior railroad official onboard, he has the authority to change or alter procedures, including, but not limited to, survey schedules (traffic permitting.) All instructions regarding operation of instrumentation and data collection shall be made through the Contractor's Assistant Survey Director and all instructions regarding measurement train operations shall be made through the Survey Director. He may appoint others as Acting Survey Director.
Assistant Survey Director	Designated in charge of all instrumentation and data collection connected with the survey. His primary responsibility is to ensure that all required equipment is calibrated and functional for the measurement series. He shall provide support and assist the Survey Director in all of his responsibilities and duties.
Support Engineer	He shall provide support and assist the Assistant Survey Director in all of his responsibilities and duties. He is designated in charge of all instrumentation and data collection activities in the absence of the Assistant Survey Director.
Forward Observer	Responsible for the naming of crossroads and mileposts. He is responsible for advising the Data Specialist of significant events that are pertinent to the data collection process.

Data Specialist	Responsible for computer operations and for logging all test data. He ensures that all information chronologically acquired is properly listed and any information germane to the data is properly noted, using the Log Sheets provided. He is responsible to ensure that all pertinent data is recorded on the Brush chart in a timely fashion. He will clearly mark all channels to identify the data content. He will ensure proper time is marked on the chart.

ANALOG RECORDING FOR T-2/T-4

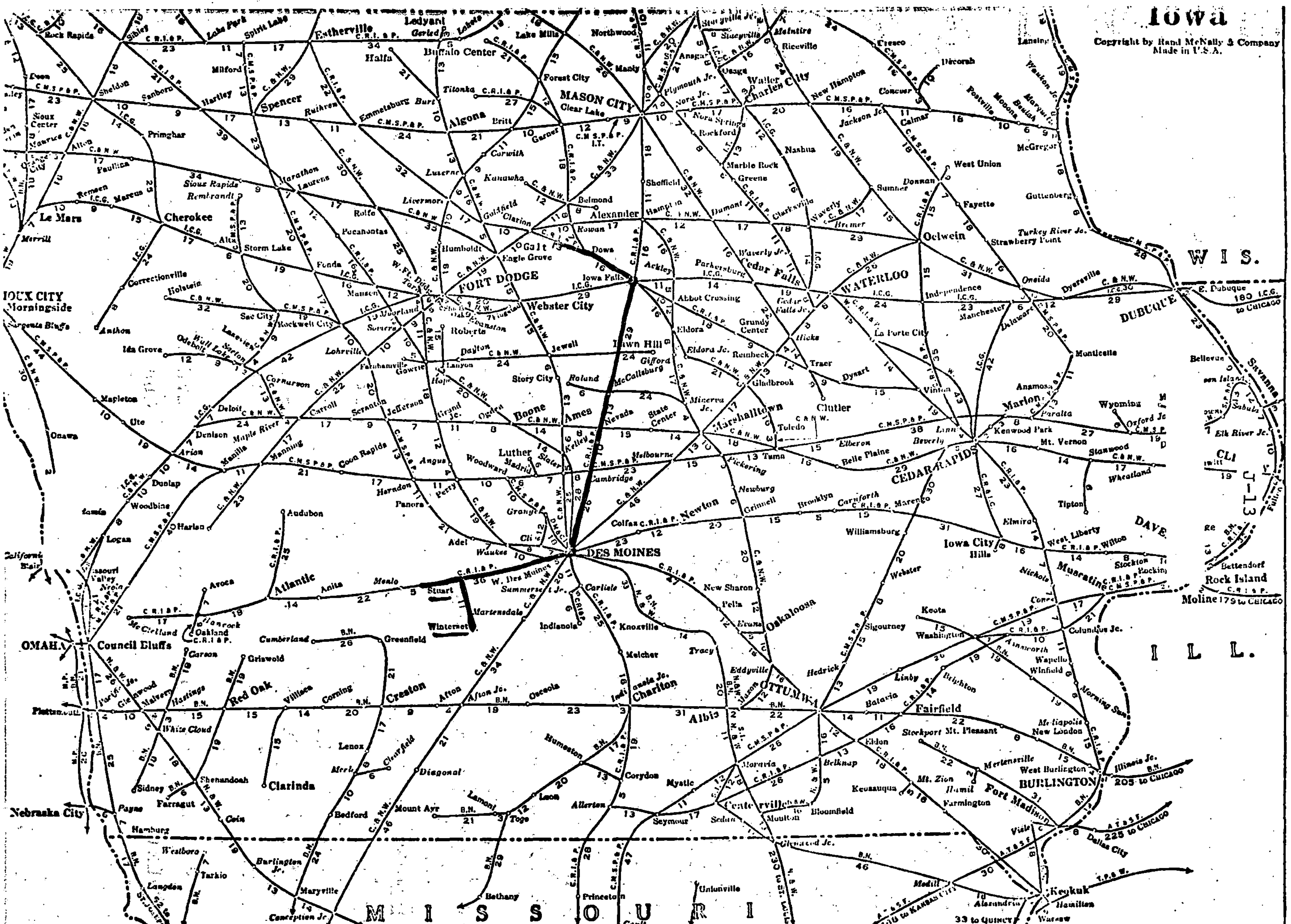
Normal analog recording is accomplished by the use of three distance drive strip chart recorders, a Brush Model 200 (eight-channel) and two Brush's Model 260 (six-channel).

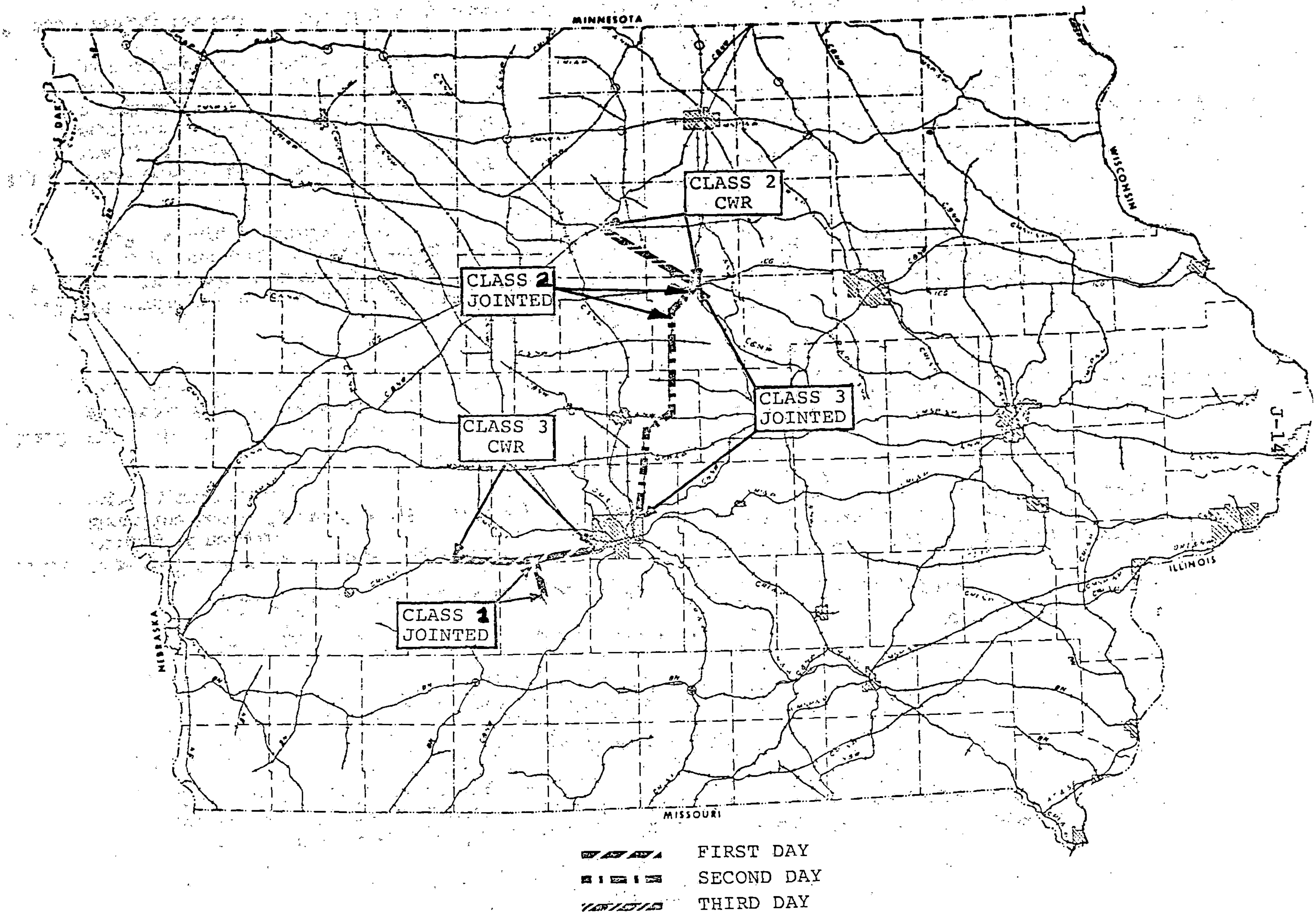
A. For the eight-channel recorder:

Channel	Assignment	Display Limits
1	Speed	0 - 150 miles per hour
2	Left Rail Profile	±5 inches, 62-foot chord
3	Right Rail Profile	±5 inches, 62-foot chord
4	Crosslevel	±6.25 inches
5	Curvature	±10 degrees (or as required)
6	Capacitive Gage	56 - 58 inches
7	Magnetic Gage	56 - 58 inches
8	ALD, MP, Xings, etc.	EVENT
EVENT 1	FOCC	EVENT
EVENT 2	Time	One second marks

B. For the six-channel recorders:

Channel	Assignment	Display Limits
1	Right Rail Profile	±5 inches, 62-foot chord
2	Left Rail Profile	±5 inches, 62-foot chord
3	Crosslevel	±6.25 inches
4	Curvature	±10 degrees (or as required)
5	Gage	56 - 58 inches
6	ALD, MP, Xings, etc.	EVENT
EVENT	Time	One second marks


Iowa
Copyright by Rand McNally & Company
Made in U.S.A.
WIS.
ILL.
MISSOURI
J-13
DES MOINES
MASON CITY
FORT DODGE
Webster City
Boone
Ames
Marshalltown
Newton
Iowa Falls
Cedar Falls
WATERLOO
CEDAR RAPIDS
Iowa City
DUBUQUE
Oelwein
Charles City
Algona
Spencer
Estherville
Cherokee
Le Mars
Storm Lake
Carroll
Atlantic
Council Bluffs
OMAHA
Red Oak
Creston
Clarinda
Shenandoah
Charlton
Albia
Oskaloosa
OTTUMWA
Fairfield
BURLINGTON
Fort Madison
Keokuk
Muscatine
Rock Island
Moline
Centerville
Nebraska City
Clear Lake
Humboldt
Webster
Ackley
Grundy Center
Vinton
Marion
Manchester
Independence
Decorah
West Union
McGregor
Osceola
Indianola
Knoxville
Pella
Grinnell
Colfax
Denison
Harlan
Sac City
Ida Grove
Onawa
Logan
Sheldon
Rock Rapids
Sibley
Emmetsburg
Clarion
Eagle Grove
Jefferson
Perry
Adel
Winterset
Stuart
Greenfield
Corning
Afton
Leon
Corydon
Mount Ayr
Bedford
Sidney
Glenwood
Washington
Sigourney
Mt. Pleasant
Wapello
Columbus Jc.
Tipton
Wilton
Anamosa
Maquoketa
Bellevue
Sabula
Clinton
Davenport
Lansing
Waukon
Cresco
New Hampton
Waverly
Hampton
Belmond
Forest City
Lake Mills
Northwood
Osage
Riceville
Nashua
Traer
Toledo
Tama
Belle Plaine
Marengo
Williamsburg
Brooklyn
Montezuma
Hedrick
Eddyville
Moravia
Seymour
Bloomfield
Keosauqua
Farmington
Donnellson
Mediapolis
Wapello
West Liberty
Stanwood
Mt. Vernon
Lisbon
Hamilton
Warsaw
Quincy
Kansas City
Chicago
Dallas City
Galesburg


MINNESOTA
WISCONSIN
ILLINOIS
MISSOURI
NEBRASKA
CLASS 2
CWR
CLASS 2
JOINTED
CLASS 3
JOINTED
CLASS 3
CWR
CLASS 1
JOINTED
FIRST DAY
SECOND DAY
THIRD DAY

SCHEDULE

This section describes in detail, the locations and activities for collecting the data required for this research task. It is generated from on-the-ground observation of the data collection track segments.

1.0 FIELD WORK - PHASE A

Scheduled for the second week of October, 1977 for the collection of data under dry roadbed conditions

1.1 Phase A - First Day

Collection Site A, Winterset Branch: Subdivision 5 A, Class I jointed

FRA TRAIN	IOWA TGC
1.1.1 Crew call 7:00 A.M. Crew safety meeting, Fueling if needed. Shortline Yard - "Rocket" track. Receive days instructions.	1.1.1 Safety meeting with FRA crew, shortline yard. Pick-up Rock Island on board representative. Receive day's instructions.
1.1.2 FRA train travels from Shortline Yard to Winterset Branch - mile post 386 (0.5 miles off main line)	1.1.2 TGC travels by highway from Shortline Yard to county road crossing 599-462 near Marquett plant at mile post 386 on the Winterset Branch.
1.1.3 * FRA train proceeds to mile post 386.5 for left curve calibration, to milepost 386.6 for right curve calibration and to milepost 386.9 for tangent calibration.	1.1.3 TGC sets on track at county road crossing 599-462 after FRA train has passed the crossing. TGC is calibrated in that area.
1.1.4 After completion of calibration, the FRA train, if necessary, backs-up a distance sufficient to allow it to reach a speed of 5 mph at the data collection segment start point at mile post 387.1, just past county road crossing 599-464	1.1.4 After the FRA train starts its collection run, the TGC proceeds to milepost 386.9 and waits for notification by radio that the FRA train has completed its collection run.

* The asterisk indicates which of the paired events should be begun or completed before the other

FRA TRAIN

1.1.5 The FRA train collects data at 5 mph
* from milepost 387.1 to milepost 389.1. A check for data collection problems is performed and a rerun is made if needed. The TGC is notified by radio upon completion of data collection.

1.1.6 FRA train proceeds to county road crossing
* 559-466 at milepost 389.8, passing it to allow the following TGC to set off the track.

1.1.7 The brush charts from both vehicles are
* compared to determine if any gross difference exists which would indicate the need for one of the vehicles to rerun the segment.

1.1.8 If no reruns are needed, the FRA train backs to the north side of the crossing a sufficient distance to allow it to reach data collection speed of 5 mph at the collection segment start point of milepost 390 (about 0.2 miles past the crossing)

1.1.9 FRA train waits for the TGC to complete its collection run and notify by radio that it has cleared the track.

1.1.5 Upon notification from the FRA train that its collection run is completed, the TGC attains the speed of 5 mph and collects data from milepost 387.1 to milepost 389.1. A check for data collection problems is performed and a rerun made if needed.

1.1.6 The TGC proceeds to county road crossing 599-466 at mile post 389.8.

1.1.7 (See FRA train 1.1.7)

1.1.8 If no reruns are needed, the TGC sets off the track, allows the FRA train to back over the
* crossing, and then sets on the track.

1.1.9 The TGC attains the collection speed of 5 mph
* by the time it reaches the collection segment start point at milepost 390 and the TGC collects data from milepost 390 to milepost 392 and proceeds to county road crossing 599-475 at milepost 392.8. Prior to leaving the track, verification of data being recorded is made. If no rerun is needed the TGC sets off the track and notifies the FRA train that it is clear.

FRA TRAIN

1.1.10 The FRA train attains collection speed of 5 mph prior to milepost 390. It begins data collection at milepost 390 and ends collection at milepost 392. It proceeds to milepost 392.8 where brush charts from both vehicles are compared to determine if any gross error exists which would require a rerun.

*

1.1.11 If no rerun is needed, the FRA train backs out of the Winterset branch and travels west on the main to the next collection site. If recalibration is felt necessary, there is a left curve at milepost 384.5 and a right curve at milepost 384.8 which are approximately one mile east of the Winterset branch at Winear.

IOWA TGC

1.1.10 The TGC waits for the FRA train to complete its collection run. Then brush charts are compared (see FRA train 1.1.10)

1.1.11 The TGC travels by highway to State highway 232 crossing in Earlham at milepost 387.5.

1.2 PHASE A - FIRST DAY

Collection Site B, Des Moines - Atlantic Main, Subdivision 5, Class III CWR

FRA TRAIN

1.2.1 The FRA train, after calibration if needed, travels to a point just east of Earlham to await completion of the next TGC collection run.

1.2.2 The FRA train waits for notice that the TGC is clear.

1.2.3 Upon notification that the TGC is clear of the collection segment and on its way to the next segment, the FRA train attains a speed of 20 mph and collects data from milepost 388 through milepost 390.

1.2.4 After completion of the collection run, a check is made for data collection problems and the segment rerun if necessary. If a rerun is not required, the FRA train waits for notification that the TGC is clear of the next collection segment.

IOWA TGC

1.2.1 * The TGC sets on track at Milepost 387.5, the State highway 232 crossing. The TGC attains test speed of 20 mph and begins data collection at milepost 388. The TGC collects data through milepost 390.

1.2.2 * Having completed the collection of data from milepost 388 to 390, the data is briefly checked for anomolies, and notification given to the FRA train by radio of the need for a rerun or that the TGC is proceeding to the next collection segment.

1.2.3 * After notifying the FRA train of clearing the milepost 388 to 390 collection segment, the TGC procedes to the next collection segment attaining the speed of 10 mph. The TGC collects data beginning at milepost 394 through milepost 396.

1.2.4 After completion of the collection run, a check is made for data collection problems and a rerun made if necessary. If no rerun is required, the TGC proceeds to milepost 398.4 in Stuart and sets off the track at crossing 603 293 on county road P28. Radio notification is given to the FRA train that the TGC is clear.

FRA TRAIN

1.2.5 * After receiving notification that the TGC has cleared the track, the FRA train attains the speed of 10 mph and collects data from milepost 394 through milepost 396.

1.2.6 * After completion of the collection run a check is made for data collection problems and a rerun made if needed. If no rerun is required the train proceeds to milepost 398.4.

1.2.7 * The FRA train stops west of the crossing. The brush charts of the two vehicles are compared for gross differences that may indicate a data collection problem. If a problem is found, a rerun of the appropriate segment by the vehicle or vehicles is made.

1.2.8 * The FRA train attains the speed of 20 mph and collects data from milepost 399.1 through milepost 401.1. Upon completion of the run, a check is made for data collection problems and a rerun is made if needed. Notice of satisfactory run completion is radioed to the TGC.

1.2.9 * Following the check for data collection problems, the FRA train attains the speed of 10 mph and collects data from milepost 404 through milepost 406.

1.2.5 The Iowa TGC waits for the FRA train to complete its data collection run from milepost 394 through milepost 396.

1.2.6 The TGC awaits the completion of the FRA train collection run.

1.2.7 While the brush charts are being compared, the TGC sets on the track following the FRA train.

1.2.8 The TGC awaits notification of acceptable completion of the collection run by the FRA train.

1.2.9 Following the notice of the FRA train moving to next collection site, the TGC attains the speed of 20 mph and collects data from milepost 399.1 through 401.1.

1.3 PHASE A - SECOND DAY

Collection Site C Des Moines - Mason City Main Subdivision 12 Class III jointed

FRA TRAIN

1.3.1 Crew call 8:00 A.M. Crew safety meeting, fueling if needed. Receive days instruction.

1.3.2 The FRA train travels to milepost 77.3 for left curve calibration, to milepost 77.6 for tangent calibration and to milepost 78.4 for right curve calibration.

1.3.3 The FRA train travels to and waits at milepost 79.5 for notification by radio that the TGC has completed its collection run.

1.3.4 Having received notice that the TGC has cleared the collection segment, the FRA train attains the speed of 20 mph and collects data from milepost 80 through 82.

1.3.5 After completion of the collection run, a check for data collection problems is performed and a rerun made if required.

IOWA TGC

1.3.1 Crew safety meeting with FRA. Pick up Rock Island on board representative. Receive day's instructions.

1.3.2 * The TGC travels to highway crossing at N.E. 22nd street (north of Swanwood siding), sets on track and performs calibrations.

1.3.3 * The TGC attains the speed of 20 mph and collects data from milepost 80 through milepost 82. Upon run completion a check for data collection problems is made and a rerun is performed if needed. When collection is complete, the FRA train is notified by radio.

1.3.4 * The TGC continues to the next collection segment attaining the speed of 10 mph and collectiong data from mile post 87 through milepost 89.

1.3.5 After completion of the collection run, a check for data problems is performed and a rerun made if needed. At the completion of data collection, the TGC proceeds to milepost 89.3, sets off the track at State highway 87 crossing number 876-029, and notifies the FRA train that the track is clear.

FRA TRAIN

1.3.6 * After completion of data collection the FRA train proceeds to mile post 86.5 and waits for notification from the TGC that it has cleared the track. Upon notification, the FRA train attains the speed of 10 mph and collects data from milepost 87 through milepost 89.

1.3.7 * Upon completion of the collection run a check for collection problems and a comparison of brush charts from both vehicles is made to determine if another collection run is required and, if so, it is made.

1.3.8 * The FRA train attains the speed of 20 mph and collects data from milepost 90 through milepost 92. A check of the collected data is performed to determine the need for a rerun. After all collection work is completed the TGC is notified.

1.3.9 * The FRA train proceeds to the next collection segment attaining a speed of 10 mph. Data is collected from milepost 100 through milepost 102. A check for data collection problems is performed and a rerun is made if required. The TGC is notified when all collection work is completed.

1.3.6 The TGC waits for completion of data collection by the FRA train.

1.3.7 (See FRA train 1.3.7)

1.3.8 After notification that the FRA train has cleared the collection segment, the TGC attains the speed of 20 mph and collects data from milepost 90 through milepost 92. A check of the collected data is performed to determine the need for a rerun.

1.3.9 After notification from the FRA train that the collection segment is clear, the TGC proceeds to the next collection segment attaining a speed of 10 mph. Data in collected from milepost 100 through milepost 102.

FRA TRAIN

1.2.10 * Upon completion of the collection run, a check is made for collection problems and a rerun is made if needed. When the collection or the rerun is completed, notification by radio is given to the TGC and FRA train proceeds to and clears the main at the elevator siding at milepost 410.4.

1.2.11 The FRA train awaists the completion of data collection by the TGC.

1.2.12 The brush charts of the two vehicles are compared for gross difference that my indicate a data collection porblem. If a problem is found, a rerun of the appropriate segment by the vehicle or vehicles is made.

1.2.13 Following acceptance of the last data collection run, the FRA train performs a run-around and runs light back to its tie-up location in the Shortline Yard.

IOWA TGC

1.2.10 After the collection run, a check for data collection problems is made and a rerun of the segment made if needed. The TGC then awaits notification from the FRA train that it has completed work on the next collection segment.

1.2.11 * The TGC proceeds to the next collection segment attaining a speed of 10 mph. Data collection being at milepost 404 and ends at milepost 406. A check for collection problems is made and a rerun if needed is made.

1.2.12 * Upon completion of the data collection run, the TGC proceeds to milepost 410.1 where the brush chart comparison, listed under the FRA train 1.2.12, is accomplished. When all collection work is completed, the TGC sets off the track at State highway 25 crossing number 603 291.

1.2.13 Following acceptance of the last data collection run the Iowa TGC picks up the FRA train data tape(s) and travels back to Des Moines by highway.

1.3.10 * The FRA train proceeds to milepost 102.7 where, upon completion of the collection run by the TGC a comparison of the brush charts is made for a gross collection problem requiring a rerun of the vehicles. A rerun is made as needed.

1.3.11 * The FRA train proceeds to the next collection segment attaining a speed of 20 mph. Data is collected from milepost 128.5 through milepost 130.5. A check for data collection problems is performed and a rerun is made if required.

1.3.12 Upon completion of the TGC collection run a check for collection problems and a comparison of brush charts from both vehicles is made to determine if another collection run is required.

1.3.13 After notification that the TGC is clear of the track the FRA train inspects from milepost 140.0 through milepost 142.0 at 10 mph. This inspection is then repeated at 20mph.

1.3.14 * After a comparison of the brush charts shows that a rerun is not required the FRA Train runs light to the Iowa Falls Yard where it ties up on the depot spur behind the Rock Island depot.

1.3.10 (See FRA Train 1.3.10).

1.3.11 After notification from the FRA train that the collection segment is clear, the TGC proceeds to the next collection segment attaining a speed of 20 mph. Data is collected from milepost 128.5 through milepost 130.5.

1.3.12 * (See FRA Train 1.3.12). Both vehicles repeat this run at 10 mph.

1.3.13 * The TGC is positioned in front of the FRA train and proceeds to the next collection segment. Milepost 140.0 through milepost 142.0 are inspected at 10 mph. This inspection is immediately repeated at 20mph.

1.3.14 The TGC travels to Iowa Falls by highway.

1.4 PHASE A - THIRD DAY

Collection Site D, Iowa Falls - Galt, Subdivision 12A, Class II CWR

FRA TRAIN

1.4.1 Crew Call 8:00 A.M. Crew safety meeting, fueling if needed. Receive day's instructions.

1.4.2 The FRA train travels to milepost 101.9 for left curve calibration and to milepost 102.1 for tangent calibration. No right curves available for calibration.

IOWA TGC

1.4.1 Crew safety meeting with FRA. Pickup Rock Island on-board representative at Iowa Falls Yard. Receive day's instructions.

1.4.2 TGC travels to county road S-25 crossing at milepost 104.6 sets on track and performs calibrations.

FRA TRAIN

1.4.3 FRA train travels to milepost 104.5 and waits for notification by radio that the TGC has completed its data collection run.

1.4.4 * Having received notice that the TGC has completed its collection run and has cleared the segment, the FRA train attains the speed of 20 mph and collects data from milepost 104.9 through milepost 106.9. Upon completion of the run, a check for data collection problems is performed and a rerun made necessary.

1.4.5 * A comparison of brush charts from both vehicles is made to check for data collection problems. It a rerun by either vehicle's needed, it is made.

1.4.6 * If a right curve calibration is deemed necessary it can be made at milepost 112.0

1.4.3 * The TGC completes calibration, backs east of county road S-25 crossing, achieves a speed of 10 mph through the crossing and 20 mph at the start of the data collection segment at milepost 104.9. The TGC collects data through milepost 106.9. Upon run completion a check for data collection problems is made and a rerun performed if needed. When collection is complete, the FRA train is notified by radio.

1.4.4 The TGC proceeds to Dows, sets off the track at the main street crossing, or is run into a siding, and waits for the FRA train to pass. The TGC then sets on the through track following the FRA train.

1.4.5 (See FRA train 1.4.5)

1.4.6 TGC travels to milepost 111.5 if FRA train performs calibrations and to 114.5 if it doesn't and waits for notice that the FRA train has completed its data collection run.

FRA TRAIN

1.4.7 The FRA train attains a speed of 20 mph
* prior to milepost 115.0 and collects data from milepost 115.0 through milepost 117.0. A check for data collection problems is made and a rerun performed if needed. After completion of data collection notice is given by radio to the TGC.

1.4.8 The FRA train proceeds to milepost 118.0
* and waits for the TGC to complete its run. Brush charts are the compared to check the need for a rerun by either vehicle.

1.4.9 (See TGC 1.4.9)

1.4.7 The TGC waits for notice that the FRA train has completed its data collection run.

1.4.8 Having received notice that the FRA train has completed its collection run, the TGC attains the speed of 10 mph through the crossing at milepost 114.8 and 20 mph by milepost 115.0. The TGC collects data from milepost 115.0 through 117.0. A check for data collection problems is performed, a comparison of brush charts is made, and reruns made if necessary.

1.4.9 The TGC sets off the track and collects the data tapes from the FRA train. The TGC leaves for Ames and delivers the tapes to the computer center.

APPENDIX K

IOWA DOT EQUIPMENT REQUIREMENTS AND DESIGN SPECIFICATIONS

The following items represent some of the equipment requirements and design specifications that the Iowa DOT recommends for a high-rail survey vehicle. This partial list was used in seeking a replacement TGC in Iowa and contains several items that were identified from our past association with a high-rail survey vehicle.

1. All wiring and cables under the vehicle shall be in sealed conduit and shall not sag below the chassis structure.

2. Air intake for the generator system shall be filtered and located at the roof level.

3. All gauges on the vehicle -- oil, water, etc. -- shall be electric.

4. Driver's seat shall be shock mounted.

5. Vehicle shall be capable of operating at 25 mph in both forward and reverse movement.

6. Driver shall have an unobstructed view in all directions when occupying the driver's seat.

7. Vehicle shall have built-in fire fighting equipment and fuel cells in the gas tanks. Separate extinguisher systems shall be installed in the engine, generator and computer compartments.

8. Computer system shall have excess capacity so that additional measurement parameters can be added at a latter date.

9. High-rail system shall have an auxillary hydraulic system or a manual override.

APPENDIX L

RAILROAD REHABILITATION COST ESTIMATING METHODOLOGY STUDY

PHASE 1 REPORT

Prepared for:

Iowa Department of Transportation
Planning and Research Division
Transportation Research Office

Prepared by:

Henningson, Durham & Richardson, Inc.
Omaha, Nebraska

February, 1979

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FOR APPENDIX L

LIST OF FIGURES

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

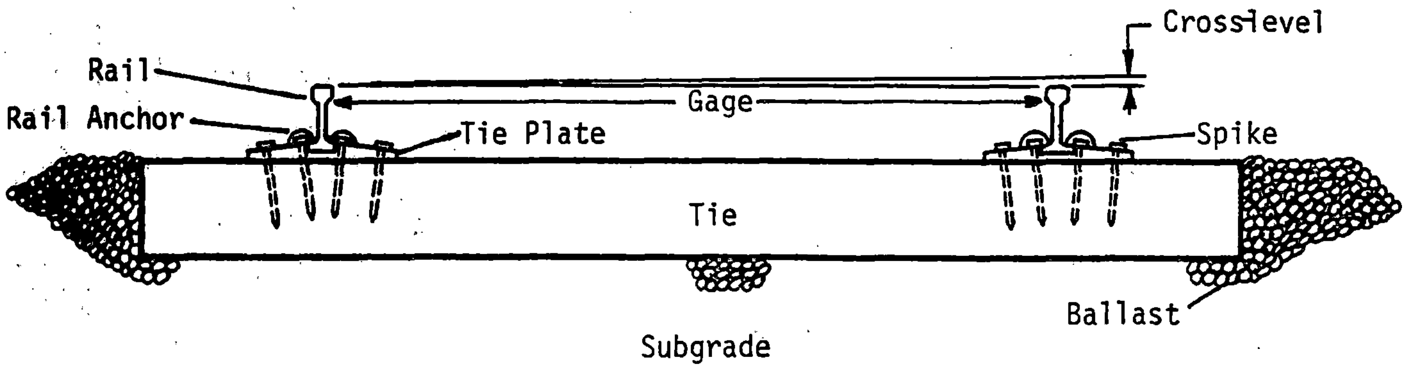
This section of the report summarizes components of the track structure, and how degradation of their quality may be detected by the TGC. As a point of reference, FRA track standards and TGC features are briefly presented. This discussion will set the stage for the sections of the report which follow.

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 super-elevation. 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

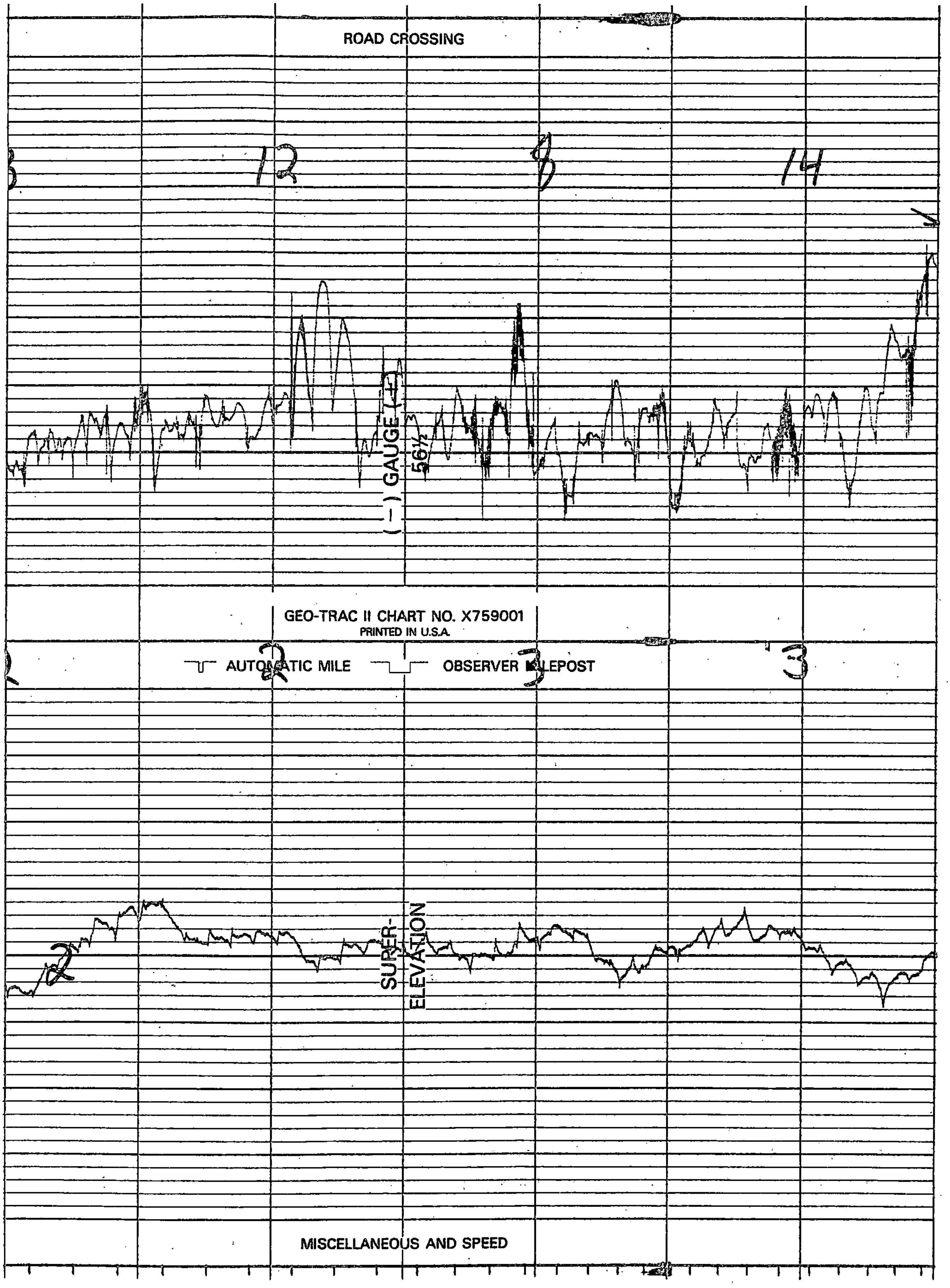


FIGURE 2.2
ANALOG STRIP CHART

TGC TRACK EXCEPTION REPORT
75297 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	997	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.

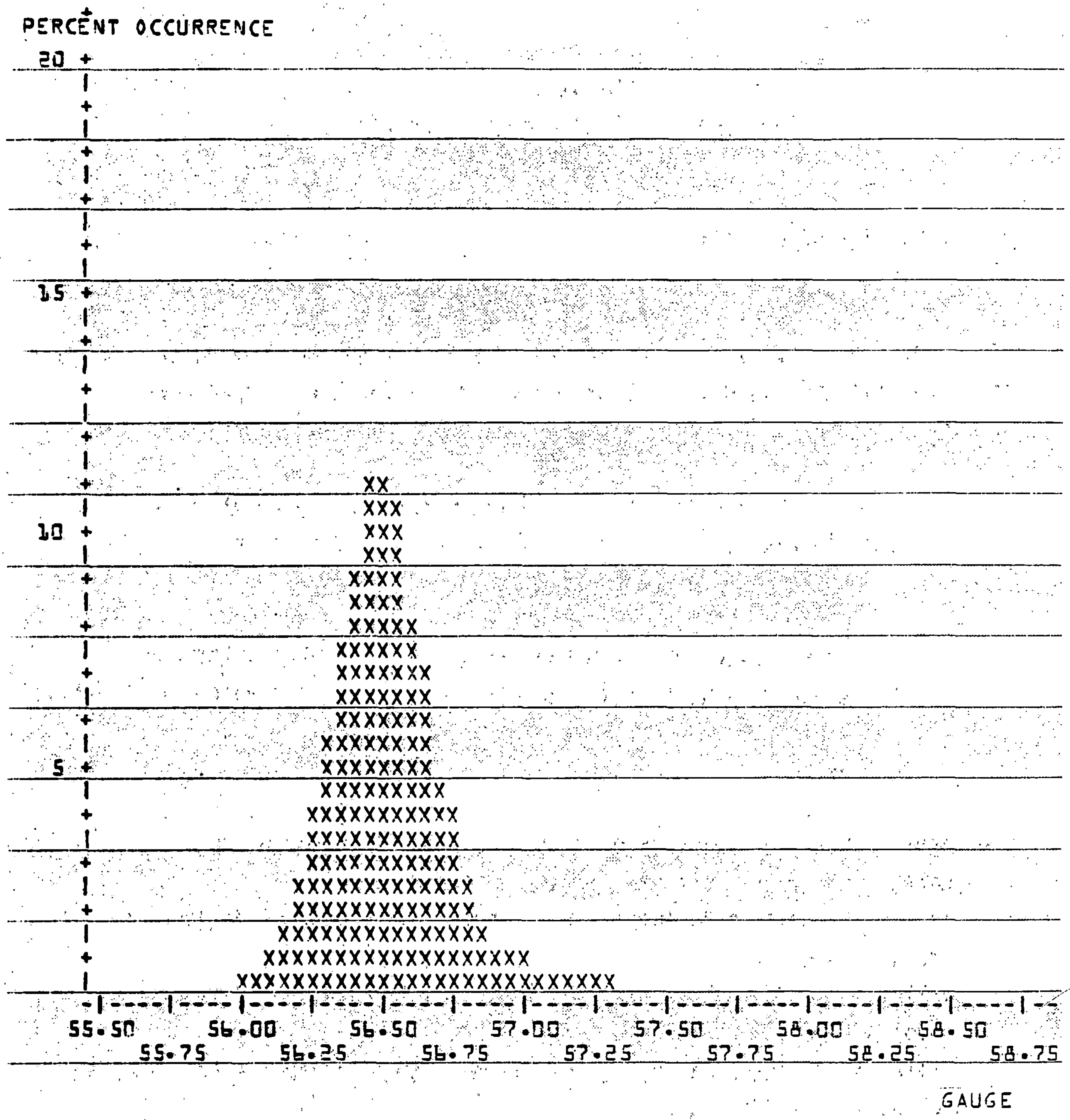


Figure 2.4
TYPICAL GAGE HISTOGRAM

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.

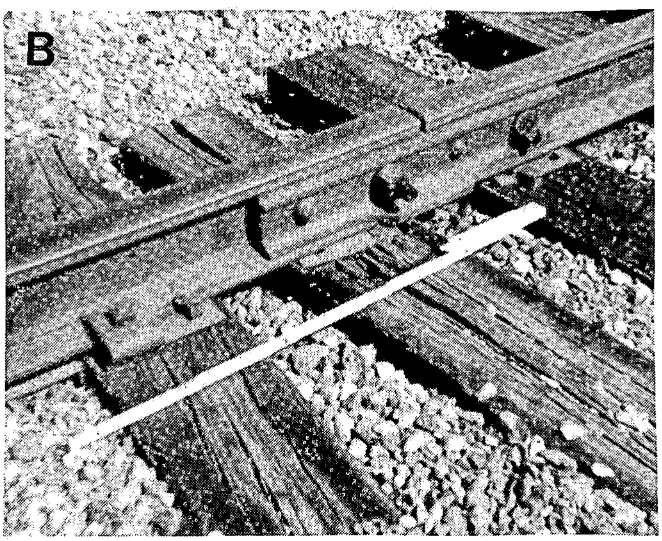
The rail exhibited normal wear along the running edge. The most prominent undesirable condition with the rail is in the joint area. Lack of maintenance has permitted the rail ends to be bent down at the joints. Of course, the joint bars are deformed with the rail ends. The old design of the joint bars 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:

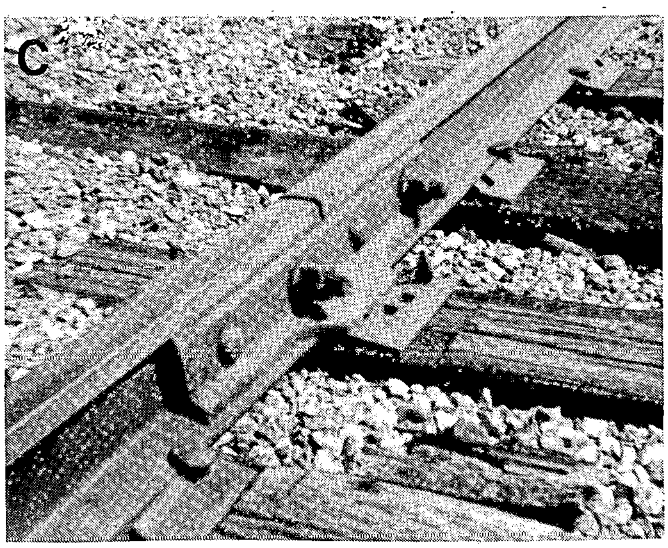
The slued ties could cause tight gage. The low joints along with missing spikes at the joints could cause wide gage and cross-level deviations. The

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.

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:

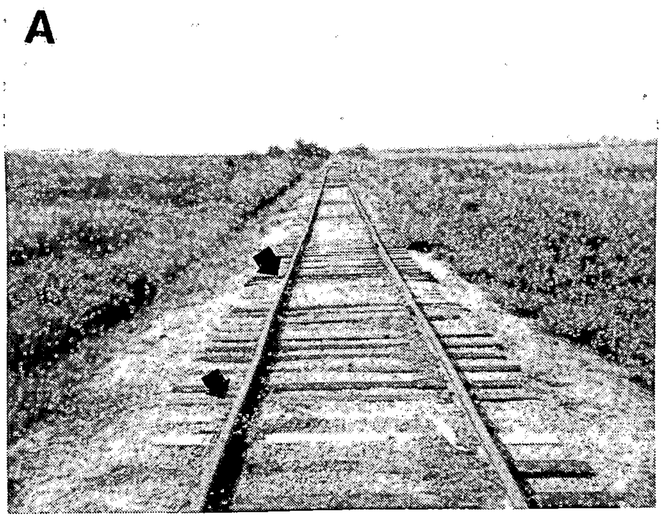
A. Track Classification: Class 1

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

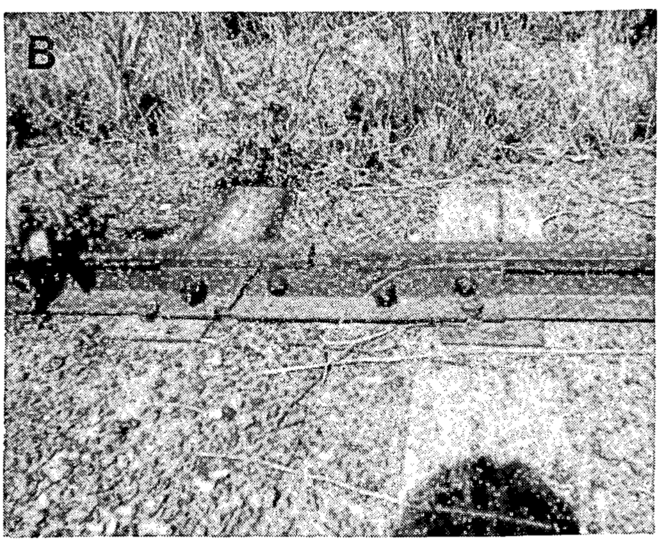
C. Observations:
In general, the overall condition of the track is poor, due primarily to the age of the facility and its components. A large number of the ties have been in place since the 1930's.

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.

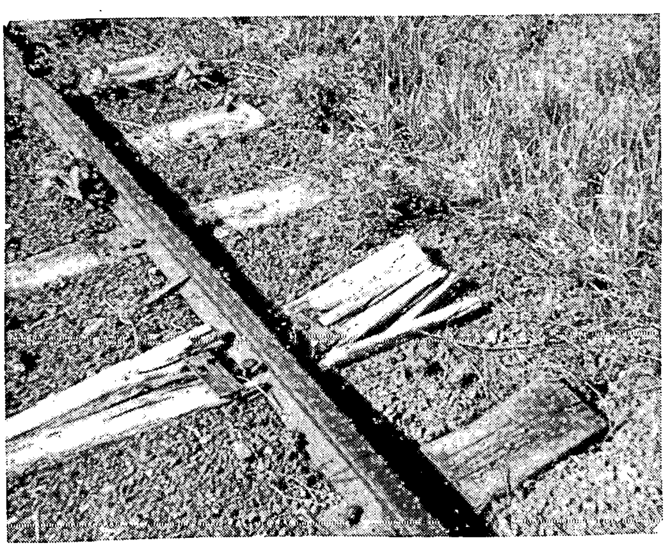
E. Rehabilitation Recommendations:
1. Replace 30% to 50% of the cross ties.
2. Apply additional ballast and surface track.
3. Replace rail with a heavier section.
4. Apply rail anchors.



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

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:

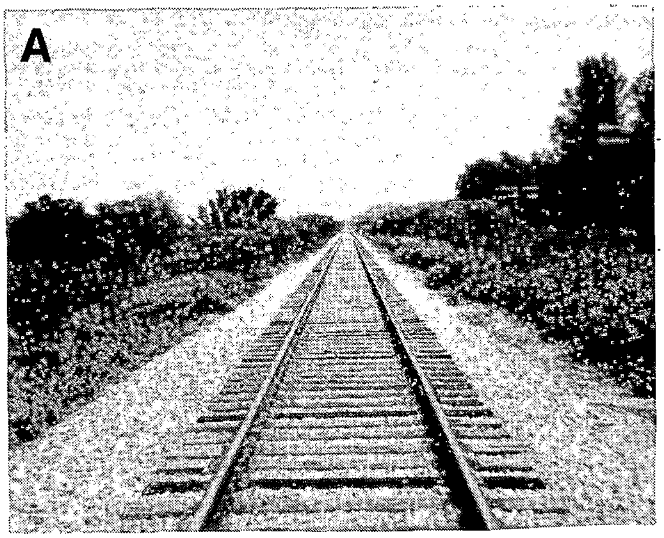
This track is in good condition.

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 <u>gage index</u> and <u>cross-level index</u> 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 per mile 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.

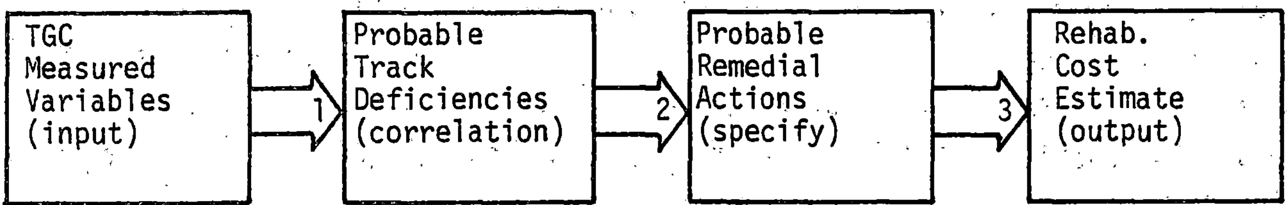
The ultimate purpose of the model is to provide a method of estimating rehabilitation costs from TGC measured variables. Thus a model which would allow the direct calculation of rehabilitation costs without going through the two intermediate steps would meet the objective of the project. Such a direct 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:

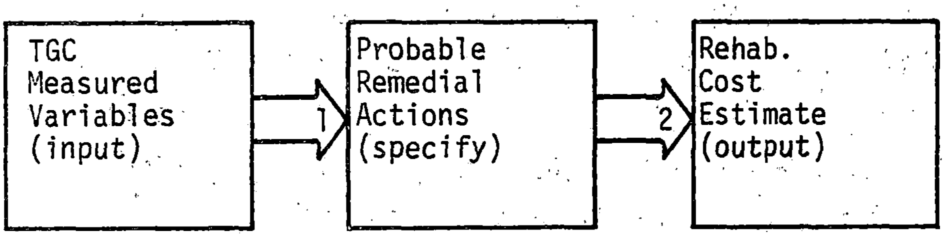
$$Y=A+(K_1 \times DG)+(K_2 \times WG)+(K_3 \times NG)+(K_3 \times TG)+(K_4 \times DC)+(K_5 \times TC)+\sum_{i=6}^{k}(k_i \times Si)$$

A BASIC MODEL STRUCTURE



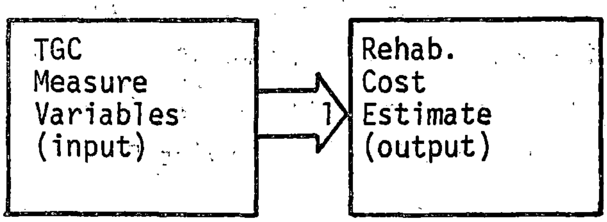
1. Synthesize regression equations
2. Apply railroad engineering practice
3. Utilize historical repair costs

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 insuffficent 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

<u>Labor</u>

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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3. Preliminary Standards, Classification, and Designation of Lines of Class 1 Railroads in the United States, Volume 1, Secretary of Transportation, U.S. DOT, August, 1976.

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5. Bulletin 666, Proceedings Volume 79, American Railway Engineering Association, pg. 141-174, Jan-Feb, 1978.

6. Track Geometry Measurements and Data Processing Developments in the Rail Research Program, L. From, ENSCO, INC., FRA-OR&D - 75 - 14, October, 1974.

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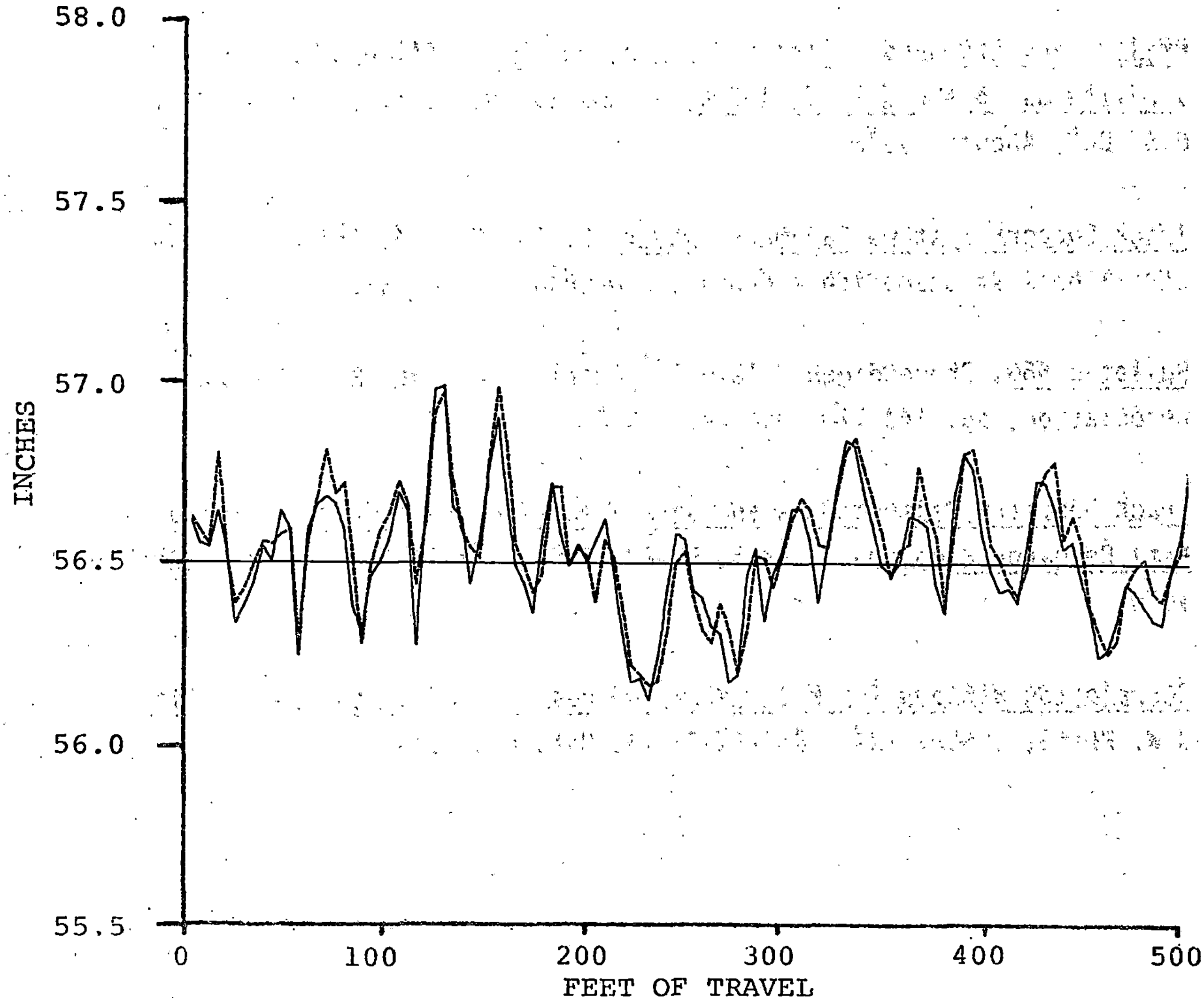
APPENDIX M
ANNALOG COMPARISONS

TRACK SEGMENT 1
CLASS I - JOINTED RAIL
FRA FIRST - 5 MPH



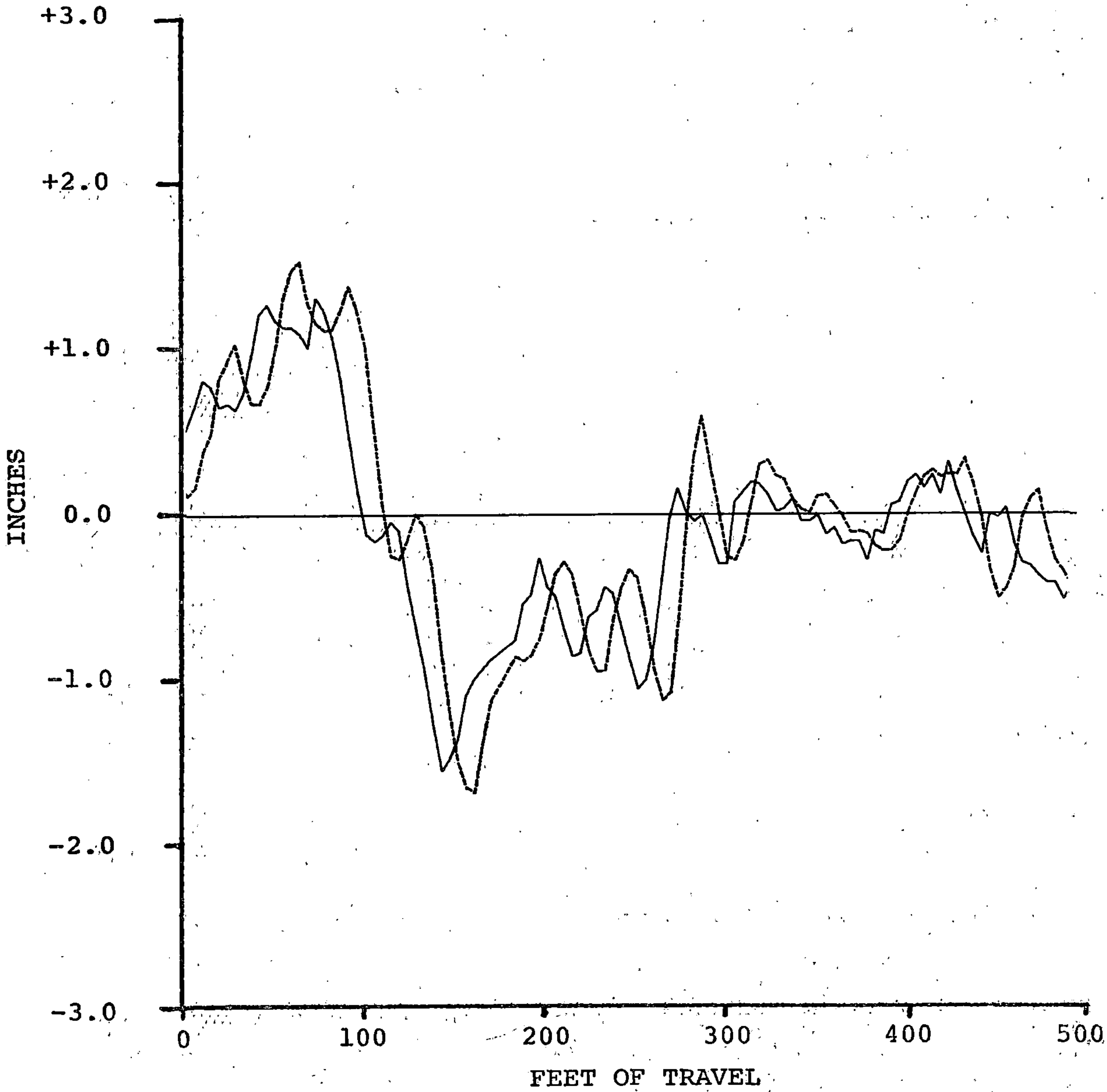
—— Gage by TGC Measurement

---- Gage by FRA Measurement

TRACK SEGMENT 1

CLASS I - JOINTED RAIL

FRA FIRST - 5 MPH

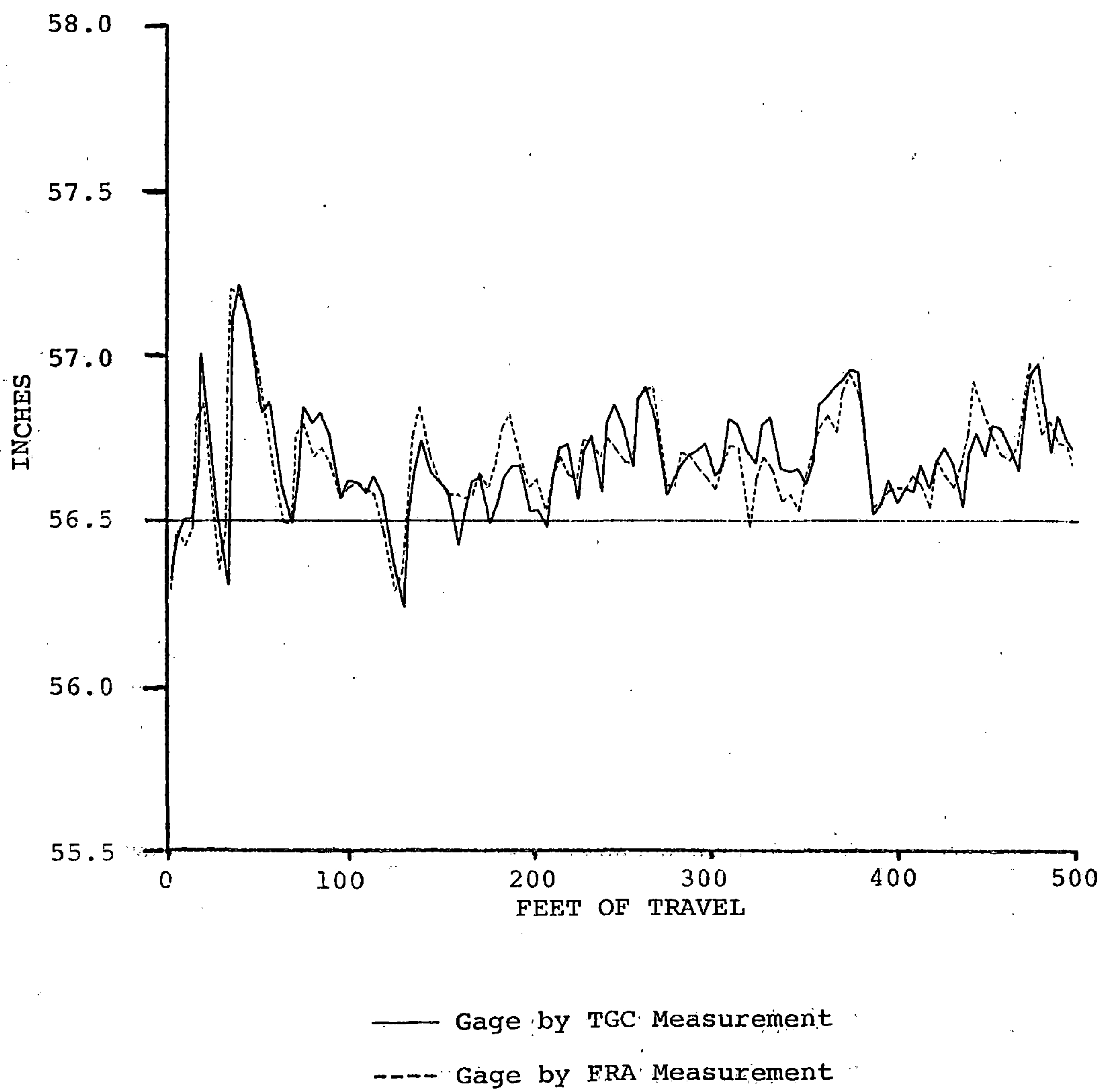


——— X-Level by the TGC Measurement

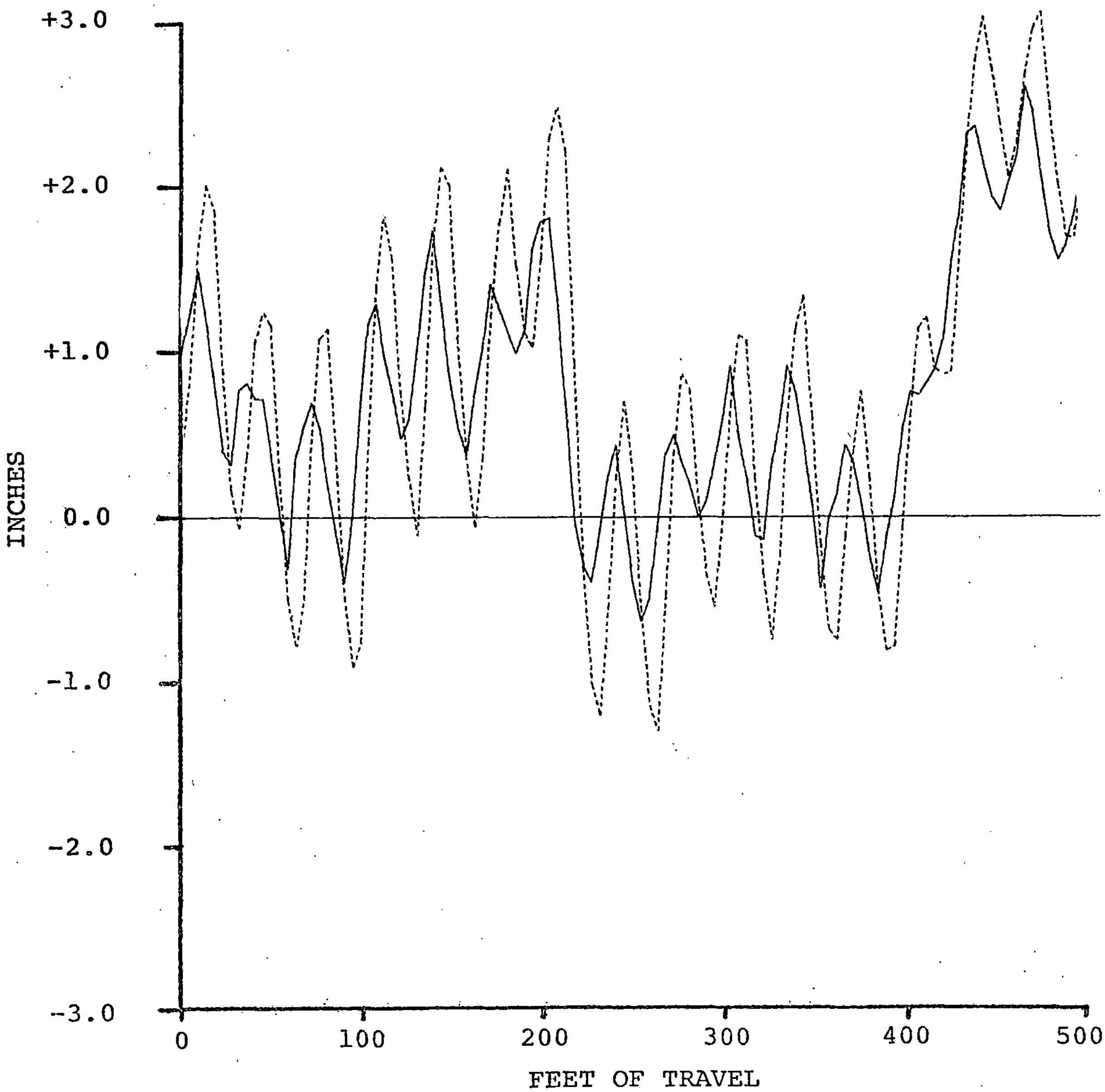
---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

TRACK SEGMENT 2
CLASS I - JOINTED RAIL
TGC FIRST - 5 MPH



TRACK SEGMENT 2
CLASS I - JOINTED RAIL
TGC FIRST - 5 MPH

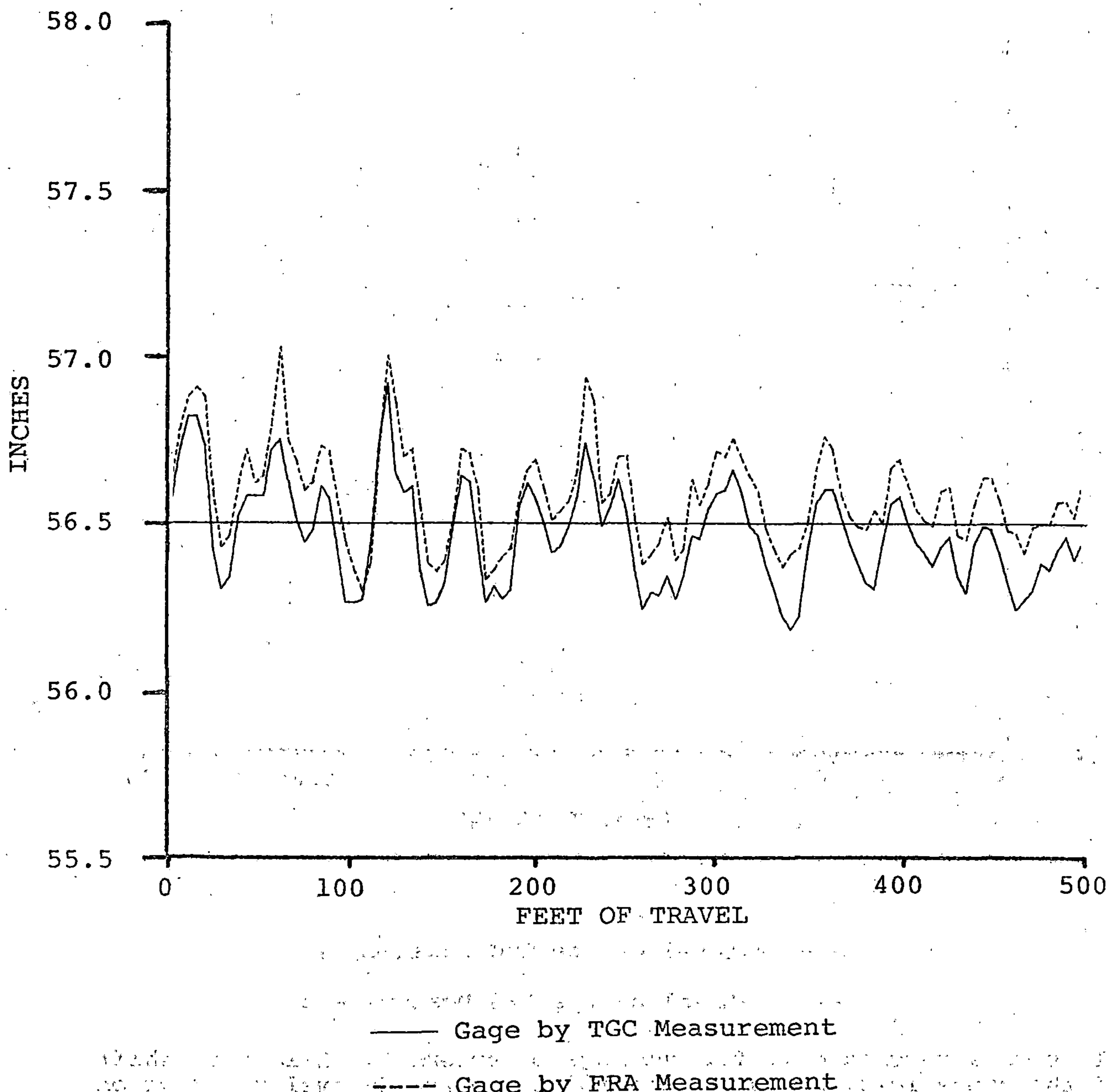


—— X-Level by the TGC Measurement

---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

TRACK SEGMENT 3
CLASS II - JOINTED RAIL
FRA FIRST - 10 MPH



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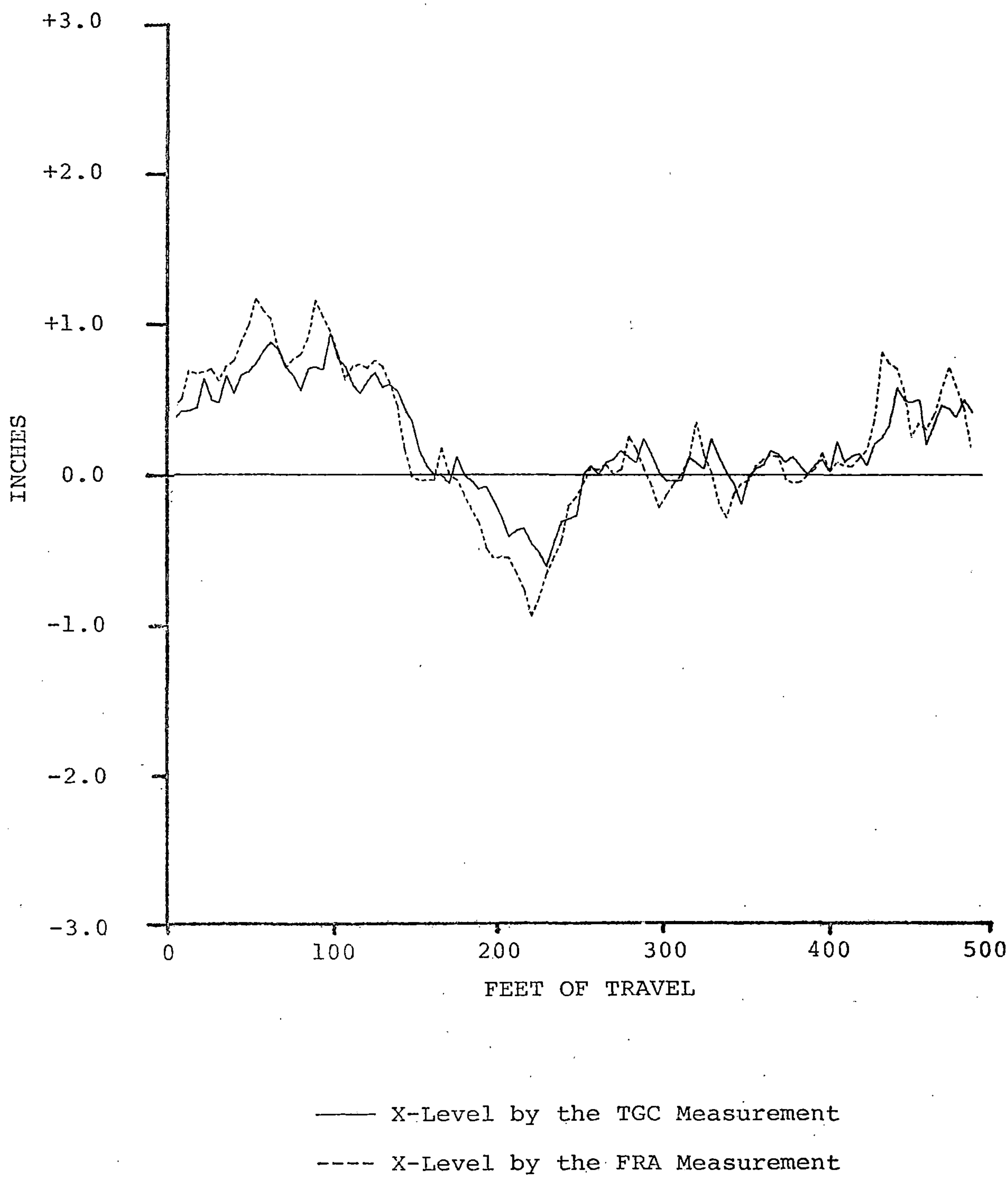
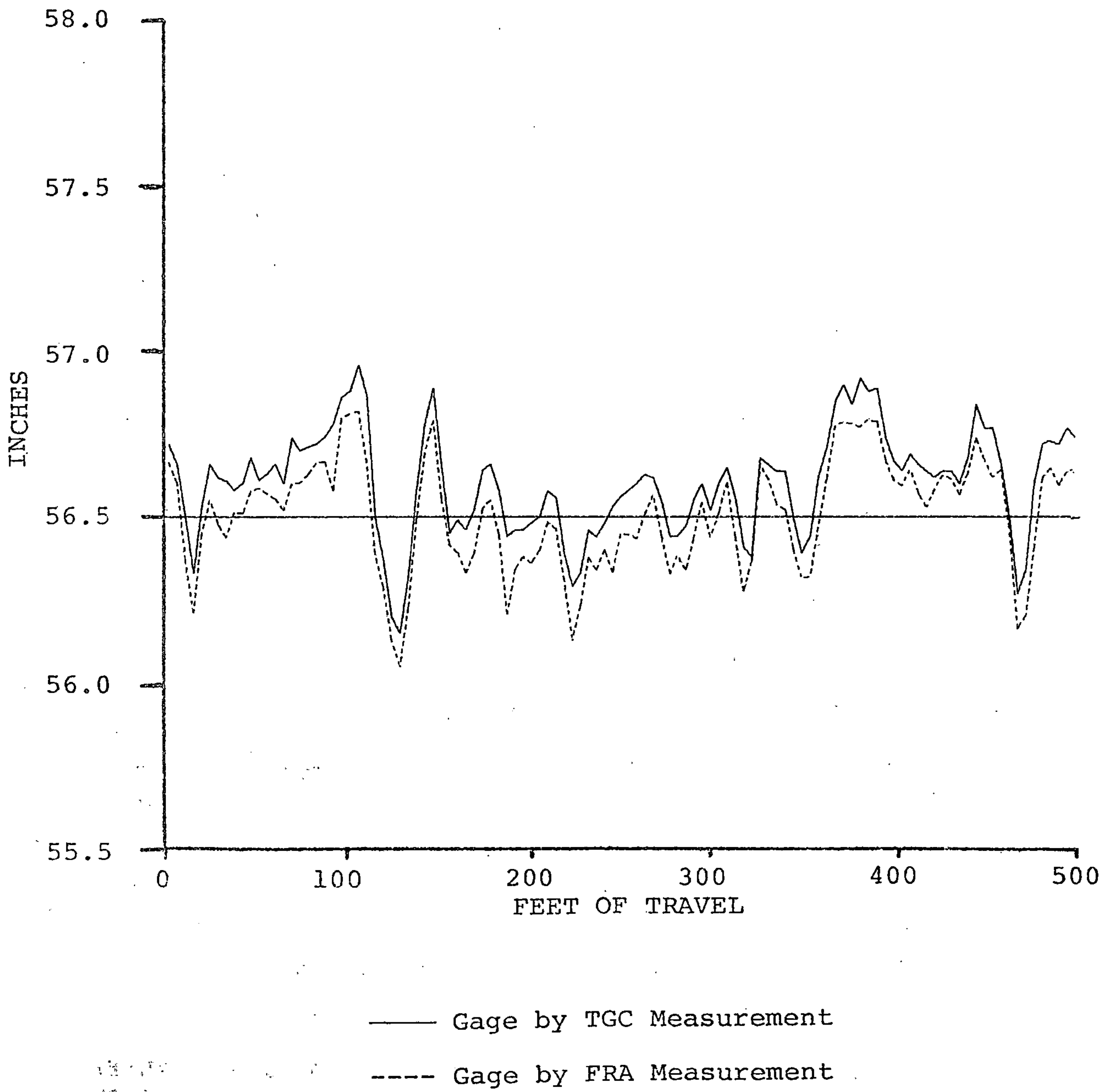
CLASS II - JOINTED RAIL
FRA FIRST - 10 MPH



Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage sensors.

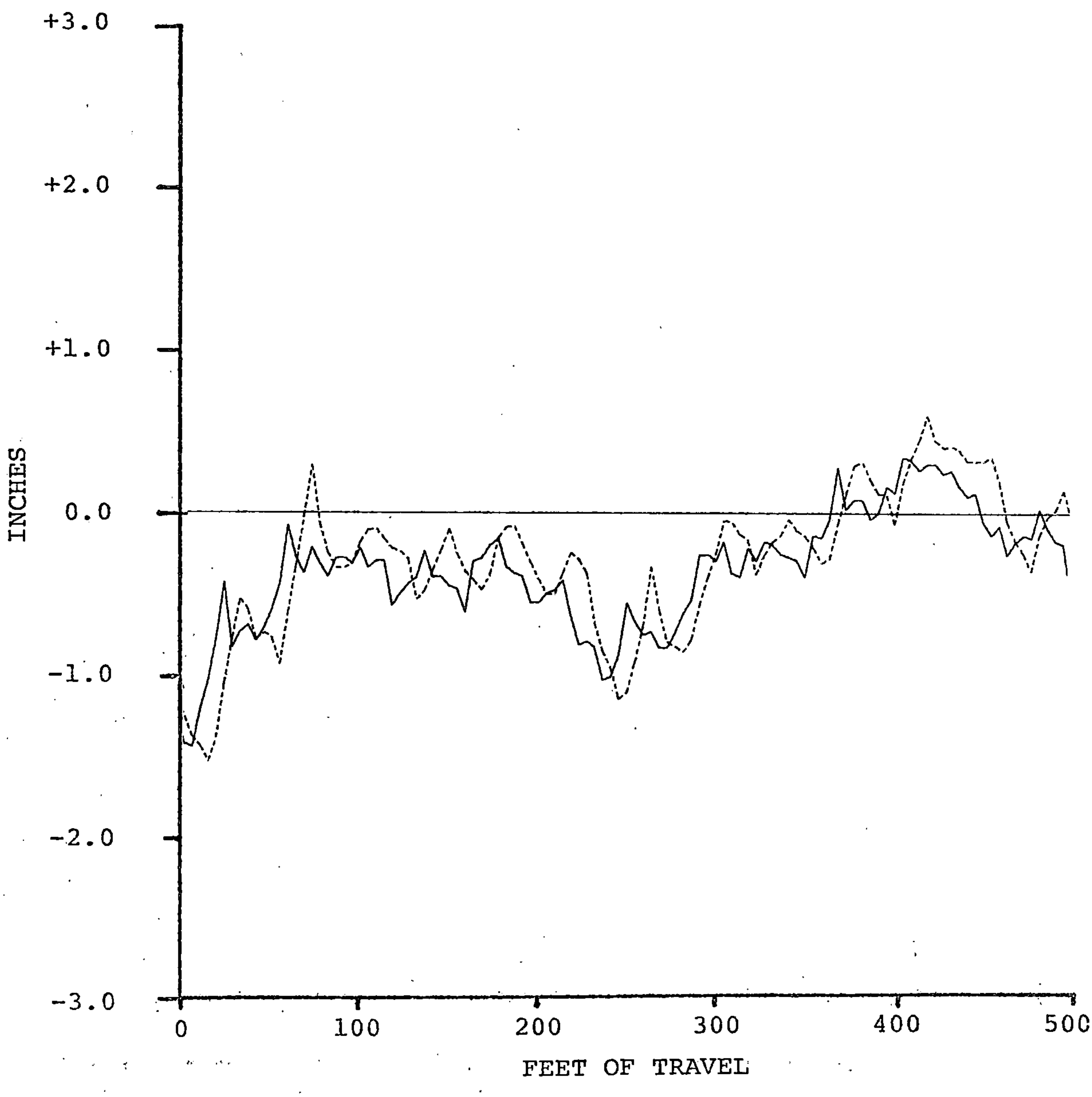
TRACK SEGMENT 4
CLASS II - JOINTED RAIL
TGC FIRST - 10 MPH



TRACK SEGMENT 4

CLASS II - JOINTED RAIL

TGC FIRST - 10 MPH

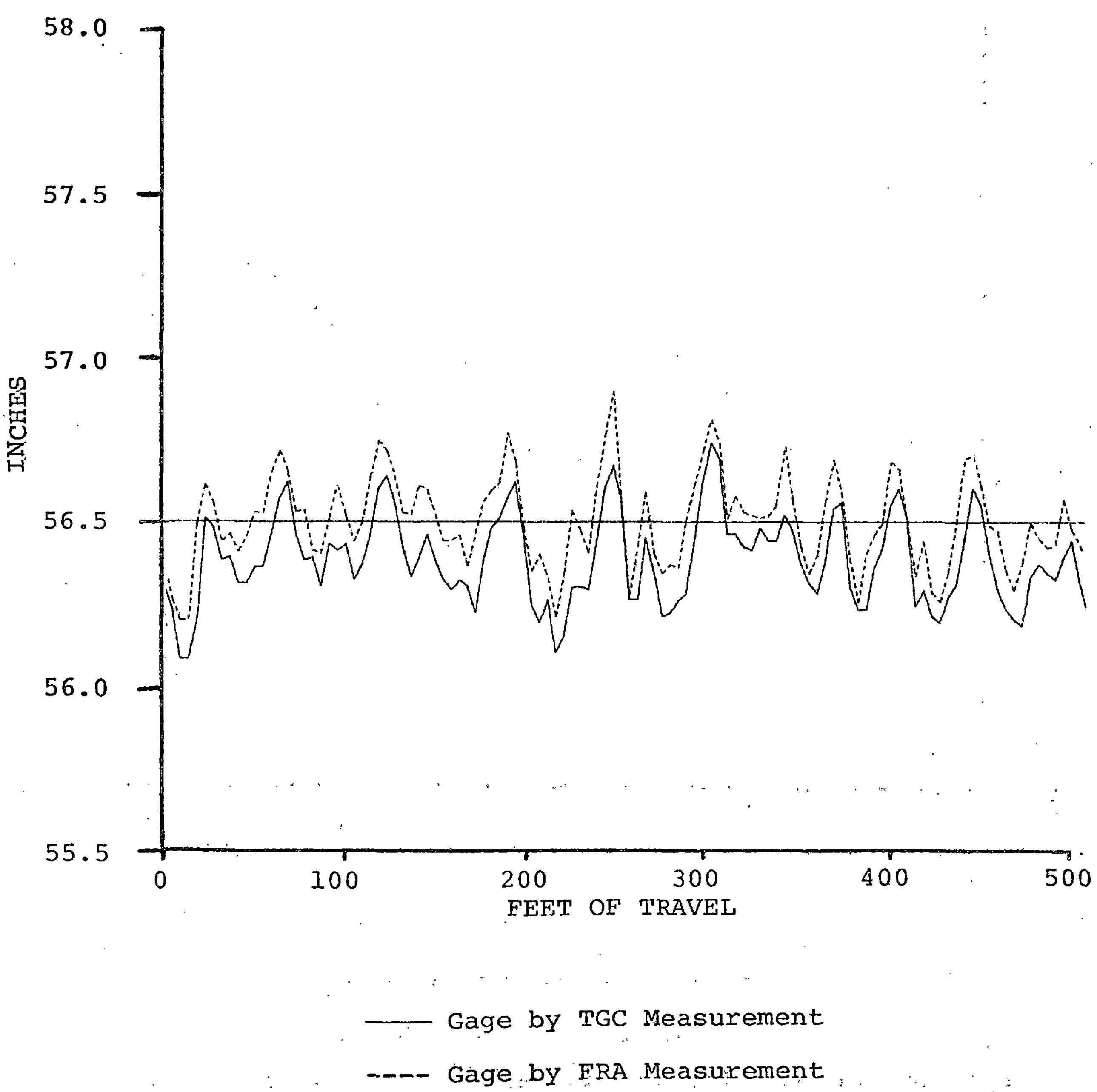


——— X-Level by the TGC Measurement

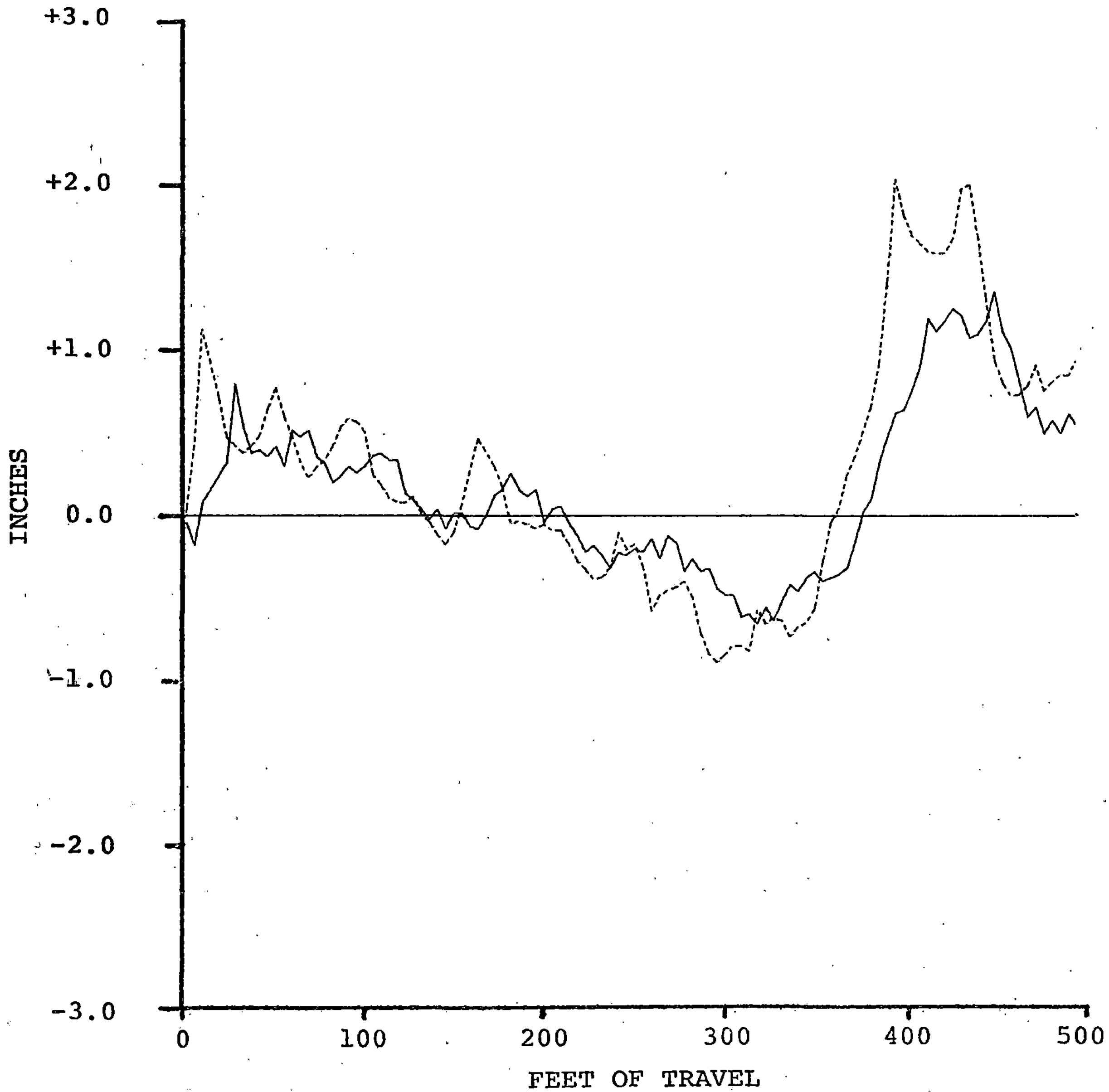
---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

TRACK SEGMENT 5
CLASS II - JOINTED RAIL
FRA FIRST - 20 MPH



TRACK SEGMENT 5
CLASS II - JOINTED RAIL
FRA FIRST - 20 MPH

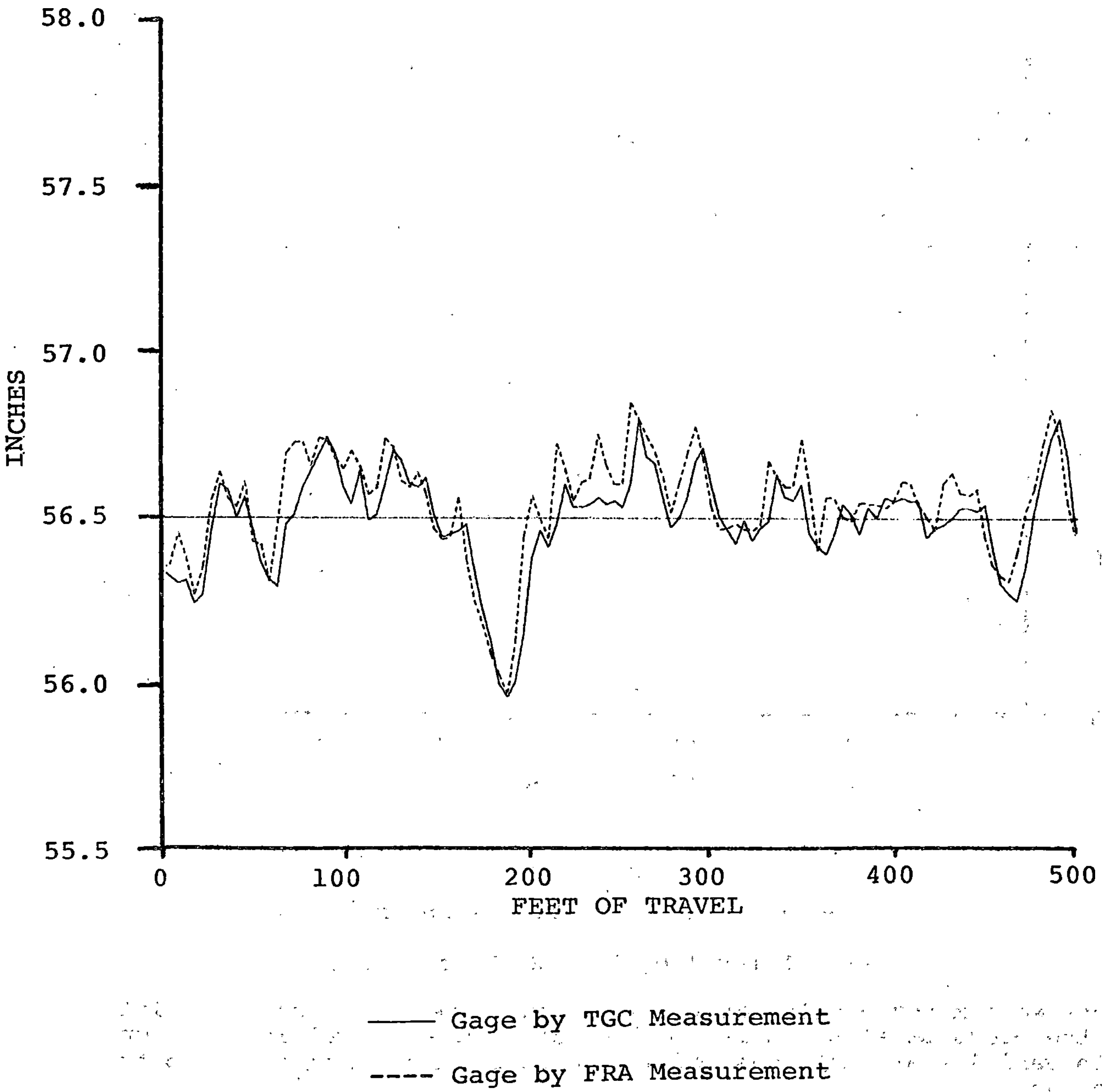


—— X-Level by the TGC Measurement

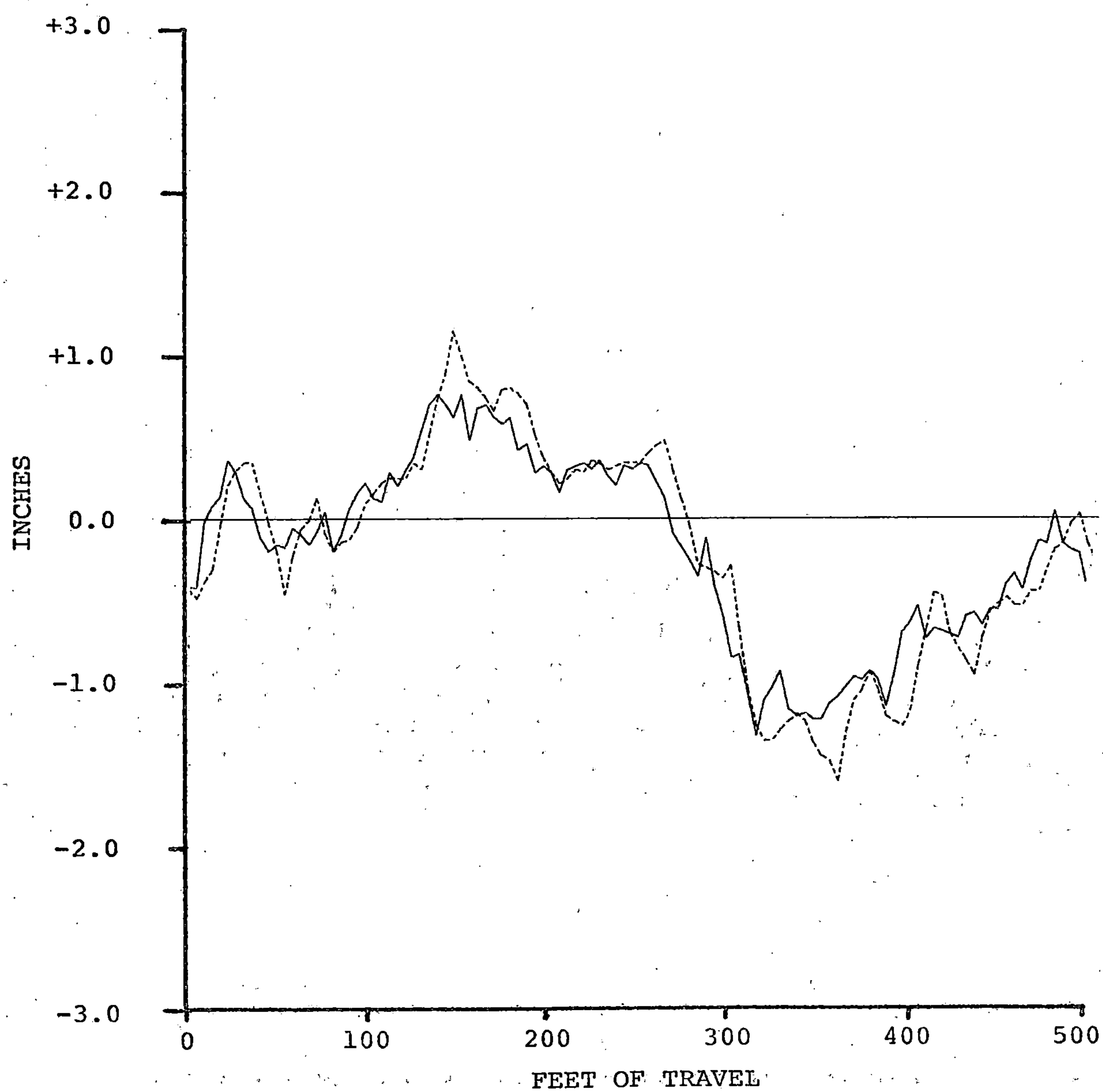
---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

TRACK SEGMENT 6
CLASS II - JOINTED RAIL
TGC FIRST - 20 MPH



TRACK SEGMENT 6
CLASS II - JOINTED RAIL
TGC FIRST - 20 MPH

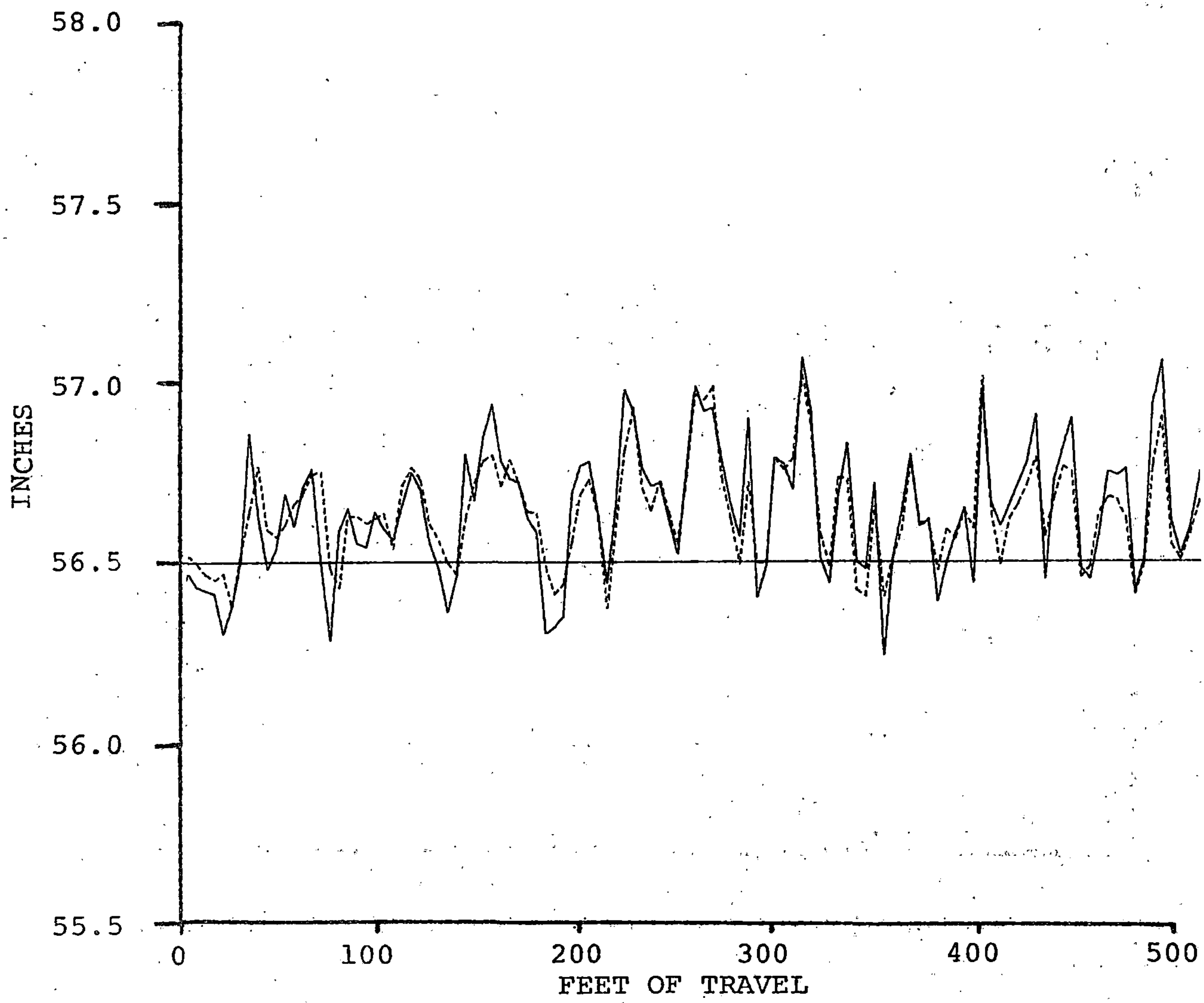


—— X-Level by the TGC Measurement

---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

TRACK SEGMENT 7
CLASS II - WELDED RAIL
FRA FIRST - 20 MPH



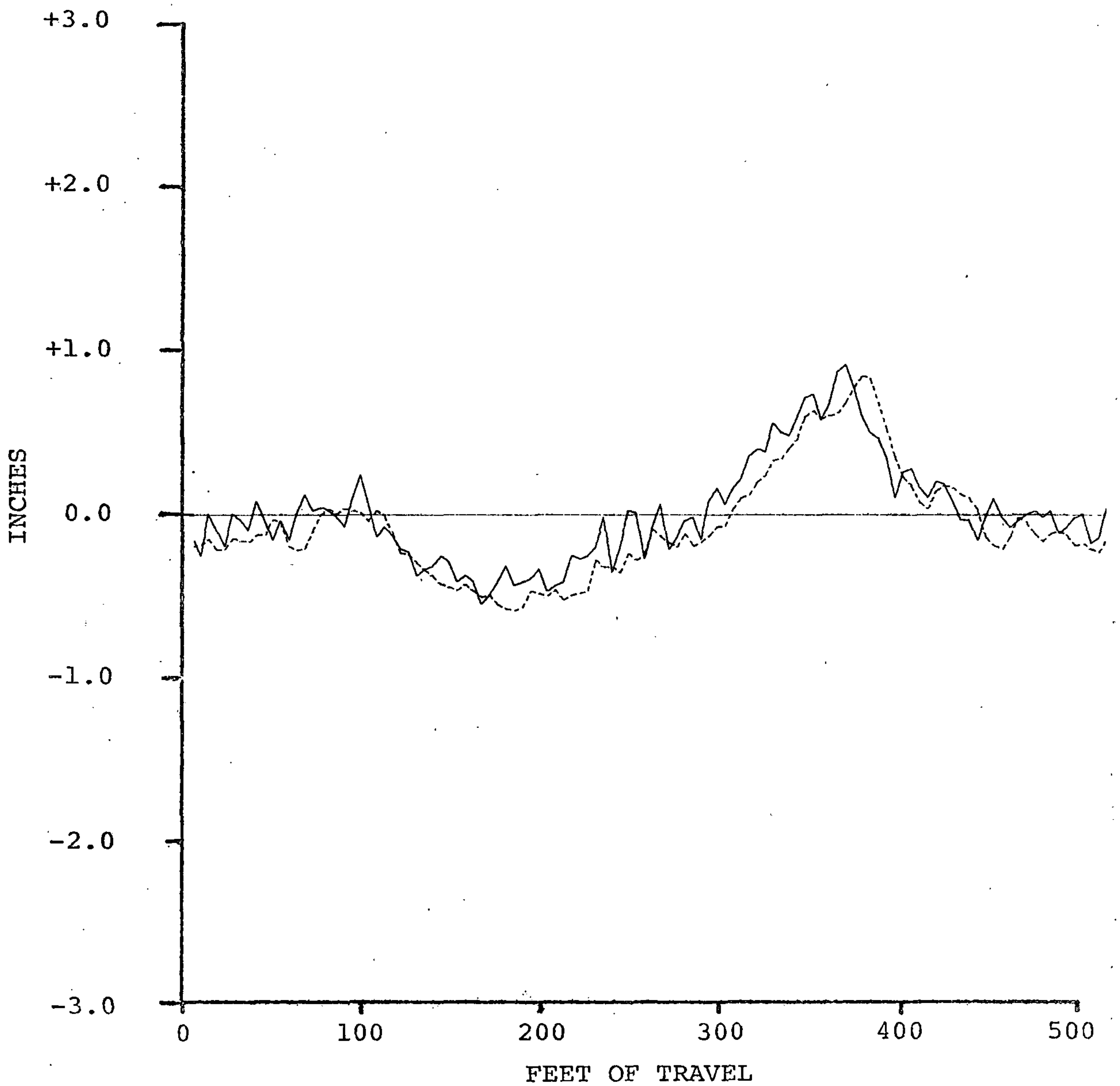
—— Gage by TGC Measurement

---- Gage by FRA Measurement

TRACK SEGMENT 7

CLASS II - WELDED RAIL

FRA FIRST - 20 MPH

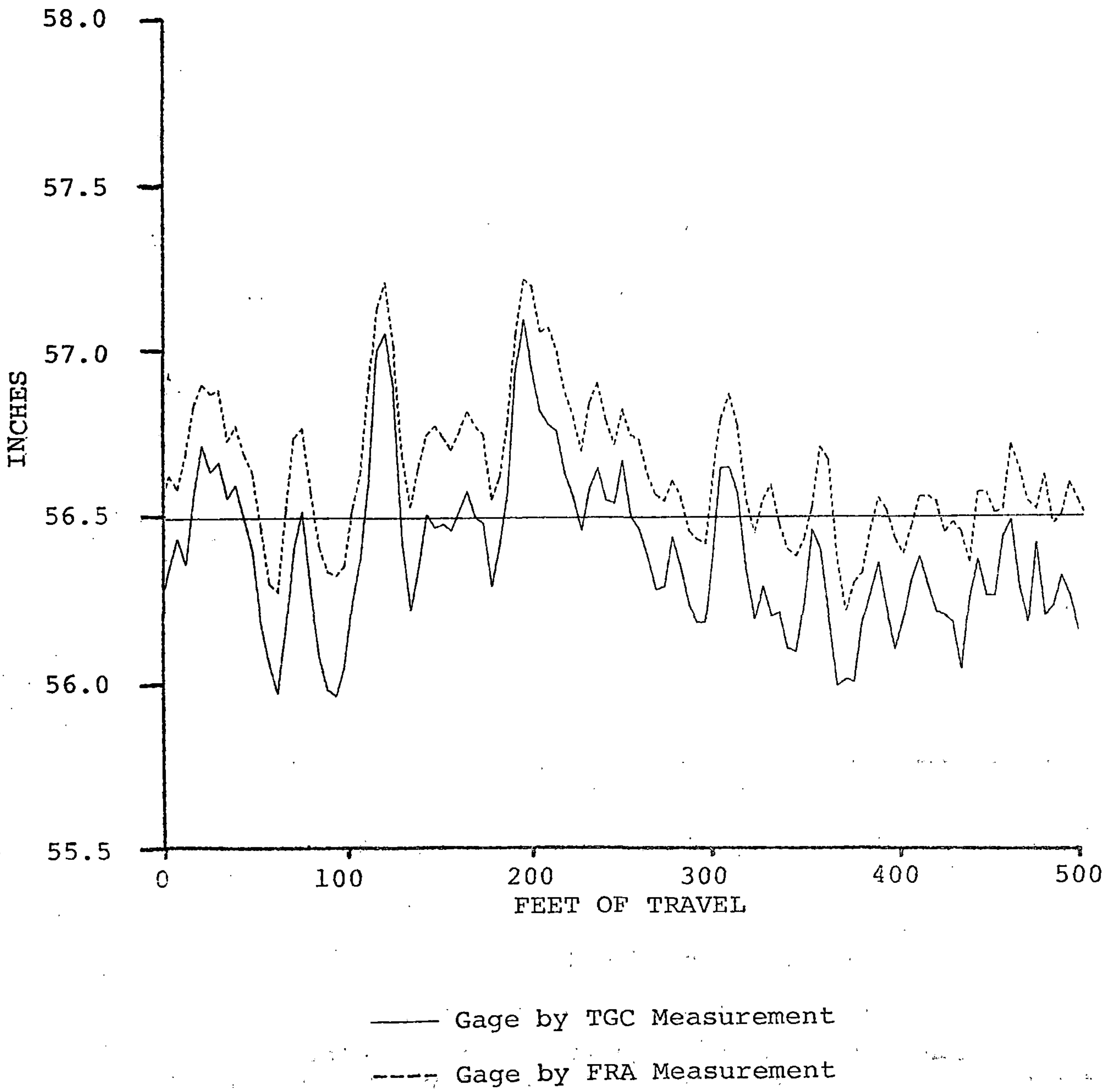


—— X-Level by the TGC Measurement

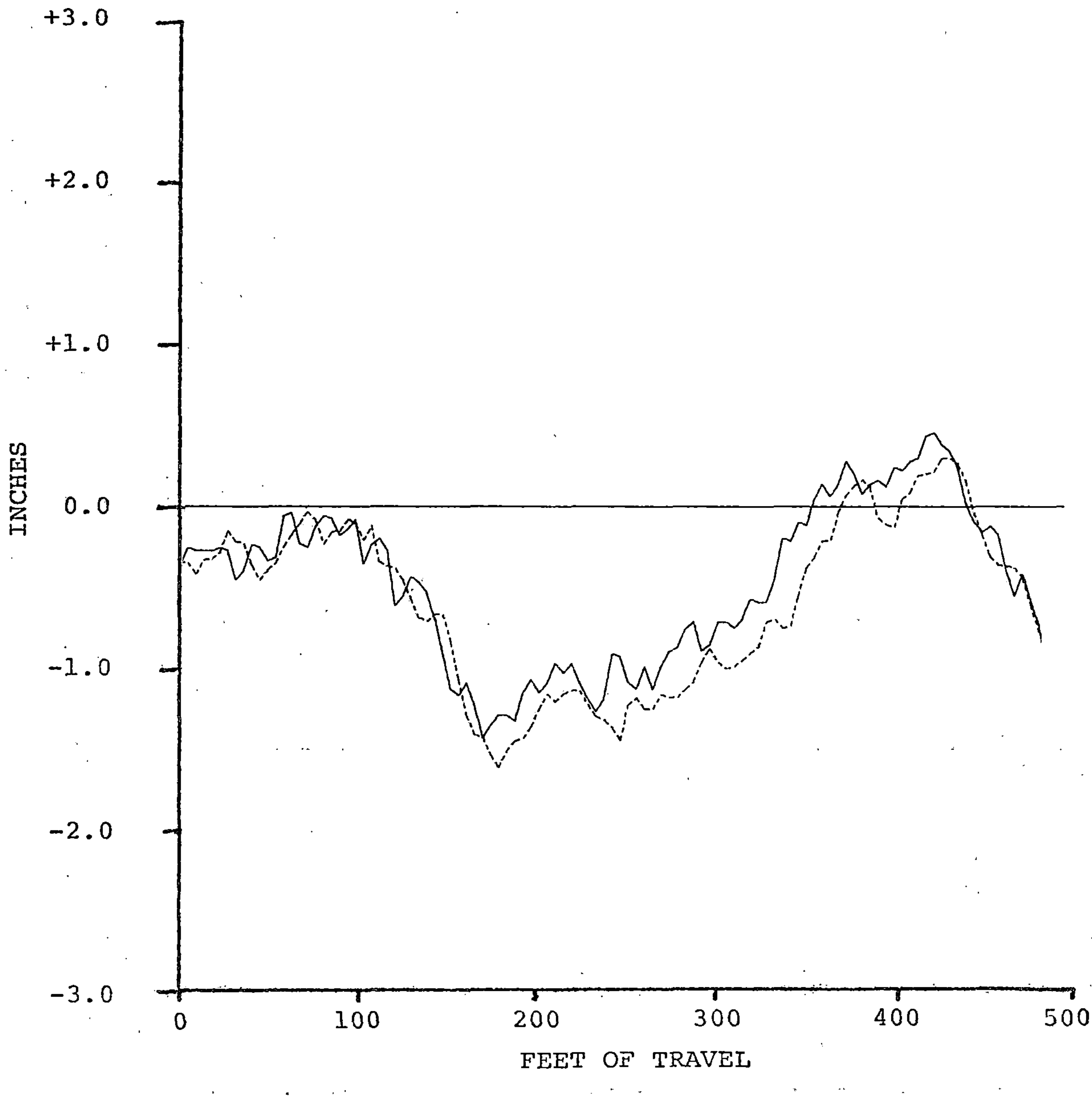
---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

TRACK SEGMENT 8
CLASS II - WELDED RAIL
TGC FIRST - 20 MPH



TRACK SEGMENT 8
CLASS II - WELDED RAIL
TGC FIRST - 20 MPH

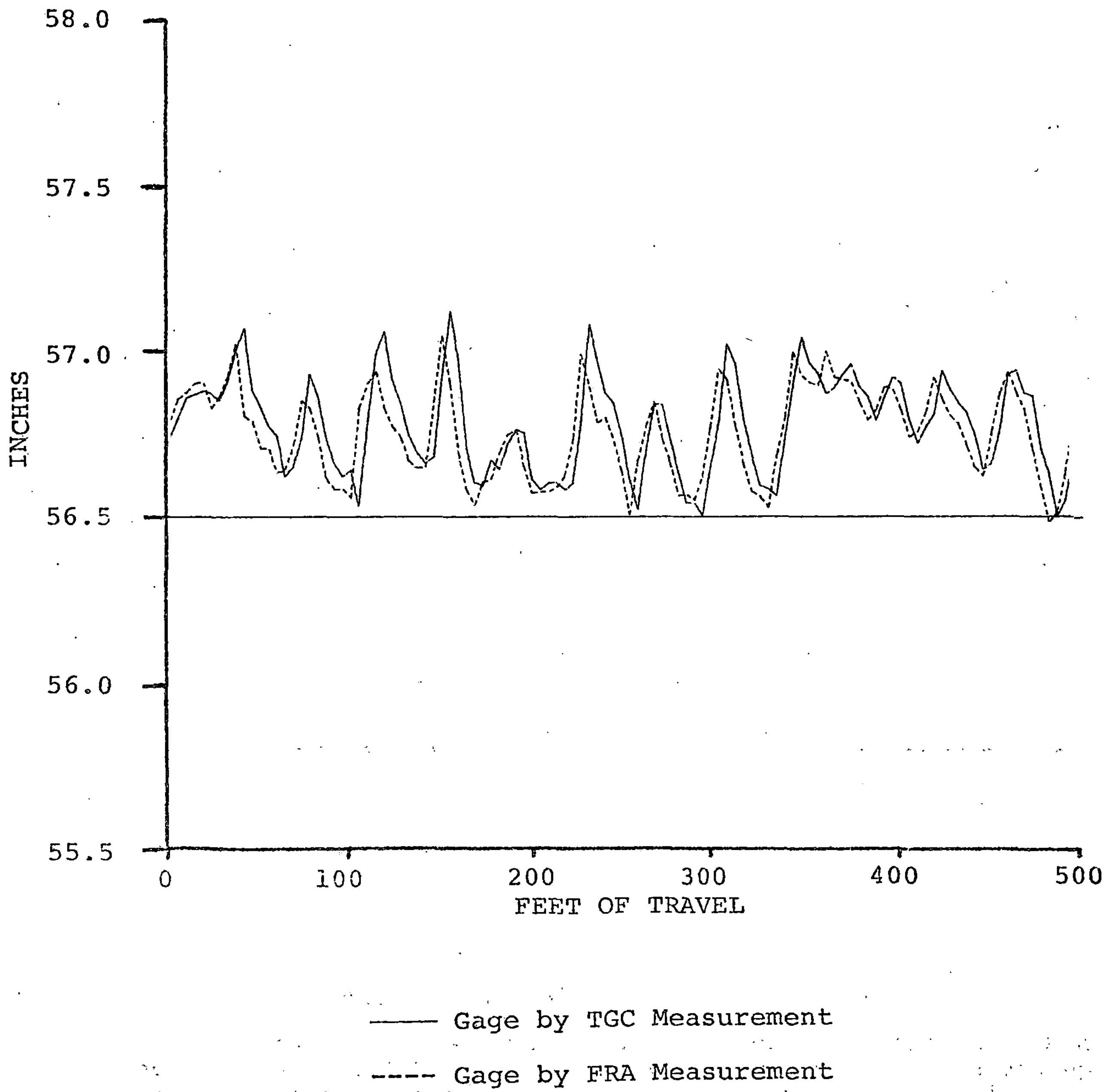


—— X-Level by the TGC Measurement

---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

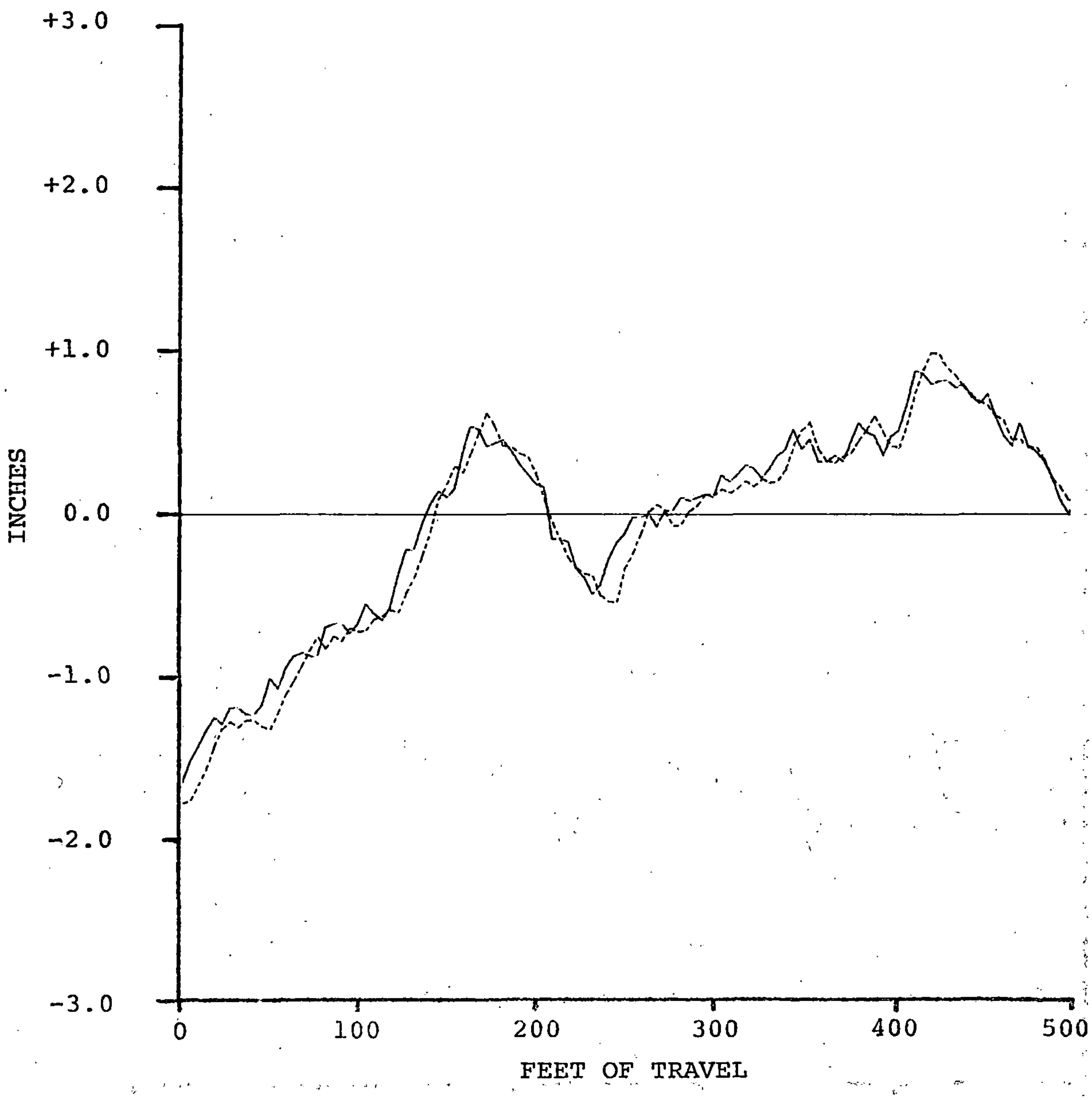
TRACK SEGMENT 9
CLASS III - JOINTED RAIL
FRA FIRST - 10 MPH



TRACK SEGMENT 9

CLASS III - JOINTED RAIL

FRA FIRST - 10 MPH

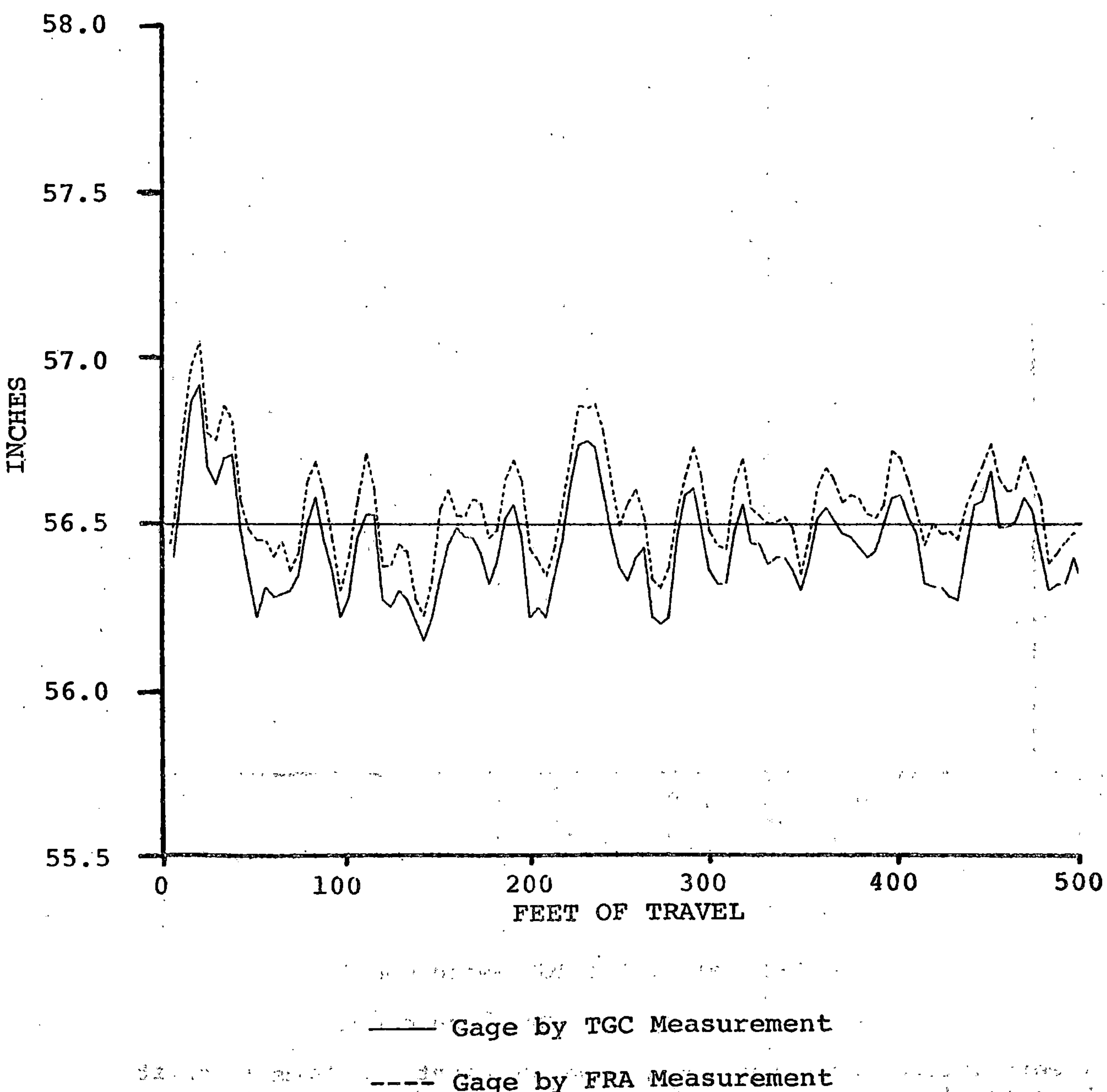


——— X-Level by the TGC Measurement

---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

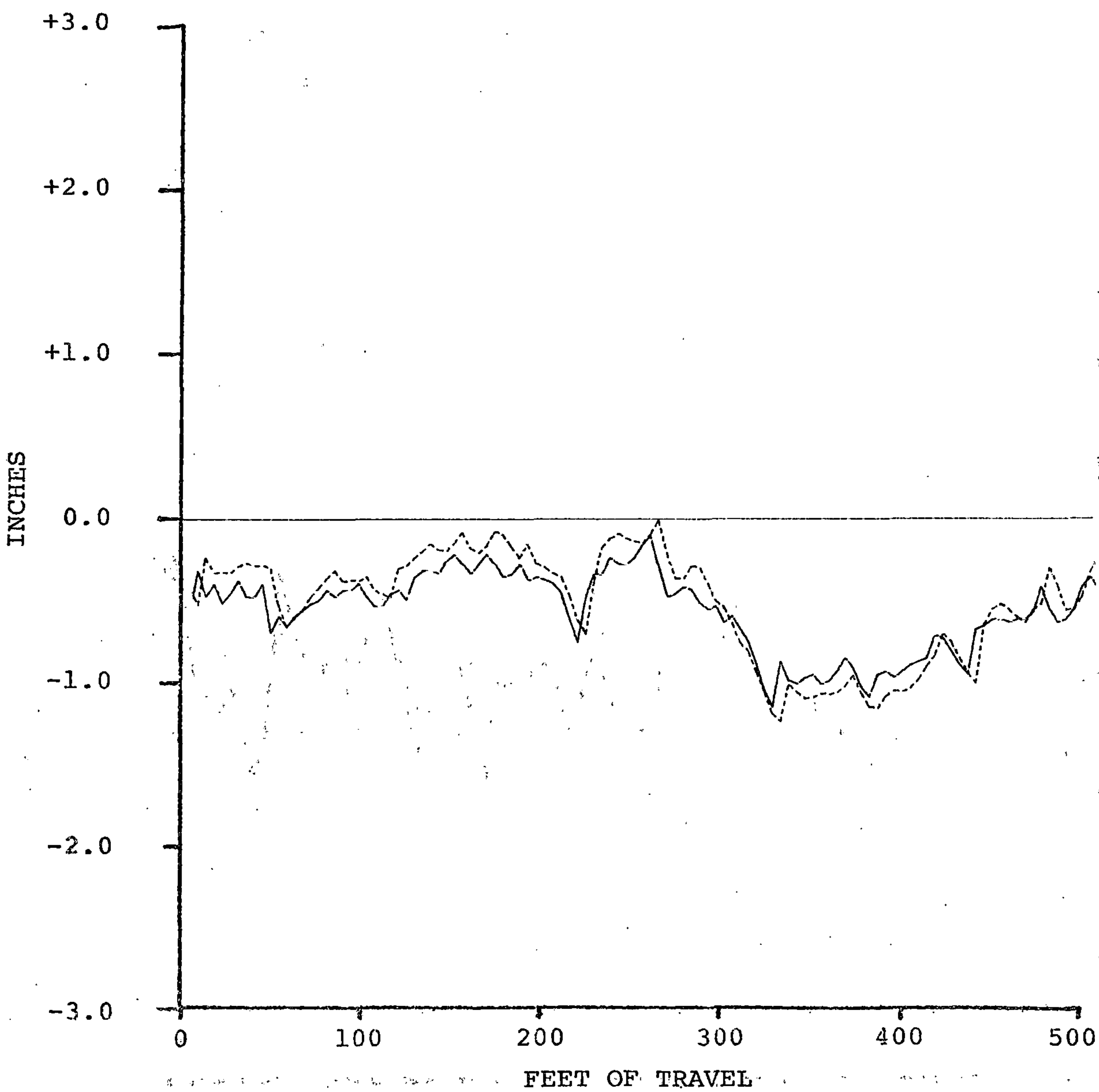
TRACK SEGMENT 10
CLASS III - JOINTED RAIL
TGC FIRST - 10 MPH



TRACK SEGMENT 10

CLASS III - JOINTED RAIL

TGC FIRST - 10 MPH

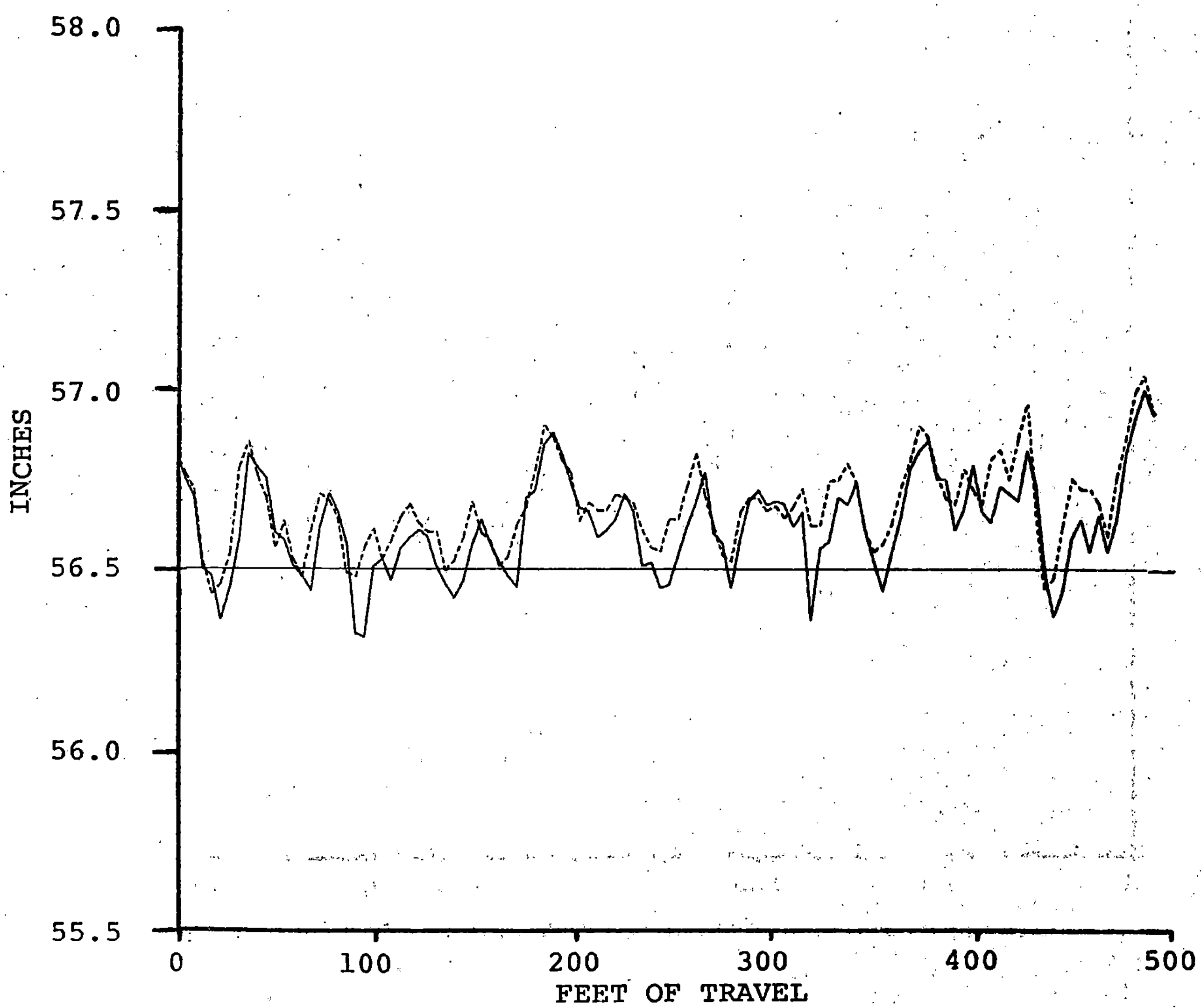


——— X-Level by the TGC Measurement

---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

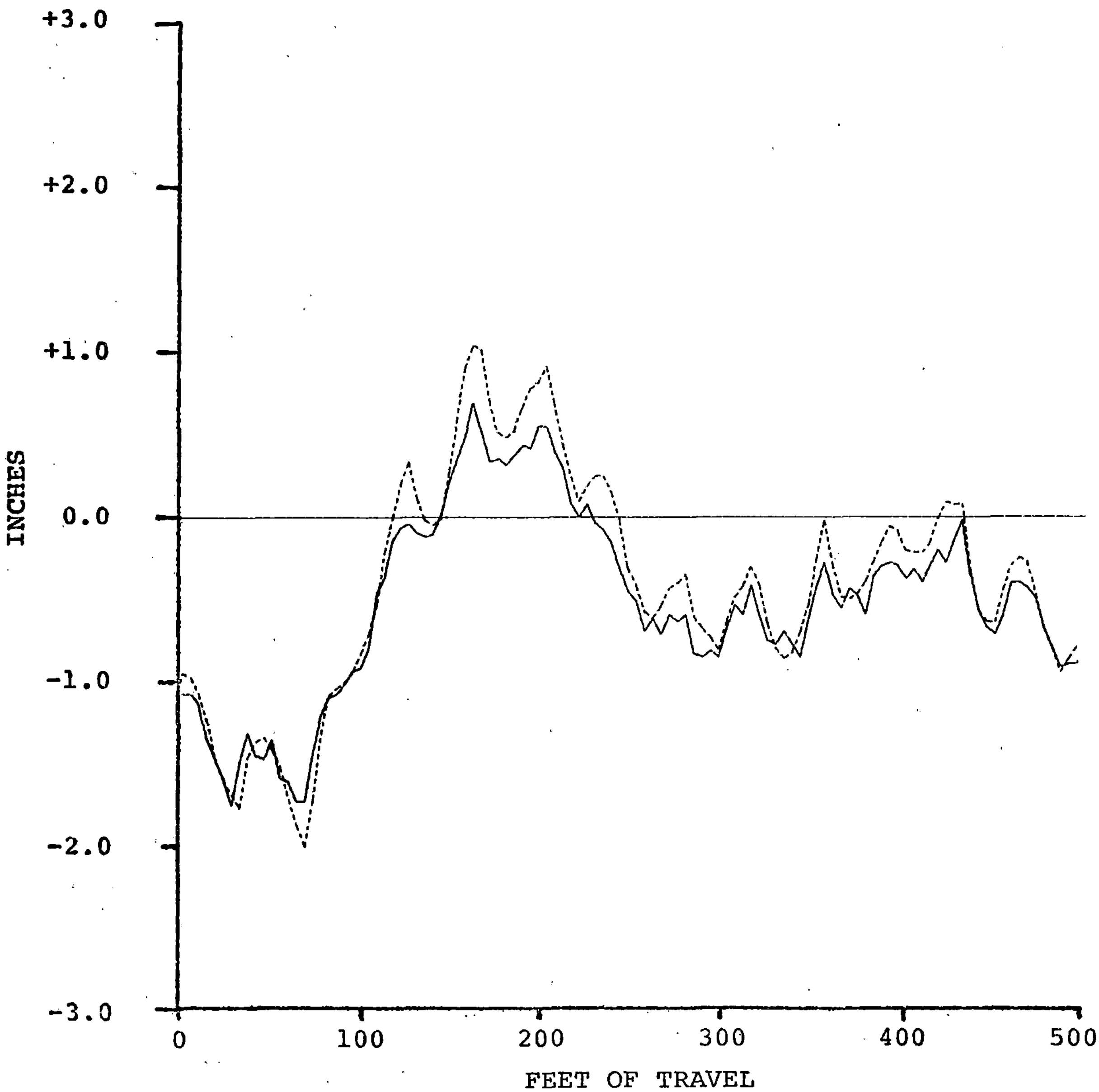
TRACK SEGMENT 11
CLASS III - JOINTED RAIL
FRA FIRST - 20 MPH



—— Gage by TGC Measurement

---- Gage by FRA Measurement

TRACK SEGMENT 11
CLASS III - JOINTED RAIL
FRA FIRST - 20 MPH

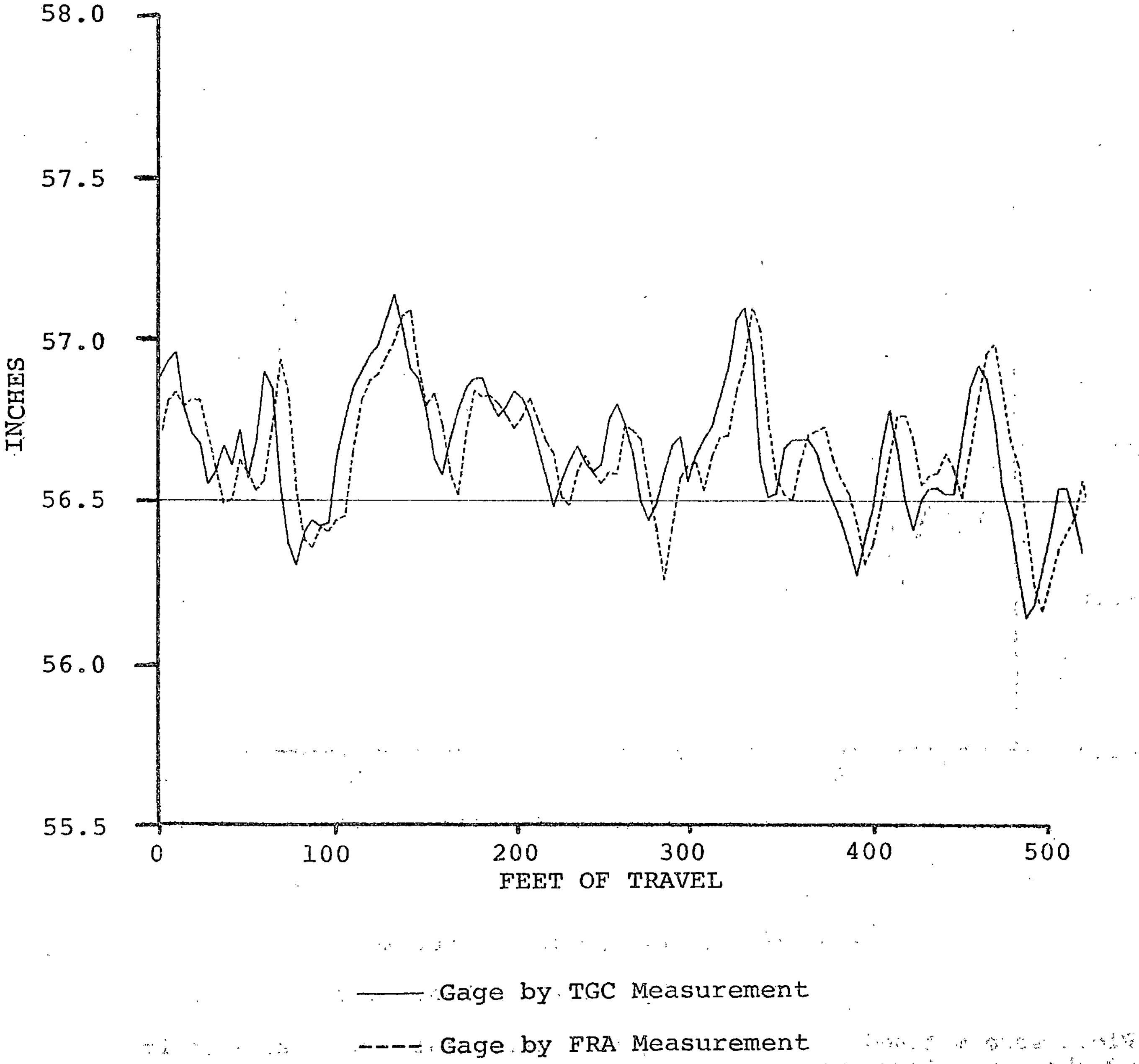


——— X-Level by the TGC Measurement

---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

TRACK SEGMENT 12
CLASS III - JOINTED RAIL
TGC FIRST - 20 MPH



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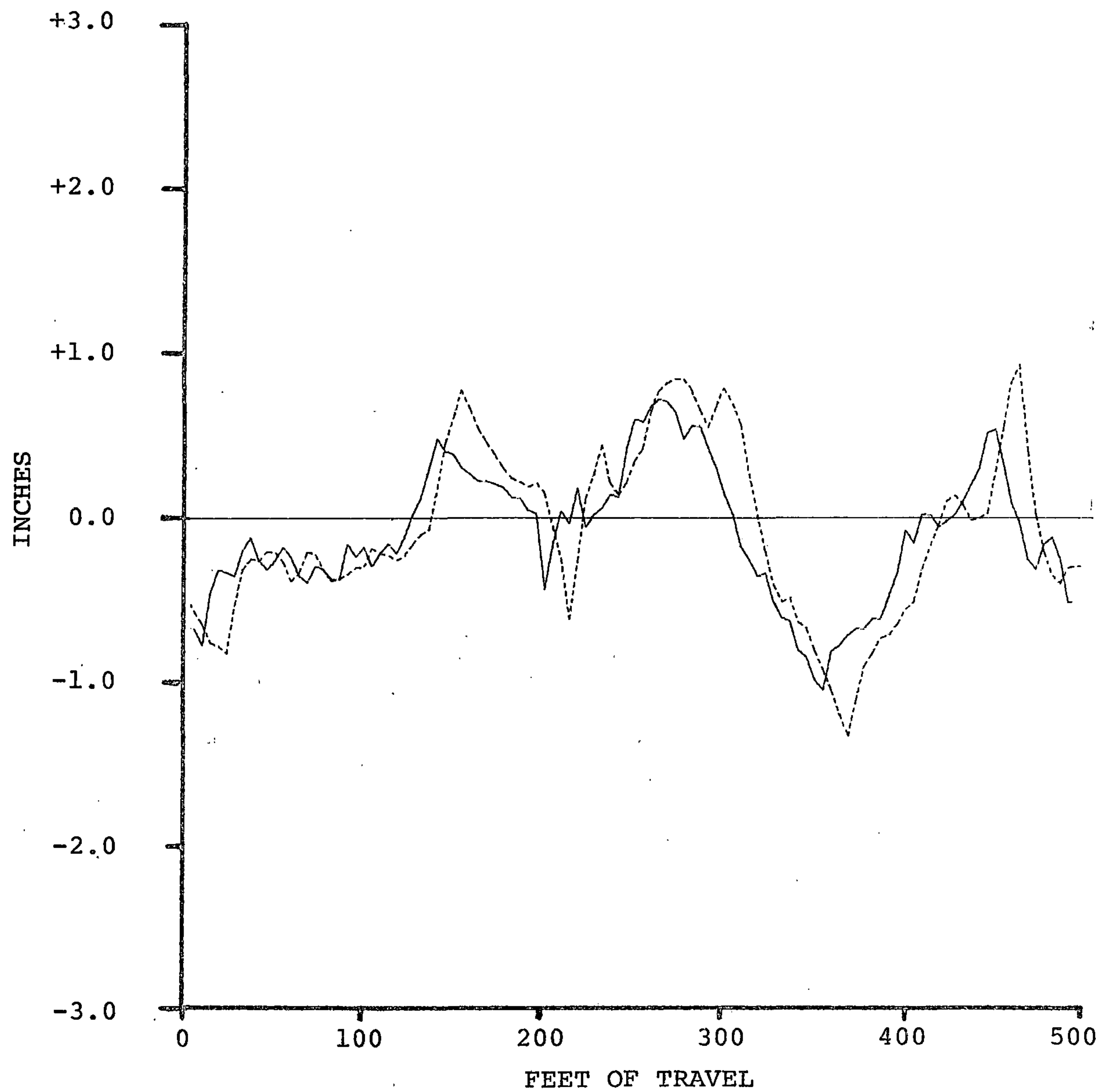
TRACK SEGMENT 12

CLASS III - JOINTED RAIL

TGC FIRST - 20 MPH

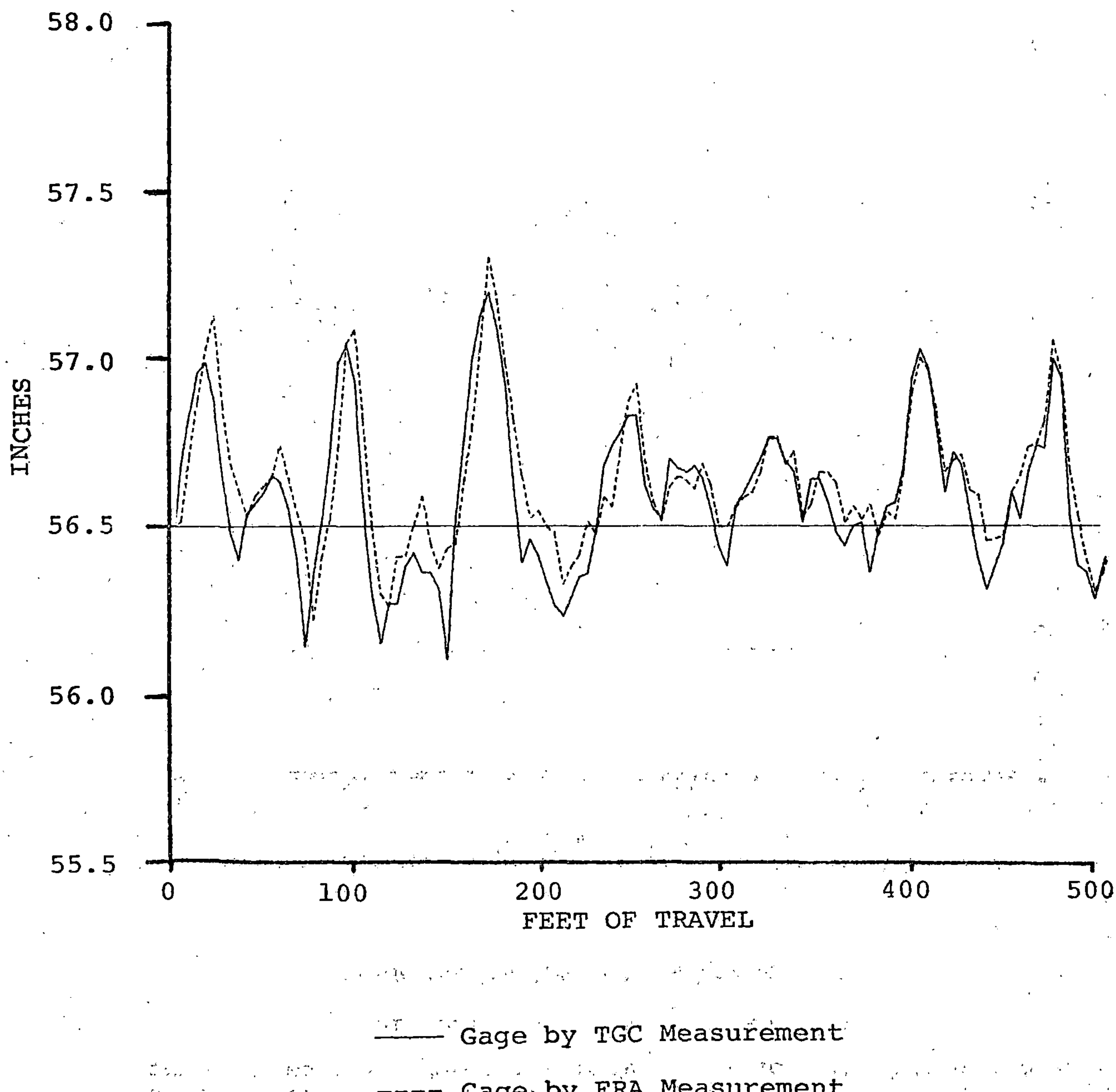


—— X-Level by the TGC Measurement

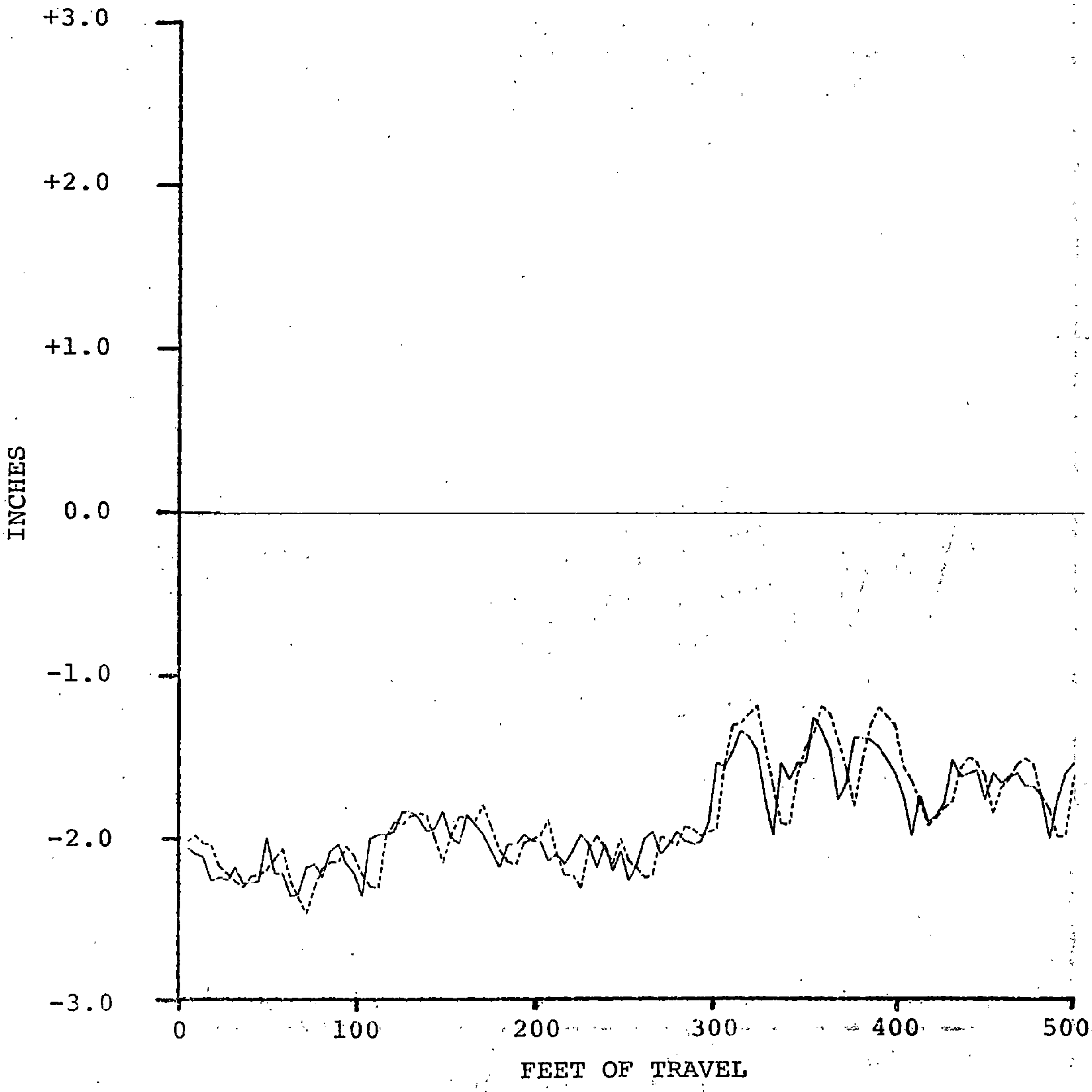
---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

TRACK SEGMENT 13
CLASS III - WELDED RAIL
FRA FIRST - 10 MPH



TRACK SEGMENT 13
CLASS III - WELDED RAIL
FRA FIRST - 10 MPH



——— X-Level by the TGC Measurement

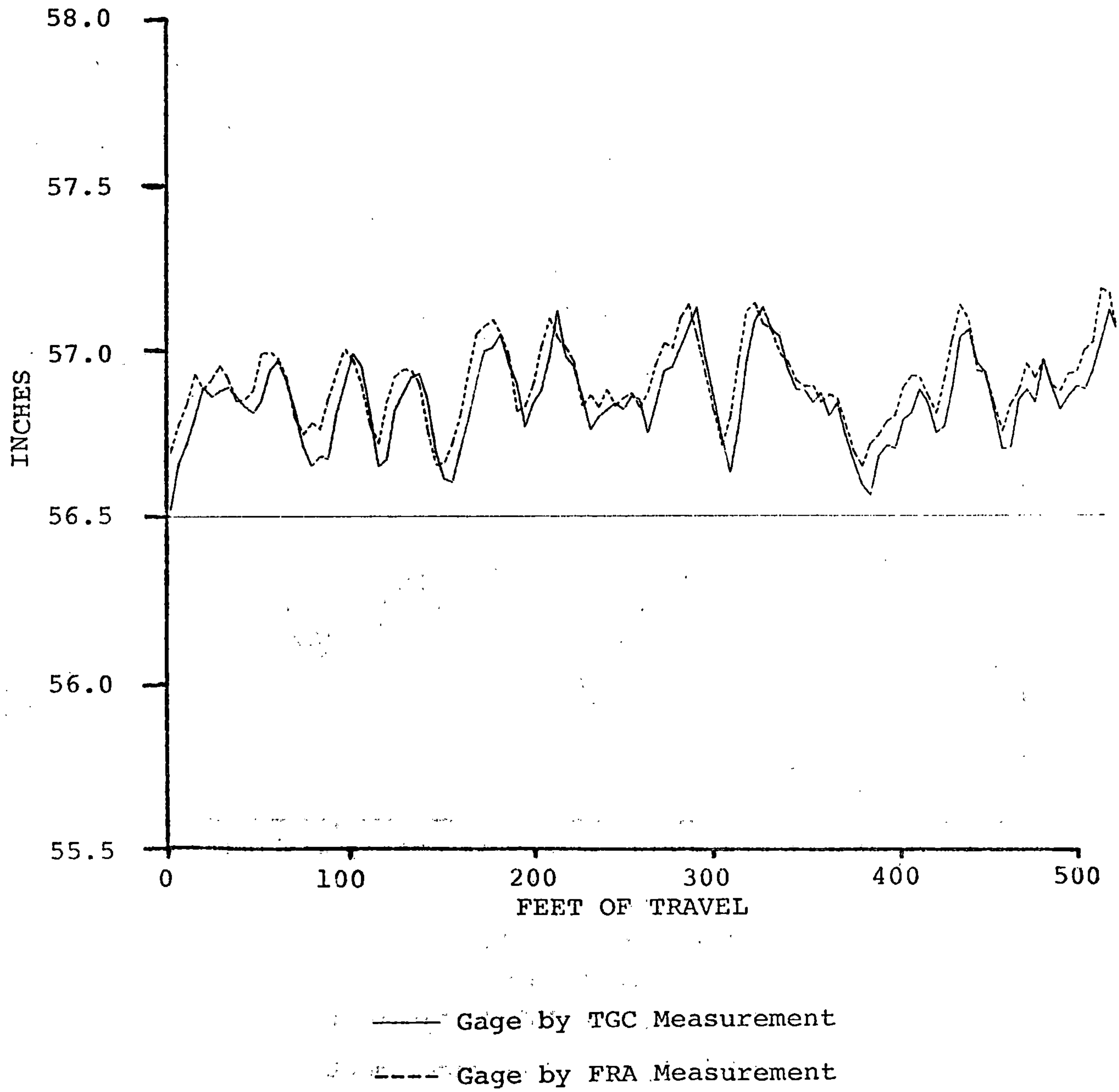
---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

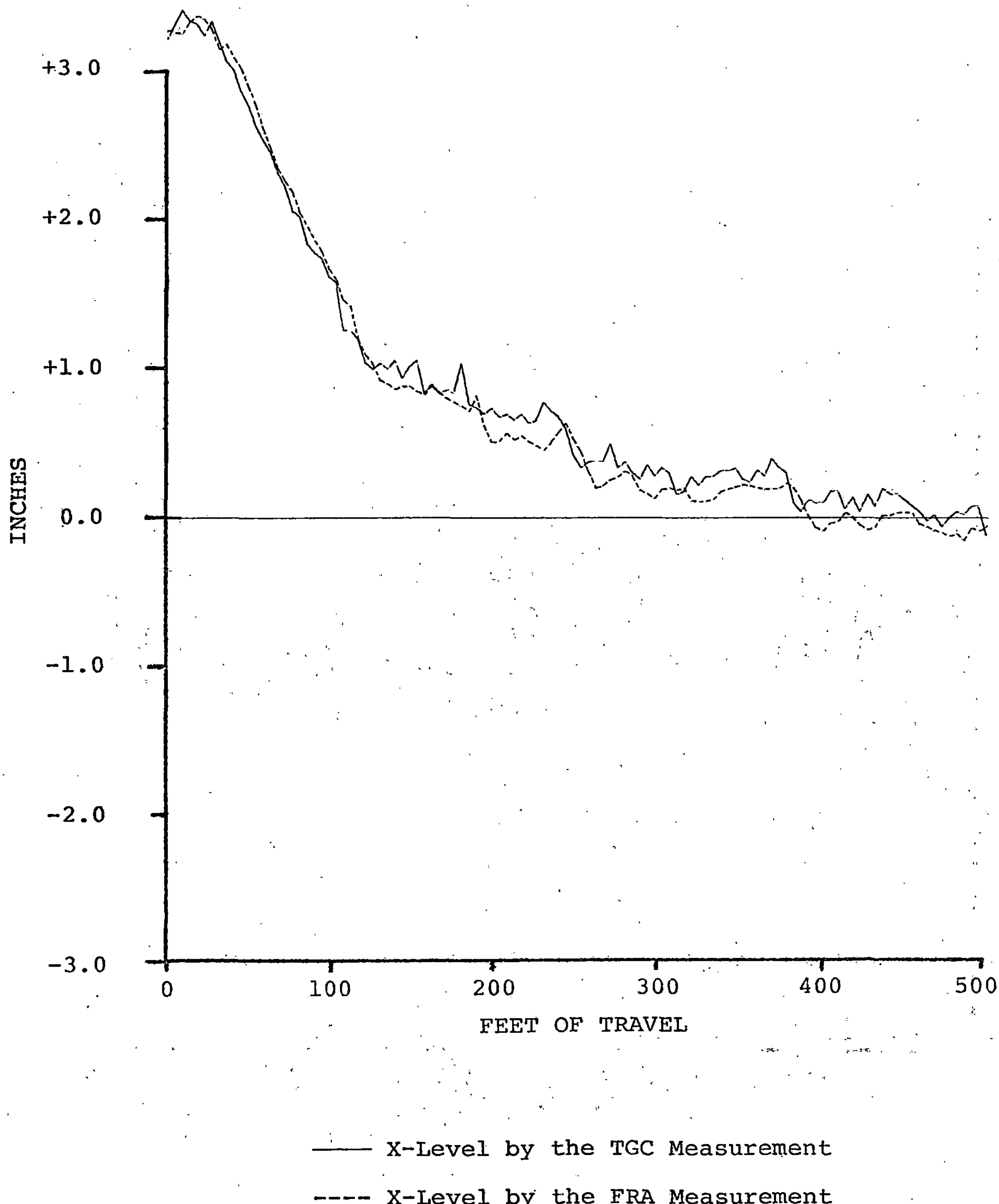
TRACK SEGMENT 14

CLASS III - WELDED RAIL

TGC FIRST - 10 MPH

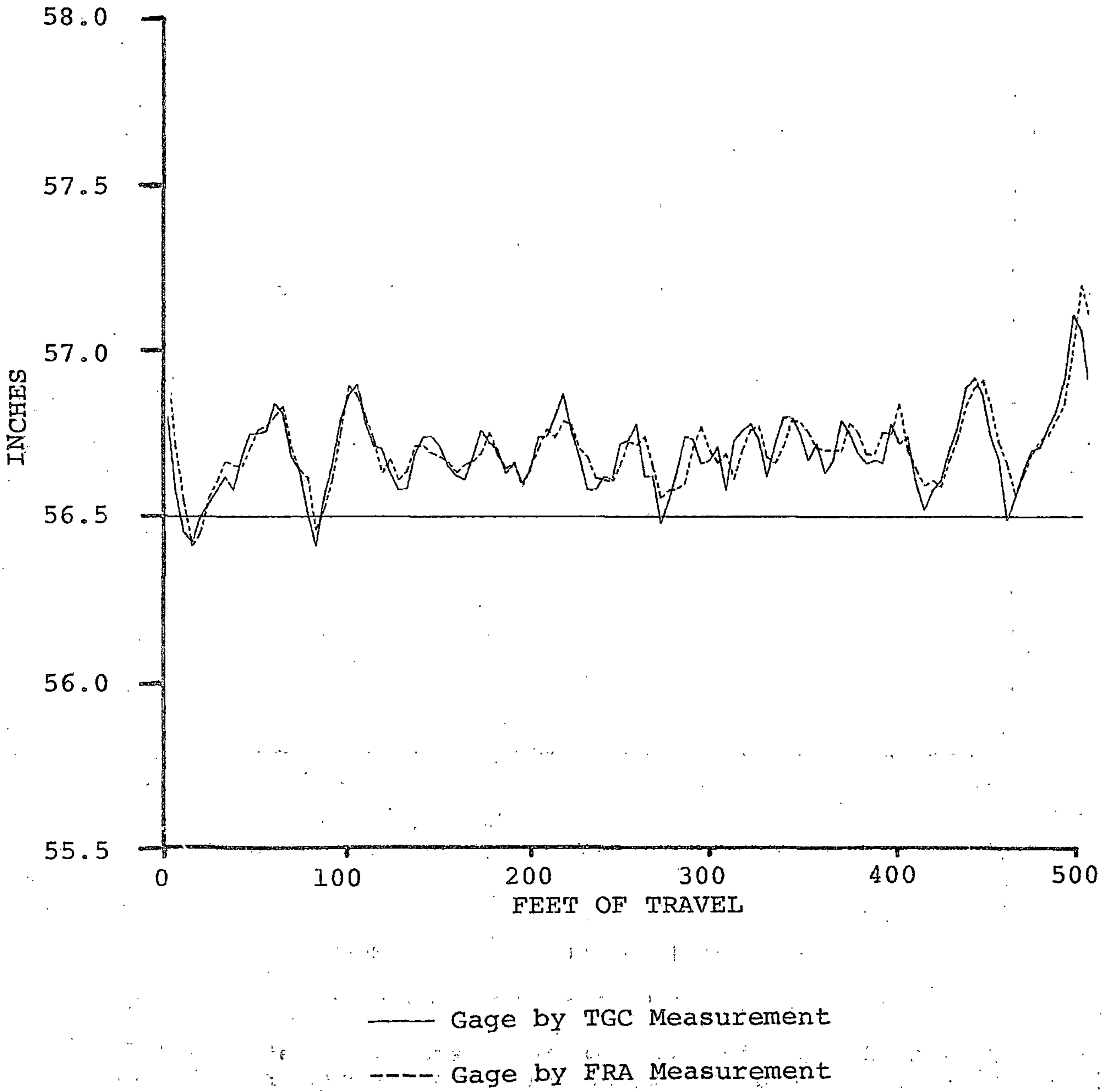


TRACK SEGMENT 14
CLASS III - WELDED RAIL
TGC FIRST - 10 MPH

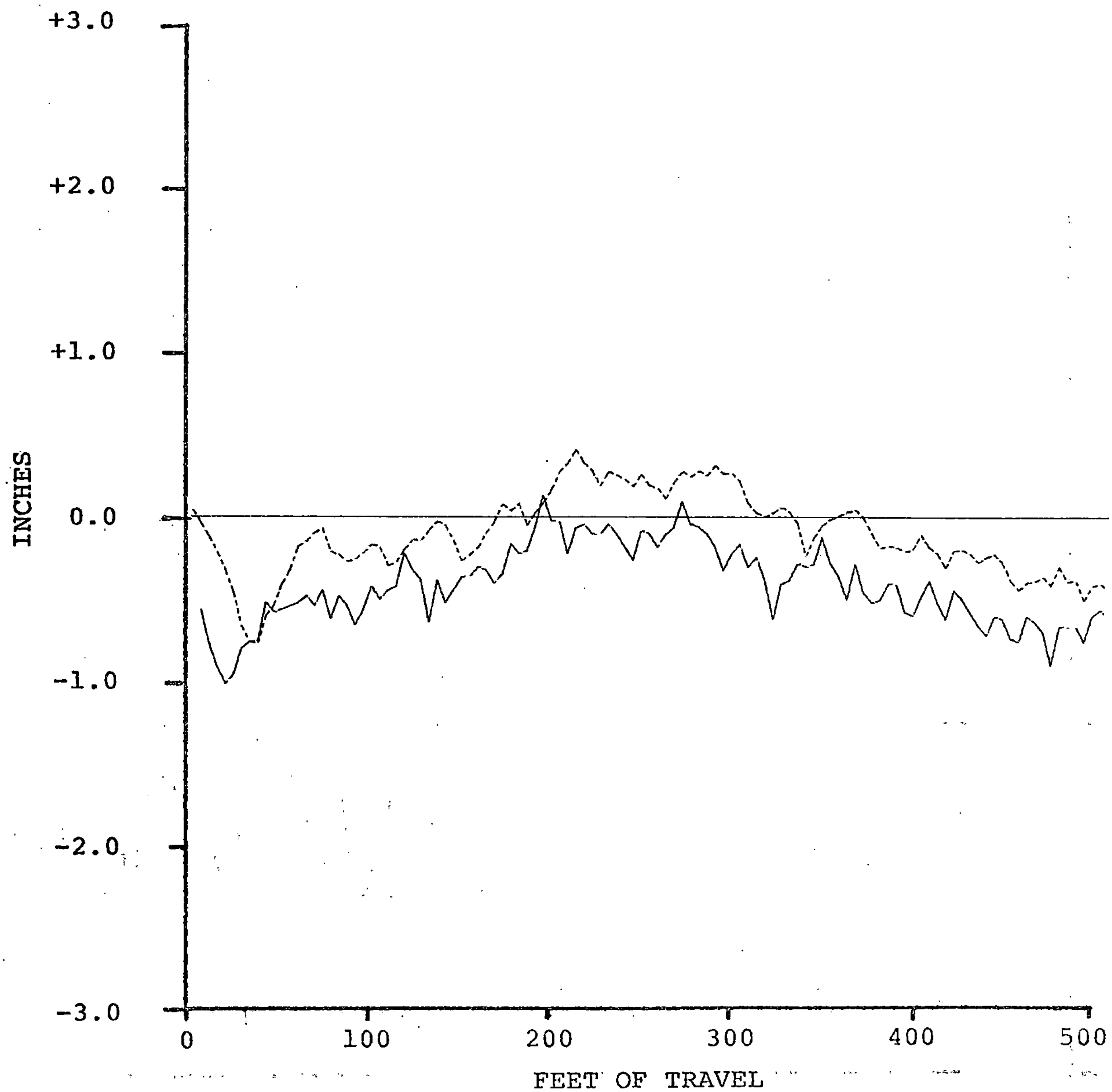


Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

TRACK SEGMENT 15
CLASS III - WELDED RAIL
FRA FIRST - 20 MPH



TRACK SEGMENT 15
CLASS III - WELDED RAIL
FRA FIRST - 20 MPH



——— X-Level by the TGC Measurement

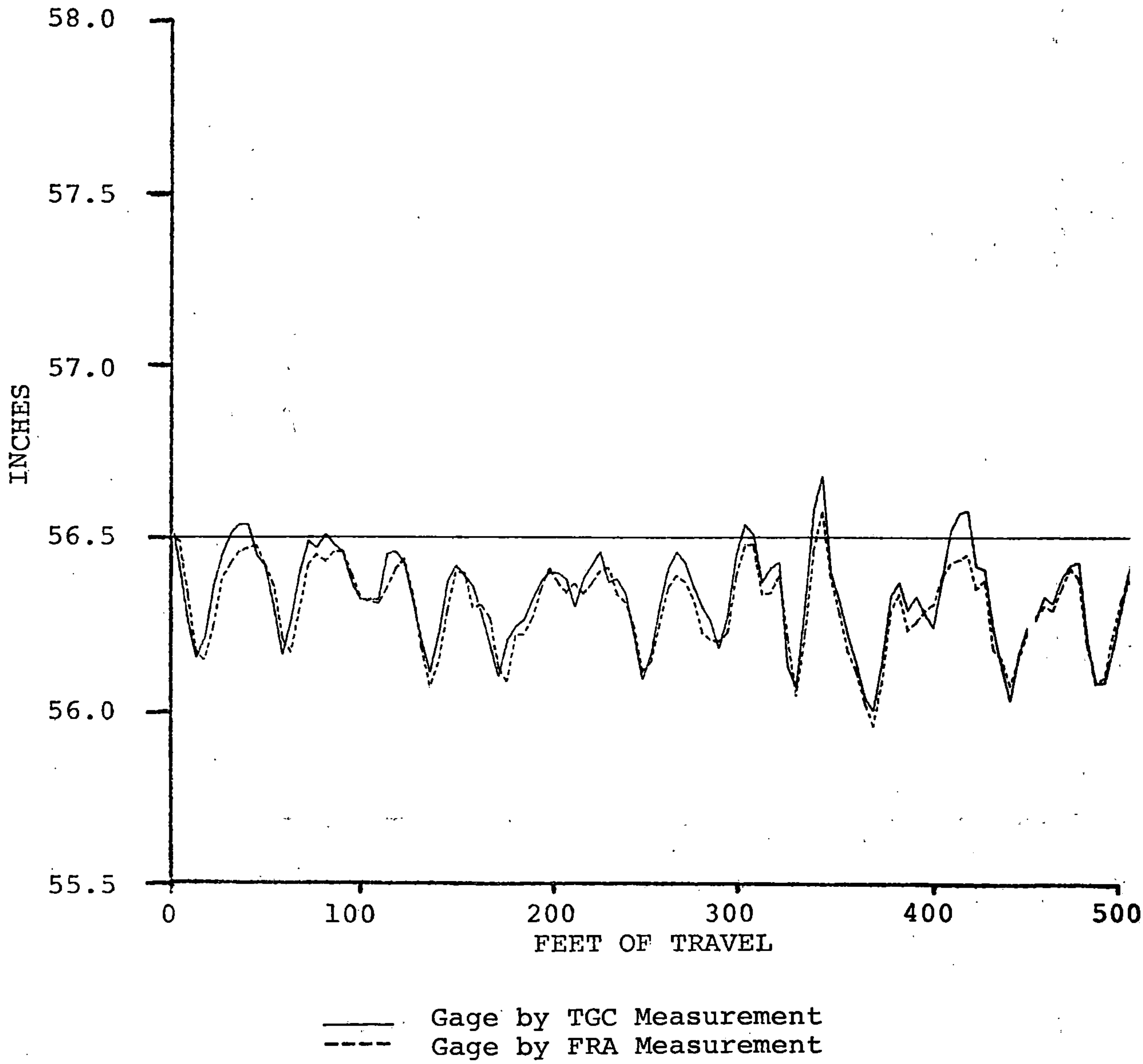
---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

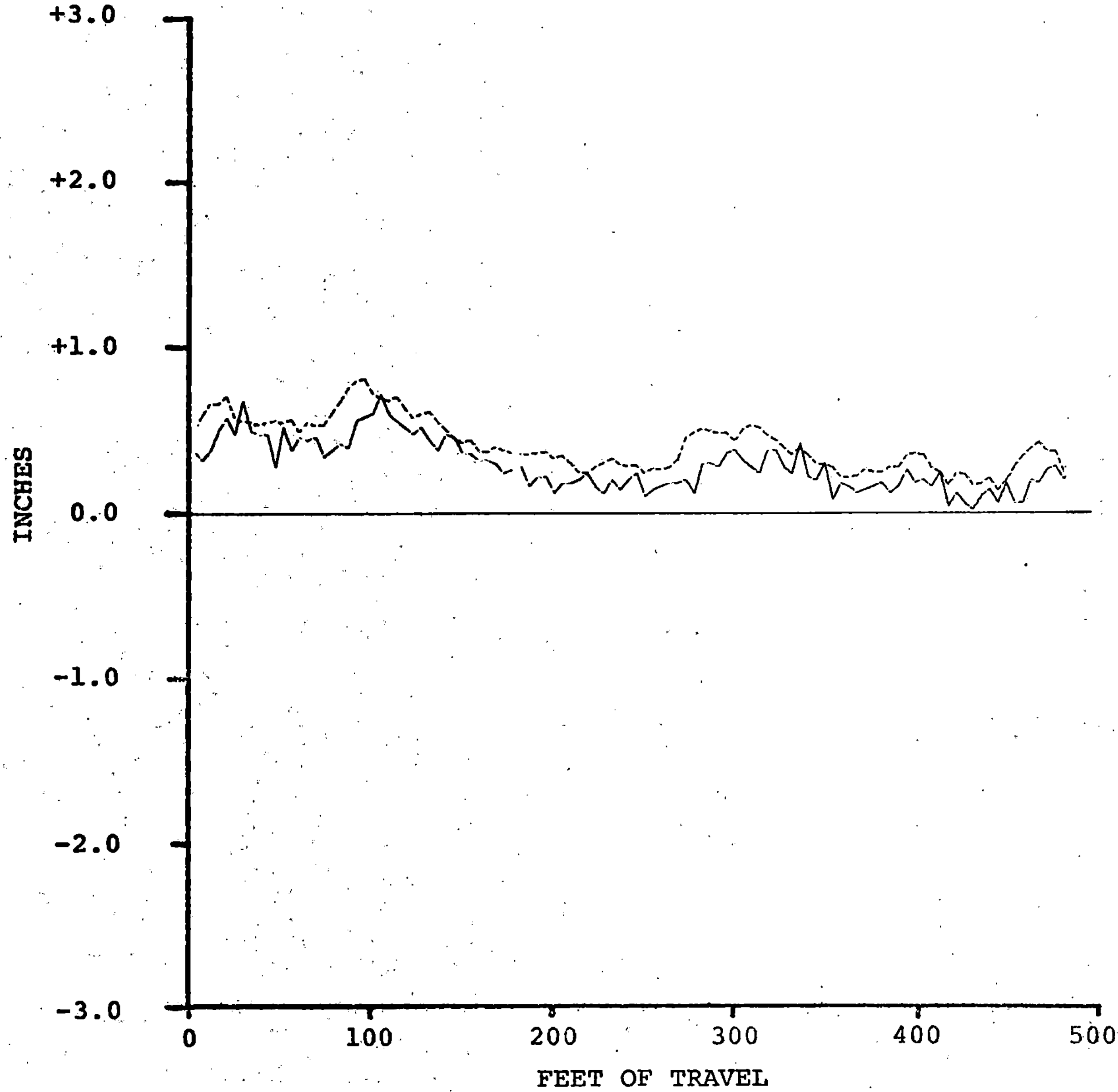
TRACK SEGMENT 16

CLASS III - WELDED RAIL

TGC FIRST - 20 MPH



TRACK SEGMENT 16
CLASS III - WELDED RAIL
TGC FIRST - 20 MPH



—— X-Level by the TGC Measurement

---- X-Level by the FRA Measurement

Plots were matched only for the gage measurement. A lateral shift of the cross level plots is required since the X-level readings on both vehicles are not measured at the same location in relation to the gage.

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