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REPORT NO. FRA/ORD-80/44 PB-

USE OF AUTOMATICALLY ACQUIRED TRACK GEOMETRY DATA FOR MAINTENANCE-OF-WAY PLANNING

FINAL REPORT
APRIL 1980

Document is available to the public through the
National Technical Information Service,
Springfield, Virginia 22161.

Prepared for

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL RAILROAD ADMINISTRATION
OFFICE OF RAIL SAFETY RESEARCH
WASHINGTON, D.C. 20590

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16. Abstract

This report covers a joint FRA/Rail Industry Program to develop maintenance planning techniques based on regularly-scheduled automated track-geometry-measurements and maintenance-of-way reports. The study was conducted from 1971 through 1978 with the cooperation of the Bessemer and Lake Erie, and the Denver and Rio Grande Western Railroads. As a result of the program, maintenance-of-way reports generated from track-geometry-measurement data have been used by the participating railroads in their maintenance planning and in the improvement of their overall track safety.

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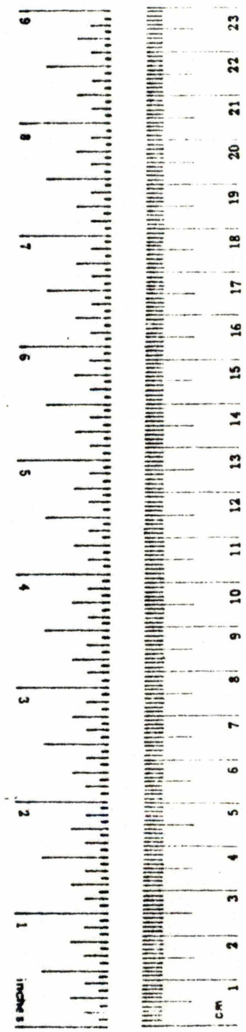
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

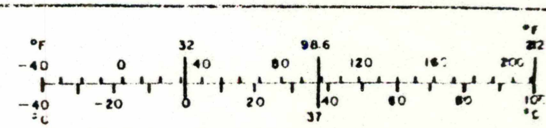
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	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



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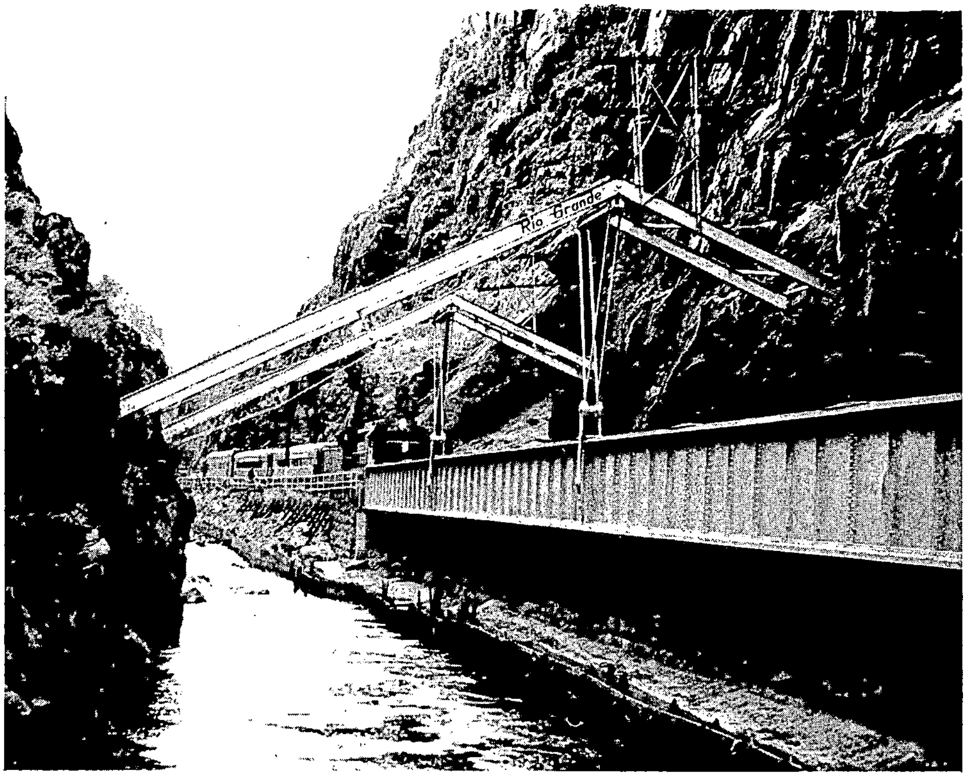


Denver and Rio Grande Western

Bessemer and Lake Erie

Frontispiece

1.0 INTRODUCTION AND OVERVIEW

1.1 PURPOSE OF PROGRAM

In 1971, FRA started a joint Government/Industry Maintenance-of-Way (MOW) Program to develop maintenance planning techniques based on automated track-geometry-measurements. The objectives of the program have been:

- To develop methods that can produce quantitative track rating information.
- To develop measurements of changes in track quality.
- To establish a mathematical basis for track maintenance planning in the areas of critical and programmed preventive maintenance.

1.2 BACKGROUND

In 1967, the Federal Railroad Administration started a research program to develop an automated track inspection vehicle. The goal of the program was to improve the safety of the country's railroads by assuring that track was able to meet its functional requirements as defined by a set of geometric parameters. The functional requirements of track can be defined as the ability to support passenger and freight service safely at reasonable speeds without causing physical discomfort to passengers, damage to freight or derailment. The FRA Office of Safety developed Track Safety Standards which established a set of requirements based on track geometry. The track geometry standards set requirements for gage, alignment, surface, elevation of the outer rail and speed limitations for curved track. This research program resulted in the development of a fleet of automated track-geometry-measurement vehicles to verify industry compliance with safety standards.

The MOW Program provides information on specific sites indicating whether the participating railroad is complying with Federal Track Safety Standards, and with the more stringent requirements set by the railroad. The program also provides Figures of Merit for segments of track which are used in planning the yearly preventive track maintenance activity.

1.3 INDUSTRY PARTICIPANTS

The rail-industry participants in this program have been the Bessemer and Lake Erie (B&LE) Railroad and the Denver and Rio Grande Western (D&RGW) Railroad. The B&LE has been surveyed for track geometry semi-annually in the spring and fall while the D&RGW has been surveyed in the fall during the period 1971 through 1978. The B&LE surveys were conducted on their 200-mile main line and most of their 40 miles of branchline. The D&RGW surveys were conducted on their 1,000-mile main line.

1.4 SUMMARY OF THE FIRST TECHNICAL REPORT

The first report* published under this program in March 1975 was the result of four years of effort to format data so that it could be evaluated by railroad personnel. It describes the early track geometry instrumentation, the initial MOW reports and the MOW reports as they existed in 1975. The capacitive proximity sensing system was sensitive to mositure and not usable in inclement weather. The problems encountered with the track-geometry-measurement instrumentation have led to significant improvements. The initial MOW reports were produced for each track geometry parameter. Each report contained information required by management for planning purposes and by maintenance personnel for correcting critical defects. It was evident that data in this format was unmanageable. Some of the track quality indices were evaluated for effectiveness during the program in terms of their definitions and the possibility of

*Acquisition and Use of Track Geometry Data in MOW Planning, March 1975, PB No. 241196.

their duplicating one another. Some of the graphic programs used to display data for detailed analysis by engineers were discussed. These included histograms and power spectral densities (PSD's) used to display probability densities and wavelength characteristics of data collected on a track segment. A comparison program to overlay histograms and PSD's from different runs was also conducted.

1.5 ORGANIZATION OF THE REPORT

This report documents industry use of automatically acquired track geometry data. This document also describes the all-weather measurement system which was implemented and evaluated after the first report (PB No. 241196) was published. The currently used track quality indices and the present MOW report formats are also discussed. These topics are covered briefly in Section 2.0 and are analyzed in detail in the appendices.

Section 3.0 describes how the railroads utilize the data. This section also covers their maintenance planning procedures and other proposed uses for the data. Conclusions and recommendations are listed in Section 4.0.

2.0 DEVELOPMENT OF THE MAINTENANCE REPORTS

2.1 INTRODUCTION

At the beginning of FRA research into automated track inspection, four Budd Silverliners were purchased and designated T-1 through T-4. These four cars operate in pairs (T-1/T-3 and T-2/T-4). One car in each pair is an instrumentation car and the other is a support car.

T-1/T-3 has served as the prime track-geometry-survey consist during the MOW program. T-3 contains the track-geometry-measurement instrumentation and the data acquisition system while T-1 provides survey-crew support. The track geometry data collected by T-3 has been used to develop track quality indices. These indices are designed to help MOW engineers in maintenance planning.

The advanced electronic sensing and data processing systems onboard T-3 are capable of measuring track geometry at speeds up to 150 miles per hour. The instrumentation in the consist provides raw measurements of track geometry in the form of continuous analog signals. Data processing provides real-time, onboard computation and analog strip-chart reports of track geometry characteristics as well as digital records of both raw and computed data. The data tapes are off-line processed on a digital computer using software programs which are designed to present the data as maintenance-of-way reports. Track geometry parameters are processed into indices to rate track segments.

Since the beginning of the MOW program, improvements have been made to the instrumentation and data acquisition systems in the T-1/T-3 consist and to the software programs which are used to process the track geometry data and generate the MOW reports. This section describes the current system and the data processing to provide a basis for further discussion of the uses and benefits of automated track-geometry-data collection, and of the MOW reports generated from same and sent to the participating railroads.

2.2 SYSTEM CONCEPT

The major subsystems and the signal paths of the track geometry measurement system are shown in Figure 2-1. Each subsystem is configured to measure, record and display a particular parameter of track geometry. The parameters are:

- Profile
- Gage
- Crosslevel
- Curvature
- Location

The layout of the coordinate reference system of the car is shown in Figure 2-2. Each subsystem utilizes one or more electro-mechanical, all-weather sensors which produce raw measurement data in the form of continuous analog signals.

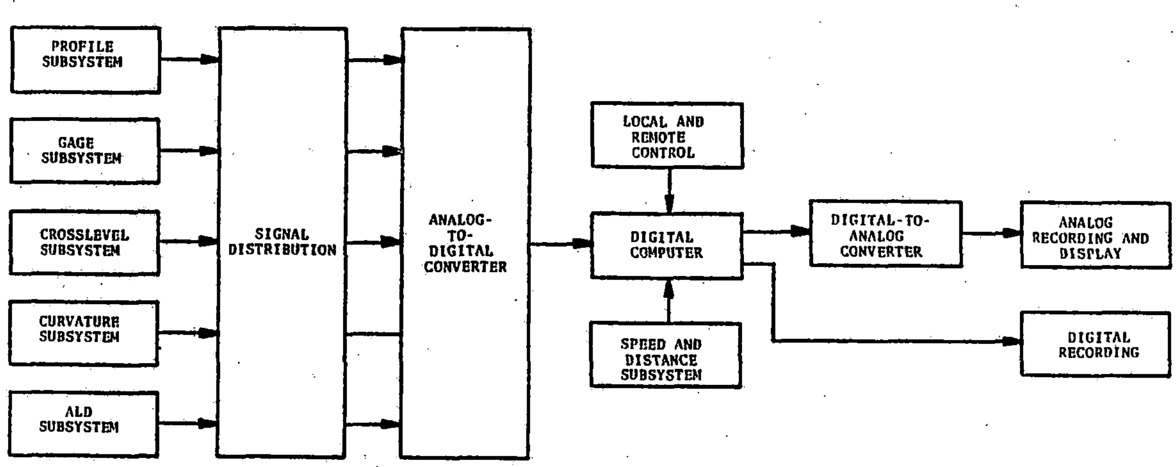
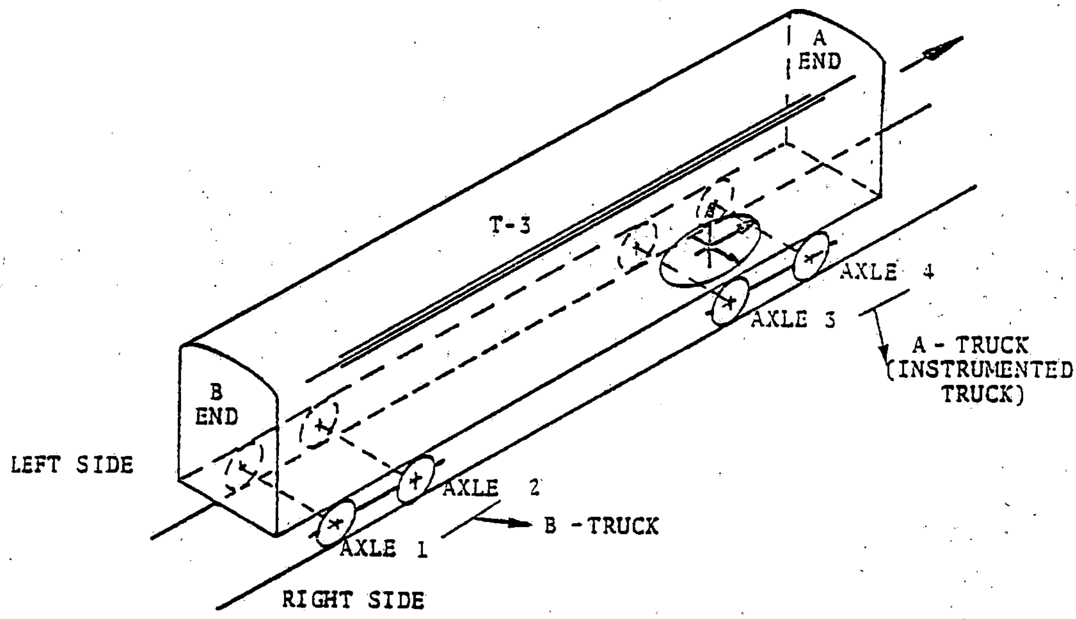


Figure 2-1. Track Geometry Measurement System Block Diagram



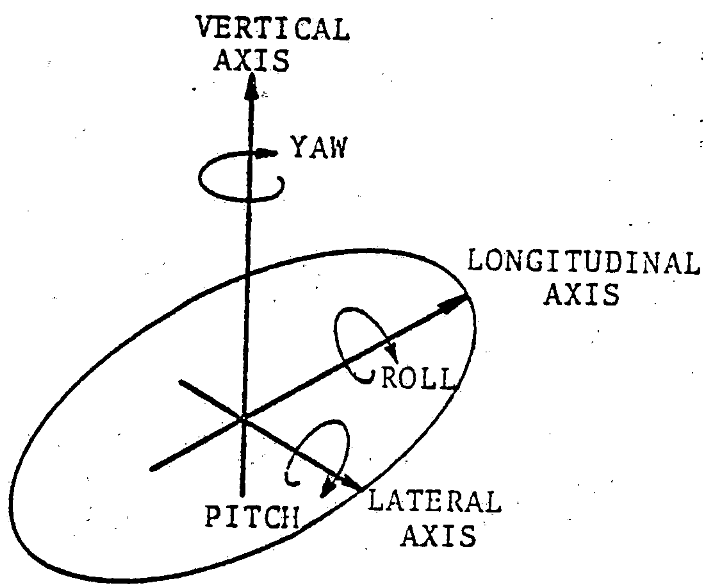


Figure 2-2. Layout of Coordinate Reference System on T-3

The data acquisition system converts the signal to digital format in real time and records the digital data on magnetic tape for off-line processing. The data acquisition system also computes track-geometry parameters from raw measurement data and converts them to analog signals for real-time visual display on a strip-chart recorder. The sensors in the track-geometry-measurement subsystems are described in the following paragraphs. The digital and analog subsystems are discussed in Section 5.1.

2.2.1 Profile Subsystem

Profile is a measure of the vertical position of each railhead in a track structure. The profile measurement subsystem is composed of inertially referenced instruments (profilometers) that produce signals which are proportional to deviations from that reference.

2.2.1.1 Profile Instrumentation

The profile measurement subsystem uses two profilometers mounted directly over axle No. 3 of the A-truck on each side of T-3 (Figure 2-3). The profilometer consists of a mass which is attached to a wheel (axle) of the test car through a spring and damper assembly. The mass is restricted in movement to the vertical plane by low-friction guides. An accelerometer is attached to the mass and a linear-variable-differential-transformer type displacement transducer (LVDT) is connected between the mass and the wheel (axle).

Profile is defined as the mid-point of a 62-foot chord in the vertical plane. As the vehicle moves along a track, the mass acts as an inertial reference in the vertical plane. Vertical displacement of the rail act as inputs to the profilometer, and are measured directly by the displacement transducer. At low speeds, low frequency inputs (which fall below

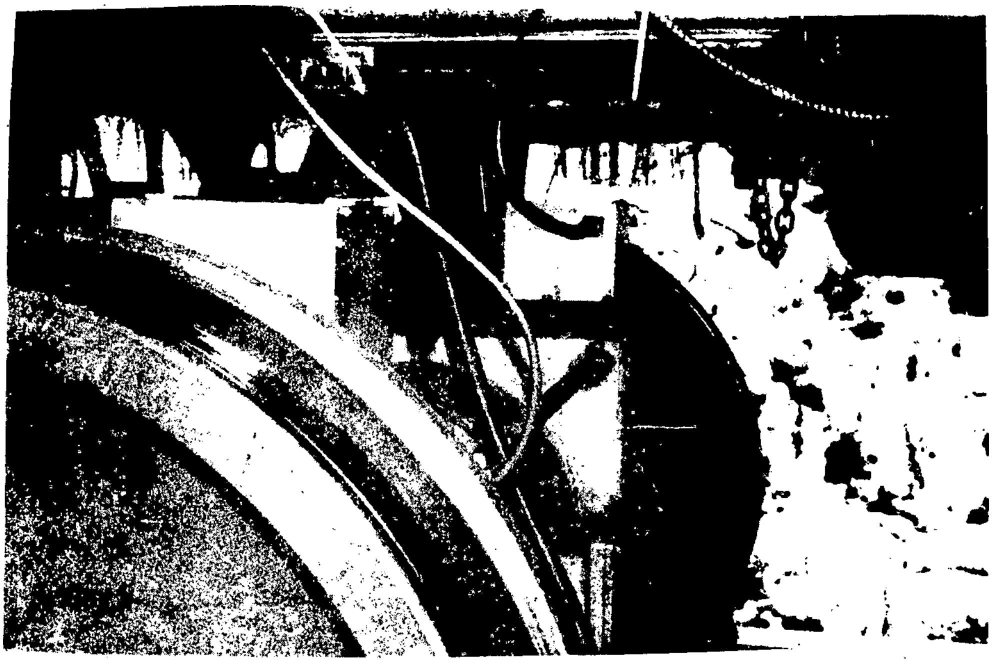


Figure 2-3. Profile Measurement Sensors on T-3

the natural frequency of the profilometer) are measured by double integration of the output of the accelerometer and added to the output of the displacement transducer.

Due to limitations on the undercarriage of T-3, the profilometer transducers are mounted inboard on the wheels. Thus, the points of measurement (Z_L and Z_R) are offset from the actual location (Z_{LT} and Z_{RT}) of the transducers (Figure 2-4). The offset is corrected by compensation circuits which consist of operational amplifiers with gain characteristics which provide the required gain and cross-compensation between the opposite sides.

The output signals from the profilometers are analog space curves of the absolute vertical positions of the rails with respect to an inertial reference. These output signals are subsequently filtered to remove long term trends associated with grade, and then converted to a 62-foot, mid-chord offset (MCO) measurement for comparison with the FRA Track Safety Standards.

2.2.2 Gage Subsystem

Gage is defined as the distance between the two rails at a position 5/8-inch below the top of the railhead. At present, a servomagnetic gage system is used for the gage measurement subsystem.

2.2.2.1 Gage Instrumentation

The gage measurement subsystem uses two servo-positioned magnetic sensors to detect changes in gage. When operating, the non-contact sensors (Figure 2-5) are located between the axles of the A-truck facing directly toward the gage side of the railhead. As gage varies or the truck moves laterally, a feedback servo-control system maintains a 1/2-inch, sensor-face to rail gap. If this gap is larger or smaller than 1/2-inch the magnetic sensors will produce error signals. To eliminate this source of error, the position of the magnetic sensor with respect to the truck is measured using a linear displacement transducer (LDT). This position signal combined with the signal from the sensor yields a relative gage signal for the respective side of the truck. Adding the outputs of the two LDT's to the known distance between them produces the gage measurement.

Since the magnetic sensor is servo-controlled, it will not always be riding within the clearance profile created by the flange of the wheel. Whenever the sensor moves away from the protection of the flange, it may be damaged by highway crossings, railroad crossings, and frogs. To minimize possible damage to the sensor arm assemblies, the sensor can be retracted or moved to the protected position within the clearance profile of the flange by the operator. The system will still measure gage data in the protected position, but a reduction in accuracy proportional to the gap between the sensor face and the gage point on each rail will occur. The sensor system has three operating modes:

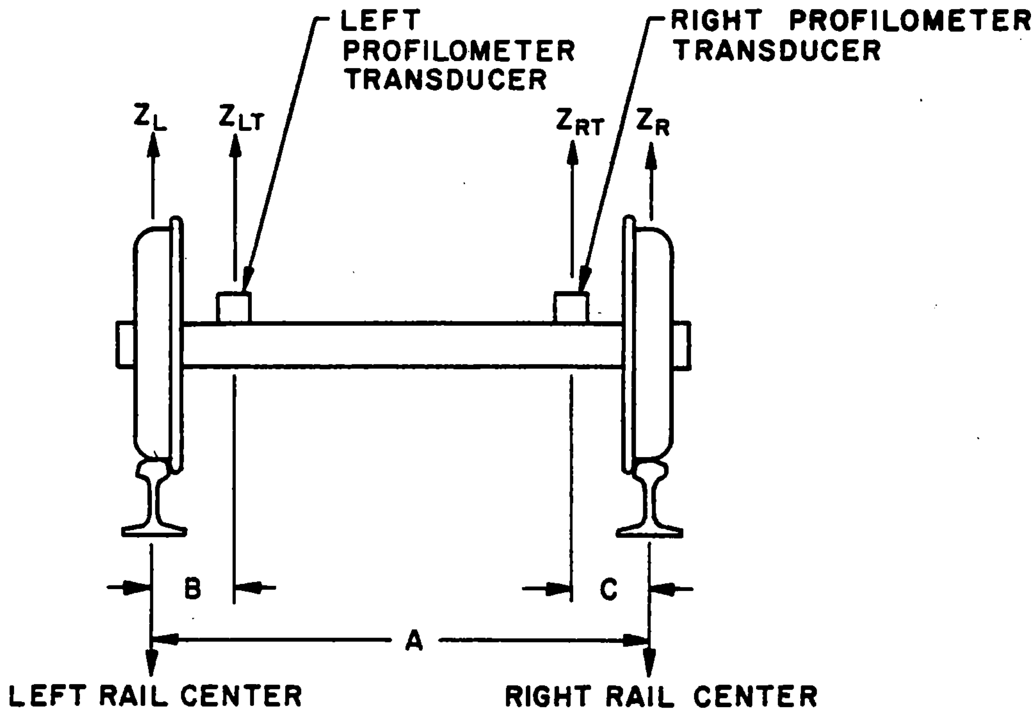


Figure 2-4. Location of Profilometers

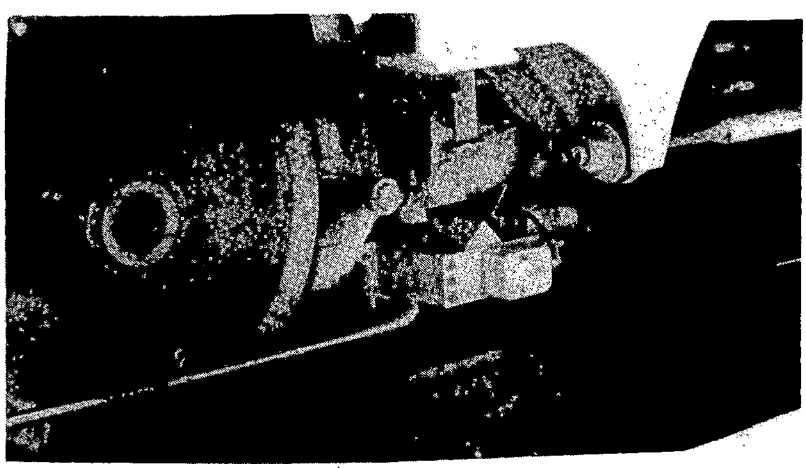


Figure 2-5. Gage Sensor in the Raised Position

- RETRACT - The sensors are in the raised position to avoid obstacles in the roadbed, to prevent damage to the sensor by contact with road crossings, frogs, or other track features or to allow sensor adjustment or replacement. This position is used for maximum sensor protection during non-operating periods.
- ACTIVATE - The sensors are in their normal operational position.
- WITHDRAW LEFT and/or RIGHT - The sensors are in a protected position in the shadow of the wheel flange (Figure 2-6).

2.2.3 Crosslevel Subsystem

Crosslevel is defined as the difference in elevation between the right and left rails. This system measures crosslevel in inches. A positive reading indicated that the left rail is higher than the right rail and a negative reading indicates that the right rail is higher than the left.

2.2.3.1 Crosslevel Instrumentation

The Compensated Accelerometer System (CAS) is used to measure crosslevel. It is composed of three sensors mounted at specific location on T-3 (Figure 2-7). These consist of a vertical reference sensor and two displacement transducers. The CAS assembly (Figure 2-8) consists of an inclinometer and a roll rate gyro which is mounted on the floor of the carbody directly over the instrumented truck. The two displacement transducers are mounted underneath each side of the carbody over the No. 3 axle of the vehicle to measure the angle between the carbody and the truck. The system compensates for lateral acceleration errors by using a yaw rate gyro, two velocity transducers and a tachometer.

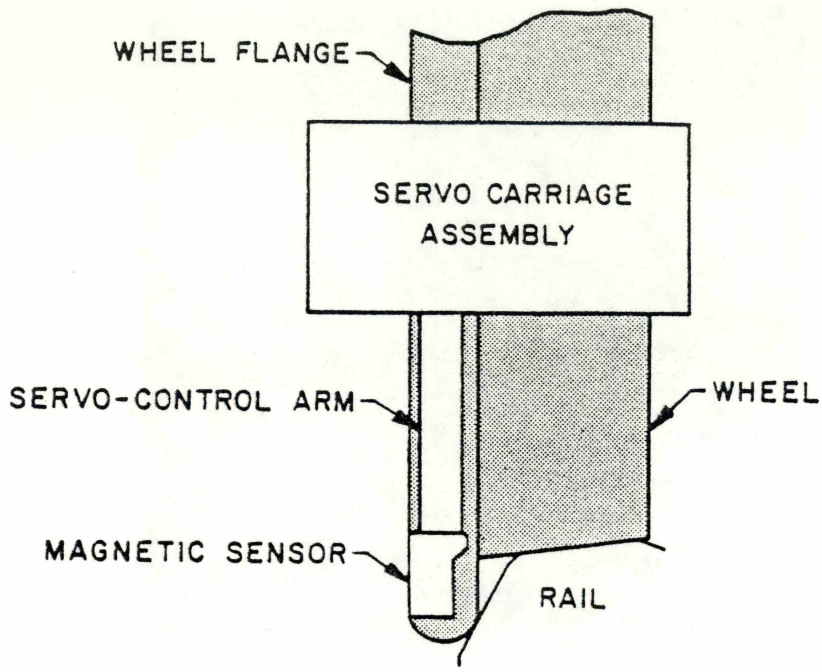


Figure 2-6. Sensor Arm in Protected Position of the Wheel Flange

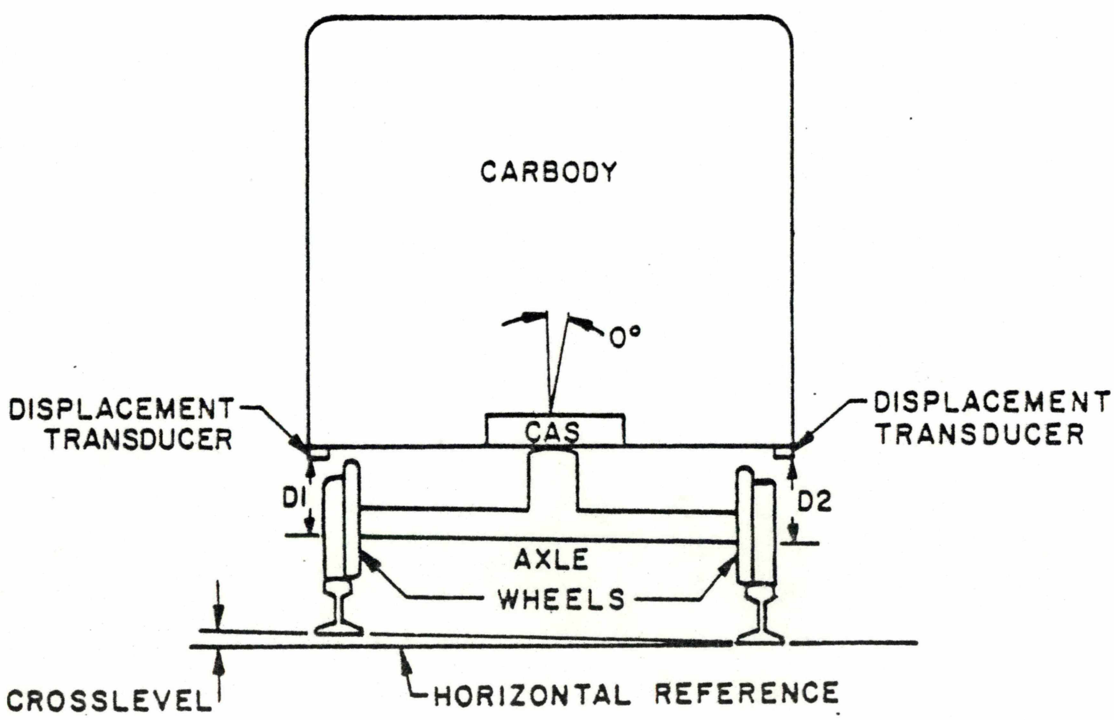


Figure 2-7. Location of Compensated Accelerometer Assembly and Displacement Transducers on T-3

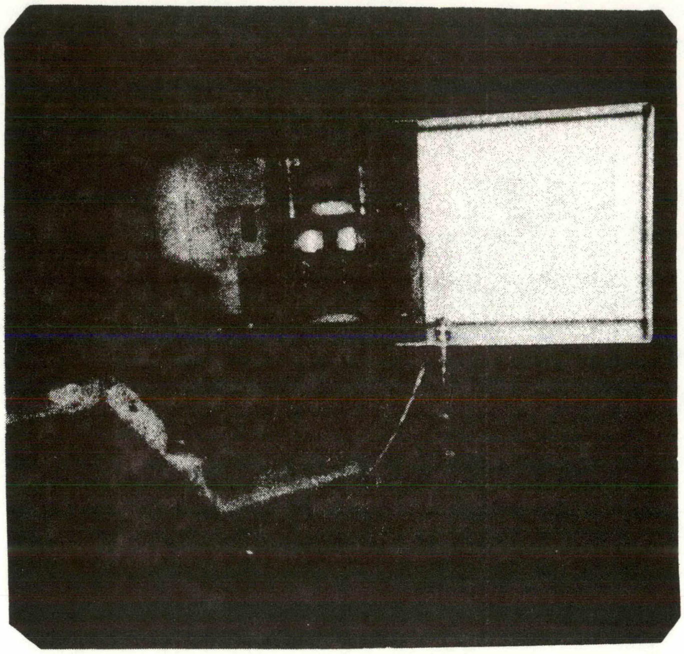


Figure 2-8. CAS Assembly

2.2.3.2 Warp Measurement

Warp is the difference in crosslevel between any two sample points up to 62 feet apart in tangent track and curves, and not more than 31 feet apart in spirals. It is a measure of the variation of the horizontal plane of the track over these selected chord lengths. Warp, which is the spatial rate of change in crosslevel, is calculated during off-line processing.

2.2.3.3 Rock-and-Roll Measurement

Rock-and-roll is also calculated during off-line processing of the crosslevel measurement. For this measurement, the crosslevel signals are differenced at 19.5-foot intervals to obtain an indication of alternating low joints on the two rails. If the processed signals indicate that three consecutive left and right rail joints are low, that zone of track has the potential for generating a sustained rock-and-roll in the carbody. The maintenance-of-way report will indicate the location, the extent and the severity of the rock-and-roll zone.

2.2.4 Track Curvature Subsystem

The track-curvature-measurement subsystem measures the angular rate of change of track direction in degress per hundred feet. The basis for track-curvature-measurement is the number of degrees of central angle subtended by a 100-foot chord (figure 2-9).

2.2.4.1 Curvature Instrumentation

The principal elements of this subsystem include a carbody-mounted, yaw-rate gyroscope and two velocity transducers, one mounted on each truck. The rate gyroscope produces a signal which is proportional to the rate of carbody rotation about its vertical axis including rotation caused by track curvature. The two velocity transducers provide correction signals proportional to carbody yaw with respect to the trucks of the car.

2.2.5 Automatic Location Detection Subsystem

The Automatic Location Detector (ALD) subsystem is used to detect features which are unique to a particular section of track. The detected features are used to correlate track geometry data with specific physical locations.

2.2.5.1 ALD Instrumentation

The ALD sensor (Figure 2-10) is a non-contact capacitive device mounted below the test car on a frame approximately in the center of the A-truck on T-3. It faces the roadbed between the rails and detects the proximity of metallic objects over which it passes (figure 2-11). The sensor consists of a 1/8 by 4 by 7-inch fiberglass board that is copper clad on the exposed side to form one plate of a

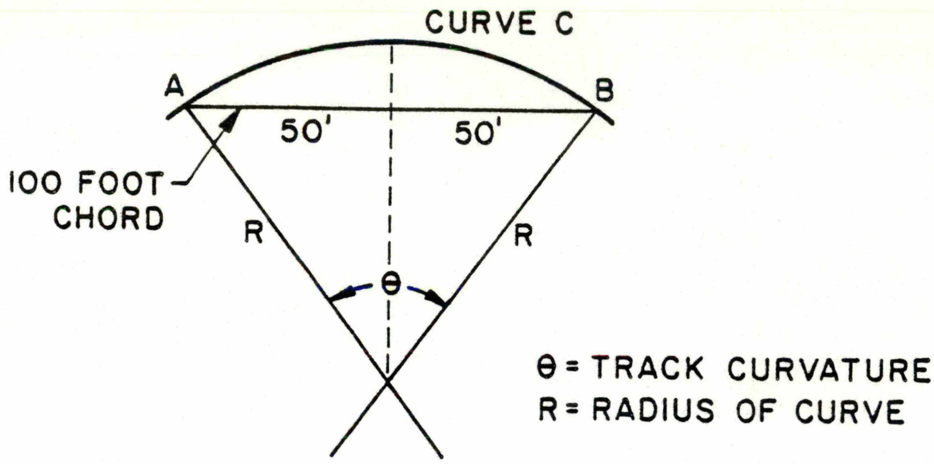


Figure 2-9. Definition of Track Curvature

capacitor. The other plate of the capacitor is the roadbed. As the train moves along a track, a metallic object causes the capacitance between the sensor and the ground to change abruptly. This change in capacitance produces a signal voltage proportional to the height, size and composition of the object.

In addition to the detection of anamolies in the track, the ALD system also detects and records known structure (turnouts, road crossings, and other objects which can be related to a specific location).

2.2.6 Speed and Distance Subsystem

The speed and distance measurement subsystem is used to determine instantaneous vehicle speed and to indicate total number of miles traveled. An optical tachometer and a speed and distance processor are the principle components of this

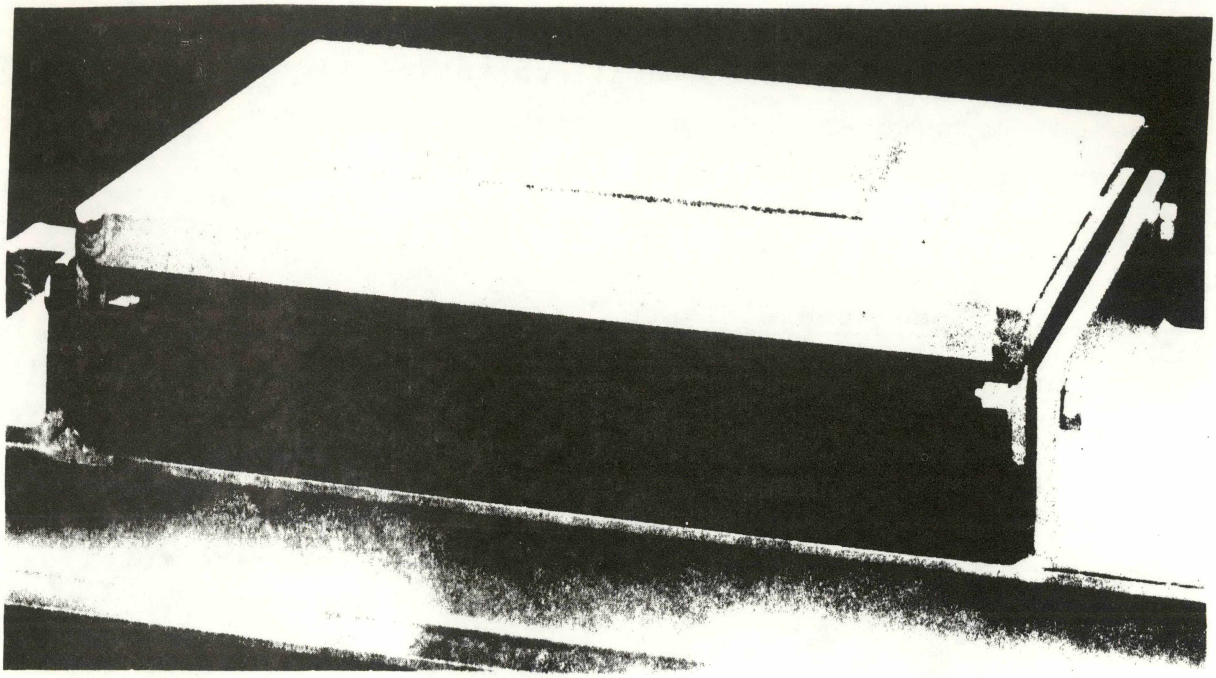


Figure 2-10. ALD Sensor Mounted on Frame

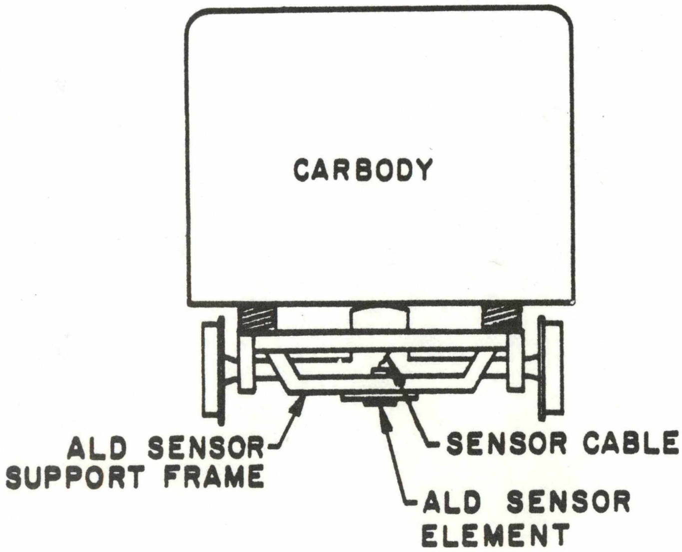


Figure 2-11. Location of ALD Sensor

subsystem. The speed and distance subsystem provides distance-based, computer-interrupt signals which control data acquisition, computer sampling, and computation and recording of track geometry data.

2.2.6.1 Speed and Distance Instrumentation

The optical tachometer (figure 2-12) is belt-driven. It is located on the left side of Axle 3 and produces 1,000 pulses during each revolution of the wheel. The pulses are counted over a fixed time interval by the speed and distance processor to determine instantaneous speed, and to indicate total distance traveled.

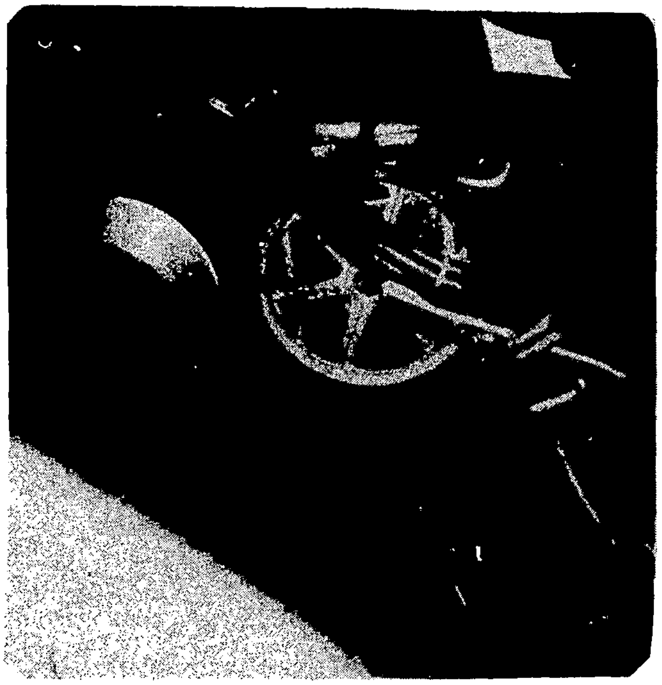


Figure 2-12. Optical Tachometer

2.3 MAINTENANCE INDICES

The Maintenance-of-Way Planning (MOWP) and Geoplot reports present four track geometry measurement parameters in the form of indices to facilitate the rating of track segments. These indices are computed for quarter-mile track segments. The maintenance indices used to describe each parameter are listed below:

- Profile
  - Profile Area Index
  - Profile Slopes
- Gage
  - Gage Area Index
  - Gage Standard Deviation
  - Gage 99 Percent Value
- Crosslevel
  - Crosslevel Area Index
- Curvature
  - Curvature Area Index

Indices for all four parameters can be normalized for various lengths of track. With the present report formats, the D&RGW prefers the indices normalized to exactly one mile while B&LE prefers the indices normalized on a one-fourth mile basis with ALD locations initiating the segments.

2.3.1 Area Index

The area index for each track-geometry parameter can be defined as the area between two curves, one obtained by plotting the actual track geometry measurements, the other obtained by plotting the ideal condition of the track.

2.3.1.1 Gage Area Index

For gage, the ideal condition is a gage measurement of 56.5 inches; therefore, the curve for the ideal condition will be a straight line, which when plotted would be perpendicular to the y-axis at 56.5 inches. The actual curve would vary around this reference line as shown in Figure 2-13.

The shaded region is the area to be calculated and summed together to obtain the area index for this section of track. The area above the 56.5-inch line is positive while that below the line is negative. The sign is important for the gage index since the index can be positive, negative or zero. A positive index will indicate a segment of track with generally wide gage while a negative index will indicate that the gage is generally tight.

2.3.1.2 Profile Area Index

Profile is determined by comparing the vertical position of the top of the railhead to a reference curve obtained from the equipment. The reference curve is a representation of a perfect track crossing a particular terrain. An example of the graph of the actual measurement curve compared to the perfect curve is shown in Figure 2-14.

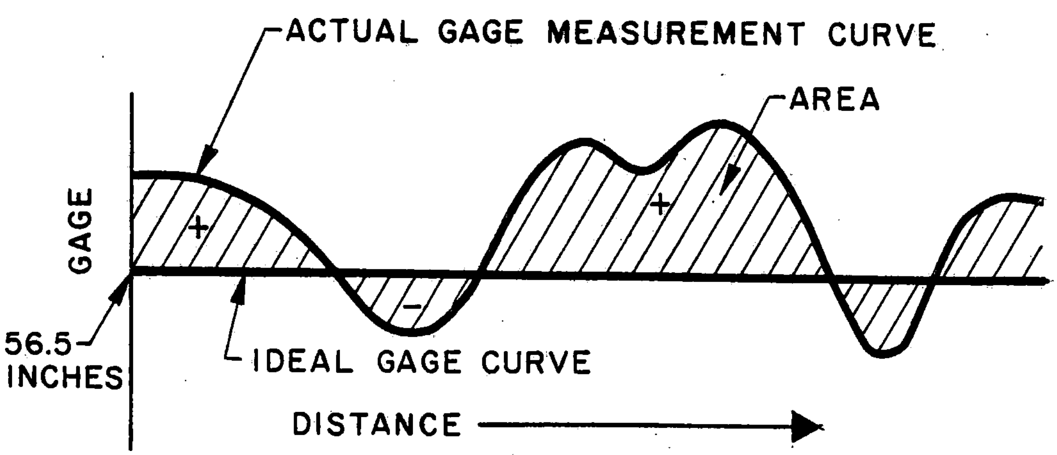


Figure 2-13. Gage Area Index

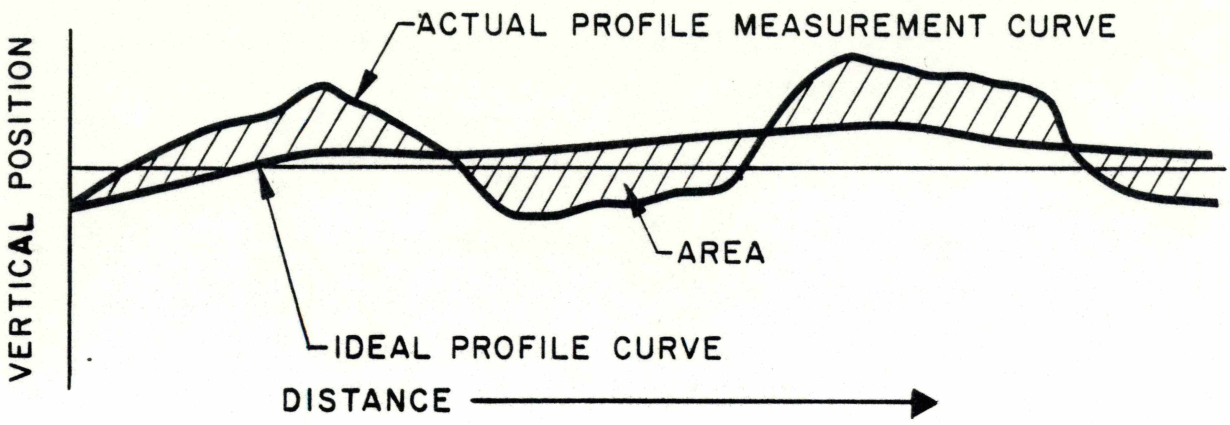


Figure 2-14. Profile Area Index

The area of the shaded region is used to determine the Profile Area Index. For profile, unlike gage, the absolute values of the areas are used. Therefore, the profile index must always be positive.

2.3.1.3 <u>Curvature and Crosslevel Area Indices</u>

The area indices for curvature and crosslevel are determined in the same way as gage and profile. The reference curve, however, for curvature and crosslevel is a filtered or smooth version of the actual measurement curve (Appendix B) as shown in Figure 2-15.

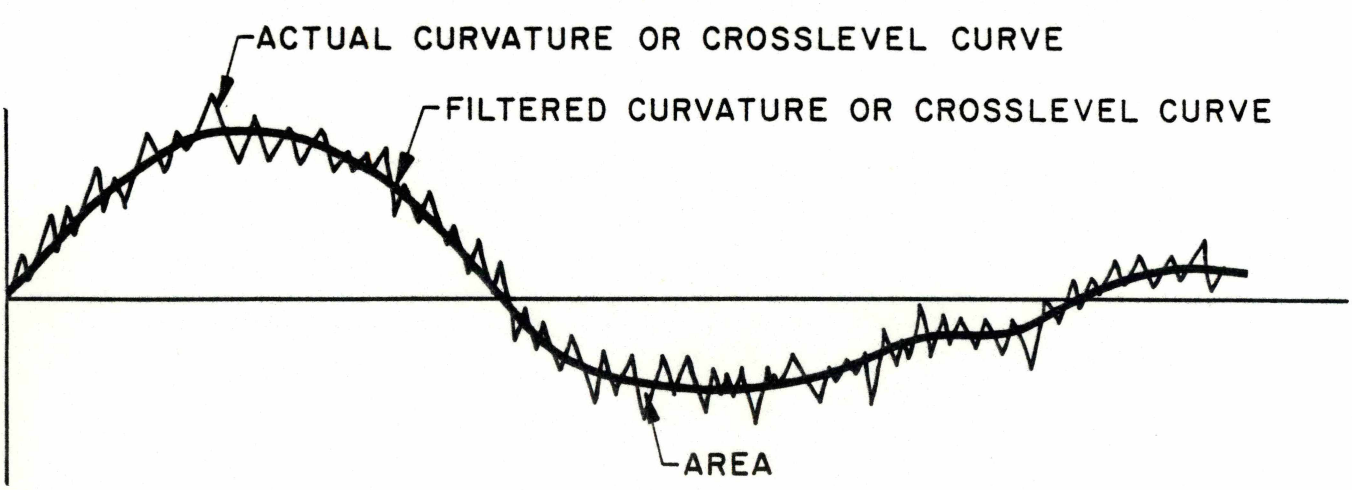


Figure 2-15. Curvature and Crosslevel Area Indices

The absolute value of the area is used in the determination of the Curvature and Crosslevel Area Index. This is represented by the area shown in Figure 2-15.

2.3.2 Gage Standard Deviation Index

The standard deviation is determined by calculating the mean ($\overline{X}$) using equation 2.1.

$$\overline{X} = \frac{\sum_{i=1}^{n} X_i}{n} \tag{2.1}$$

where X_i is the actual gage measurement at the ith position and n is the number of measurements.

The standard deviation (σ) is then calculated using equation 2.2

$$\sigma = \sqrt{\frac{1}{n-1} \sum_{i=1}^{n} (X_i - \overline{X})^2} \tag{2.2}$$

When σ is small, the gage measurements vary minimally from the mean ($\overline{X}$) as shown in Figure 2-16.

When σ is large, the gage measurements vary greatly from the mean (Figure 2-17).

Therfore, the larger the standard deviation the more irregular or more variant the gage of a particular section of track.

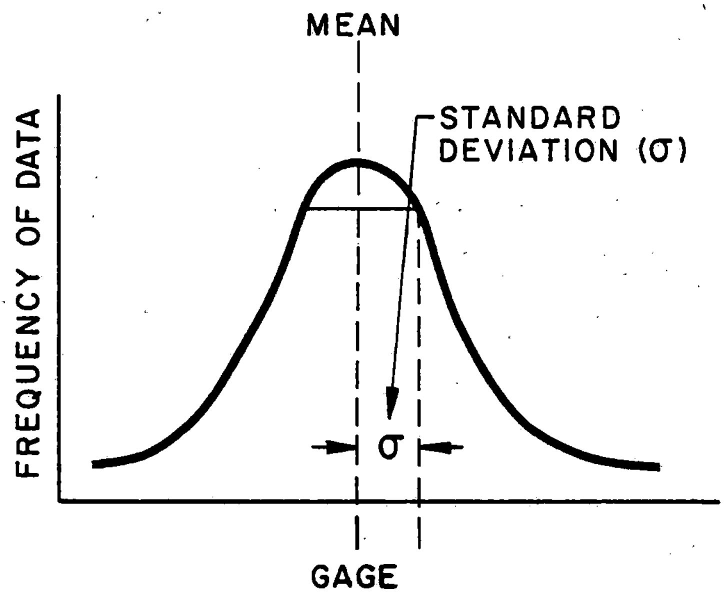


Figure 2-16. Small Standard Deviation

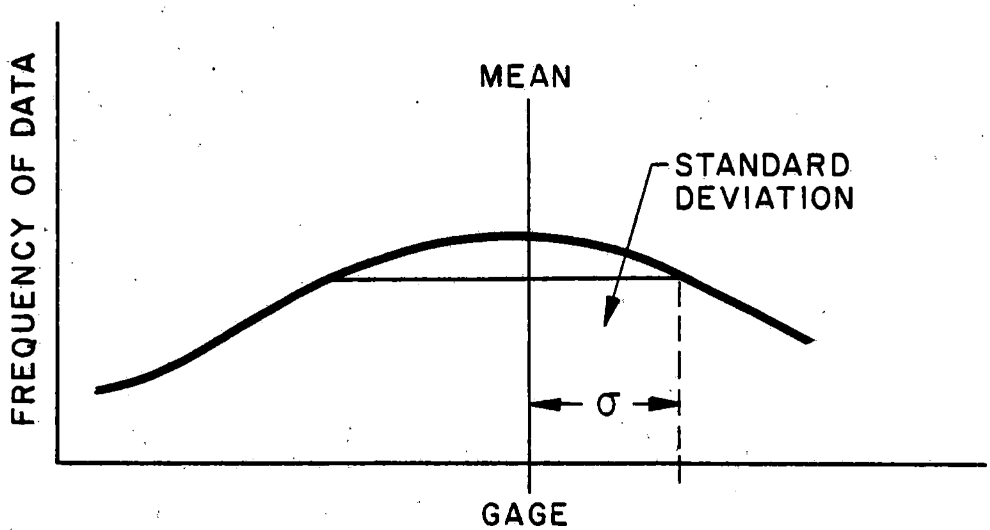


Figure 2-17. Large Standard Deviation

2.3.3 Gage 99-Percent Value

The 99-percent value is a cut-off value below which 99-percent of the data points lie. For example, the 99-percent value for gage could be 57 inches. This means that 99-percent of the gage measurements are less than 57 inches while one percent are greater than 57 inches (refer to paragraph 2.3.1.1).

In the maintenance-of-way studies, 547 data points or samples are collected for each quarter mile segment with a 2.41-foot sample interval in the case of T-3. The 99-percent level will be a gage value above which one percent or five of the samples lie. This one percent includes the gage measurements that vary the most from 56.5 inches.

2.3.4 Slopes

"Slopes" is used to describe the profile of a section of track. It is a measure of the number of times the difference (ΔY) between two consecutive profile measurements divided by the sampling distance (ΔX) exceeds a selected threshold. Figure 2-18 shows the relationship between ΔY and ΔX on a graph of profile. The value $\Delta Y/\Delta X$ can then be plotted as shown in Figure 2-19.

The slopes value is the number of times $\Delta Y/\Delta X$ is greater than the threshold value. For the example in Figure 2-19, the slopes value would be 5, since there are five points outside the threshold value. One of the points outside the threshold is not considered because it lies at a cusp and is therefore considered only once, not twice.

2.4 MAINTENANCE-OF-WAY REPORTS

Once the track geometry data has been processed to provide the MOW indices (or exceptions to FRA or industry thresholds), the information is tabulated in a variety of summary reports for distribution and use at various levels of MOW management

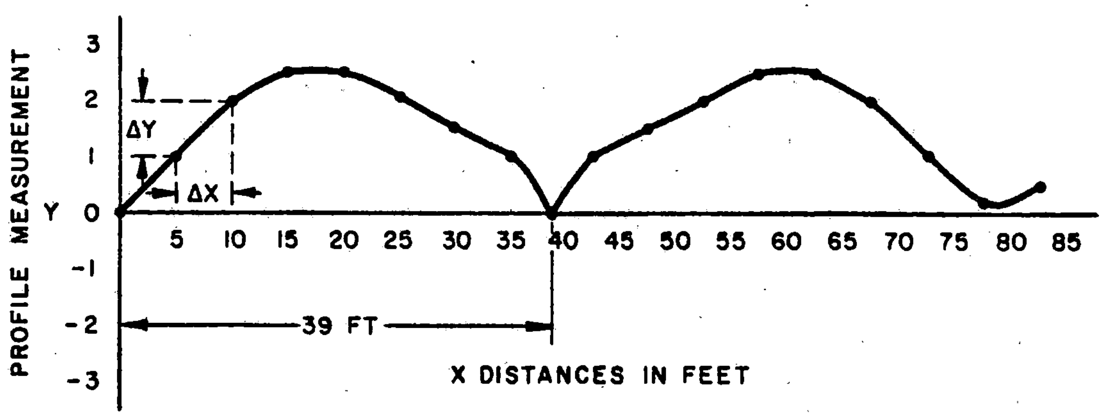


Figure 2-18. Profile Measurements Versus Distance

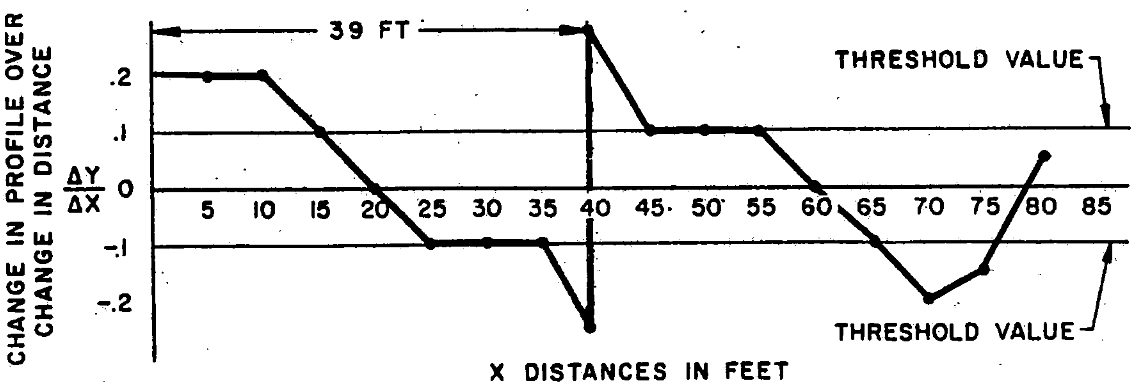


Figure 2-19. Change in Profile Over Change in Distance Versus Distance

for their maintenance-of-way operations. These reports present the track geometry data in three formats: the Maintenance-of-Way Standards Report, the Maintenance-of-Way Planning Report and the Geoplot Report.

The Maintenance-of-Way Standards Report lists exceptions to track geometry standards established by FRA and the railroads. The Maintenance-of-Way Planning Report and the Geoplot Report show the maintenance indices in formats that can be used for rating track segments.

2.4.1 MOW Standards Report

The Maintenance-of-Way Standards Report (MOWS) shows a comparison at each data value with railroad-selected standards and FRA Safety Standards. Appendix C includes examples and detailed explanations of each section of the report.

The MOWS Report includes:

- A detailed report listing location, magnitude and length of each exception to both FRA and railroad standards for all measured parameters.
- A Class Summary showing class per mile based on the worst exception found.
- An Exception Count Summary showing the number of exception counts per mile surveyed.
- A Curve Summary showing the beginning and end points of each curve as well as length, average elevation, average curvature and limiting speed exceptions.
- An ALD Events Summary showing location of switches and road crossings.
- Curvature speed and rock-and-roll exception information.
- A Report Threshold listing FRA and Railroad Standards.

2.4.2 MOW Planning Report

The Maintenance-of-Way Planning Report (MOWP) lists track quality indices for multiple sections of track (sections may be any length up to approximately five miles). It also sorts track quality indices by parameter according to severity. Appendix C includes a sample of an MOWP Report.

2.4.2.1 SORT Report

Part of the MOWP is the SORT Report (Appendix C). In this report, the track segments are sorted for their index values and are listed from worst (largest index value) to best (smallest index value). A SORT Report is developed for each of the four indices corresponding to the four measurement parameters.

2.4.3 Geoplot Report

The Geoplot Report is made up of bar charts of track quality index values of each segment on the Track Parameter Quality Index Chart (Appendix C). This chart can be used to overlay the indices of up to three different surveys to show degradation or improvement.

2.4.4 Limitations in Data Collection and Processing

There are several difficulties in the utilization of the 99-percent value generated by track geometry surveys for use in maintenance planning.

The 99-percent value of gage involved two problems. First, it is dependent on the particular measurement consist used on a survey. The T-1/T-3 consist has a 2.41-foot sample interval which produces 546 samples per quarter-mile segment. T-6 and T-2/T-4 have a one-foot sample interval and generate 1320 samples per quarter-mile segment. The 99-percent value for T-1/T-3 means that five points in the quarter-mile segment exceed the 99-percent value while for T-6 and T-2/T-4 there are 13 points that exceed the 99-percent value. Secondly, the gage measuring system may be withdrawn at the discretion of the forward observer when passing road crossings. During one survey, a forward observer might estimate that there is sufficient clearance at a crossing and leave the instrumentation down, but during the next survey, another forward observer might be cautious and withdraw the sensors. Since road crossings are difficult to maintain, the second survey would miss the worst portion of the quarter-mile segment and consequently, the 99-percent value would be significantly lower. Care in interpreting the MOW Planning Report could eliminate this discrepancy. If the number of samples column is monitored properly, a difference in the number of gage samples from one survey to the next for a quarter-mile segment would indicate that the 99-percent value is not comparable between the two surveys.

3.0 USE OF THE MAINTENANCE-OF-WAY REPORTS

3.1 DISTRIBUTION OF THE REPORTS

The distribution of the MOW reports within the Bessemer and Lake Erie and the Denver and Rio Grande Western varies because of their differing corporate structure. In general, the distribution for each report is:

- Strip charts - The six-channel strip chart recording (Figure 3-1) is used by the track supervisor, the person directly responsible for the track, to perform the most urgent spot maintenance. The eight-channel strip chart is used in conjunction with the Standards Report by the senior engineer to determine what spot maintenance should be done.

- MOW Standards Report - In general, a copy of the Standards Report is distributed to the senior engineer, to the engineer-track, and one is split up into each section and distributed to each area supervisor.

- MOW Planning Report - The MOW Planning Report is sent to upper management where it is used for maintenance planning and allocation of maintenance resources.

- Geoplot Report - The Geoplot Report is sent to upper management and used to plan maintenance and allocate maintenance resources.

3.2 HOW THESE REPORTS HAVE BEEN USED BY THE RAILROADS

The Bessemer and Lake Erie and the Denver and Rio Grande Western have different maintenance philosophies. However, both railroads have been able to use the various reports for spot maintenance, short-term maintenance planning, quality control and in other areas of maintenance planning.

TRACK GEOMETRY DESIGNATIONS

NOTE

CROSSLEVEL (Channel 3)

Crosslevel chart can be used to show: (1) Deviation from 0 crosslevel on tangent; (2) Difference in crosslevel in 62' on tangent and full body of curve (warp); (3) To compare crosslevel on curve with designed elevation; (4) Deviation from designed elevation on spirals (different limits than in Items 1 thru 3); (5) Change in crosslevel in 31' on spirals (warp) (different limits than Items 1 thru 4).

CURVATURE (Channel 4)

Curvature chart can be used to show: (1) Deviation of alignment in 62' from uniformity on tangent and curves; (2) Existing degree of curvature in curves; (3) Comparison of elevation and curvature on curves and spirals.

PROFILE: 62' Midchord Offset (Only Valid Above 20 mph)		CROSSLEVEL			CURVATURE: 1° = 1" (62' Chord)			GAGE		
Class	Deviation From Profile	Class	Spiral	Non Spiral	Class	Tan	Curve	Class	Tan	Curve
1	3.00"	1	1.75	3.00"	1	5.00°	5.00°	1	57.75"	57.75"
2	2.75"	2	1.50	2.00"	2	3.00°	3.00°	2	57.50"	57.75"
3	2.25"	3	1.25	1.75"	3	1.75°	1.75°	3	57.50"	57.75"
4	2.00"	4	1.00	1.25"	4	1.50°	1.50°	4	57.25"	57.50"
5	1.25"	5	0.75	1.00"	5	0.75°	0.625°	5	57.00"	57.50"
6	0.50"	6	0.50	0.05"	6	0.50°	0.375°	6	56.75"	57.00"

ALD

Shows Mileposts, Switches and Road Crossings

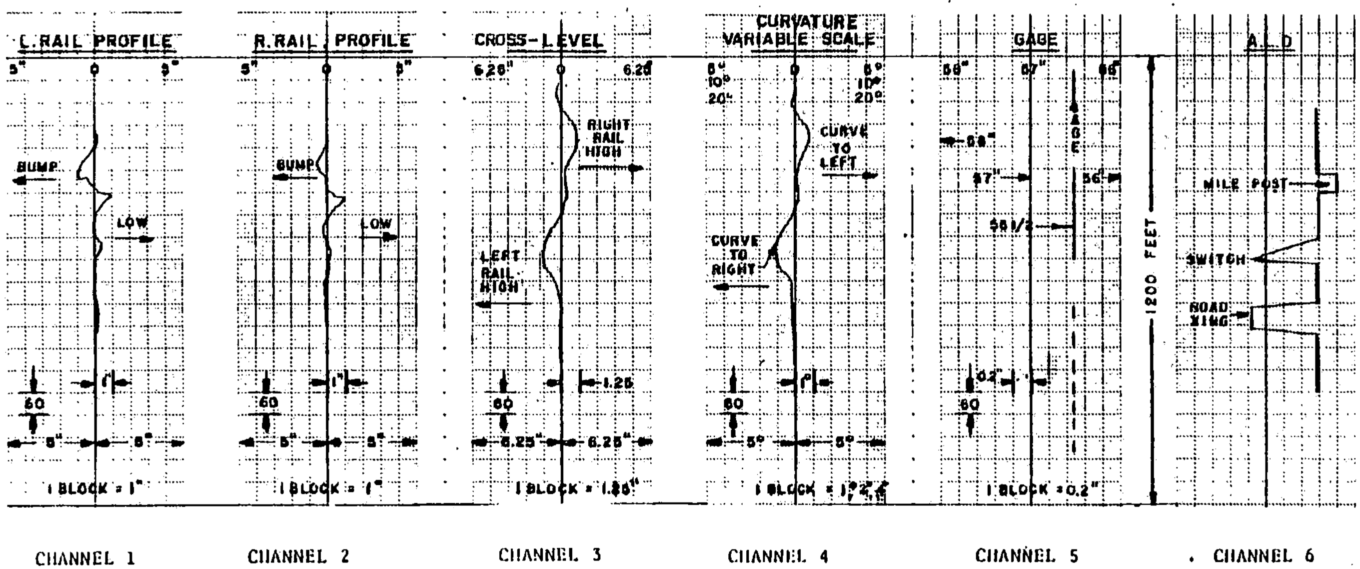


Figure 3-1. Sample 6-Channel Strip Chart Recording

3.2.1 Spot Maintenance

The six-channel strip chart and the MOW Standards Report are used for spot maintenance work. The strip chart (Figure 3-2) is generated during the survey; this enables the track supervisor to mark the chart for critical defects, to take the chart with him when he leaves the test consist, and to dispatch repair crews quickly. There have been occasions when a critical defect has been observed that required immediate action. On these occasions, the onboard mobile telephone has been used to dispatch a repair crew.

When the MOW Standards Report is delivered (Figure 3-3), the senior engineer analyzes the report and locates every defect that exceeds FRA standards for the track that was inspected. He also checks for violations of railroad standards.

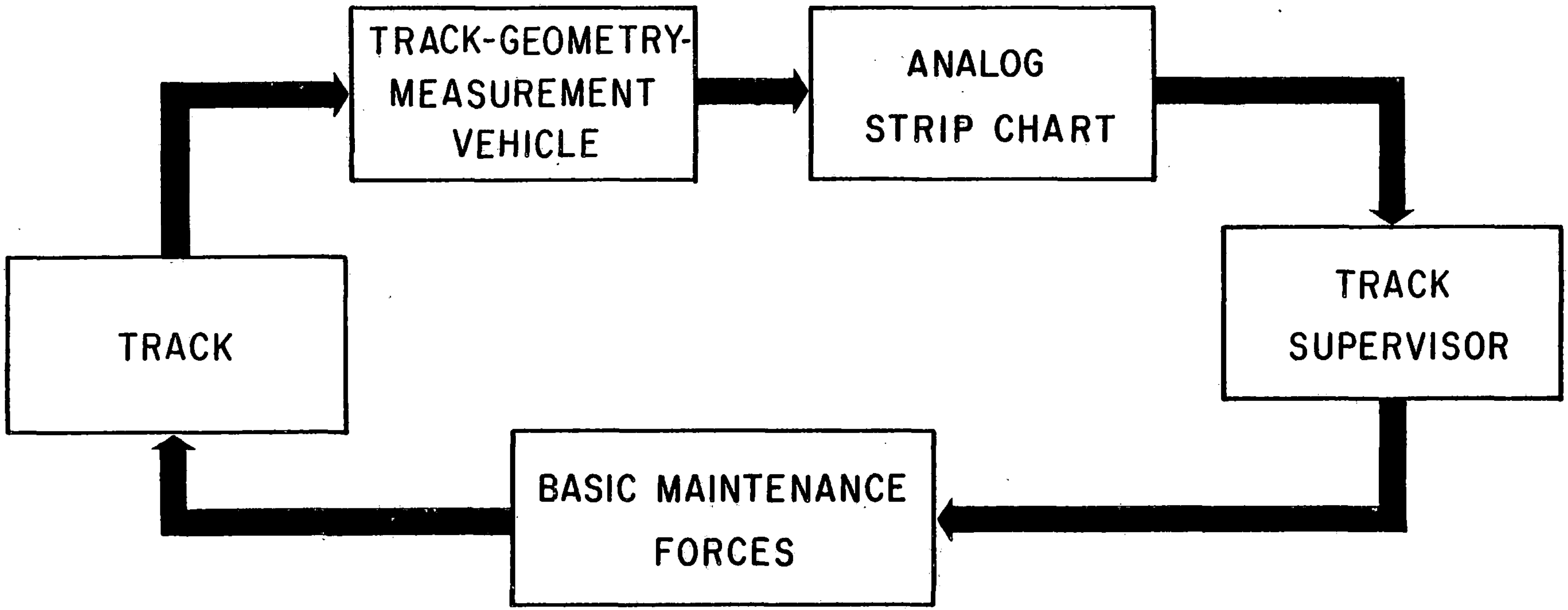
The senior engineer then compares the MOW Standards Report to the track supervisor's strip chart and to the repairs the supervisor has already made and determines the need for additional repairs. Violations of FRA standards are repaired quickly, violations of railroad standards may be repaired at a later time since the railroad standards only indicate that a section of track is approaching the limits of federal track safety standards.

The copy of the MOW Standards Report distributed to the engineer-track is used as a reference source when track condition is questioned.

3.2.2 Short-Term Line Maintenance

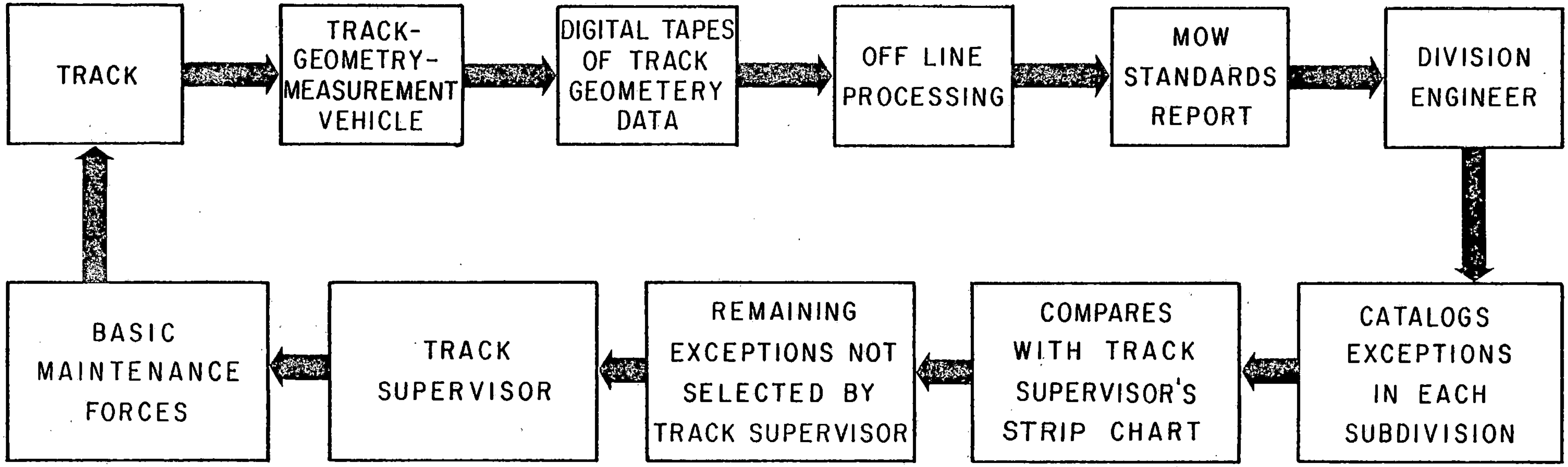
For short-term line maintenance, the MOW Planning and Geoplot reports are used as inputs to the final maintenance plans.

The MOWP and Geoplot reports (Figures 3-4 and 3-5) are used in conjunction with traffic predictions, division engineer requests and an evaluation of available maintenance resources to determine what maintenance will be performed during the coming year.



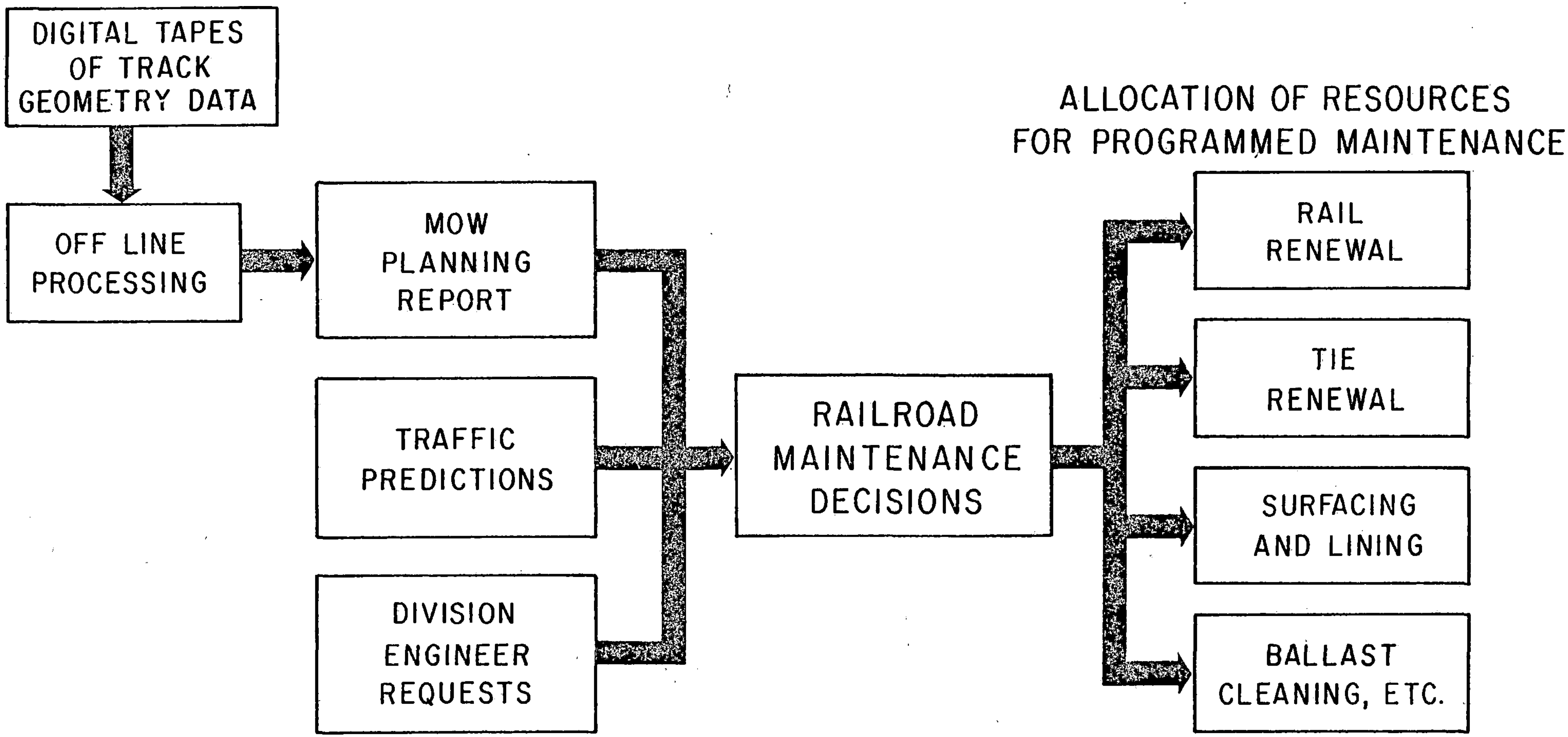
1. FRA TRACK GEOMETRY VEHICLES SURVEY TRACK
2. TRACK SUPERVISOR RIDES SURVEY VEHICLE AND MARKS BRUSH CHART FOR DEFECTS
3. TRACK SUPERVISOR HI-RAILS TRACK WITH TRACK FOREMAN AND BRUSH CHARTS TO LOCATE DEFECTS
4. MAINTENANCE FORCES DISPATCHED

Figure 3-2. Use of the Strip Chart



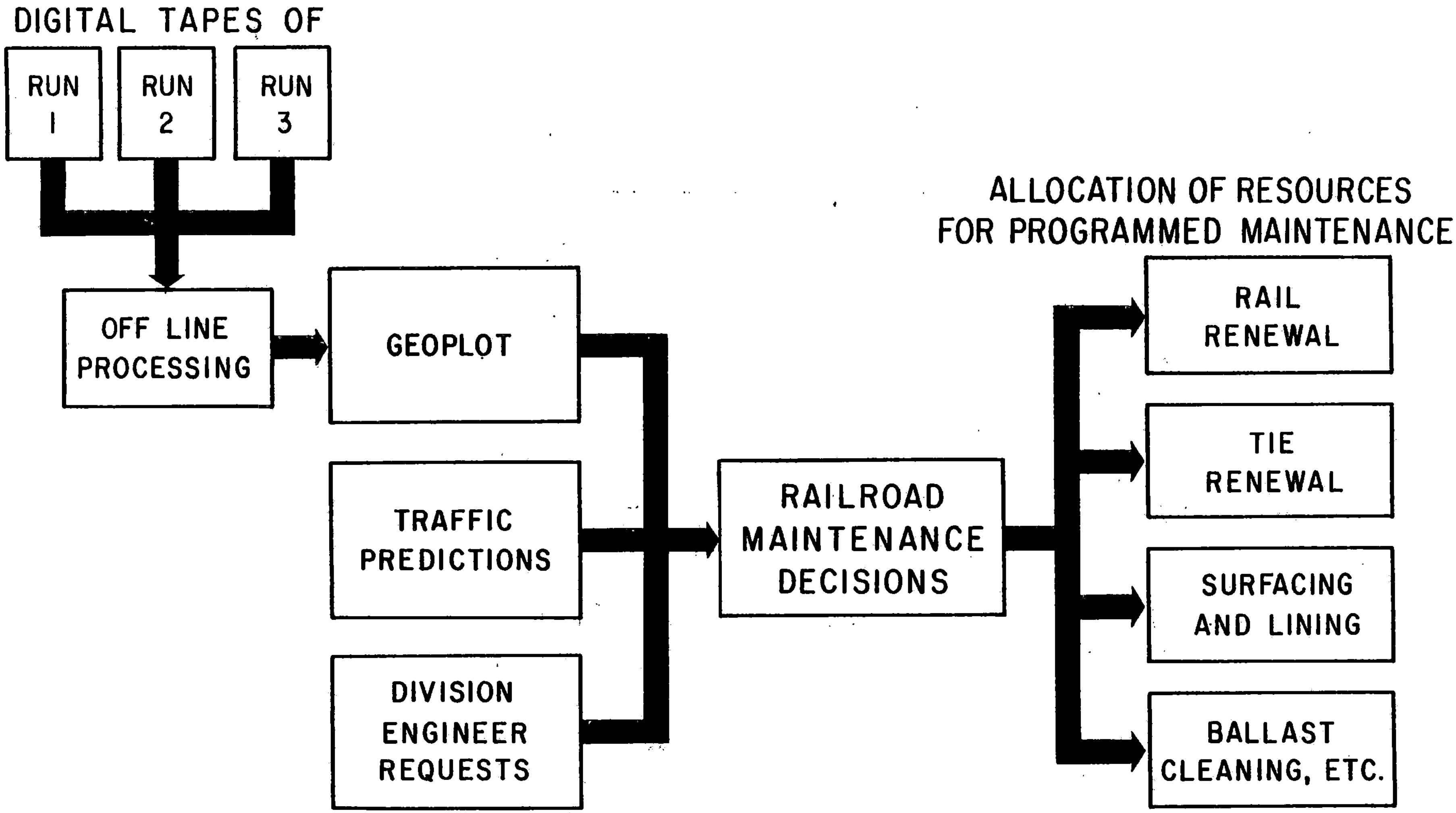
1. FRA TRACK-GEOMETRY-MEASUREMENT VEHICLE SURVEYS TRACK
2. DIGITAL TAPES OF TRACK GEOMETRY DATA ARE PROCESSED INTO MOW STANDARDS REPORT
3. DIVISION ENGINEER COMPARES MARKED UP TRACK SUPERVISOR'S STRIP CHART WITH MOWS REPORT FOR EACH SUBDIVISION
4. REMAINING EXCEPTIONS ARE NOTED ON THE MOWS REPORT AND IT IS FORWARDED TO TRACK SUPERVISOR
5 TRACK SUPERVISOR DISPATCHES THE REQUIRED MAINTENANCE FORCES

Figure 3-3. Use of the MOWS Report



1. DIGITAL TAPES OF TRACK GEOMETRY DATA ARE PROCESSED INTO MOW PLANNING REPORT
2. DIVISION LEVEL MAINTENANCE REQUESTS AND TRAFFIC PREDICTIONS ARE COMPARED WITH TRACK SEGMENT RATINGS IN MOWP REPORT
3. CHIEF ENGINEER-MOW, MAKES DECISION ON ALLOCATION OF RESOURCES FOR PROGRAMMED MAINTENANCE.

Figure 3-4. Use of the MOWP Report



1. DIGITAL TAPES FROM PREVIOUS RUNS ARE PROCESSED INTO GEOPLOT
2. DIVISION LEVEL MAINTENANCE REQUESTS AND TRAFFIC PREDICTIONS ARE COMPARED WITH RELATIVE DETERIORATION RATE OF TRACKS IN GEOPLOT REPORT
3. RESOURCES ARE ALLOCATED FOR THE PROGRAMMED MAINTENANCE ACTIVITY

Figure 3-5. Use of Geoplot

The MOWP and GEOPLOT reports provide information on the relative condition of the track segments surveyed and on their relative rates of deterioration. The reports alone provide a good deal of information about the quality of the track segments but they also require analysis and interpretation. Scheduling of surfacing and lining (programmed maintenance) is primarily based on profile indices and to a lesser extent on crosslevel indices. Visual inspection is necessary for planning tie renewal, but gage and curvature indices can provide more objective information. In curves, wide gage is indicative of aging ties which do not adequately support lateral loads. On tangent track, however, narrow gage indicates aging ties that have been cut into by the tie plates allowing the rail to cant-in under load. While rail renewal can be required because the rail is curve worn or end battered, these anomalies cannot be characterized through track geometry measurements. Track profile will, however, characterize a surface-bent condition and lengths of main line over which that condition prevails may be replaced with new rails while the bent rail is cropped and used on secondary track. Referring to Figures 3-4 and 3-5, the automatically acquired track geometry data is weighted more heavily in the allocation of funds for surfacing and lining than it is for rail or tie renewal. The values of the indices are based on quarter-mile segments of track. However, programmed maintenance is usually planned for track segments of two to five miles. Therefore, the reports must be studied for groups of segments that have thw worst index values. Track segments with high index values that are supported by segments with low indices are normally repaired by spot maintenance crews rather than by a programmed maintenange gang.

The MOWP and GEOPLOT reports are primarily used for allocation of maintenance resources. The Chief MOW Engineer uses the reports each fall to decide what maintenance will be done during the upcoming year. This decision is based on inputs from the division engineers, upcoming traffic predictions, the amount of available maintenance resources and the MOW Planning report.

3.2.2.1 Maintenance Indices Used for Planning

From a maintenance planning standpoint, the most used maintenance indices are:

- Gage area index
- Gage standard deviation
- Gage 99-percent value
- Profile slopes or index

With the gage indices, there is no overlap of information. Each parameter tells its own story and when combined with the other gage indices, yields a very complete picture of gage in a particular section of track. The gage area index indicates the mean or average gage over a section of track. The standard deviation shows whether or not the gage is uniform. These two indices taken together tell a very complete story. For example, a section of track with a high area index and a small standard deviation has general gage widening.

The 99-percent value completes the picture by indicating the worst gage values in a section of track. A section of track with general gage widening may or may not be in need of maintenance. The 99-percent value indicates the worst measurements in that section of track. If the 99-percent value is less that 57-1/2 inches, immediate attention is not requried since this is not a critical situation.

With the profile indices, the area index and the slopes yield similar information. Railroad people prefer the area index because it is the true measurement of the difference between the actual curve and the theoretical curve. Since it is an actual measurement, the index values obtained at the 2.41-foot sample interval can be more easily compared than the slope values. The slopes index gives a good indication, for jointed track, as to how many low joints exist in a 1/4-mile segment. On continuously welded rail the area index is more effective.

The railroads rarely allocate maintenance funds solely on the basis of the crosslevel and curvature indices. There is a a problem in physically interpreting the meaning of these indices, since crosslevel and curvature are normally thought of in combination as they are related to speed limitations or superelevation deficiencies. These indices do relate to roughness in crosslevel or curvature, and consequently to deviations from the original design.

3.2.2.2 GEOPLOT

GEOPLOT was used to complete the maintenance planning procedure, since it compares the surveys of the last two years with the current survey to show whether or not a section of track has deteriorated. This is useful in maintenance planning because it highlights sections of track which need to be repaired. For example, a section of track with gage that is widening from one year to the next, will need maintenance. However, a section of track whose gage has not changed over three years will not need maintenance.

GEOPLOT is also useful because it is the easiest report to read and understand. It is a graphic representation of the condition of the track.

3.2.3 Comparison of Maintenance Techniques

The MOW reports could be used to evaluate the effectiveness of various maintenance techniques. However, more research is needed before an objective comparison of maintenance techniques can be made. In addition, a comparison of maintenance techniques and an evaluation of the effectiveness of the maintenance techniques on the track must be made. Also, the cost-effectiveness of the techniques must be evaluated. In addition to evaluating the effectiveness of various maintenance techniques, the MOW reports could be used to evaluate the effectiveness of maintenance devices available from different manufacturers.

3.2.4 Quality Control

Quality control is primarily assuring that the line maintenance crews are effectively accomplishing their mission. The MOW reports, generated during this study, have had limited use in quality control. This has been due to the large time interval between surveys.

3.2.4.1 Short-Term Quality Control

To be useful for short-term quality control, track geometry surveys must be conducted on an as-needed basis. Surveys should be conducted after programmed maintenance has been performed on a track segment and after there has been sufficient traffic to consolidate the ballast. Survey scheduling would be difficult to justify on the basis of survey cost versus forseeable benefits.

3.2.4.2 Long-Term Quality Control

Long-term quality control is the effective use of the yearly surveys to correct track defects. For long-term quality control, the reports are being used effectively to monitor the quality of the track, the effectiveness of track maintenance and the amount of track degradation which occurs during the time between surveys.

3.2.5 Allocation of Maintenance Resources

Both the MOWP and the GEOPLOT reports are used to determine the allocation of maintenance resources as illustrated in Figures 3-3 and 3-4. As mentioned in Section 3.2.2, the engineer-track uses these reports to determine what maintenance should be done. He then determines how much of this maintenance the railroad can afford to do. Finally, he selects the maintenance to which he will commit his maintenance resources.

An important potential use of the planning reports in the allocation of maintenance funds is the determination of which branch lines should be upgraded. This determination begins with an analysis of the future revenue a branch line would generate as compared to other branch lines, if it were upgraded. This analysis involves traffic predictions and new business the line would generate.

Then, an evaluation of the costs involved in upgrading the branch line are determined; the MOWP and GEOPLOT reports are used in this determination. From the reports, the amounts of time and money necessary to upgrade each branch line can be determined.

Finally, a cost-effective comparison is made between the branch lines. The cost to upgrade each line is compared to the amount of new revenue each line will generate in order to determine which branch line will yield the greatest profit per maintenance dollar.

3.2.6 Acceptance of the Validity of the Reports

The biggest obstacle to the effective use of the survey data and the MOW reports was a reluctance by railroad personnel to accept their validity. To overcome this lack of acceptance, a great deal of care and patience was required.

Acceptance of the reports began with upper management and spread through the rest of the railroad personnel. Acceptance of the report by the maintenance crews depended to a large extent on the attitude of upper management toward the reports.

When upper management received the MOW reports, they went to the track supervisors, showed them the reports and the track defects indicated thereon, and asked them what they had done or were going to do to correct same.

By management asking what the track supervisor intended to do to improve his track rather than ordering him to go out and prove that the reports were correct, management hastened the acceptance of the reports by field personnel.

During the first two years of this program, confidence in the MOW reports and the indices grew. As confidence in the reports grew, the feedback from the railroads involved helped to improve the format and design of the reports.

3.2.6.1 Training

Because of the large amount of information and experience required to be a good supervisor, the track-geometry-measurement vehicles and the MOW reports are only tools to be used in training a supervisor. They do, however, complement the training procedure for a supervisor.

A benefit in using the track-geometry-measurement vehicles and the MOW reports in the training of supervisors is that each supervisor so trained will accept the survey results and the MOW reports and will know how to use the reports effectively from the start of his career as a track supervisor.

3.2.7 Derailment Investigation

Another use for MOW reports is in the investigation of derailments. The reports are used to determine if a derailment could have been caused by defective track.

3.3 ECONOMIC CONSIDERATIONS

In general, there is difficulty in quantifying the economic benefits resulting from this program. However, the participating railroads feel that they have been allocating their resources more effectively as a direct result of using the MOW reports. The main difficulty in quantifying economic benefits is with the standard procedures for recording spot maintenance costs. Generally, the recording procedure is not site-specific. Records of location, number of ties installed and expended manhours are requried to perform an accurate economic analysis. An MOW Program being started with Conrail has established new reporting procedures designed to overcome these difficulties.

There are several economic trade-offs that can be directly affected by the automated track-geometry-measurement program. These will be discussed in the following sections.

3.3.1 Spot Maintenance/Programmed Maintenance

To determine when it is cost-effective to defer programmed maintenance for a segment of track, the cost of increased spot maintenance must be considered. If programmed maintenance is deferred, it is normally because of a lack of resources. However, the amount of spot maintenance necessary to keep track within FRA Safety Standards will increase and the cost of spot maintenance is higher than that of programmed maintenance for equivalent lengths of track. Therefore, a balance between spot and programmed maintenance must be established in order to use maintenance resources effectively.

3.3.2 Track Geometry Standards

The participating railroads have established track geometry requirements that are more stringent than the FRA Safety Standards. The railroads have been using these tighter requirements to find sections of track which are approaching the limits set by FRA Safety Standards.

Good track deteriorates at a slower rate than poor track. For example, if joints are allowed to pump, the rail will become surface-bent and this will cause a good surfacing job to deteriorate very quickly. If the rail were straight, the surfacing job would last much longer. Therefore, it would seem that very tight track geometry standards would ensure longer programmed-maintenance-cycles. However, if the standards are too tight, more frequent maintenance cycles would be required to keep the track within the standards. Therefore, it is necessary to find an optimum set of standards that would reduce the number of maintenance cycles required to maintain a section of track.

3.3.3 Other Studies

There are also potential benefits in other studies which include:

- A comparison of different combinations of track structure components, e.g., rail weights, tie type and spacing, ballast type and depth.
- A comparison of various production machines.
- A comparison of maintenance techniques, e.g., surfacing one month after tie renewal versus two months.
- A comparison of the effectiveness of production gangs.

3.4 LONG-RANGE PLANNING

The definition of long-range is subject to several interpretations. The B&LE and D&RGW railroads have interpreted long-range consistent with their current programmed maintenance philosophies. This section covers these interpretations and the applicability of the current FRA track geometry measurement system, the track quality indices and the reporting formats in meeting the needs of the railroads for long-range planning.

3.4.1 What Is Meant by Long-Range

Each major programmed maintenance operation requires its own definition of long-range. Rail renewal requires the longest lead time for ordering material. The heavier weights of rail, particularly 140 pounds, are not normally produced. Therefore, the manufacturers of rail cannot economically change their roll sizes for small quantities. Consequently, the rail demands for a small railroad over the next five to ten years must be anticipated in order to obtain the minimum lot size that can be produced without paying a premium price in the form of nonrecurring cost per rail length associated with tooling changes.

Tie renewal, on a programmed basis, does not have the long lead time for ordering material associated with rail renewal.

The service life of ties (20-25 years) is the primary consideration for long-range planning, since programmed tie renewal is performed only when twenty percent or more of the ties in a two-mile or longer segment require replacement. This limits the definition of long-range to four or five years for tie renewal on particular segments of track.

Programmed surfacing is not normally dependent on material availability. Its frequency is more dependent on the integrity of the entire track structure. The condition of the rail, whether it is surface bent or end battered, whether it has adequate tie support, whether there is ballast contamination and whether there is subgrade stability all combine with traffic conditions to affect the length of time a section of track takes to degrade after a surfacing operation. On heavily used track, three years is the maximum cycle for programmed surfacing without an inordinate amount of spot surfacing. Gaging is not normally accomplished on a programmed basis.

Spot maintenance budgeting on a long-range basis is subject to so many variables that it cannot be effectively predicted. A general long-range allocation can be established on a historical basis at the division level in conjunction with long-range programmed maintenance plans. Towards the end of a programmed maintenance cycle, the spot maintenance costs are higher than at the beginning. However, due to overlapping cycles for tie renewal and surfacing, it is very difficult to estimate trends in spot maintenance costs.

3.4.2 Track Quality Indices/Track Deterioration

The track quality indices, obtained during track geometry surveys, provide information on the relative condition of segments of track. Periodic surveys when compared to one another can be used to determine the relative deterioration of the segments when the repeatability of the measurement system is taken into consideration. Appendix B contains information on the practical implications of system repeatability.

In general, there are some indices that are more sensitive than others to a lack of repeatability in the track-geometry-measurement parameters. Gage index, for example, is sensitive to any bias in the raw gage measurement. Theoretically, gage measurements may have up to one-tenth of an inch bias from day to day or from year to year due to calibration procedures, temperature changes, etc. During a single day's run, the gage measurement system is repeatable to within one thirty-second of an inch. One-tenth of an inch bias in gage would yield a gage index bias of about 1300. However, when considering relative deterioration rates of track segments, the bias does not enter into the problem. The relative rates of deterioration are obtained by comparing the differences in the gage index from segment to segment for one survey with the differences from segment to segment for another survey. By comparing these differences, the effect of the bias is removed making this system an effective means for determining relative deterioration rates of the track segments.

Gage area index is sensitive to any bias in the measurement system. This is not the case with the profile, crosslevel and curvature indices where filtering removes biases or d-c components from the signals. These indices are effective for evaluating absolute track deterioration rates.

3.5 QUANTIFICATION OF TRACK QUALITY INDICES

The B&LE and D&RGW have not been able to quantify the relationship between the changes in track quality indices to the physical and maintenance parameters that have a tendency to affect them. Therefore, development of the quantifiable relationship between the indices and the parameters is the next logical step in the MOW program. The new program with Conrail is being conducted toward that goal. There are two types of parameters which affect the values of these track quality indices; maintenance related parameters which would improve the values of the indices, and various physical parameters which would tend to degrade the values of same.

3.5.1 Maintenance Related Parameters

Spot maintenance parameters are difficult to quantify since more information is required than is currently available from the records of the participating railroads. Spot maintenance operations that are expected to affect the indices must be monitored and reported for each segment of track in terms of the number of new ties installed, the length of track surfaced, etc. Normally, spot maintenance would have little effect on the indices, but there are occasions when relatively long stretches of track are repaired by spot crews.

The three types of programmed maintenance already discussed would have a greater effect on the indices than spot maintenance. If the work is effective, certain indices would be reset to some value that would be consistent with the track class and FRA Safety Standards. Current reporting procedures for programmed maintenance operations are sufficient to determine the effect of maintenance operations on the indices.

3.5.2 Physical Parameters

The physical parameters that affect the indices tend to cause a gradual deterioration in the values of the indices rather than jumps or steps in same. What is of interest, is the relationship between dependent variables (indices) and independent variables (physical parameters). The development of this relationship is termed regression analysis. The parameters that affect track degradation are numbered, the ones selected by the railroads because they have the greatest effect on track quality are:

- Tonnage - cumulative and annual (millions of gross tons).
- Percent heavy wheels - percentage of 100-ton capacity, 4-axle vehicles.
- Average train speed (miles per hour).
- Rail type (welded or jointed).
- Rail weight (pounds per yard).
- Curvature (central angle per hundred foot chord length).
- Rail profile (surface bent or not).
- Ballast condition (degree of contamination).
- Drainage (effective or not).
- Climate conditions (temperature range, precipitation, etc.).

In order to accomplish the regression analysis and the generation of the subsequent predictive equations, the track must be segmented on a different basis than has been used in this program. Homogeneous segmentation of the track must be accomplished by grouping sections of track together with respect to similarity of physical parameters and especially maintenance history.

Projected values of the physical parameters would be used in the predictive equations developed through regression analysis to predict future index values for the homogeneous segments. These index values would then be used in the tradeoff study of spot versus programmed maintenance to plan an optimum long-range maintenance schedule.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 GENERAL CONCLUSIONS AND RECOMMENDATIONS

- The need for spot maintenance work is made evident by the six-channel strip chart and the MOW Standards Report.
- The MOW Standards Report is used as a reference when track condition is questioned.
- The need for line maintenance is made apparent by the use of the MOW Planning Report and the Geoplot Report in conjunction with traffic predictions and division engineer requests.
- Gage and profile indices have been effectively used by railroad personnel in planning line maintenance but the crosslevel and curvature indices have not been given as much weight in maintenance-fund allocation.
- The Geoplot Report is a graphic representation of track condition and is used to determine the relative deterioration rates of track segments.
- More research is needed in the area of evaluation of the effectiveness of maintenance techniques and devices.
- For quality control, the MOWP and Geoplot Reports have been effectively used to monitor the general quality of the track from survey to survey but the surveys are not frequent enough to monitor the effectiveness of the track maintenance gangs.
- Upgrading branch lines is an effective use of the MOW Planning Report. A comparison of the reports from candidate branch lines gives an indication of the relative costs associated with each upgrade.
- Training track maintenance supervisors can be improved through the use of track geometry measurement vehicles and MOW reports.
- The economic benefits resulting from this program have been difficult to quantify. Quantification can only be accomplished through more detailed spot maintenance cost and site reporting.

4.2 HAS THE PROGRAM BEEN SUCCESSFUL

The success of this program has been demonstrated by the fact that the participating railroads use the maintenance-of-way reports to augment their spot-maintenance and production maintenance programs and consequently to improve the safety of their track. The B&LE and the D&RGW know the condition of their track from a track-geometry viewpoint and are able to decide when and where to allocate their maintenance funds when geometry, revenues, potential traffic changes and requests from division engineers are all taken into consideration. The railroads have been using the information provided in the reports even when the instrumentation was less than adequate. Over the years, railroad personnel have come to accept the validity of the data generated during the track-geometry surveys. This acceptance started with upper management and filtered down through the organization to the track-foreman level.

From the Government's viewpoint, since it is mandated to ensure safe rail surface for the general public, the program has been very successful. The Office of Safety now has a fleet of track-geometry-measurement vehicles that inspect the nation's railroads through the Automatic Track Inspection Program (ATIP). The development and evaluation of instrumentation, data processing procedures and reporting formats were refined through use on this program. As new vehicles became operational, their initial tests were conducted with the cooperation of the participating railroads.

The objectives of this program have been accomplished. Methods have been developed for producing quantitative track rating information in the areas where:

- Immediate or timely corrective maintenance is required. This is obtained from the MOW Standards Report.
- Preventive Maintenance needs to be planned. This is obtained from the MOW Planning Reports.

Measurements of changes in track quality have been developed in the form of maintenance indices that are included in the MOW Planning Reports. A mathematical basis has been established for track maintenance planning through the reduction of parametric track geometry measurements to the user-oriented formats of the MOW Standards and the MOW Planning Reports.

4.3 POTENTIAL BENEFITS TO THE GENERAL RAIL INDUSTRY

While this program was being implemented, the railroad industry witnessed the bankruptcies that affected the rail carriers in the Northeastern United States. The 4-R Act reorganized those railroads to ensure that the general public would not be adversely affected by a lack of essential freight and passenger service. There is concern that other regions of the United States, especially the mid-continent region, could experience a similar catastrophe leading to more quasi-government railroads.

This program, which has proven to be successful on the B&LE and the D&RGW, and the recommendations to upgrade the program which follow, can be implemented on other railroads to improve planning and maintenance-fund allocation. The railroads that suffer from severe economic problems cannot undertake the track improvement programs required to meet their service responsibilities without federal financial assistance. The technical assistance provided by a program similar to the program implemented on the B&LE and the D&RGW can help to ensure proper allocation of federal-assistance funds. Currently, a program is being implemented with CONRAIL which represents a continuation of FRA research into using automatically collected track-geometry-measurement data for maintenance planning as opposed to enforcement of federal regulations.

4.4 RECOMMENDATIONS FOR UPGRADING THE PROGRAM

4.4.1 Predictive Equations for the Indices

Utilizing the parameters discussed in Section 3.5, predictive equations can be developed for track quality indices by employing regression analysis. Quantification of most of these parameters can be accomplished by minor modifications to reporting procedures currently employed by the railroads. The maintenance parameters: tonnage, percent heavy wheels, train speed, rail type, rail weight and curvature are all available now or can be made available from the railroads in enough detail to meet the needs of the program. The three remaining parameters: rail profile, ballast condition and drainage are currently quantifiable only through a special visual inspection by experienced personnel. Development of a real-time, onboard, track-stiffness-measurement system and an unloaded, rail-profile-measurement system compatible with and usable on the FRA track-geometry fleet would eliminate the need for that visual inspection.

The regression analysis requires three track surveys for the development of the predictive equations which would be usable on any track having maintenance and physical parameters within the range of those studied on the B&LE and the D&RGW.

4.4.2 Simplified MOW Standards Report

The MOW Standards Report is designed to make the railroads aware of points in their track which require immediate maintenance. The track foreman is responsible for locating a specific defect and taking the proper corrective action, e.g., spot surfacing or tie replacement. Many of the defects, which occur in track, generate characteristic signatures on the analog strip charts of track-geometry parameters. These signatures can appear in a single parameter or in a combination of parameters.

The job of the track foreman could be simplified, if the MOW Standards Report was supplemented by a listing of the positions and probable causes of critical track defects. To accomplish this, it would be necessary that experienced track inspection personnel survey the track in conjunction with a track-geometry-measurement survey. The notes as to the position of a defect, its cause and the corrective action required could be used in conjunction with a signature analysis of track-geometry parameters. Once the confidence limits are established (in the correlation of signature to defect), a simplified version of the MOW Standards Report could be supplied to the track foreman to augument the detailed report.

4.5 ADDITIONAL MEASUREMENT PARAMETERS

The railroads are very interested in two other measurements. These measurements could be used in the future to develop maintenance indices. One is track alignment, and although surfacing and lining decisions are currently accomplished simultaneously based on profile and crosslevel indices, the possibility exists that areas which only require lining are being overlooked. The second measurement is track modulus or stiffness. An index relating zones of contaminated ballast or areas with poor drainage would be very useful in planning the yearly ballast cleaning and ditching programs.

Alignment has been measured previously with capactive type instrumentation. The T-6 measurement system has an accelerometer-based alignment measuring subsystem. However, it is not feasible to implement this system on T-1/T-3 at present because of limitations in the onboard data processing system.

ENSCO has been conducting research since 1974 into an onboard Track Stiffness Measurement System in cooperation with the Improved Track Structures Research Division of ORSR. The system has been useful in detecting problems (at track speeds) in the track structure that are not evident from track-geometry measurements. It has detected drainage problems, sections of deteriorated ties, pumping rail joints not adequately supported by ties, and short-panel wooden bridges with uneven stiffness among the bents.

The Track Stiffness Measurement System requires additional development before it can be considered an effective survey tool that can be implemented on the existing track-geometry-measurement vehicles. The research to date has been conducted using the Southern Railway R1 research car and off-line processing. Since the track-geometry-measurement fleet is made up of two-axle-truck vehicles while R1 has three-axle trucks, a hardware modification would be required to use the stiffness equipment on the track-geometry-measurement vehicles. A real-time, onboard, processing system would also be required to make the system effective.

APPENDIX A
TRACK GEOMETRY INSTRUMENTATION

A.1 INTRODUCTION

The major subsystems and the signal flow of the track-geometry-measurement system are shown in Figure A-1. Each subsystem is configured to measure, record and display a particular parameter. These parameters are:

- Profile
- Gage
- Crosslevel
- Curvature
- Location

Each subsystem utilizes one or more electro-mechanical, all-weather sensors which gather raw measurement data, analog instrumentation to process the raw data, a digital computer to calculate the parameters and process the data, and recording instruments to provide permanent digital and analog records. The components associated with each subsystem are described in the following paragraphs.

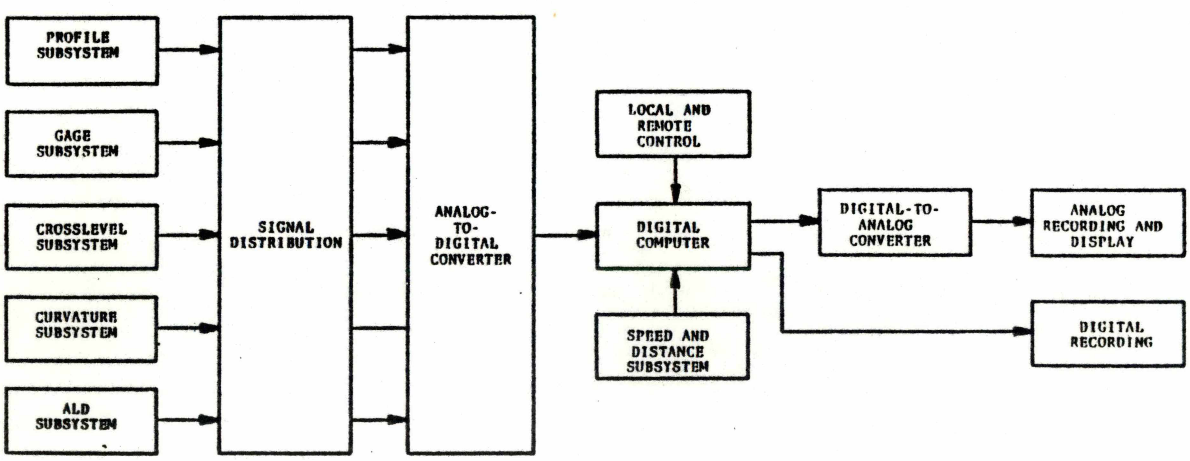


Figure A-1. Track Geometry Measurement System Block Diagram

A.2 PROFILE INSTRUMENTATION

As explained in Section 2.2.1, the profile instrumentation consists of a mass attached to an axle of the test car through a spring and damper assembly to measure displacements in the vertical direction. This mass, after being attached to a linear variable differential transformer (LVDT), measures the input displacements at high speeds caused by the difference in height of the railheads. This difference is the profile of the track. At low speeds, an accelerometer attached to the mass is used. Its signal is double integrated to obtain the displacement of the railheads.

A.2.1 Signal Processing

The profilometer signals are processed by an electronic package which provides signal conditioning amplifiers, filtering and scaling functions. The signals are routed through the analog terminal unit to the analog multiplexer at the digital computer. Track profile is measured by the profilometer as a pseudo space curve representation of track. The space curve is processed by the computer into a chordal representation (nominally, a 62-foot chord). A block diagram of the profile measurement subsystem is shown in Figure A-2.

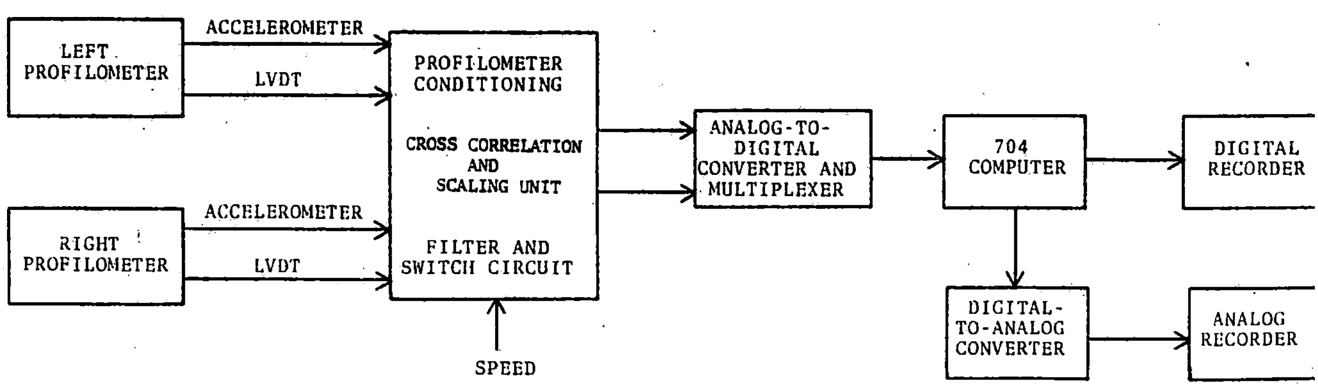


Figure A-2. Profile Subsystem Block Diagram

A.2.2 Data Recording and Display

Profile signals are recorded in digital format on magnetic tape for off-line processing. To provide real-time visual display and a permanent record in analog form, data are also reproduced on strip chart recorders.

A.2.3 Track Profile Measurement Theory

The behavior of the profilometer (Figure A-3) is described by

$$M\ddot{Z} = K(W - Z) + D(\dot{W} - \dot{Z}) \tag{1}$$

where

M = sensor mass (lb - sec^2/ft)

K = spring constant (lb/ft)

D = damping coefficient (lb/sec/ft)

$W(t)$ = forcing function of the track profile relative to the inertial reference

$Z(t)$ = forcing function of the sensor mass relative to the inertial reference

$\dot{}$ = first derivative

$\ddot{}$ = second derivative

Letting $Y(t) = W(t) - Z(t)$, where $Y(t)$ is the forcing function of track profile relative to the sensor mass, Equation (1) becomes

$$M\ddot{W} = M\ddot{Y} + D\dot{Y} + KY \tag{2}$$

Rewriting Equation (2) in LaPlace notation and rearranging terms yields an expression describing the motion of the sensor mass relative to the track surface as:

$$\frac{Y(s)}{W(s)} = \frac{s^2}{s^2 + (D/M)s + K/M} \tag{3}$$

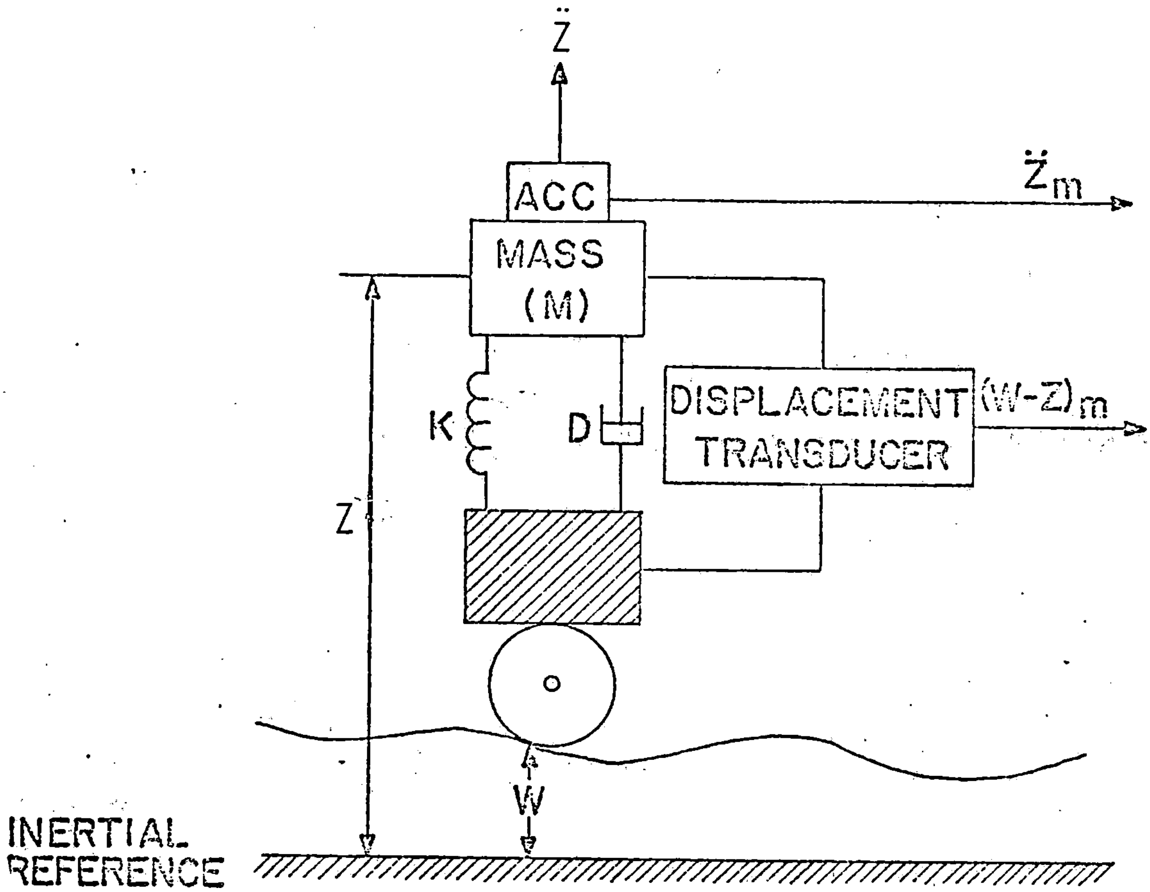


Figure A-3. Profilometer Sensor Schematic

where $\quad s$ = LaPlace variable

$F(s)$ = LaPlace transform of $F(t)$, in this case $W(t)$ and $Y(t)$

This is the transfer function of a second order high-pass system of the form:

$$\frac{Y(s)}{W(s)} = \frac{s^2}{s^2 + 2RW_n s + W_n^2} \qquad (4)$$

where $\quad W_n$ = natural frequency = $\sqrt{K/M}$

$R = \frac{0.5D}{\sqrt{MK}}$ = damping ratio

From Equation (4), it can be shown that for short wavelength track profile variations, the mass will act as an inertial reference and profile variations can be directly measured by the displacement transducer. Unfortunately, attenuation is high for input frequencies below the natural frequency of the profilometer mechanism. Thus, for track profile variations below W_n, the mass will not act as an inertial reference but will follow the path of the track. As a result, zero relative displacement will exist between the mass and the track, consequently, a constant output will be obtained from the displacement transducer.

This situation is resolved by adding the displacement of the mass relative to an inertial reference position to the relative displacement between the wheel and mass. The displacement of the mass relative to the inertial plane is determined by double-integrating the output of the accelerometer. The transfer function describing the motion of the sensor mass relative to the inertial reference plane is:

$$\frac{Z(s)}{W(s)} = \frac{(D/M)\ (s + K/D)}{s^2 + (D/M)s + K/M} \tag{5}$$

By substituting R and W_n,

$$\frac{Z(s)}{W(s)} = \frac{2RW_n s + W_n^2}{s^2 + 2RW_n s + W_n^2} \tag{6}$$

This simplifies to:

$$1 - \frac{Y(s)}{W(s)} \tag{7}$$

or the complement of the transfer function of the relative motion between the wheel and mass. The overall system response becomes

$$\frac{Y(s)}{W(s)} + \left(1 - \frac{Y(s)}{W(s)}\right) = 1 \tag{8}$$

Profile data is high-pass filtered to eliminate integration errors and undesirable inputs such as traversing mountains and valleys. The filter selected has the form

$$\frac{W'(s)}{S(s)} = \frac{s^3}{s^3 + (2\delta_f + 1)w_f s^2 + (2\delta_f + 1)w_f^2 s + w_f^3} \tag{9}$$

where $W'(s)$ = filtered output

δ_f = damping ratio of the filter

w_f = natural frequency of the filter

Once the filtered profilometer sensor outputs have been correctly scaled, a mid-chord offset calculation of profile (this measurement is defined in the Federal Track Standards) is computed. The mid-chord offset algorithm is performed in real time, and the chord length is selectable. The basic equation for this conversation is

$$MCO = \frac{Y(x) + Y(x - L)}{2} - Y(x - L/2) \tag{10}$$

where $Y(x)$ = profile at location x

x = running distance

L = chord length

MCO = mid-chord offset

Profile is measured over a wide range of speeds but usually not below 15 mph. As a result, track profile input frequencies are speed dependent, as given by

$$f = \frac{V}{\lambda} \tag{11}$$

where f = frequency in the time domain
V = velocity of the vehicle (ft/sec)
λ = track input wavelength (ft/cycle)

A.3 GAGE SUBSYSTEM

Gage is defined as the distance between the two rails at a position 5/8-inch below the top of the railhead. The instrumentation used on T-3 to measure gage is covered in Section 2.2.2.1.

A.3.1 Gage Signal Processing

The signals are processed by signal conditioning amplifiers, and are routed through the analog terminal unit to the analog multiplexer at the digital computer. The signals are sampled and stored in a manner similar to that used for the profile signals previously discussed except that a 62-foot mid-chord offset is not measured. A block diagram of the gage measurement subsystem is shown in Figure A-4.

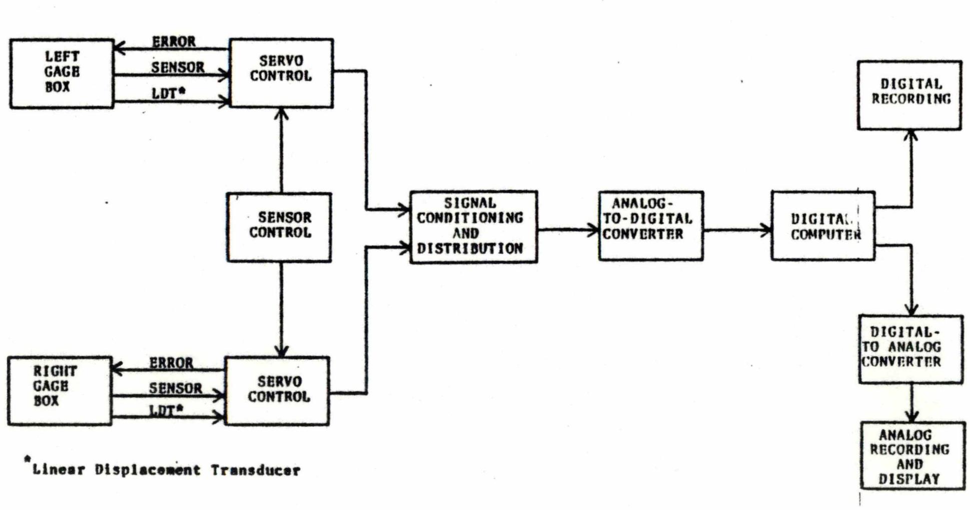


Figure A-4. Gage Subsystem Block Diagram

A.3.2 Data Recording and Display

Gage measurements are recorded and displayed in digital and analog form in a manner corresponding to that used for profile data.

A.3.2.1 Theory of Operation

The magnetic gage subsystem uses non-contact magnetic sensors to measure gage between 55.75 and 58.25 inches with an accuracy of ±0.1 inch. The two sensors are made up of encapsulated, solenoidal, inductive coils electromagnetically coupled to each railhead. The signal representing the distance between the rail and the sensor $(d + \varepsilon_L)$ is compared to a voltage corresponding to the fixed gap-width distance (d). If the two distances are not equal, the error signal for the difference (ε_L or ε_R) is amplified and routed to a servomotor, which drives the sensor in the direction needed to maintain the gap-width. Thus, as the distance between the rail and the reference (i.e., a point on the truck) varies, the sensor position is also varied to maintain a constant distance from the rail. The distance between the sensor and the reference is measured by a displacement transducer.

As shown in Figure A-5,

$$\text{Gage} = (\varepsilon_L + \varepsilon_R) + (LDT_L + LDT_R) + 2d + D \qquad (12)$$

where d = the optimum sensor to rail distance

ε = the variation from d

D = the distance between the linear displacement transducer

LDT_L = the actual displacement of the linear displacement transducer on the left side

LDT_R = the actual displacement of the linear displacement transducer on the right side

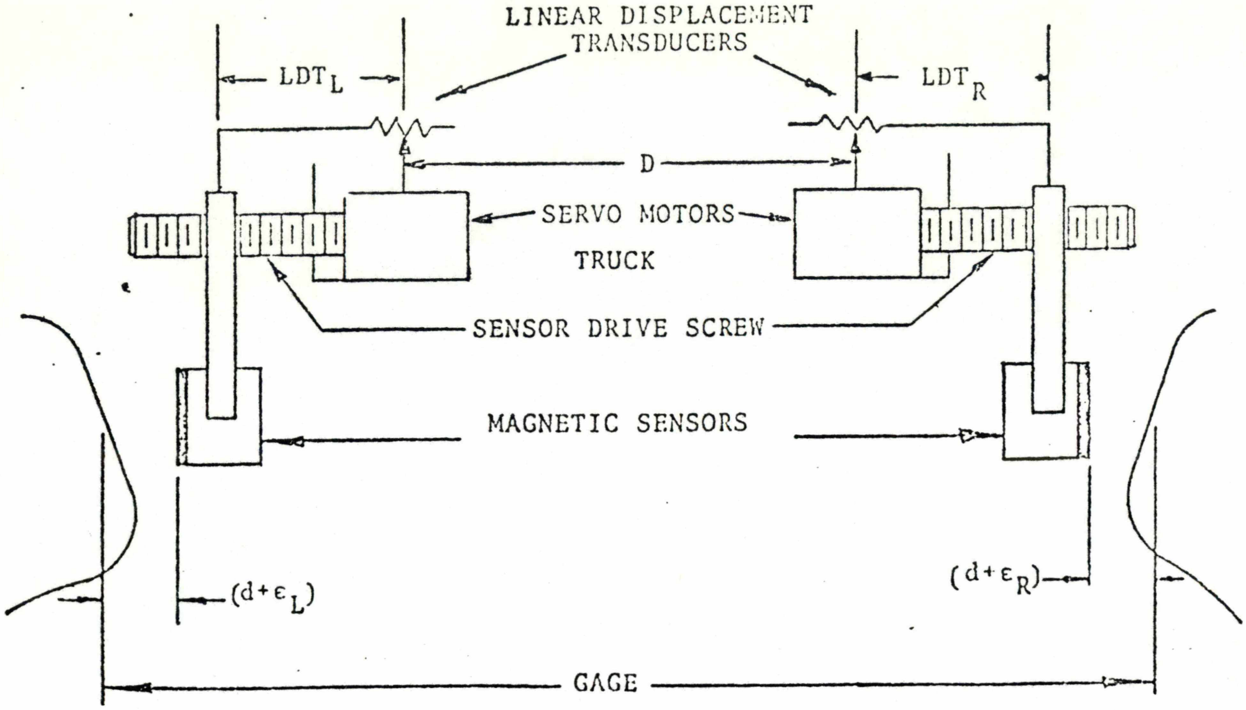


Figure A-5. Servomagnetic Gage Sensor Subsystem

Since the magnetic sensor is servo-controlled, it will not always be riding within the clearance profile created by the flange of the wheel. Whenever the sensor moves away from the protection of the flange, it could possibly be damaged by such track features as highway crossings, railroad crossings and frogs. To minimize possible damage to the sensor-arm assemblies, the sensor can be retracted or moved to a protected position within the clearance profile of the flange by the operator. The system will still measure gage data in the protected position, but with a reduction in accuracy proportional to the gap between the sensor face and the gage point on each railhead. This inaccuracy produces a serious weakness in the gage measurement system, since the areas around and through highway crossings, railroad crossings and frogs tend to deteriorate more than the rest of the track.

A.4 CROSSLEVEL SUBSYSTEM

Crosslevel is defined as the difference in elevation between the right and left rails. This system measures crosslevel in inches, with a positive reading indicating the left rail is higher than the right rail. Section 2.2.3.1 includes a description of the crosslevel instrumentation.

A.4.1 Signal Processing

The Compensated Accelerometer System (CAS) provides outputs which are combined in a mixing circuit with the lateral acceleration signal to obtain a wide-band roll signal proportional to the angle of inclination of the carbody about its longitudinal axis. This signal is combined with the output signals of the displacement transducers to provide a crosslevel signal. The crosslevel signal is digitized, stored on magnetic tape, converted to an analog signal and recorded for display on a strip chart recorder. A block diagram of the crosslevel measurement subsystem is shown in Figure A-6.

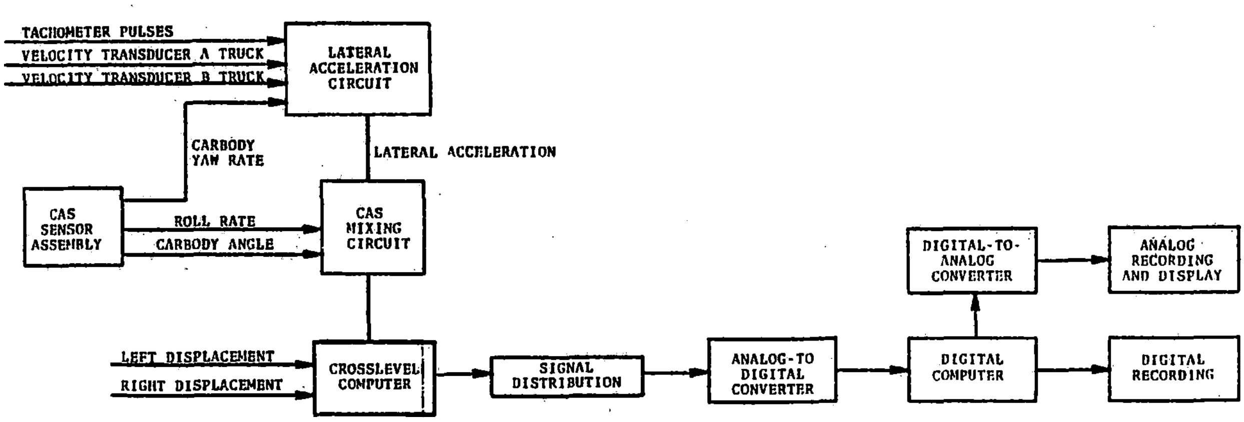


Figure A-6. Crosslevel Subsystem Block Diagram

A.4.2 Data Recording and Display

The crosslevel measurement is digitized and recorded on magnetic tape for off-line processing. The CPU also scales the crosslevel measurement and outputs it as a space curve for visual display on a strip chart recorder.

A.4.3 Warp Measurement

Warp is the difference in superelevation between any two sample points up to 62 feet apart in tangent track and curves and 31 feet apart in spirals. It is a measure of the variation of the horizontal plane of the track over these selected chord lengths. Warp, which is the spatial rate of change of crosslevel, is calculated during off-line processing.

A.4.4 Theory of Operation

The CAS package is mounted with the sensitive axis of the sensors in the roll-angle plane. The inclinometer measures linear accelerations ($g\sin\theta$) while the gyro measures roll rate ($\dot{\theta}_R$). A mixing circuit superimposes the outputs from these sensors such that low-frequency roll-angle measurements are derived from the inclinometer and higher frequency measurements are provided by the rate gyroscope. The result is a wide-frequency-band, roll-angle measurement signal as described by:

$$\text{Output} = \theta_R + \frac{a_N^1}{g} \; \frac{s + w_m^2}{s^2 + 2\delta w_m s + w_m^2} \tag{13}$$

where

- w_m = natural frequency of second order system
- δ = damping ratio of filter
- g = acceleration due to gravity
- θ_R = roll angle
- a_N^1 = lateral acceleration caused by other sources

Both displacement transducers are mounted with their sensitive axis in the roll angle plane, thus, sensor sensitivity to crossaxis or longitudinal acceleration is negligible. The inclinometer is directly affected by the lateral accelerations; therefore, its output must be compensated by using the output of the lateral acceleration circuit.

Since lateral acceleration AC = V^2/R, where V is the velocity in feet/second and R is the radius in feet, train carbody lateral acceleration (AC) is:

$$AC = \dot{\theta}V \tag{14}$$

where $\dot{\theta}(V/R)$ = curvature rate (degrees/second)
V = train speed (feet/second)

This signal is subtracted from the inclinometer output to compensate for lateral accelerations. The crosslevel computer then combines the scaled signal from the CAS mixing circuits with the displacement transducer outputs.

As shown in Figure A-7, the displacement transducers measure D_1 and D_2, the distances from the axle to the floor of the carbody. The angle θ is the measure of CAS displacement from the true vertical. If K is a constant representing distance AB (the distance between the sides of the car), then Ksinθ is the total vehicle displacement from the true level. The algebraic addition of relative vehicle displacement and total vehicle displacement from level gives

$$\text{Crosslevel} = D_1 - D_2 + K\sin\theta \tag{15}$$

Equation (15) can be proven by breaking down Figure A-7 into the appropriate geometric configurations. By letting X equal crosslevel, Equation (15) can be proven in the following steps.

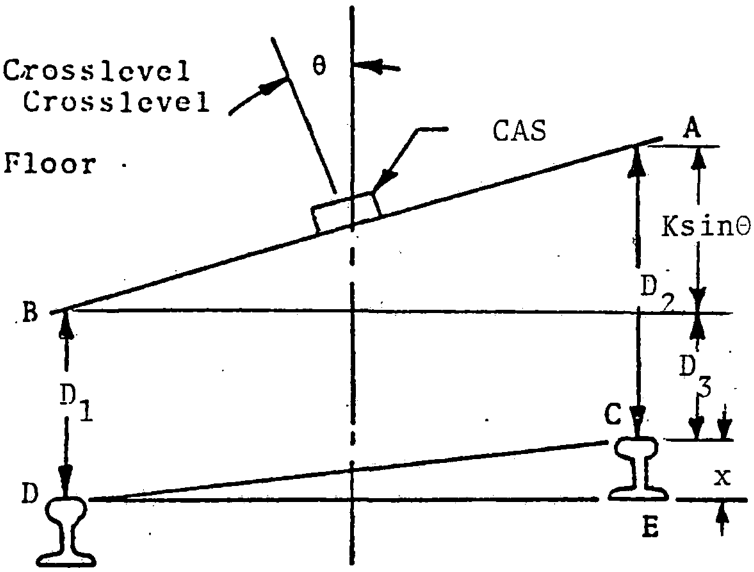


Figure A-7. Gyroscope Crosslevel Computation Technique

Let $D_1 = D_3 + X$; $D_2 = D_3 + K\sin\theta$ (16)

By substituting into Equation (15)

$$\text{Crosslevel} = D_3 + X - (D_3 + K\sin\theta) + K\sin\theta \quad (17)$$

$$= D_3 + X - D_3 - K\sin\theta + K\sin\theta$$

$$= X$$

Warp

Warp is calculated by the computer from sampled crosslevel measurements. It is of the form:

$$\text{Warp} = \theta_X - \theta_{(X - L)} \quad (18)$$

where X = position along track in feet
θ = crosslevel in inches
L = chosen chord length in feet

A.5 TRACK CURVATURE SUBSYSTEM

The track curvature measurement subsystem measures the angular rate of change of track direction in degrees per hundred feet. The basis for curvature measurement is an arc of curved track which is subtended by a 100-foot chord (Figure A-8). Track curvature measurement is accurate to better than ±0.1 degree per 100 feet for bipolar full-scale curvature ranges of 1, 5, 10 and 20 degrees and measurement speeds of 3 to 150 mph.

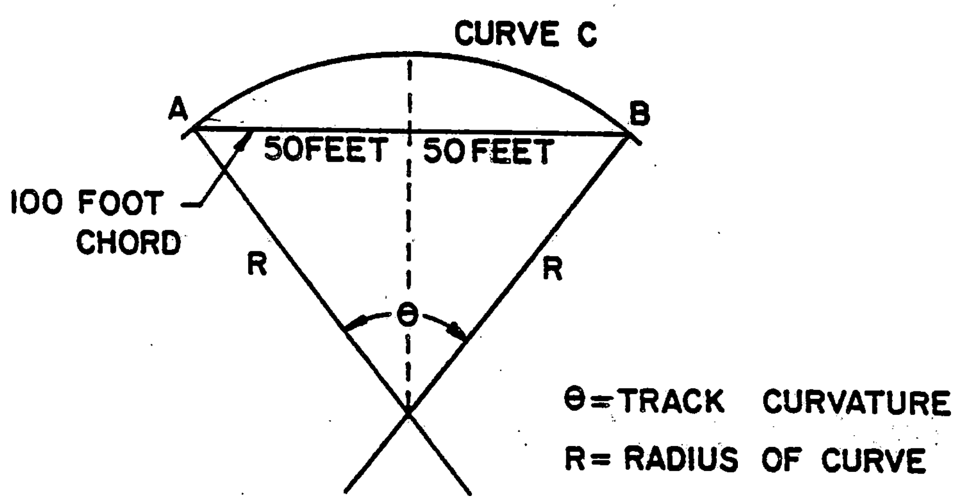


Figure A-8. Definition of Track Curvature

A.5.1 Curvature Signal Processing

A block diagram of the curvature measurement subsystem is shown in Figure A-9. The signals produced by the rate gyroscope are corrected by the signals from the velocity transducers to represent track curvature relative to degrees per second.

The raw tachometer pulses are routed to the curvature computer where they are changed to velocity signals and then converted into analog form. This analog velocity signal

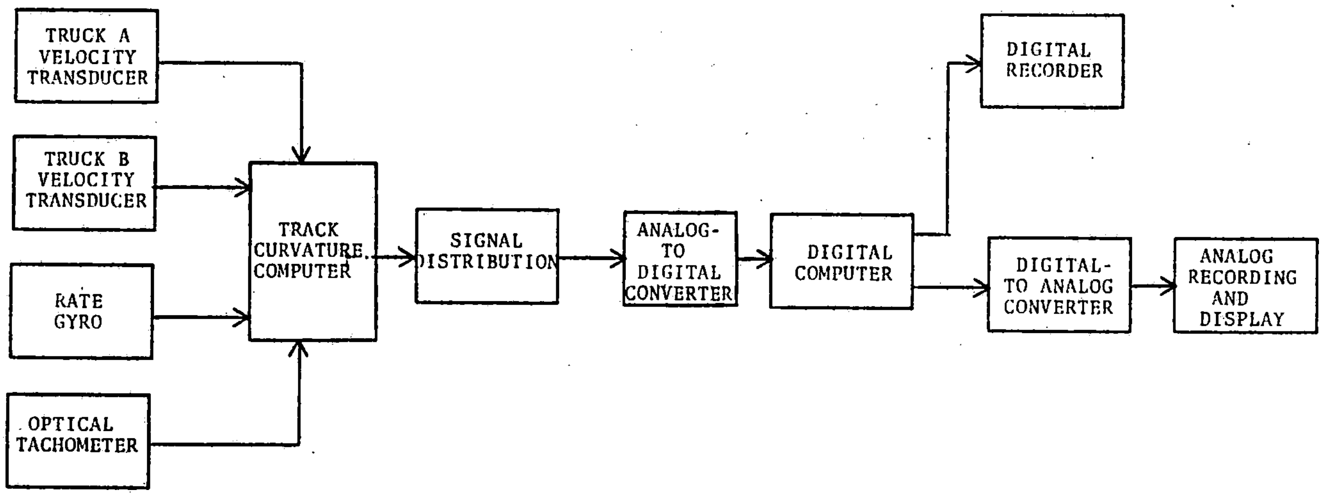


Figure A-9. Curvature Measurement Subsystem Block Diagram

is divided into the relative curvature measurement. The signal is passed through a low pass filter to produce a curvature signal which represents degrees per hundred feet. The curvature signal is digitized, stored on a magnetic tape, converted to an analog signal and recorded for display on a strip chart recorder.

A.5.2 Data Recording and Display

The curvature signal is digitized and recorded on magnetic tape; the output from the CPU is in analog form. The data can be displayed as a space curve on the strip chart recorder. Track curvature is also displayed on a digital meter on the front panel of the CPU.

A.5.3 Track Curvature Measurement Theory

Consider a vehicle traveling along Curve C in Figure A-10. If the vehicle travels an infinitesimal distance, d_m (assuming R remains constant), a corresponding angle d is subtended by a chord drawn from Point A to Point B. The distance d_m is then given by

$$d_m = \frac{R\pi d\theta}{180} = \frac{Rd\theta}{57.3} \tag{19}$$

where R = radius of the curve in feet

$d\theta$ = angle in degrees

If both sides of Equation (19) are divided by dt, the infinitesimal time it takes the vehicle to travel from Point A to Point B, Equation (20) results:

$$\frac{d_m}{d_t} = V = \frac{1}{K}\frac{d\theta}{dt} = \frac{1}{K}\dot{\theta} \tag{20}$$

where V = velocity of the vehicle in feet per second

$\dot{\theta}$ = angular rate in degrees per second

K = 57.3/R

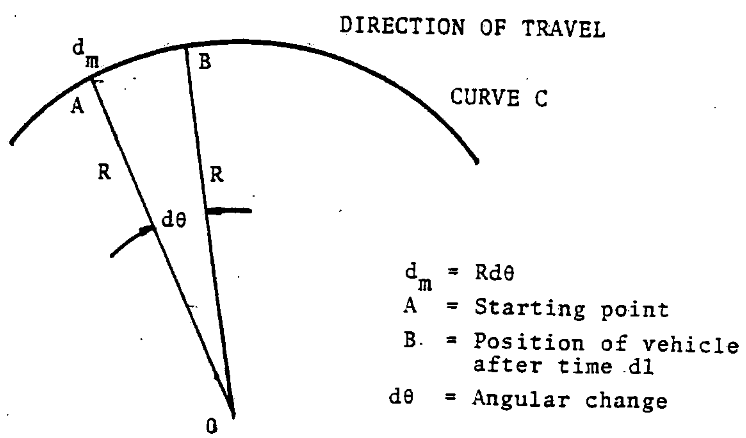


Figure A-10. Method of Measuring Track Curvature

Therefore, curvature is given by:

$$K = \frac{\dot{\theta}}{V} \tag{21}$$

Multiplying K by 100 feet gives the degrees subtended over 100 feet of travel.

Although the definition of track curvature considers the arc subtended by a 100-foot chord, the use of the 100 feet of actual travel introduces an insignificant error. Referring to Figure A-8, the length of the chord for arc C is:

$$\text{Chord Length} = 2R\sin\theta/2$$
$$\text{Arc Length} = R\theta$$

Therefore, the percentage error introduced is:

$$\%\ \text{error} = \left[1 - \frac{2\sin\theta/2}{\theta}\right]100 \tag{22}$$

The maximum track curvature expected is 12 degrees, thus:

$$\%\ \text{error} = \left[1 - \frac{2(0.10453)}{0.20944}\right]100 = 0.1814\%$$

A.6 AUTOMATIC LOCATION DETECTOR SUBSYSTEM

The automatic location detector (ALD) subsystem is used to detect features which are unique to a particular section of track roadbed. The detected features are used to correlate track geometry data with specific physical locations.

A.6.1 Signal Processing

The ALD sensor output signal is input to an instrumentation amplifier, a signal-conditioning amplifier and a peak ALD signal holding circuit. The signal is then digitized, stored on a magnetic tape, converted to an analog signal, and recorded for display on a strip chart recorder. A pulse stretcher is utilized to detect and store the maximum ALD signal that occurs between data samples. Because recognizable features of the roadbed are usually shorter than 2.41 feet, a method was required to ensure that these signals are stored until the next digital sample. The pulse stretcher provides this function by detecting the maximum signal that occurs during one sample distance (2.41 feet) and then storing that signal sufficiently long for computer acquisition. The pulse stretcher is reset after each data sample by a signal from the Speed and Distance Processor. A block diagram of the ALD subsystem is shown in Figure A-11.

A.6.2 Data Recording and Display

The ALD signal is sensed and recorded simultaneously with the track geometry data. The signal is then digitized, displayed on a strip chart recorder (Figure A-12) and stored on magnetic tape.

There are several types of manual and automatic ALD pulses displayed on the strip chart recorders.

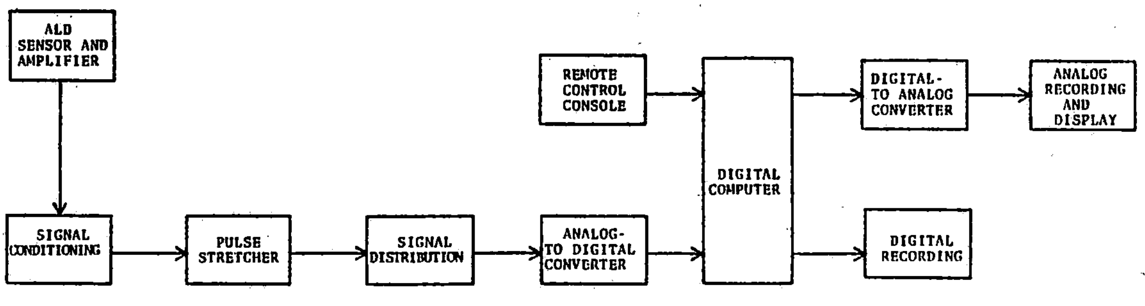


Figure A-11. ALD Subsystem Block Diagram

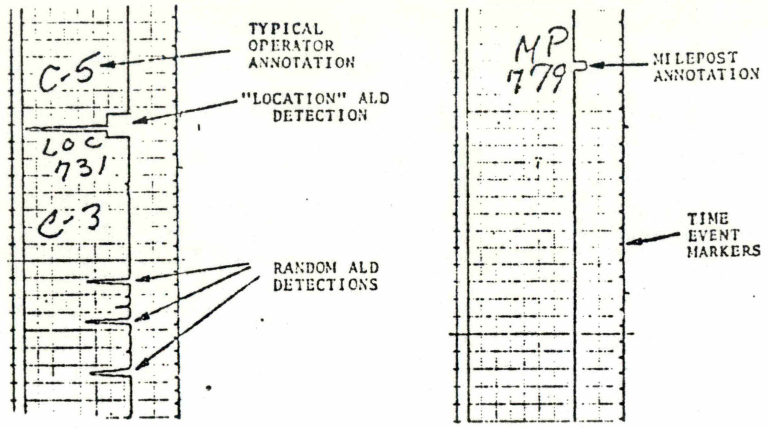


Figure A-12. Typical ALD Strip Chart Trace

MILEPOST: The milepost indication is initiated by the operator and appears as a small negative pedestal.

LOCATION: The location indication appears as a roadbed variation superimposed on a computer-generated, positive pedestal, i.e., initiated by the control operator. Specific geographic location can be found from this indication.

NORMAL: The normal ALD indication appears as random trace excursions due to variations in the track roadbed which are automatically detected by the ALD sensor.

In planning a test run, objects such as road crossings, turnouts, etc., are assigned 3-digit codes. As these objects are approached during the test run, the identifying code is entered at the remote control console. As the landmark passes under the leading vehicle, the code is keyed into the computer. when detection of the object is made by the ALD sensor, the code is recorded on the magnetic tape.

A.7 SPEED AND DISTANCE SUBSYSTEM

The speed and distance measurement subsystem is used to determine instantaneous vehicle speed and to indicate total distance traveled. An optical tachometer and the speed and distance processor, the principle components of the subsystem, provide distance based computer interrupt signals which control data acquisition, computer sampling and computation, and data recording.

A.7.1 Signal Processing

The speed and distance processor develops the signals listed in Table A-1 for timing and control of track geometry data acquisition and display. The timing signals remain in digital form for speedometer readings but are changed to analog form by frequency to voltage converters to drive the strip chart recorders. A block diagram of the speed and distance subsystem is shown in Figure A-13.

A.7.2 Data Recording and Display

Speed and distance are indicated on separate displays on the Speed and Distance Processor. Both are also recorded on digital tape for off-line processing and indirectly on strip chart recorders for visual display in analog form.

A.8 DIGITAL RECORDING SUBSYSTEM

The digital recording subsystem is used to record all pertinent track geometry data in digital form on magnetic tape as a permanent record, and to provide a copy of the data for off-line processing.

A.8.1 Signal Processing

Analog voltages are the primary measurement signals produced from the track-geometry-measurement instrumentation. A maximum of 16 channels are used as analog inputs to the data collection system.

TABLE A-1

AND DISTANCE TIMING SIGNALS

Description
1/2 digit BCD code used for speedometer splay in the processor, and in the local remote control consoles.
ming signal used to update speed logic gisters and associated displays.
ming signal occurring one for each 2.41 et of vehicle travel, or at a predetermined stance interval as required. The signal used as a computer interrupt to initiate nsor data sampling, and to reset the ALD lse stretcher.
series of timing pulses which represent ice the tachometer output frequency or in the oscillator mode, the frequency of e local oscillator speed simulator.
ning signal occurring once each 0.1 mile vehicle travel. The signal is used to date the odometer display in the processor d in the local control console.
five-volt signal (logic 1) to initiate an irm when the local oscillator (speed nulator) is supplying tachometer data ile the train is in motion.

ts are committed to proximity sensors in the
n; two channels to the profile sensors; and
to gage, ALD, crosslevel, curvature, and
pecial test data collection needs are
e remaining channels.

irious channels are scanned, digitized and
r in the digital computer (Raytheon 704).
sferred to magnetic tape in a single block

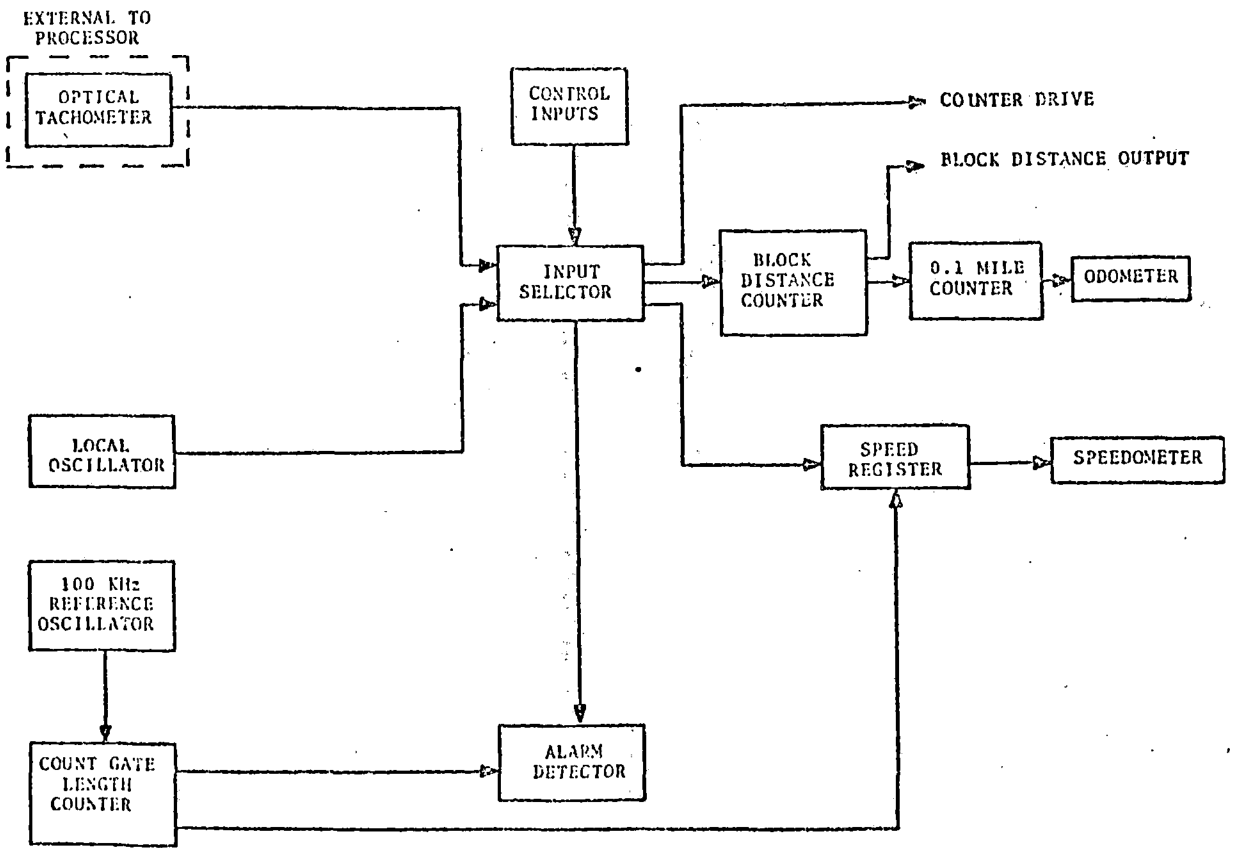


Figure A-13. Speed and Distance Measurement Subsystem after 80 scans of data have been digitized and stored. One scan of data is initiated by each block distance pulse of 2.41 feet of vehicle travel, which is supplied by the speed and distance processor. A block diagram of the digital recording subsystem is shown in Figure A-14.

A.9 ANALOG RECORDING AND DISPLAY SUBSYSTEM

The analog recording subsystem consists of three strip-chart recorders, their associated preamplifiers, and the data-channel selection equipment.

All data parameters which have been processed by the computer can be displayed and permanently recorded on an eight-channel strip chart recorder (Brush MK 200) and on two six-channel portable strip chart recorders (Brush MK 260). The data supplied to the eight-channel recorder are assigned as follows:

Channel 1 - Speed	Channel 5 - Curvature
Channel 2 - Left Profile	Channel 6 - Gage
Channel 3 - Right Profile	Channel 7 - ALD
Channel 4 - Crosslevel	Channel 8 - Spare

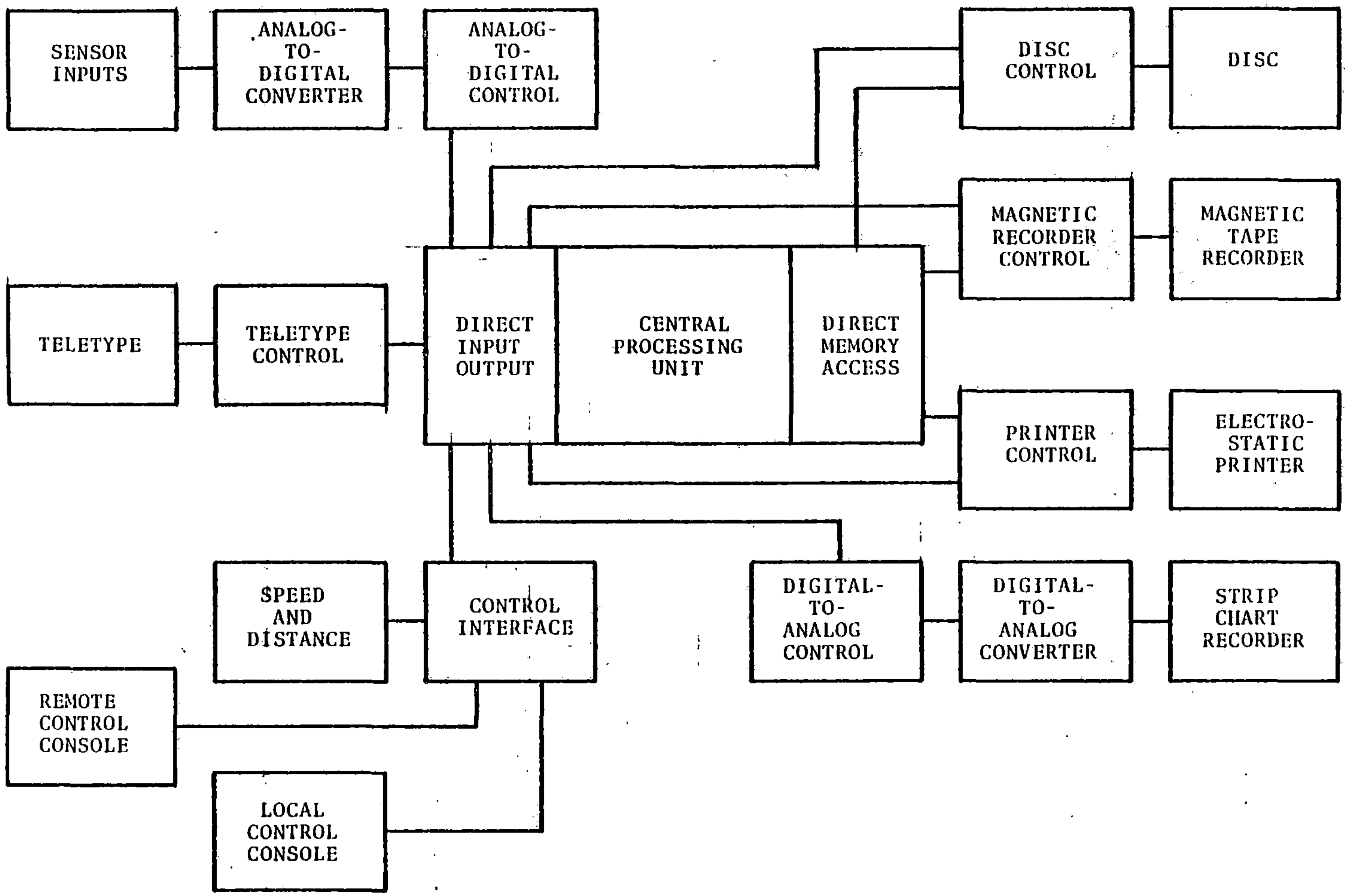


Figure A-14. Digital Processing and Recording Block Diagram

APPENDIX B

COMPUTATIONAL ALGORITHMS FOR INDICES
REPEATABILITY RUN T2-287
PREDICTIVE EQUATIONS FOR INDICES

B.1 COMPUTATIONAL ALGORITHMS FOR TRACK QUALITY INDICES

The mathematical reasoning for each of the track quality indices was presented in Section 2.3 in the main body of the report. Table B-1 lists the algorithms that are used in the digital computations. The notations are standard statistical and digital processing terminology. The 62-foot, mid-chord-offset (MCO) is explained in Appendix A.

B.2 REPEATABILITY RUN T2-287

In November of 1977, a repeatability run was conducted on B&LE track. Run one was conducted northbound the first day of the survey with T-2 (the measurement car) being pulled at the rear of the consist. Run two was also conducted the first day of the survey southbound with T-2 being pushed at the front of the consist. The second day of the survey run was accomplished northbound with T-2 being pulled at the rear of the consist. During the survey's fourth day, run four was completed southbound with T-2 being pulled at the rear of the consist.

The following pages give a graphical indication of the repeatability of each index for quarter-mile segments of the test zone.

The gage index shows an average bias of about 1300 between runs one and two and runs three and four. An examination of the analog plots of the raw gage data for those runs indicates that there was an 0.1-inch bias between them. This was most probably due to calibration differences. The other indices have a repeatability that is adequate for MOW application.

TABLE B-1

TRACK QUALITY INDICES

Index	Measurement	Comments	Formula
Gage Index	$y_i = g_i - g_o$	g_o = 56.5 inches	$\alpha\overline{y}$
Crosslevel Index	x_i $x'_i = \alpha_1 x_{i-1} + \alpha_2 x_i + \beta_1$ $x''_i = x_i - x'_{i+I}$ $y_i = \lvert x''_i \rvert$	Unfiltered cross-level Low-pass filter α_i and β_i are two pole Bessel filter coefficients High-pass filter $I = [d/\Delta s]$ d = 75-foot delay	$\alpha\overline{y}$
Curvature Index	$y_i = \lvert c''_i \rvert$	Same process as above	$\alpha\overline{y}$
Profile Index	$y_i = \lvert p_i \rvert$	Profile is the average of right and left 62-foot MCO profile	$\alpha\overline{y}$
Profile Slopes Index	$A_i = \{\lvert \Delta p_i \rvert > p_o$ $\Delta p_i = p_i - p_{i-1}$ $y_i = I_{A_i}(p)$	$I_{A_i}(p) = 1$ if A_i occurs. = 0 otherwise Counting measure p_o = 0.1 inches	Σy_i
Standard Deviation of Gage	$\frac{1}{(N-1)} \Sigma (g_i - \overline{g})^2$	$\overline{g}$ = Sample mean biased version formula	$\sqrt{\overline{y}}$
99% Point of Gage	$y_i = g_{(i)}$	$g_{(i)}$ = its ordered statistic in sample of n measurements. $M = [0.99n]$	y_M

Δs = Sampling interval (feet)
α = Normalizing constant
$\alpha = N\Delta s$
N = Number of samples in standard length segment

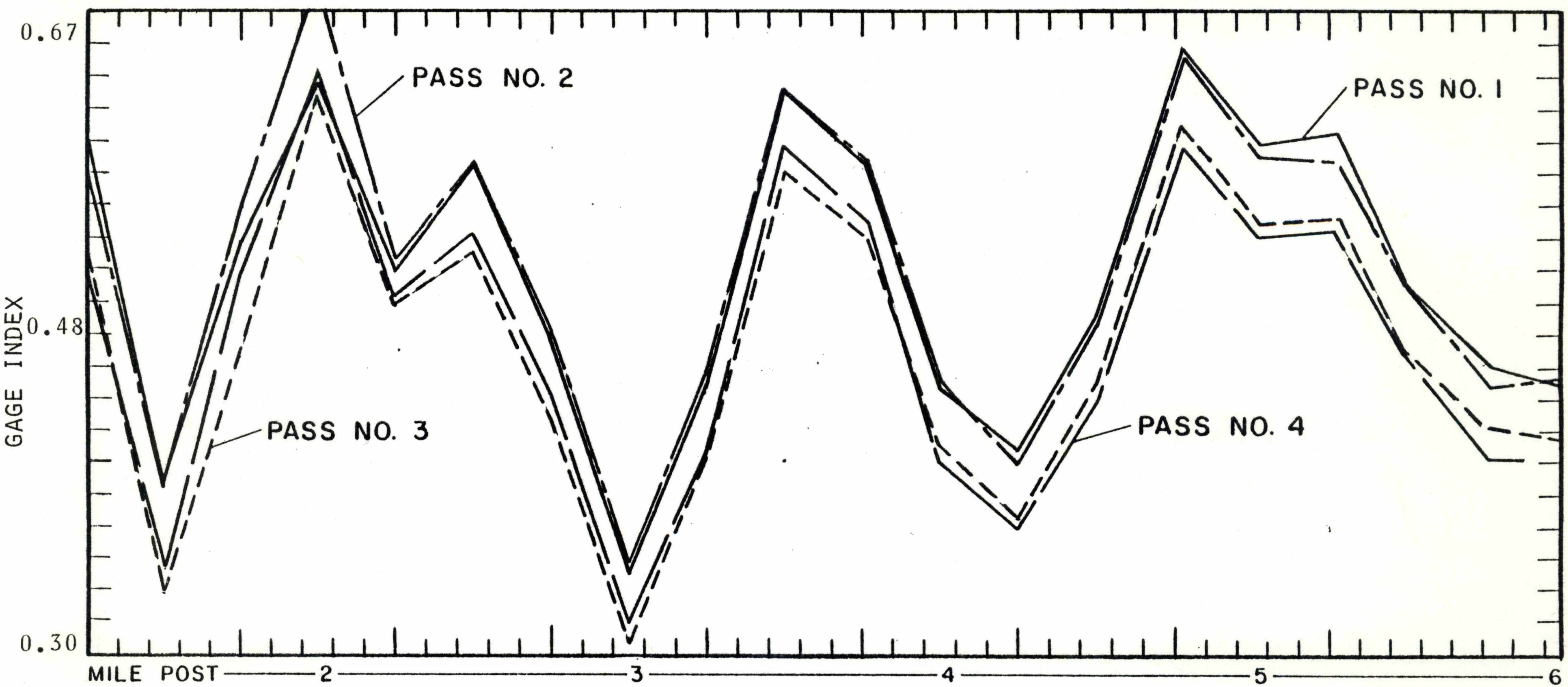


Figure B-1. Gage Index Repeatability, Quarter-Mile Segments, MP 1-6

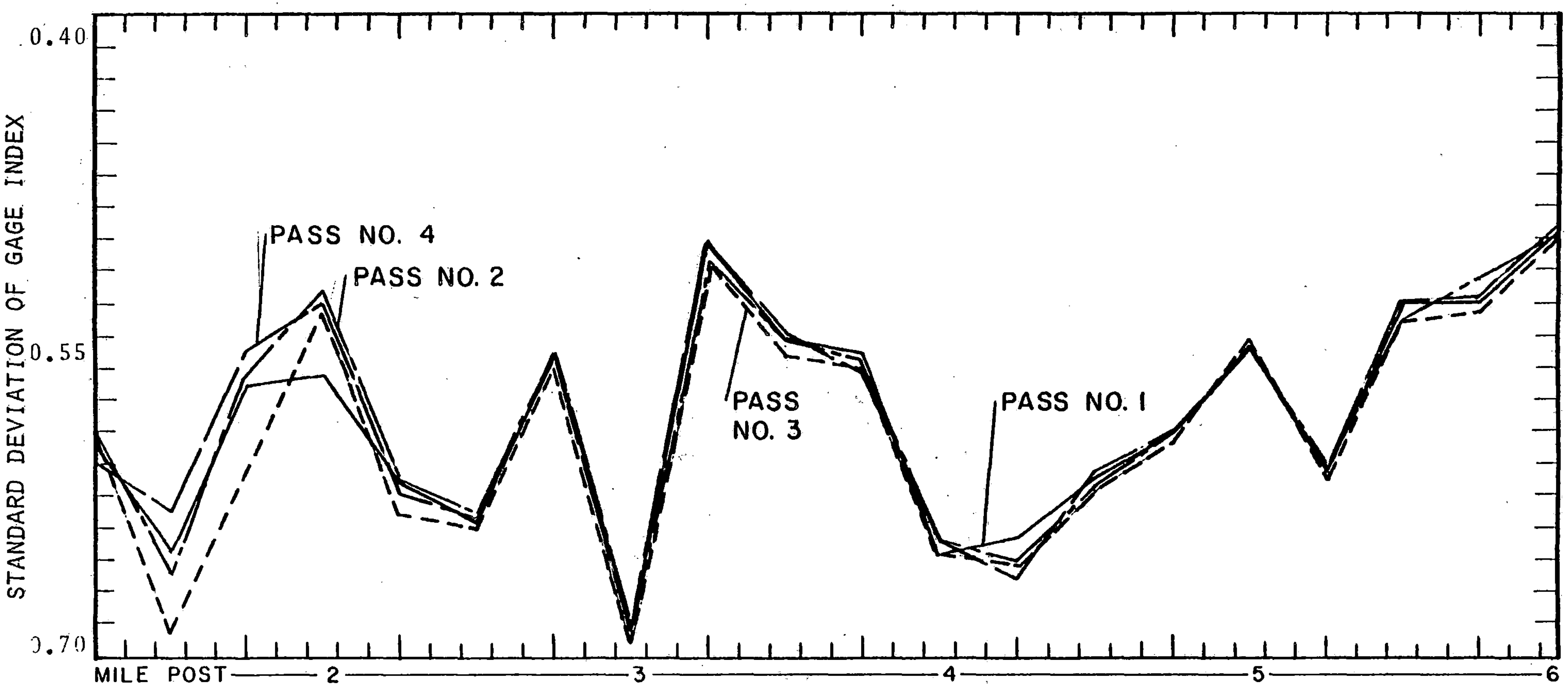


Figure B-2. Standard Deviation of Gage Index Repeatability, Quarter-Mile Segments, MP 1-6

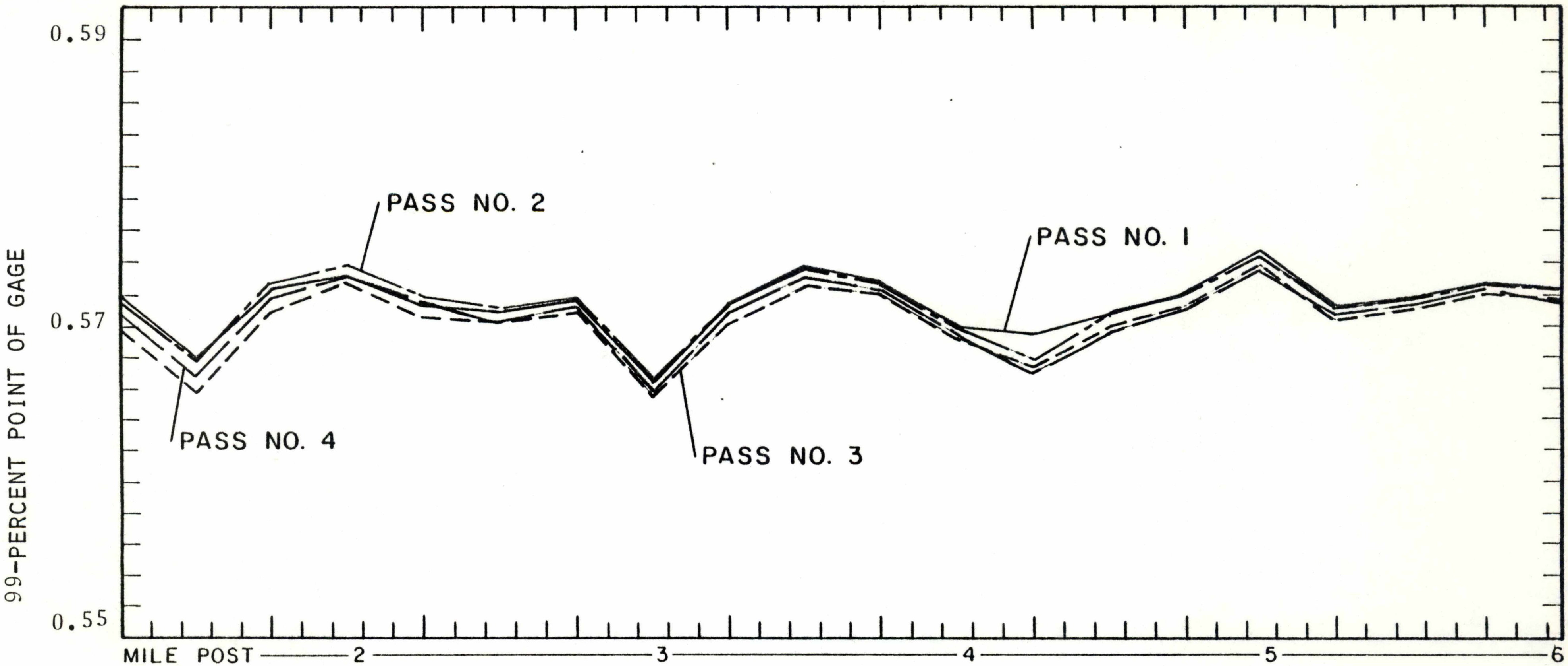


Figure B-3. Ninety-Nine Percent Point of Gage Index Repeatability, Quarter-Mile Setments, MP 1-6

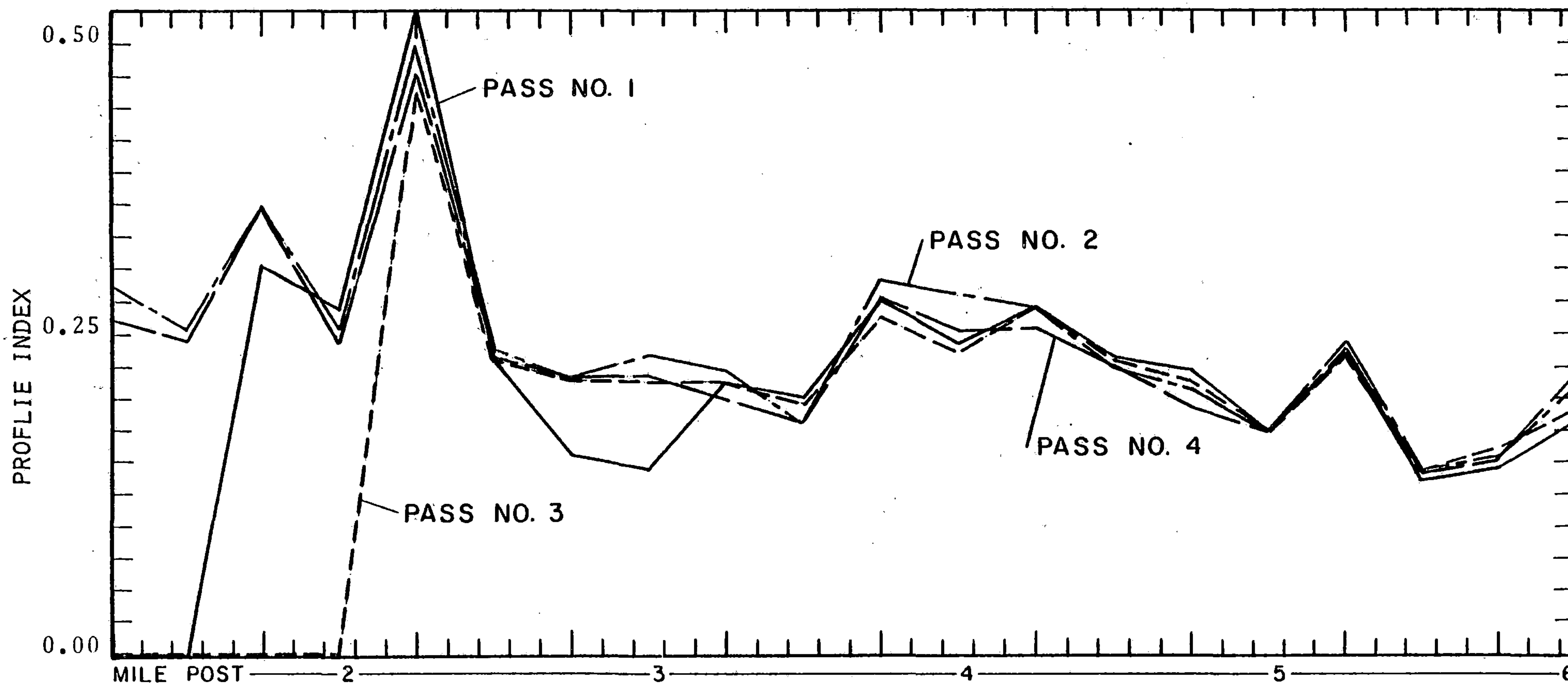


Figure B-4. Profile Index Repeatability, Quarter-Mile Segments, MP 1-6

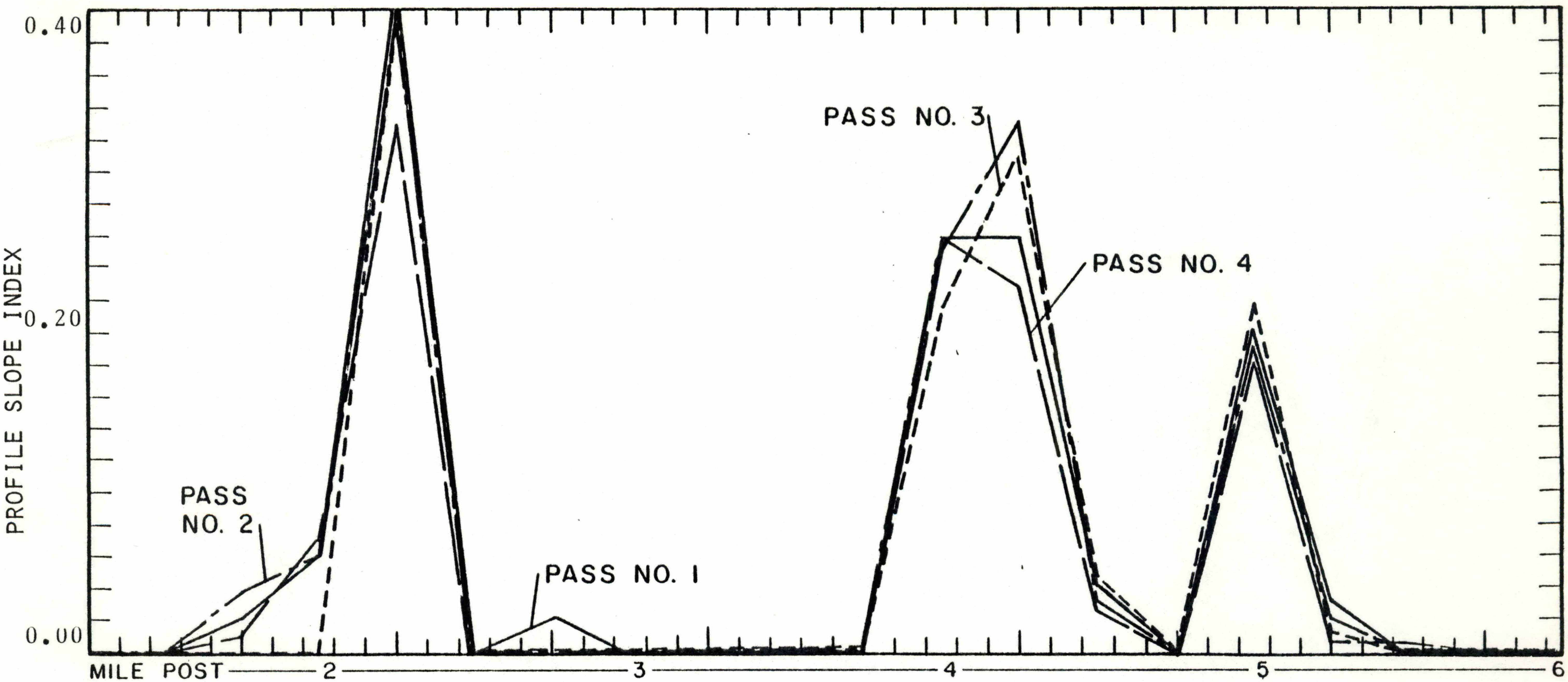


Figure B-5. Profile Slope Index Repeatability, Quarter-Mile Segments, MP 1-6

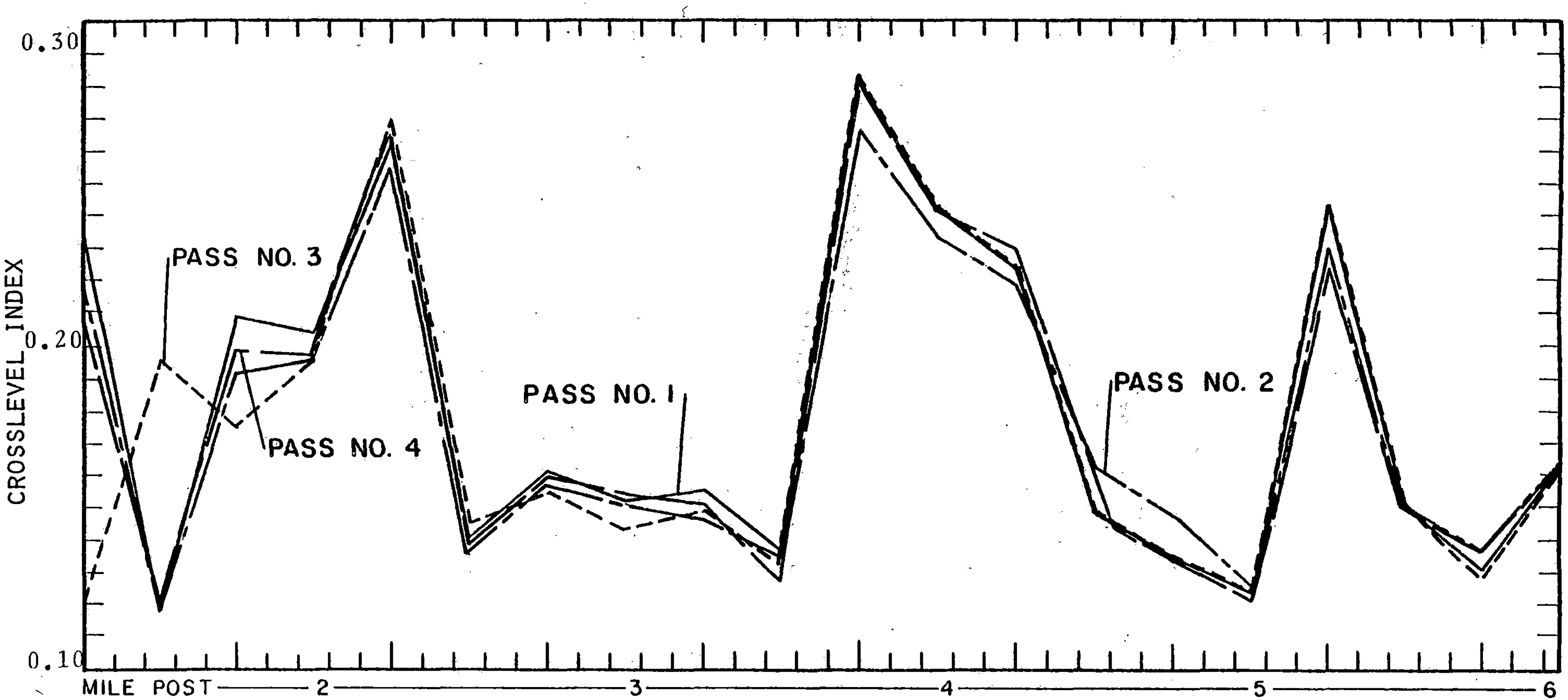


Figure B-6. Crosslevel Index Repeatability, Quarter-Mile Segments, MP 1-6

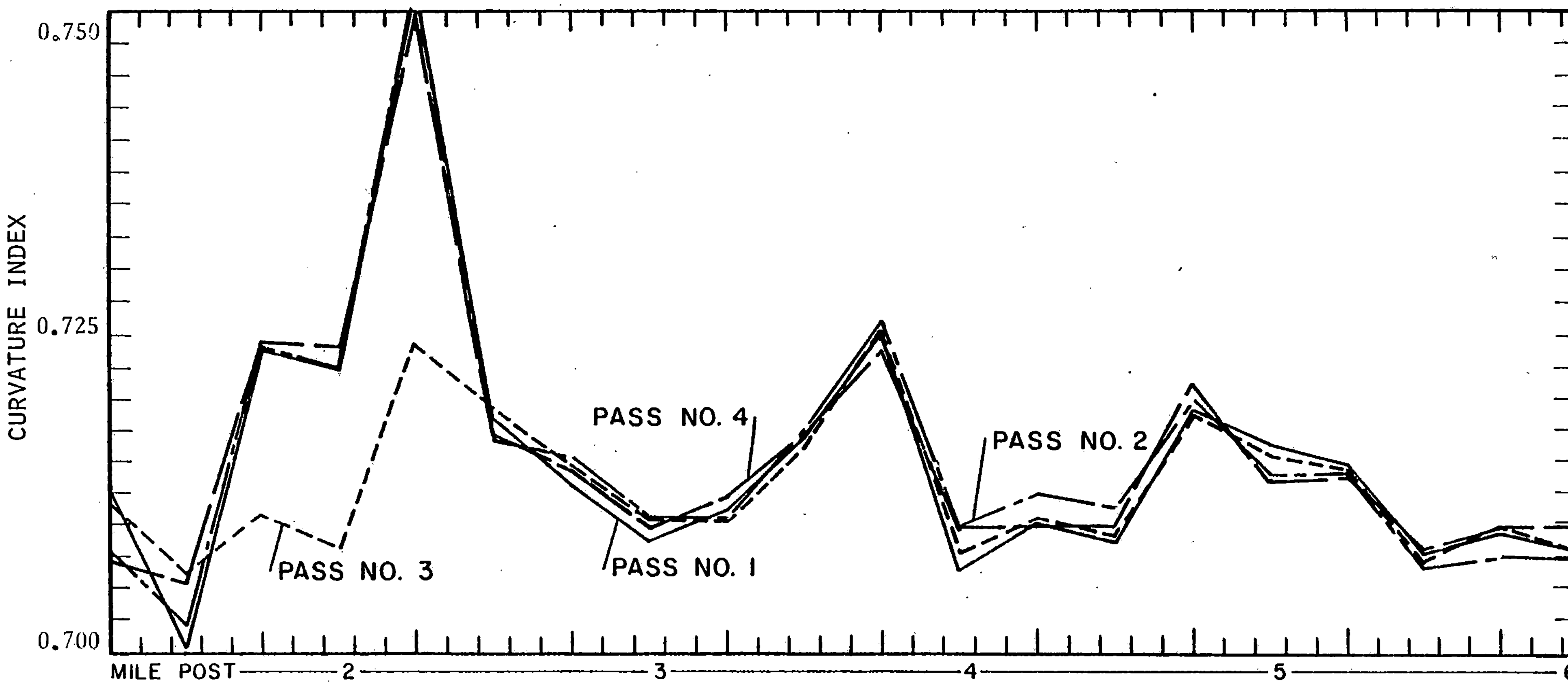


Figure B-7. Curvature Index Repeatability, Quarter-Mile Segments, MP 1-6

APPENDIX C
MAINTENANCE-OF-WAY REPORTS

C.1 MAINTENANCE-OF-WAY STANDARDS (MOWS) REPORT

The MOW Standards Report contains a general information report, a summary report, a detailed exception report and an exception plot. A block diagram of the MOW Standards Report processing procuedure is shown in Figure C-1. Section C.1.5 describes the method for calculating each parameter with respect to railroad and FRA Track Safety Standards.

C.1.1 General Information Report

The General Information Report lists the railroad and FRA Track Safety Standards, applicable notes and a summary of track class changes.

C.1.1.1 Standards and Notes

The FRA track class (Class 1 through Class 6) is printed across the top of the MOWS Report Thresholds (Figure C-2), along with the limiting thresholds for tangent and curved track for each of the track geometry parameters of the left column. The EXC (EXCEPTION) thresholds are set by the railroad company. The SEV (SEVERE) thresholds, for all parameters except curvature and rock and roll, are set by the FRA. The EXC thresholds are a more stringent limit than the SEV and act as an indicator of potential problems with a section of track. The MAXIMUM ALLOWABLE SPEED is given both for passenger and freight traffic over each class track. Explanatory notes (Figure C-3) are located on a separate page to explain symbols used in the report. The notes also indicate the geographic direction of travel, which is indicated by the sign of the crosslevel and curvature average figures in the curve summary.

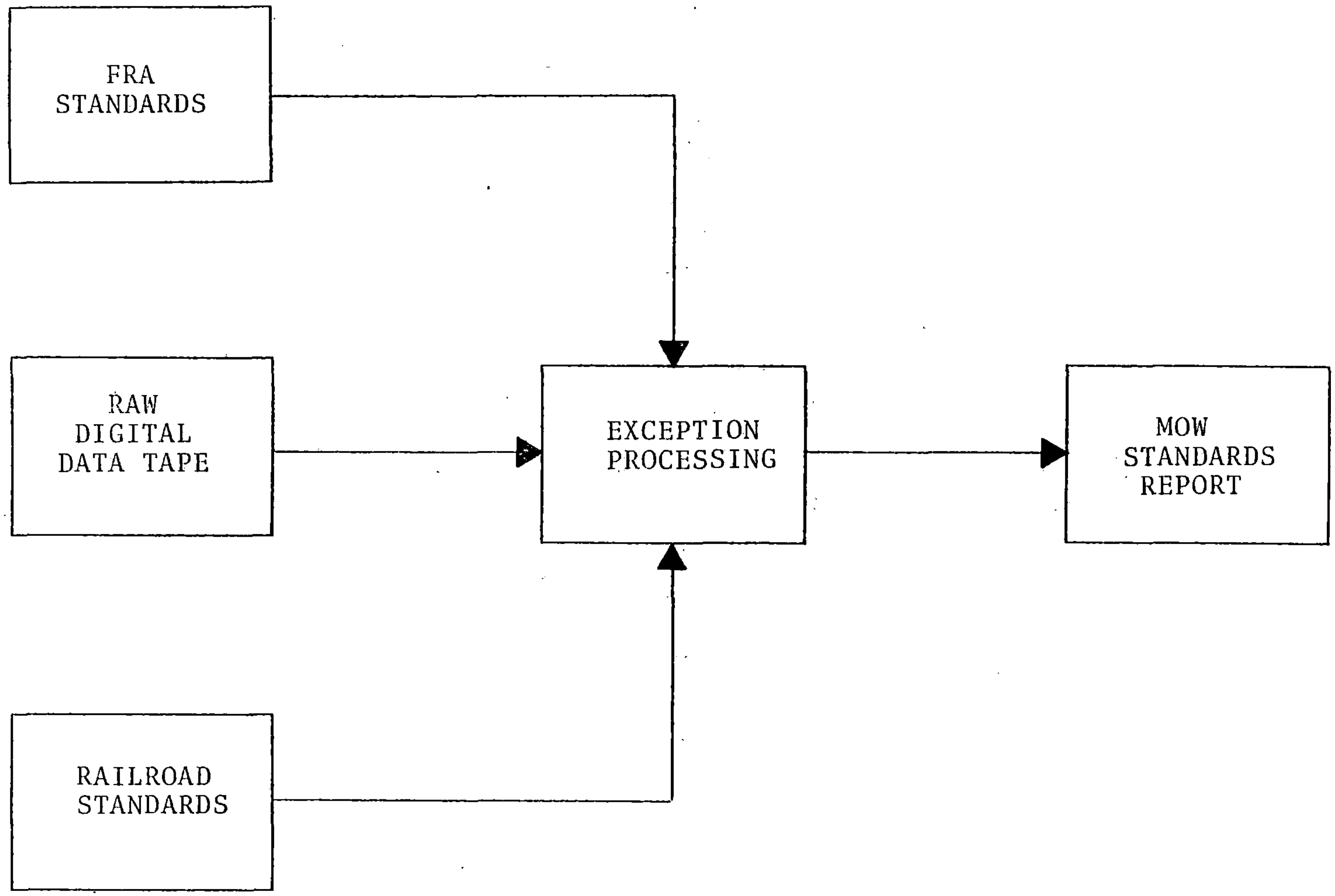


Figure C-1. Processing of MOW Standards Report

TRACK CLASS-----		
PROFILE (IN.)		EXC
		*SEV
GAGE (IN.)	TANGENT	EXC
		*SEV
	CURVES(BODY-SPIRAL)	EXC
		*SEV
TIGHT GAGE (IN.)		*EXC
CURVATURE (DEG.)	TANGENT	EXC
		SEV
	CURVES(BODY-SPIRAL)	EXC
		SEV
CROSSLEVEL (IN.)	TANGENT-CURVE BODY	EXC
		*SEV
	SPIRAL	EXC
		*SEV
MAXIMUM CROSSLEVEL (IN.)		EXC
WARP (IN.)	TANGENT-CURVE BODY	EXC
		*SEV
	SPIRAL	EXC
		*SEV
ROCK AND ROLL (IN.)		EXC
		SEV
MAXIMUM ALLOWABLE SPEED (MPH) -----		
	PASSENGER	
	FREIGHT	

Figure C-2. Sample

MAINTENANCE OF WAY STANDARDS REPORT

REPORT THRESHOLDS

1	2	3	4	5	6
2.000	1.750	1.500	1.250	1.000	0.500
3.000	2.750	2.250	2.000	1.250	0.500
57.500	57.500	57.250	57.250	57.000	56.750
57.750	57.500	57.500	57.250	57.000	56.750
57.500	57.500	57.500	57.500	57.500	57.000
57.750	57.750	57.750	57.500	57.500	57.000
56.000	56.000	56.000	56.000	56.000	56.000
3.000	2.000	1.500	1.000	0.750	0.500
5.000	3.000	1.750	1.500	0.750	0.500
2.500	2.000	1.500	1.000	0.625	0.375
5.000	3.000	1.750	1.500	0.625	0.375
2.000	1.500	1.500	1.000	1.000	0.500
3.000	2.000	1.750	1.250	1.000	0.500
1.500	1.250	1.000	1.000	0.750	0.500
1.750	1.500	1.250	1.000	0.750	0.500
6.000	6.000	6.000	6.000	6.000	6.000
2.000	1.500	1.250	1.000	0.750	0.625
3.000	2.000	1.750	1.250	1.000	0.625
1.750	1.500	1.250	1.000	0.750	0.500
2.000	1.750	1.250	1.000	0.750	0.500
1.000	1.000	1.000	1.000	1.000	1.000
1.500	1.500	1.500	1.500	1.500	1.500
15	30	60	80	90	110
10	25	40	60	80	110

* -- FRA STANDARDS

MOW Standards Report

NOTES

EXPLANTION OF SYMBOLS USED IN THIS REPORT

* - NEXT TO MILEPOST NUMBER ON LEFT MARGIN OF REPORT. THIS INDICATES THAT THE MILEPOST APPEARS ON THE BRUSH CHART.

R - NEXT TO CROSSLEVEL AND WARP EXCEPTIONS IN DETAILED REPORT. THIS APPEARS WHEN SUPERELEVATION IS MEASURED BEFORE A CURVE WAS DETECTED. THESE EXCEPTIONS DO NOT AFFECT AFFECT ONE MILE CLASS AND EXCEPTION SUMMARY REPORTS.

L - NEXT TO CROSSLEVEL AND CURVATURE IN DETAILED REPORT. WHEN LIMITING SPEED EXCEPTIONS ARE PRINTED THE CROSSLEVEL AND CURVATURE VALUES AT THAT POINT ARE ALSO INCLUDED. ALL THESE VALUES ARE PRINTED ON THE SAME LINE. (ALL LIMITING SPEED EXCEPTIONS MUST EXCEED POSTED SPEED BY 5MPH TO BE LISTED IN DETAILED REPORT. THIS DOES NO AFFECT CURVE SUMMARY.,

OV - NEXT TO CROSSLEVEL IN DETAILED REPORT. THIS ONLY APPEARS WHEN CROSSLEVEL EXCEEDS MAXIMUM CROSSLEVEL THRESHOLD. THE EXCEPTION DOES NOT AFFECT CLASS OR ADD TO NUMBER OF EXCEPTIONS.

* - NEXT TO PROFILE, GAGE, CURVATURE, CROSSLEVEL, WARP AND ROCK AND ROLL EXCEPTIONS IN THE DETAILED REPORT. THIS ONLY APPEARS WHEN EXCEPTION INDICATED EXCEEDS SEVERE THRESHOLDS.

T, S, OR C - IN FACT COLUMN. THESE INDICATE TYPE OF TRACK AS DEFINED BY CURVATURE. T=TANGENT, S=SPIRAL, C=CURVE BODY

0, 1, 2, 3, 4, OR 5 - IN FACT COLUMN. 0=EXCEPTION DOES NOT MEET CLASS 1 THRESHOLDS, 1, 2, 3, 4 OR 5=EXCEPTION LOWERS TRACK TO SPECIFIED CLASS (THESE ONLY APPEAR WHEN SEVERE THRESHOLDS ARE FRA STANDARDS)

IN CURVE SUMMARY REPORT SIGN CONVENTION IS AS FOLLOWS:

1) CROSSLEVEL
   + = EAST RAIL HIGH
   - = WEST RAIL HIGH
2) CURVATURE
   + = CURVE TO WEST
   - = CURVE TO EAST

--SENSORS UP-- MESSAGE INDICATES LOSS OF GAGE ONLY
PA ERR. - 193 FT. NOT ANALYZED
-OR-
SE ERR. - 193 FT. NOT ANALYZED - MESSAGES INDICATES MAGNETIC TAPE ERROR AND LOSS OF 193FT. OF DATA TO ANALYZE

SAMPLE RATES FOR T-CAR CONSIST:
T1/T3 - 2.41666 FT.
T2/T4 - 1.0 FT.
T6 - 1.0 FT.

Figure C-3. Notes for MOW Standards Report

C.1.1.2 Summary of Class Changes

The Summary of Class Changes (Figure C-4) provides a complete listing of the location where each posted-class-change occurred. The posted class is supplied by the railroad. The column marked MILEPOST is the milepost number, and the column marked DISTANCE is the distance in feet from the current milepost. TRACK is the track number for the posted class. The NEW CLASS column is the class after the change point. The PAGE column is the page number in the detailed report where the change occurred.

C.1.2 Summary Reports

The summary report section consists of three types of reports:

- Curve Summary
- One Mile Class Summary
- One Mile Exception Summary

C.1.2.1 Curve Summary Report

The Curve Summary Report (Figure C-5) gives the location and speed exception information for each curve over 30 minutes. The ACQUISITION date is the date on which the data were collected, and the PROCESSED date is the date the report was prepared. The TRACK NUMBER is the surveyed track number. The start of the curve (tangent-spiral) and the end of the curve (spiral-tangent) are listed by the START and END milepost number and the distance in feet. An asterisk in front of the milepost number indicates the milepost was entered manually on the strip chart. CURVE length is the overall length of the curve from the point of spiral to the point of tangent. AVERAGE CURVATURE and AVERAGE ELEVATION give the average of all points measured in the body of the curve (point of curve to point of spiral).

```
**************** SUMMARY OF CLASS CHANGES ****************
*                                                PAGE  1  *
*                                                         *
*                                                         *
*                                                         *
*     MILEPOST  DISTANCE     TRACK     NEW CLASS  PAGE    *
*                                                         *
*                                                         *
*        51       1878         1           4        1     *
***********************************************************
```

Figure C-4. Summary of Class Changes

MAINTENANCE OF WAY STANDARDS - CURVE SUMMARY REPORT(T1/T3) ACQUISITION 4/17/78 PROCESSED 04/28/78 PAGE 1

TRACK NUMBER : 1 F = SPIRAL OUT OF CURVE NOT DETECTED

	START MP	START DIST	END MP	END DIST	CURVE LENGTH	AVERAGE CURVATURE DEG/MIN	AVERAGE ELEV. INCHES	AVERAGE SPEED MPH	EQU. SPEED MPH	POSTED SPEED MPH	LIMITING SPEED: MAX ALW SPEED MPH	POINT LIMIT MP/FT	CURVATURE DEG/MIN	ELEVATION INCHES	TOTAL EXCEPT. FEET
	51	2032	51	3299	1266	-6/10	4.77	62	38	45	40	51/ 2511	-6/30	4.62	812
	51	3734	51	4635	901	3/ 0	-2.73	61	34	45					
	51	4635	52	800	1462	5/10	-5.52	51	36	45	43	52/ 537	5/30	-4.40	19
*	52	1805	52	3190	1385	-2/10	1.12	64	28	45					
*	53	2165	53	3282	1117	4/55	-4.99	62	40	45	39	53/ 3064	5/ 0	-2.50	68
*	54	998	54	1740	742	0/35	0.89	116	46	45					
*	55	3473	55	4609	1136	3/ 5	-2.40	72	36	45					
*	56	3311	56	5167	1856	3/ 5	-3.16	62	39	45					
*	57	1204	57	1653	449	1/50	-1.35	89	31	45					
*	57	2069	57	3453	1385	-4/15	3.98	66	35	45					
*	58	343	58	1027	684	-3/45	3.26	81	44	45					
*	58	1027	58	3093	2066	-1/ 5	1.21	77	38	45					
*	60	3415	60	4703	1288	3/ 5	-2.55	63	35	45					
*	61	3320	61	4084	764	-1/50	1.07	86	32	45					
*	61	4381	62	534	1426	2/50	-2.45	64	37	45	39	61/ 5082	3/55	-1.38	53
*	62	3681	63	19	1605	-3/10	2.82	60	34	45	44	62/ 5065	-3/15	1.58	2
*	63	703	63	1646	942	-2/ 5	1.74	73	34	45					
*	63	2243	63	3879	1636	1/55	-1.11	65	29	45					
*	63	3934	64	561	1875	-3/30	3.54	66	40	45	43	63/ 4333	-4/30	3.00	70
*	64	853	64	1590	737	3/30	-2.98	81	44	45					
*	64	3043	64	4171	1129	3/40	-4.05	67	43	45					
*	65	1711	65	2714	1003	-1/ 5	0.90	83	34	45					
*	65	2835	65	4007	1172	-1/40	0.89	73	28	45					

Figure C-5. Curve Summary Report

AVERAGE SPEED is the computed average speed for all points in the curve using the three-inch imbalance formula given below. Equilibrium speed (EQU. SPEED) is the computed avarage speed for all points in the curve using the limiting speed formula without the three-inch imbalance factor. POSTED SPEED is the track speed which is supplied by the railroad.

The next five columns give limiting speed information for each curve. Limiting speed is computed for each point in the curve using the three-inch imbalance formula given in the FRA Track Safety Standards:

$$\text{Limiting speed} = \sqrt{\frac{\text{crosslevel (inches)} + 3.0}{0.0007 \times \text{curvature (degrees)}}}$$

The MAXIMUM ALLOWABLE SPEED column shows the lowest speed calculated for the curve using the average elevation in the above formula. POINT LIMIT is the point where the maximum allowable speed is computed. The milepost number and feet from the milepost are given for the point of limit. When the limiting speed is less than the posted speed, as shown in Figure C-5, POINT LIMIT exceptions are shown. The CURVATURE column is the curvature in degrees and minutes, and the ELEVATION column is the elevation in inches at the point of limit. The column TOTAL EXCEPT. FT. shows the total number of feet where the computed speed is lower than the posted speed.

For a compound curve, each curve body is listed on a separate line without spacing between lines. An F appearing next to the curve length, indicates that the spiral out of the curve was not detected by the program. Because the end of the curve body cannot be detected in this case, average elevation and curvature are omitted.

C.1.2.2 One Mile Class Summary Report

The One Mile Class Summary Report (Figure C-6) shows class information for each track geometry parameter. The ACQUISITION and PROCESSED headings are the same as in the Curve Summary Report. The MILEPOST column gives the START/END milepost and the distance (DIST) between mileposts. TRK is the track number of the measured track.

The lowest class in each mile for each of the track geometry parameters is listed in the next six columns. Any parameter for which no exceptions are located will be listed at the posted class. When there is a class change within the mile, only the lowest class in the mile will be shown. Curvature and rock and roll class are computed from railroad thresholds while the other parameter classes are computed from railroad and FRA standards.

The OVERALL TRK CLASS column gives the lowest computed track class for that mile using railroad and FRA thresholds. The POSTED CLASS column provides the class of track supplied by the railroad. At the end of the report, the Total Tested Miles Per Class are summarized for each parameter. The Total Posted Miles Per Class, which are supplied by the railroad, are also summarized.

C.1.2.3 One Mile Exception Summary Report

The One Mile Exception Summary Report (Figure C-7) lists the number of exception samples found by the inspection vehicle for each track geometry parameter. The ACQUISITION, PROCESSED, MILEPOST, and TRK headings are the same as in the previous report. CURVATURE and ROCK AND ROLL exceptions are computed from railroad thresholds while the PROFILE, GAGE, XLEVEL, and WARP exception columns are computed from railroad and FRA standards. The PROFILE exceptions are listed

MAINTENANCE OF WAY STANDARDS - ONE MILE CLASS SUMMARY REPORT(T1/T3) ACQUISITION 4/17/78 PROCESSED 04/28/78 PAGE 2

	MILEPOST START	END	DIST	TRK	CURVATURE CLASS (RR)	ROCK+ROLL CLASS (RR)	PROFILE CLASS (RR/FRA)	GAGE CLASS (RR/FRA)	XLEVEL CLASS (RR/FRA)	WARP CLASS (RR/FRA)	OVERALL TRK CLASS (RR/FRA)	POSTED CLASS
*	74	75	5196	1	4	4	2/4	4/4	4/4	3/4	2/4	4
*	75	76	5271	1	4	4	4/4	2/3	4/4	4/4	2/3	4
*	76	77	5266	1	4	4	4/4	4/4	4/4	4/4	4/4	4
*	77	78	5254	1	4	4	4/4	4/4	4/4	4/4	4/4	4
*	78	79	5280	1	4	4	1/4	2/3	4/4	4/4	1/3	4
*	79	80	5271	1	4	4	3/4	4/4	4/4	4/4	3/4	4
*	80	81	5261	1	4	4	2/4	4/4	3/3	3/4	2/3	4
*	81	82	5268	1	4	4	2/4	4/4	3/3	3/4	2/3	4
*	82	82	2907	1	4	4	2/4	4/4	4/4	3/4	2/4	4

		CLASS 0	CLASS 1	CLASS 2	CLASS 3	CLASS 4	CLASS 5	CLASS 6
TOTAL TESTED MILES PER CLASS	RR	2	7	10	4	9	0	0
	FRA	0	1	4	11	16	0	0
TOTAL POSTED MILES PER CLASS		0	0	0	0	32	0	0

TOTAL MILES COVERED IN REPORT : 32

Figure C-6. One Mile Class Summary Report

MAINTENANCE OF WAY STANDARDS - ONE MILE EXCEPTION SUMMARY REPORT(T1/T3) ACQUISITION 4/17/78 PROCESSED 04/28/78 PAGE 1

	MILEPOST			T R K	C L S	CURVATURE		ROCK+ROLL		PROFILE EAST RAIL		PROFILE WEST RAIL		GAGE		XLEVEL		WARP	
	START	END	DIST			EXC	SEV	EXC	SEV	EXC	SEV	EXC	SEV	EXC	SEV	EXC	SEV	EXC	SEV
	51	52	5297	1	4							6						6	6
*	52	53	5232	1	4					8		7						4	
*	53	54	5288	1	4	1				5		4				13	8	6	1
*	54	55	5273	1	4														
*	55	56	5261	1	4														
*	56	57	5227	1	4													2	1
*	57	58	5220	1	4											24	12	2	
*	58	59	5278	1	4														
*	59	60	5266	1	4									6	6	3	2	2	1
*	60	61	5254	1	4									2	2				
*	61	62	5273	1	4	4				5		4						2	
*	62	63	5266	1	4					1		10						2	
*	63	64	5249	1	4	11				7		1		2	2			4	1
*	64	65	5264	1	4							3				15	2	1	
*	65	66	5259	1	4														
*	66	67	5278	1	4														
*	67	68	5261	1	4														
*	68	69	5273	1	4									5	5				
*	69	70	5268	1	4									2	2				
*	70	71	5266	1	4					1		13		11	11				
*	71	72	5278	1	4							2							
*	72	73	5268	1	4					7		8	4						

Figure C-7. One Mile Exception Summary Report for each rail. The rails are defined as either EAST/WEST or NORTH/SOUTH, depending on the direction in which the measurement cars are traveling. The EXC and SEV columns list the number of exception samples between the start and end mileposts of the posted class. In addition, messages referring to various tape problems, such as sequence or parity errors, are also printed in this report.

C.1.3 Detailed Report

The Detailed Report (Figure C-8) lists the location of each exception. The ACQUISITION and PROCESSED information has been previously discussed. The second line of the header gives the overall geographic location number and name (LOC). CLASS THRESHOLDS lists the posted class of track. RAILROAD THRESHOLDS lists the thresholds for tangent track (T), spiral (S) and curve (C) for each of the listed track geometry parameters for the posted class of track. MP DIST is the milepost number and distance in feet from it where each exception is located. Footage proceeded by a minus (-) sign indicates that milepost numbers are in decreasing order. TRK is the track number.

The PROFILE column is divided into two rails, as discussed in the One Mile Summary Exception Report. The GAGE, CURVATURE, and CROSSLEVEL columns list the maximum exception value (MAX EXCEPTION) and the OVERALL DISTANCE that each exception extends. When crosslevel exceeds the maximum crosslevel threshold an "OV" is listed next to the crosslevel value. WARP lists the exception (EXC) and the distance between the two points over which warp is measured (LENGTH).

ROCK AND ROLL (19.5 feet) EXCEPTION lists exceptions generated from a 19.5-foot chord. SPD POSTED/MAXIMUM ALLOW lists the railroad posted speed versus the maximum allowable speed calculated as in the Curve Summary Report. When limiting

LOC X16 CLASS 4 THRESHOLDS

	MP	DIST	TRK	PROFILE (62.0 FT) EAST RAIL	PROFILE (62.0 FT) WEST RAIL	GAGE MAXIMUM EXCEPTION	CURVATURE MAXIMUM EXCEPTION	XLEVEL MAXIMUM EXCEPTION	OVERALL DISTANCE	WARP EXC	WARP LENGTH	ROCK+ROLL (19.5 FT) EXCEPTION	SPD(MPH) POSTED/ MAXIMUM ALLOW	AVERAGE CURVATURE (DEG/MIN)	FACT	
RAILROAD------- THRESHOLDS(IN.)				(1.250)		T-(57.25) C-(57.50)	T-(1.000) C-(1.000)	T-(1.000) S-(1.000)		T-(1.000) S-(1.000)		(1.000)				
	51	1912	1	********** SWITCH **********											T	
	51	1938	1		-1.46				2						T	
	51	1953	1		-1.56				12						T	
	51	1970	1							-1.45 R	60.4				T	
	51	1989	1		---SENSORS DOWN--											
	51	2030	1					1.28 R	10						T	
	51	2119	1							1.12*	29.0				S	3
	51	2151	1							1.42*	29.0				S	2
	51	3052	1							1.10*	29.0				S	3
	51	3163	1							1.16*	29.0				S	3
	51	3236	1							1.19*	29.0				S	3
	51	3845	1							1.17*	29.0				S	3
	51	4116	1	********** ROAD CROSSING **********										3/10	C	
*	52	295	1					-6.240V	12					5/10	C	
*	52	464	1							1.19	60.4			5/10	C	
*	52	476	1					-6.250V	10					5/10	C	
*	52	742	1		-1.75				10						S	
*	52	2349	1							1.13	43.5			- 2/10	C	
*	52	2393	1		-1.60				7					- 2/10	C	
*	52	3376	1		---SENSORS UP---											
*	52	3444	1							1.19	53.2				T	
*	52	3490	1	********** SWITCH **********											T	
*	52	3509	1							1.12	41.1				T	
*	52	3552	1	-1.90					19						T	
*	52	3560	1		---SENSORS DOWN--											
*	53	655	1							1.25	60.4				T	
*	53	718	1							1.82*	60.4				T	2
*	53	723	1		-1.51				5						T	
*	53	730	1					1.52*	17						T	3
*	53	732	1				1.30		2						T	
*	53	761	1	-1.50					7						T	
*	53	771	1	********** SWITCH **********											T	
*	53	781	1							1.16	60.4				T	
*	53	860	1		---SENSORS UP--											
*	53	955	1	********** SWITCH **********											T	
*	53	955	1							1.22	60.4				T	
*	53	1017	1							1.19	55.6				T	
*	53	1022	1	-1.56					5						T	
*	53	1025	1					-1.46*	14						T	3

Figure C-8. Detailed Report (MOW Standards) speed exceptions exceed the posted speed by 10 mph, an L is printed next to the crosslevel and curvature values listed at that point. All these values are printed on the same line. The AVERAGE CURVATURE column is computed as the Curve Summary Report. The FACT column describes the kind of track (S for spiral, C for curve and T for tangent) as well as the computed class of the track, with Class 1 and 0 being offset to make the classes stand out.

The Detailed Report lists ALD events. These events list by location all switches and road crossings encounted; this is done by an analysis of the ALD trace. The MP and DIST columns give the milepost number and fottage of the ALD event. An asterisk to the left of the milepost indicates that the Forward Observer entered the milepost as it was passed. The events are printed below the GAGE MAXIMUM EXCEPTION column. Under this events column the SWITCH or ROAD CROSSING is printed to indicate each event. In areas where high ballast exists, the ALD is masked and switches or road crossings are, therefore, not shown. Note that the event is marked as it ends rather than where it begins.

The body of the detailed report also notes the following information:

- Change of class of track and a list of the new class thresholds.
- Track changes.
- Beginning and end of deleted data for each track geometry parameter where:

  GA = GAGE

  XL = CROSSLEVEL

  WA = WARP

  CU = CURVATURE

  LP = PROFILE (LEFT)

  RP = PROFILE (RIGHT)

- Magnetic tape read parity or sequence errors (number of feet of data not processed).

- The start of a new geographic location lists the number and the name of the location.

C.1.4 MOWS Exception Plot Display

C.1.4.1 Summary

Track geometry data are processed by digital computer techniques. The results of this processing are summarized and presented as exception plots (Figure C-9). These plots display the number of feet or data samples per mile that do not comply with railroad standards or FRA Track Geometry Safety Standards. In addition, the track class consistent with track operating speeds is displayed and overlaid with the highest FRA track class for which there are no exceptions.

C.1.4.2 Description of Exception Plots

Four of the six graphical displays are presented which summarize the number of feet per mile that exceed the limits of the thresholds for each parameter. For Warp, the actual number of exceptions is displayed. Track class is determined by track operating speeds set by the railroad. A shaded area in the exception plot denotes miles where FRA Safety Standards are exceeded. The upper limit of the shading denotes the number of feet of these exceptions.

In each case, the vertical scale is between 0 and 50 feet. If the plotted value exceeds 50, the actual value is posted above the curve.

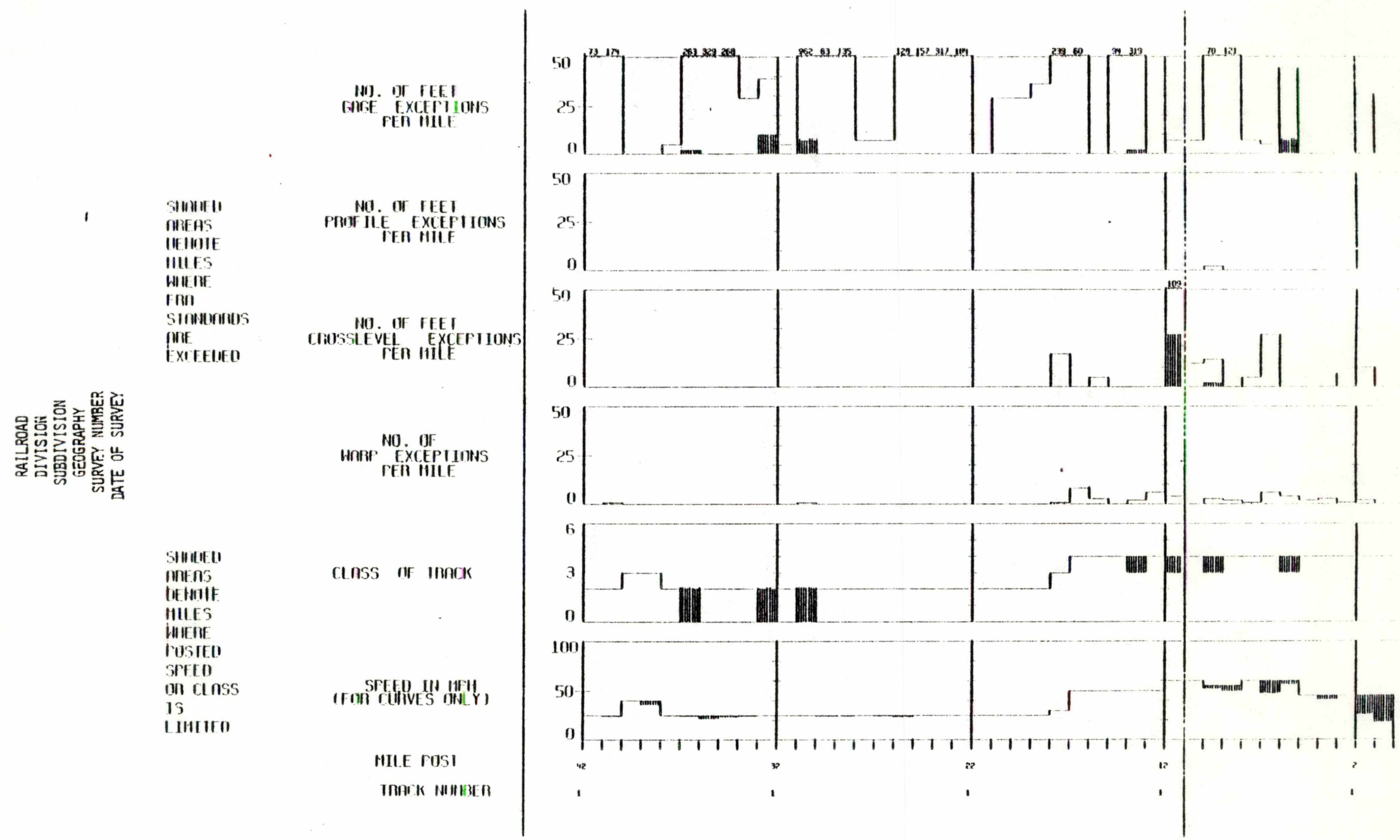


Figure C-9. Exception Plot

The four graphical displays are:

- Gage
- Profile
- Crosslevel
- Warp

An asterisk (*) on the graphic display of profile indicates that the magnitude of the exception is inaccurate due to saturation. This exception, however, does not affect the class of the track. This saturation occurs when the profilometer receives a jolt severe enough to cause the accelerometer to overload.

C.1.4.3 Track Class

This graph shows posted class and limiting class as defined by FRA exceptions in any of the above four plots. The upper line is the posted class. Shading defines a drop in class, with the bottom of the shading indicating the minimum FRA class.

C.1.4.4 Speed in Curves

This graph represents data pertaining to the railroad's posted speed and the limiting speed in curves as computed by the FRA Safety Standards equation (Section C.1.2.1). This trace is not affected by exceptions in the above four parameters. The upper line indicates the posted speed in the mile. Shading indicates a limiting speed, with the lower limits of the shading showing the maximum allowable speed in curves.

C.1.4.5 Track Number and Milepost

The track number is printed below the milepost numbers. If more than one track change occurs in a mile, the last track number will be indicated.

C.1.5 Program Computation

This section gives the method for calculating each parameter with respect to railroad and FRA Track Safety Standards.

C.1.5.1 Profile

The 62-foot Mid Chord Offset (MCO) is computed by using three points from the profilometer input. Since the mid chord method will generate two bumps for each dip, dips are only reported when they exceed the railroad and FRA standards.

The profile exceptions can be a group or a single point. If the overall distance is greater than one sample, then the exception is considered a group. To determine the number of exceptions in a group, divide the overall distance by the sample rate. The number of exceptions also shows up on the One Mile Exception Summary Report.

Occasionally a severe jolt such as a crossing diamond will cause the accelerometer to overload. When this happens a false exception will be generated. These exceptions are removed during processing and replaced with the word SATURATION. Since the magnitude of these exceptions is unknown they do not affect track class. These are indicated on the exception plot by an asterisk (*).

C.1.5.2 Gage

The gage measurement is checked for readings that exceed the railroad/FRA standards on tangent and in curves by being too wide or too tight. All gage readings are checked for at least two points outside of the standard before gage is classed as an exception. No single point exception is considered in gage computation. Single points can occur at switches, road crossings, and areas where a large amount of metal is around the rail causing the system to read wide or tight when, in fact, no exception exists. Any two points less than 22 feet apart are combined into a group with the most severe value listed in the detailed report. In actuality more than two points can occur in this group. The number of points over the threshold in the group are counted in the One Mile Exception Summary Report.

C.1.5.3 Crosslevel

The crosslevel measurement is checked for readings that exceed the railroad/FRA standards in tangent, spiral and curved track. On tangent track, the crosslevel exception is determined by deviation from zero. On curves and spirals, crosslevel is computed as the difference between the measured crosslevel and the designated elevation. The program averages the crosslevel data throughout the curve to establish the designated elevation. OV crosslevel exceptions are explained in the Detailed Report description (Section C.1.3).

C.1.5.4 Warp

The warp measurement is checked for readings that exceed the railroad/FRA standards on tangent, spiral and curved track. Warp is computed by taking the difference between two crosslevel points (N) number of feet apart. On spirals the distance (N) is 31 feet; on tangent track it is any distance between 0 and 62 feet. No group exceptions are computed for warp. The LENGTH column gives the value of N for the maximum exception.

C.1.5.5 Curvature

The curvature measurement is checked for readings that exceed the railroad/FRA standards in tangent, spiral and curved track. On tangent track, the curvature exception is determined by deviation from zero. On curves and spirals, curvature is computed as the difference between the measured curvature and the designated curvature. The program averages the curvature data throughout the curve to establish the designated curve.

The standards program uses curvature to determine spirals, the curve body and the limiting speed in a curve. Limiting speed, discussed in Section C.1.2.1, is computed for each data sample in a curve. This is compared with posted speed and printed in the detailed report when it is 10 mph or more different from the posted speed.

C.1.5.6 Rock and Roll

Rock and roll is computed in the following manner: given a particular data sample, the program looks ahead a distance of 19.5 feet and calculates the difference in crosslevel of those two points. If the difference is over the railroad threshold, the sign and magnitude of the slope calculated between two points is stored for comparison. Using the same specified distance, the program looks ahead to locate a third point. The difference between points two and three is calculated and compared to the threshold. If it exceeds the threshold, a second slope is calculated. If the sign of the second slope is opposite the first, two changes of direction have occurred. The same procedure is followed again and, if the third difference generates an exception, a third slope is calculated. If this slope is the same sign as the first, i.e., is different from the second, a possible rock and roll situation exists.

The threshold is one inch, thus all values have one inch subtracted from them for display purposes. These values are then multiplied by 10 for conversion to an integer. Any value over 10 is printed as a zero. If three consecutive slopes of +1.5-inch, -1.7-inch, +2.1-inch occur, then the printout would read +5-7+0 at the first point of the rock and roll condition. A continuation of an ongoing rock and roll situation will be shown by the display of a single value and sign, which represents the magnitude and sign of the third slope from that point.

C.2 MOW PLANNING REPORT

The MOW Planning Report (Figure C-10) lists the seven track quality indices for quarter-mile sections of track. A block diagram of the Planning Report processing is shown in Figure C-11. The ACQUISITION and PROCESSED headings are the same as in the Standards Report. The second line of the header gives the geographic location and the number of samples per one-quarter-mile track segment. The start and end of the one-quarter-mile segments are listed by the START and END milepost number and the distance in feet.

The GAGE, PROFILE, XLEVEL, and CURVATURE index columns are computed from the track geometry data. NO. SAMP gives the number of data samples for each track segment. INDEX, STD DEV, 99% VALUE, and SLOPES represent the four different indices.

The Planning Report also notes the start of a new geographic location by the number and name of the location. TRK is the track number of the track surveyed.

C.2.1 SORT Report

Another part of the Planning Report is the SORT Report (Figure C-12). This report sorts track quality indices by parameter according to severity. The first line of the header gives the geographic location. The MILEPOST column gives the start/end milepost and the distance between mileposts. GAGE, PROFILE, CROSSLEVEL and CURVATURE columns

MAINTENANCE OF WAY PLANNING REPORT (MOWP)

START		END				GAGE		
MP	DIST	MP	DIST	TRK	INDEX	STD DEV	99% VALUE	NO. SAMP
67	753	67	2073	1	5450	0.151	57.21	546
67	2075	67	3395	1	7564	0.137	57.25	546
67	3397	67	4717	1	7418	0.141	57.29	546
67	4719	68	761	1	6382	0.146	57.24	546
68	763	68	2083	1	5922	0.133	57.37	546
68	2085	68	3405	1	5468	0.151	57.16	546
68	3407	68	4727	1	5431	0.131	57.19	546
68	4729	69	771	1	3517	0.233	57.33	546
69	773	69	2093	1	7251	0.192	57.38	546
69	2095	69	3415	1	5477	0.174	57.31	546
69	3417	69	4737	1	6078	0.146	57.30	546
69	4739	70	832	1	4164	0.153	57.10	546
70	834	70	2154	1	5923	0.165	57.40	546
70	2156	70	3476	1	3620	0.255	57.37	546
70	3478	70	4798	1	4468	0.128	57.02	546
70	4800	71	809	1	5591	0.144	57.48	546
71	811	71	2131	1	5411	0.147	57.32	546
71	2133	71	3453	1	4240	0.127	57.08	546
71	3455	71	4775	1	3838	0.142	57.08	546
71	4777	72	819	1	3348	0.132	57.05	546
72	821	72	2141	1	3172	0.103	56.98	546
72	2143	72	3463	1	3482	0.117	57.04	546
72	3465	72	4785	1	2972	0.132	57.01	546
72	4787	73	827	1	2339	0.222	57.29	546
73	829	73	2149	1	3706	0.150	57.07	546
73	2151	73	3471	1	3746	0.157	57.32	546
73	3473	73	4793	1	4837	0.155	57.17	546
73	4795	74	787	1	3671	0.128	57.17	546
74	789	74	2109	1	3195	0.100	56.93	546
74	2111	74	3078	1	1765	0.139	57.05	369

LOC X23 Z+L LUMBER TO KREMIS (MP 74.6-80.2) TK 1

74	3093	74	4413	1	3777	0.101	57.00	483
74	4415	75	540	1	3740	0.125	57.07	546
75	542	75	1862	1	6843	0.192	57.38	546
75	1864	75	3184	1	4159	0.160	57.43	546
75	3186	75	4506	1	6256	0.143	57.40	546
75	4508	76	546	1	2726	0.130	57.00	546
76	548	76	1868	1	2186	0.128	56.94	546
76	1870	76	3190	1	4116	0.143	57.16	546
76	3192	76	4512	1	4847	0.149	57.20	546
76	4514	77	578	1	3956	0.113	57.07	546

Figure C-10. MO

546 SAMPLES PER 0.25 MILE TRACK SEGMENT

PROFILE INDEX	PROFILE SLOPES	PROFILE NO. SAMP	XLEVEL INDEX	XLEVEL NO. SAMP	CURVATURE INDEX	CURVATURE NO. SAMP
2416	97	546	1204	546	948	546
3085	84	546	1360	546	2524	546
1828	40	546	734	546	1404	546
2896	75	546	1211	546	1595	546
2908	89	546	1055	546	1117	546
1822	51	546	632	546	634	546
2078	46	546	881	546	952	546
3547	112	546	1279	546	1608	546
2293	79	546	950	546	2127	546
2918	128	546	1067	546	1421	546
2701	53	546	932	546	1204	546
2924	82	546	1323	546	1292	546
2418	69	546	946	546	1066	546
3864	129	546	1569	546	1171	546
3116	135	546	1280	546	1222	546
2129	42	546	815	546	1053	546
2935	102	546	1081	546	1125	546
2524	51	546	1016	546	1842	546
1975	62	546	905	546	876	546
1667	45	546	896	546	886	546
1579	34	546	851	546	906	546
1776	50	546	966	546	999	546
3632	103	546	1178	546	1462	546
2957	62	546	1370	546	2832	546
1906	28	546	1289	546	2442	546
2008	76	546	1200	546	1396	546
1692	34	546	777	546	1578	546
1893	46	546	945	546	954	546
1990	27	546	1073	546	1474	546
4366	146	400	1769	400	1644	400

2960	69	546	1193	546	1657	546
2465	38	546	1507	546	2458	546
3002	77	546	1354	546	1799	546
2857	109	546	1437	546	1010	546
1870	52	546	782	546	747	546
2256	55	546	797	546	760	546
3062	74	546	1243	546	1267	546
2341	74	546	973	546	1793	546
2558	57	546	1045	546	1400	546
3710	106	546	1136	546	1447	546

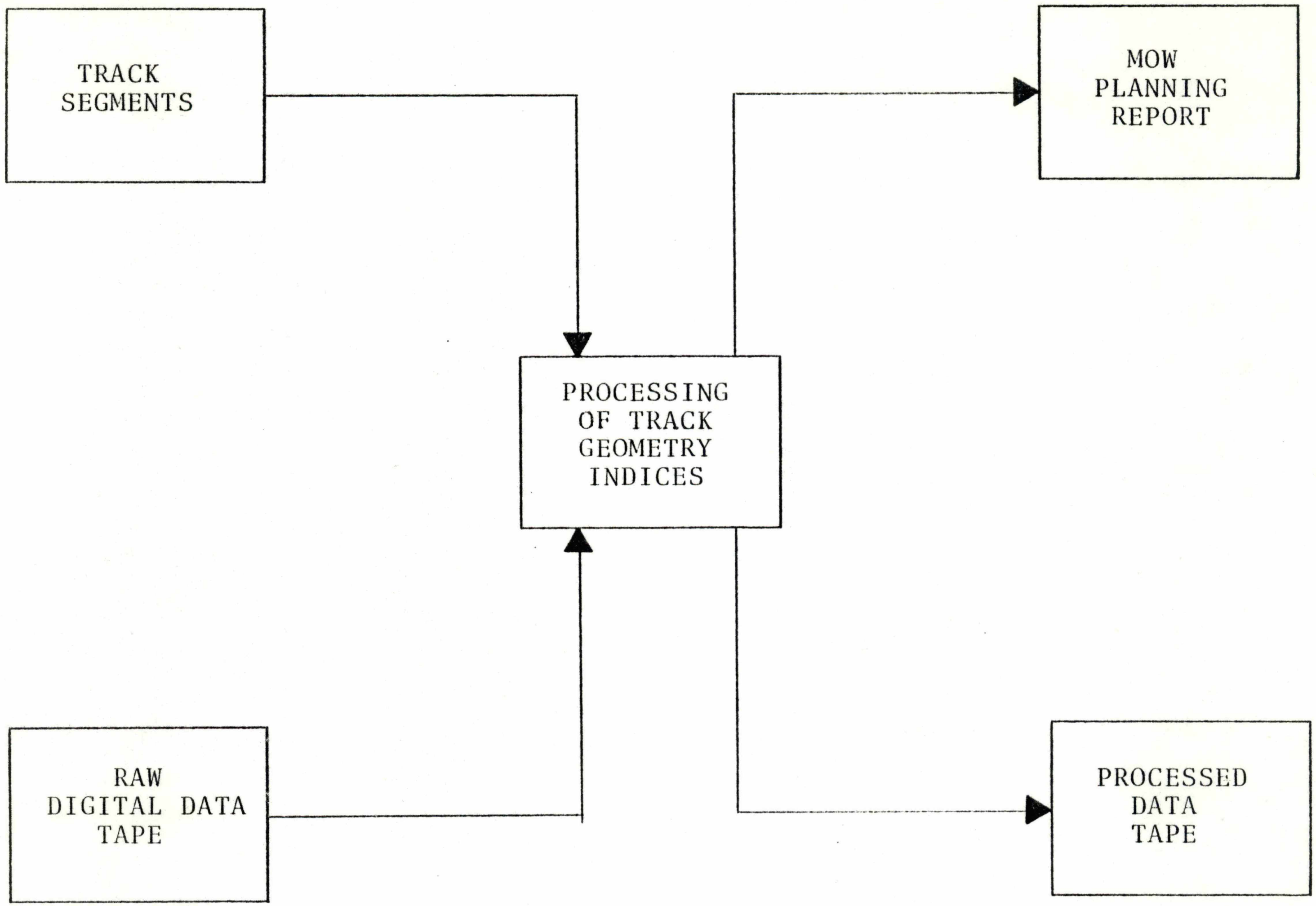


Figure C-11. Processing of MOW Planning Report

MILEPOST				GAGE	
START	DIST	END	DIST	INDEX	STD. DEV.
60	3112	60	4432	7907	0.273
63	4052	64	116	7670	0.155
67	2075	67	3395	7564	0.137
51	4522	52	545	7502	0.110
55	3494	55	4814	7448	0.270
67	3397	67	4717	7418	0.141
53	1921	53	3241	7308	0.283
69	773	69	2093	7251	0.192
75	542	75	1862	6843	0.192
77	3224	77	4544	6456	0.133
51	3200	51	4520	6432	0.169
67	4719	68	761	6382	0.146
75	3186	75	4506	6256	0.143
69	3417	69	4737	6078	0.146
51	1878	51	3198	5962	0.137
70	834	70	2154	5923	0.165
68	763	68	2083	5922	0.133
57	2239	57	3559	5825	0.256
62	4075	63	84	5685	0.223
59	1801	59	3121	5663	0.111
59	479	59	1799	5618	0.142
70	4800	71	809	5591	0.144
69	2095	69	3415	5477	0.174
68	2085	68	3405	5468	0.150
67	753	67	2073	5450	0.151
68	3407	68	4727	5431	0.131
71	811	71	2131	5411	0.147
57	917	57	2237	5255	0.150
77	1902	77	3222	4904	0.233
76	3192	76	4512	4847	0.148
59	3123	59	4443	4844	0.161
73	3473	73	4793	4837	0.155
77	4546	78	586	4767	0.171
52	1869	52	3189	4689	0.145
64	2683	64	4003	4490	0.173
59	4145	60	466	4480	0.137
70	3478	70	4798	4468	0.123
56	3519	56	4839	4460	0.154
64	118	64	1438	4310	0.152
71	2133	71	3453	4240	0.157
61	4060	62	107	4189	0.154
69	4739	70	832	4164	0.153
75	1864	75	3184	4159	0.148
76	1870	76	3190	4116	0.143
60	468	60	1788	4075	0.171
58	481	58	1801	4000	0.136

Figure C-

99% VALUE	PROFILE INDEX	SLOPES	CROSSLEVEL INDEX	CURVATURE INDEX
57.57	2520	81	1295	1671
57.42	3834	110	2034	4307
57.25	3005	84	1360	2524
57.20	3147	78	2373	1979
57.47	2907	76	1428	1497
57.29	1828	40	734	1404
57.46	3350	73	2069	2413
57.38	2293	79	950	2127
57.38	3002	77	1354	1397
57.24	2807	58	925	1954
57.32	3856	116	1705	1976
57.24	2896	75	1211	1595
57.30	1870	52	782	797
57.30	2701	53	932	1204
57.32	3905	106	2306	2909
57.40	2418	69	946	1066
57.37	2908	89	1055	1117
57.30	2121	47	1480	1709
57.38	2770	90	1379	2166
57.19	1641	25	952	718
57.18	1368	33	731	676
57.48	2129	42	815	1053
57.31	2918	128	1067	1421
57.16	1872	51	632	634
57.21	2416	97	1204	948
57.19	2078	46	881	952
57.32	2935	102	1081	1125
57.21	3088	82	1752	1562
57.37	3256	98	1068	2367
57.20	2558	57	845	1400
57.44	2334	66	1370	1153
57.17	1602	34	777	1578
57.30	3479	120	1786	2316
57.14	3279	121	1486	1568
57.12	3587	112	1935	2482
57.13	1903	63	1104	924
57.02	3116	135	1280	1222
57.55	3953	129	1891	1897
57.25	1932	43	1472	2385
57.08	2524	51	1016	1842
57.32	3387	128	1761	2700
57.10	2924	82	1343	1292
57.43	2857	101	1037	1090
57.16	2341	74	978	1790
57.19	2537	65	1143	1179
57.20	1600	17	1143	1420

-12. Sort Report

list the various indices. Each parameter is sorted by INDEX in decreasing order and the other indices are also listed. A block diagram of the Sort Report processing is shown in Figure C-13.

C.3 GEOPLOT REPORT

The GEOPLOT Report shows four of the track quality indices by one-mile segments on the Track-Parameter, Quality-Index Chart. A block diagram of GEOPLOT Report processing is shown in Figure C-14.

C.3.1 Track Parameter Quality Index Chart

The Track Parameter Quality Index Chart (Figure C-15) can be used to overlay up to three different surveys to show degradation or improvement of a section of track. The data information is the same as discussed previously. The first line of the header gives the name of the railroad and the geographic location. Also included in the header are notes explaining symbols used in the report. LOC/MP is the milepost number. The GAGE, STD. DEV, PROFILE INDEX, CROSSLEVEL INDEX, and CURVATURE INDEX columns overlay up to three different surveys. Under each column heading, the INCREMENT is listed along with the range of values.

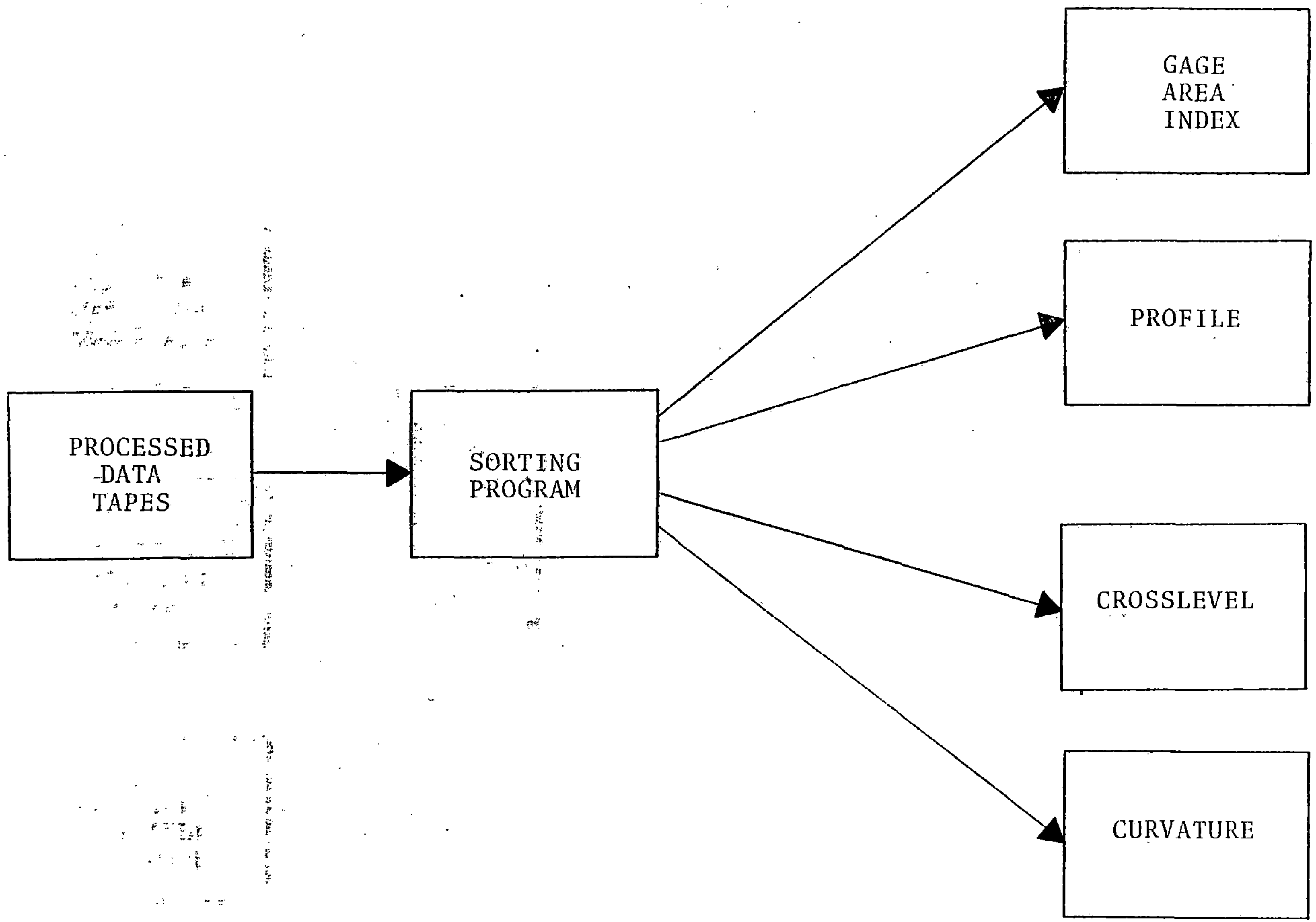


Figure C-13. Processing of Sort Report

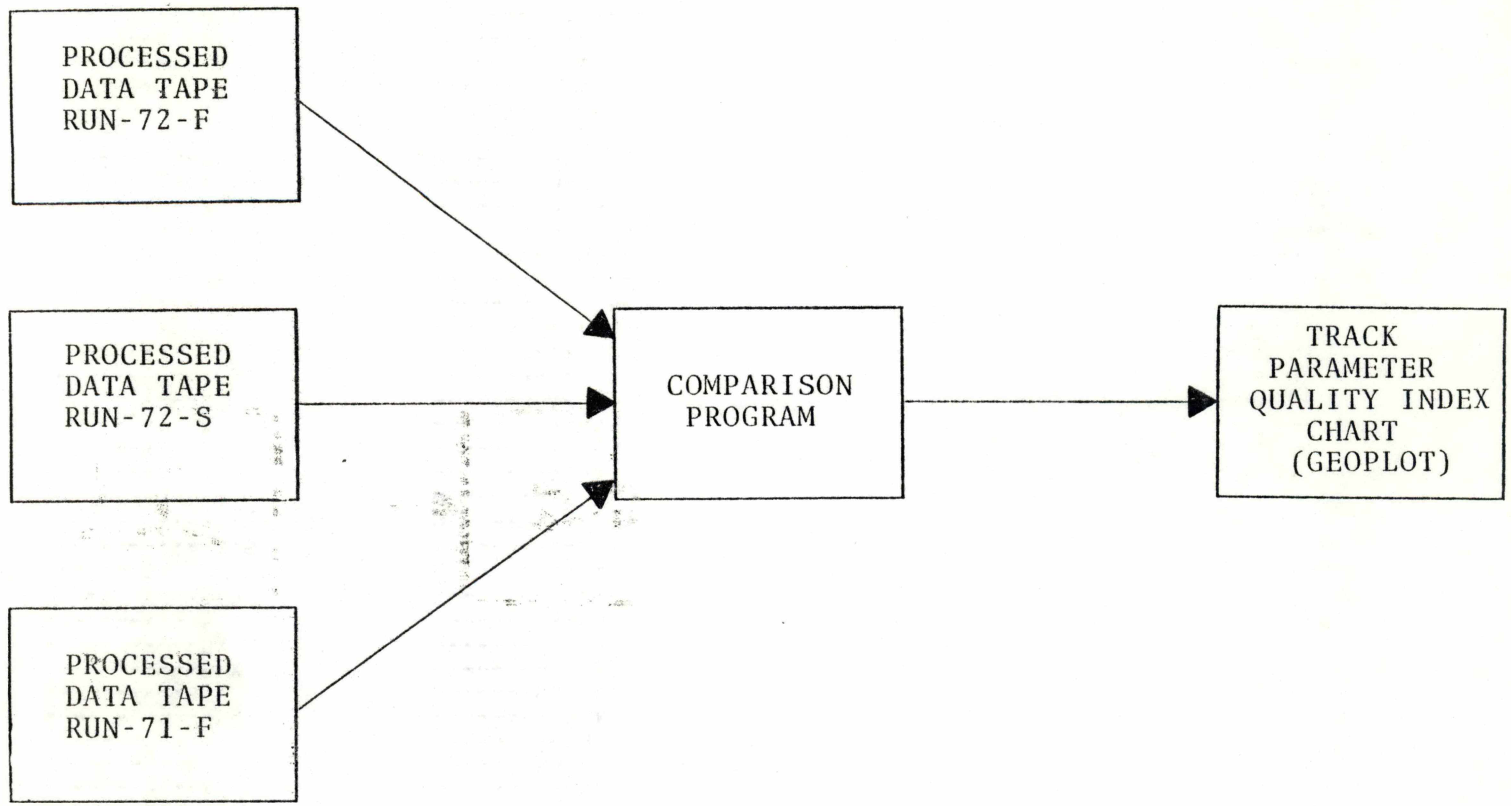


Figure C-14. Processing of Geoplot Report

```
TRACK PARAMETER QUALITY INDEX CHART          PROCESS DATE  01/14/75                                    PAGE 1
                                             X=2 OR MORE POINTS THE SAME
3 = 1973 DATA (FALL)                         N=BAD OR NO DATA
4 = 1974 DATA (SPRING)
5 = 1974 DATA (FALL)

                    GAGE                        PROFILE                     CROSSLEVEL                  CURVATURE
                 STD. DEV.                       INDEX                        INDEX                       INDEX
          INCREMENT =        .02      INCREMENT =     350.00       INCREMENT =     650.00       INCREMENT =    1150.00

(LOC/M.P.) *    .0        .2        .4 1000.0    4500.0    8000.0 2000.0    8500.0   15000.0 2000.0   13500.0   25000.0 * (M.P./LOC)
           *    I.........I.........I  I.........I.........I   I.........I.........I   I.........I.........I      *
       1.0 I    ---------5--X          -------X---4             ---------5----3-4       ------5--34                I  1.0
           *    ----5-----------X      -------5-3--4            ------------5X          ----------X5               *
           *    ---------5-X           -------X--4              --------3-45            ------34-5                 *
           *    -------5---X           -----------53--4         ------------534         --------354                *
       5.0 I    --------5-X            -------53------4         -------3-X              ------X-4                  I  5.0
           *    -------5-X             ---------53-4            ------X3                ----3X                     *
           *    ------------5X         ---------5-X             ------4--53             -----34-5                  *
           *    ----------5-X          -------53--4             -----4X                 ----3-45                   *
           *    ------------5-X        -----------5-3-4         ---------543            ---------X5                *
      10.0 I    ------------5X         -------------5-3-----4   -------53-4             -----3X                    I 10.0
           *    ------------X5         -----------53-----4      ----------345           --------X4                 *
           *    N-----------5-3        N--------5---3           N----------5-3          N------3-5                 *
           *    N------53              N------5----3            N-----5--------3        N-------3-5                *
           *    N------------3-5       N------5----3            N---5---------3         N-------X                  *
      15.0 I    N-------------5------3 N-----5-------3          N--5----------3         N-----53                   I 15.0
           *    N-------3---5          N---------5-3            N------5-------3        N----3-5                   *
           *    --------X              ----------534            ---------5---X          ------5-3-4                *
           *    -------X               --------354              --------X5              ---354                     *
           *    ------------X          -------3-4--5            ---------X              --------345                *
      20.0 I    -----------5X          -------3-4--5            -----3-X                ----3X                     I 20.0
           *    ---------5-X           -------3--X              ------534               ----X5                     *
           *    ---------X             -------3--X              --------5-4-3           -------X                   *
           *    --------X5             ----3--4---5             -------X5               ----X5                     *
           *    -----------X           --------3----54          --------3-5-4           -----3-54                  *
      25.0 I    ------------5X         -----------X-----4       --------5-34            -------5---3-4             I 25.0
           *    --------X              -------------53---4      -----5------4-3         --------534                *
           *    -----------X           -------------53---4      ------5----34           ---------3-54              *
           *    ------------X          ----------35----4        -----5---X              ----5--X                   *
           *    ----------------5X     ---------3-5-4           --------5-34            ---------5X                *
      30.0 I    N--------5-3           N---------X              N--------5--3           N---------35               I 30.0
           *    ---------5X            ---------53---4          -----5-3-4              ------X-4                  *
           *    ------------X          -----------X--4          ------------5-34        ----------354              *
           *    --------X              ----------X--4           ----------X4            -------354                 *
           *    ----------X            -------35--4             ----------X--4          -------3X                  *
      35.0 I    ---------X             -------53-4              -------5---X            -----3X                    I 35.0
           *    --------X-5            ------------35---4       ---------35-4           -----3-54                  *
           *    N-------------35       N---------X              N---------X             N---3-5                    *
           *    --------------X-----4  --------35-4             ---------X4             --------345                *
           *    ---------X             -------3--5-4            -------3X               ----345                    *
      40.0 I    -------35--4           -------3--54             --------345             ---3-X                     I 40.0
```

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Figure C-15. Geoplot Report

Use of Automatically Acquired Track Geometry Data for Maintenance-of-Way Planning Final Report - June, 1980, G. Hayes, K. Bradley, B. Price, D. Sawyer, A. Dominguez, US DOT, FRA, 01-Track & Structures