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ZETA-TECH

ZETA-TECH Associates, Inc.
900 Kings Highway North
P.O. Box 8407
Cherry Hill, New Jersey 08002
(609) 779-7795
Fax: (609) 779-7436
email:zetatech@zetatech.com

02-Track-Train Dynamics

Demonstration of
High Speed Track Maintenance
Using Objective Gage Strength Data

Revised Final Report

Federal Railroad Administration
Office of High Speed Rail

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ZETA-TECH Associates, Inc.
900 Kings Highway North
Cherry Hill, New Jersey 08034
Phone: (609) 779-7795
FAX: (609) 779-7436
Email: zarembski@zetatech.com
http://www.zetatech.com

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EXECUTIVE SUMMARY

This report presents the results of the FRA sponsored project "Demonstration of High Speed Track Maintenance Using Objective Gage Strength Data". This activity, which is part of the FRA's Next Generation High Speed Rail Program, is aimed at the development of "maintenance" criteria for track strength and associated crosstie replacement requirements for both conventional and high speed railroad track. These criteria, in turn, are based on the use of objective track strength measurement data such as taken from GRMS type inspection vehicles. As part of this maintenance criteria development, an assessment of the "minimum" level of upgrade necessary to allow for the operation of both conventional freight and high speed passenger trains on existing tracks is also made. This activity included the definition of suitable track strength maintenance criteria for existing wood tie track (to support both freight train operations and high speed passenger operations) and the determination of the relationship between these criteria and the rate of degradation (and maintenance) of the track strength.

The focus of this FRA sponsored project was on the development of maintenance parameters for ties and fasteners, and corresponding tie replacement requirements, based on objective track (gage) strength measurements. Such a maintenance approach would allow for more cost effective maintenance for both conventional and high speed track. The project made use of track strength data taken by CSX Transportation's GRMS track inspection vehicle. The study examined the CSX Transportation line segment between Richmond, VA and Washington, DC. Track 3, between MP 4 and MP 109, was selected for analysis because of data availability and history of recent tie installations. This line segment sees regularly scheduled GRMS vehicle tests and supports a mix of freight traffic to include coal, intermodal, and mixed traffics. The line segment is also a potential site for increased speed passenger operations.

The results of this activity indicate that Track Strength Quality Indices, TSQIs, can be developed which relate the GRMS output data to the general condition of the tie-fastener system. Furthermore, these TSQIs can be correlated to the number of ties installed, to develop a predictive relationship between improvements in TSQIs and ties installed. The TSQI can also be used as part of the tie installation decision making process with a potentially significant reduction of ties needed to be installed in order to achieve an acceptable level of track strength[1] from both the safety and maintenance points of view.

[1] Note, this does not necessarily include ties needed for vertical support, which may not be identified by the GRMS data. It further does not account for any additional factors of safety introduced by maintenance officers in anticipation of non-uniform future maintenance (e.g. periods of potential deferred maintenance). Thus there may be a "gap" between the theoretical minimum number of ties needed for maintaining the track on an ongoing basis, and the number of ties that are installed in anticipation of future fluctuations in budget and maintenance focus.

The TSQI parameters that were found to be most meaningful in representing the track condition were "mean" values, calculated over a mile length of track of the following key GRMS outputs:

- Loaded Gage
- Projected Loaded Gage (PLG 24)
- Delta Gage (Loaded Gage – Unloaded Gage)
- Gage Widening Ratio (GWR)

In addition, meaningful correlations were also obtained by summing the number of feet per mile (or number of ties per mile which was calculated by dividing length by tie spacing) exceeding a defined PLG24 or GWR threshold.

Analysis of the CSX tie insertion data shows a good correlation between mean PLG 24 (specifically mean PLG24 > 0.5[2]), mean GWR (GWR > 0.30) and actual tie insertions performed by a production tie gang. Furthermore, analysis of the number of feet of track, per mile, exceeding these thresholds, likewise shows a correlation with the tie insertions, though the variation in this parameter is significantly greater than for the mean value itself. This correlation supports the use of GRMS data as a maintenance management tool.

Analysis of the GRMS degradation data (between the 1996 and 1998 GRMS runs) showed that in those zones where no ties were inserted, the mean loaded gage increased in all cases, corresponding to a degradation of tie condition with time and traffic. Furthermore, the zone with the greatest traffic density, MP 4 through MP 22, had the largest increase in mean loaded gage, an increase of 80%. Overall, for all zones, the loaded gage increased from 0.19 to 0.26, an increase of 37%. Based on an average tonnage of 65 MGT over the two years, this corresponds to an increase in loaded gage of 0.0011 per MGT.

Analysis of the GRMS data for the zones where ties were inserted showed that in these cases, the average loaded gage decreased, corresponding to the improvement in track strength due to the new ties and fasteners. Using statistical regression techniques, this data resulted in the development of a correlation between the Track Strength Quality Index parameters and the number of ties inserted. The resulting correlation equation is presented in this report. A similar relationship was obtained for Loaded gage.

Examination of tangent and curve track data shows similar trends.

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[2] As used here, the PLG24 value represents the value above nominal gage of 56 ½". Thus a PLG24 value of 0.5 would correspond to a value of 57".

Based on the results of the measurements and data collected on this line, together with earlier FRA and TSC test data for track strength values, a set of maintenance thresholds for the TSQI planning index were developed. These, per mile mean limit for PLG24 (the maintenance PLG24) were set as follows:

	"Maintenance"	PLG24
Low Speed Freight (Class 3)	0.625	57 1/8"
Moderate/High Speed Track (Class 4)	0.5	57"
Passenger (Class 6)	0.375	56 7/8"

It should be noted that the limit of 0.5 (57") corresponds to the measured average of the mean PLG24 on the track that was actually timbered by CSX (thus determined by the railroad inspectors as requiring ties).

These limits allow for the determination of the number of ties to be inserted per mile, by calculating the difference between the "actual" (measured) mean PLG24 for the mile and the above defined limit. This difference is then divided by the "slope" of the PLG 24 equation to calculate the number of ties to be inserted.

Finally, application of these limits to the study track showed that for current operations (Moderate Class 4 track), the above defined mean PLG24 limits can be reached with between 50% and 80% of the actual ties installed (based on obtaining an equivalent mean average PLG24 comparable to what was actually achieved, which was of the order of 0.47 or 56.97"). *For high speed track, with the more restrictive PLG24 limit noted above (.375" corresponding to 56 7/8"), the predictive equation, developed in this study, can be used to determine the number of ties necessary to bring the track to the higher strength standard associated with high speed operations.* The results of such an application is likewise presented for several specific mileposts, specifically the number of ties that would have to be installed to reach the more restrictive PLG24 level required for high speed passenger operations.

Based on the results presented in this report, it appears that the GRMS data, when developed in the form of TSQI values, on a mile by mile or segment by segment[3] basis, can be used as part of the maintenance planning process as well as a predictor of crosstie replacement requirements.

[3] The TSQI presented in this report can be applied on a segment by segment basis, such as either mile length of track, curve vs. tangent lengths, or other lengths as appropriate.

Acknowledgement:

This work was performed under the sponsorship of the Federal Railroad Administration's Next Generation High Speed Rail Program. The author would like to acknowledge the contributions and support of Mr. Robert McCown and Mr. Steven Sill of the FRA. The author would also like to acknowledge the support of CSX Transportation and the contributions of Mr. Thomas Schmidt and Dr. Gregory Martin of CSX.

Introduction and Data Collection

This report presents the results of the FRA sponsored project "Demonstration of High Speed Track Maintenance Using Objective Gage Strength Data". This activity, which is part of the Next Generation High Speed rail program, is aimed at the development of "maintenance" criteria for track strength and associated crosstie replacement requirements for both conventional and high speed railroad track. These criteria, in turn, are based on the use of objective track strength measurement data such as taken from GRMS type inspection vehicles. As part of this maintenance criteria development, an assessment of the "minimum" level of upgrade necessary to allow for the operation of high speed passenger trains on existing tracks is also made. Specifically, this activity will focus on the definition of suitable track strength maintenance criteria for existing wood tie track (to support both freight train operations and high speed passenger operations) and to determine the relationship between these criteria and the rate of degradation (and maintenance) of the track strength. Also of specific concern is the optimization of the maintenance parameters, so as to allow for the operation of high speed passenger trains on the track with a minimum of additional maintenance.

The focus of this analysis is the CSX Transportation line segment between Richmond VA and Washington DC. Track 3, between MP 4 and MP 109, was selected for analysis because of data availability and history of recent tie installations. This line segment sees regularly scheduled GRMS vehicle tests and currently supports a mix of freight traffic to include coal, intermodal, and mixed traffics. Annual tonnage varies between 16 and 56 MGT. The line segment is also a potential site for increased speed passenger operations.

The following data was requested and received from CSX for this line between Richmond and Washington (the old RF&P line) between CFP MP4 and CFP MP109.

1. GRMS vehicle measurements
    - Date tested
    - Unloaded Gage
    - Loaded Gage
    - Delta Gage (Loaded Gage – Unloaded Gage)
    - Gage Widening Ratio (GWR)
    - Projected Loaded Gage (PLG 24)
2. Tie condition data (corresponding to GRMS test dates)
    - Bad Tie Count
    - Tie replacement history
        - 1996
        - 1997
        - 1998

3. Annual traffic level (MGT)
   traffic mix (estimated distribution of traffic by traffic type)
4. Rail replacement history

Data was received for this line segment corresponding to two GRMS inspections:

- The first performed on August 20, 1996 prior to the start of a recent series of tie replacement activities.
- The second GRMS run taken in May 1998 after the conclusion of the Spring 1998 tie insertion program.

In addition to actual tie insertion records for the period fall 1996 through Spring 1998 (between the two GRMS runs), two on the ground inspections by ZETA-TECH personnel using the *TieInspect* recording system (see Appendix A) were performed (March 1998 and November 1998).

Development of Track Strength Quality Indices

The initial focus of the analysis was on the development of a Track Strength Quality Index (TSQI) which represents a tie/fastener (track strength) maintenance condition indicator representing the condition of an extended stretch of track. Because tie data is often stored on a per mile basis (as illustrated in the tie timbering report presented in Table 1), a one mile[4] unit of track was initially postulated as a baseline length[5] for calculating the TSQI. This index is envisioned as a parallel index to the Track Quality Indices (TQIs) currently used to summarize and evaluate track geometry data from conventional track geometry recording cars. The intent is to use the multiple run GRMS data to define such a TSQI and to correlate this set of summary data with bad tie count data on that line.

In addition, actual load and track strength (deflection) data can also be used to help define appropriate limits for this TSQI. Note, this approach is not intended to duplicate or address the track strength safety issue which has already been covered by other FRA research programs. Rather, the focus of this study is on the definition of maintenance requirements for the determination of an appropriate level of track strength for both conventional and high speed train operations. Thus, these TSQI values will be in addition to any discrete track strength safety standards (e.g. PLG, Loaded gage, etc.)

Initial focus was on the use of statistical based parameter such as:

- mean (μ)
- standard deviation (σ)
- percentile value ($\mu + 2\sigma$, $\mu + 3\sigma$, etc.)

This represents a "top down" analysis approach similar to that currently used for track geometry Track Quality Indices (TQIs).

Follow up analysis also examined the data in a bottom up format, based on "threshold exceedances'.

[4] Since not all railroad miles are 5280 feet, the full length of the mile was used and normalized to 5280'.
[5] One mile was selected for the initial assessment since the railroad maintained all of its crosstie replacement data in one mile increments. In addition, one mile has been a traditional railroad "length" for use of track geometry indices (TQIs). Other lengths of track, e.g. corresponding to homogeneous segment (to include curves, tangents, homogeneous maintenance zones, etc.) may also be postulated as being meaningful from a maintenance planning point of view.

Table 1

TIMBERING WORK - MP CFP 0 TO CFP 999
FROM 01/01/95 TO 12/31/97

TRACK NAME	PREF	FROM MP	TO MP	MILES TIMB.	NEW TIES	CONC TIES	CLASS	RELAY TIES	TOTAL TIES	DATE	GANG	JOB
2	CFP	64.8	66.5	1.7	2,005	0	M	0	2,005	97/07/22	16XT3	BA7TASP003
2	CFP	65.2	69.5	4.3	2,577	0	M	0	2,577	97/08/05	16XT3	BA7TASP003
2	CFP	66.6	68.4	1.8	1,778	0	M	0	1,778	97/07/23	16XT3	BA7TASP003
2	CFP	68.1	70.2	2.1	1,741	0	M	0	1,741	97/07/24	16XT3	BA7TASP003
2	CFP	69.2	70.0	.8	441	0	M	0	441	97/08/06	16XT3	BA7TASP003
2	CFP	69.8	70.0	.2	1,866	0	M	0	1,866	97/08/07	16XT3	BA7TASP003
2	CFP	70.0	71.0	1.0	441	0	M	0	441	97/08/06	16XT3	BA7TASP003
2	CFP	71.0	72.0	1.0	441	0	M	0	441	97/08/06	16XT3	BA7TASP003
2	CFP	71.9	74.2	2.3	1,956	0	M	0	1,956	97/07/29	16XT3	BA7TASP003
2	CFP	72.0	72.4	.4	441	0	M	0	441	97/08/06	16XT3	BA7TASP003
2	CFP	74.0	75.0	1.0	582	0	M	0	582	97/08/11	16XT3	BA7TASP003
2	CFP	74.3	75.0	.7	1,071	0	M	0	1,071	97/08/13	16XT3	BA7TASP003
2	CFP	75.0	76.0	1.0	582	0	M	0	582	97/08/11	16XT3	BA7TASP003
2	CFP	75.0	76.0	1.0	1,071	0	M	0	1,071	97/08/13	16XT3	BA7TASP003
2	CFP	76.0	76.6	.6	582	0	M	0	582	97/08/11	16XT3	BA7TASP003
2	CFP	76.0	77.0	1.0	1,072	0	M	0	1,072	97/08/13	16XT3	BA7TASP003
2	CFP	76.4	79.0	2.6	824	0	M	0	824	97/08/12	16XT3	BA7TASP003
2	CFP	77.0	78.0	1.0	824	0	M	0	824	97/08/12	16XT3	BA7TASP003
2	CFP	77.0	79.1	2.1	2,147	0	M	0	2,147	97/08/14	16XT3	BA7TASP003
2	CFP	78.0	79.0	1.0	823	0	M	0	823	97/08/12	16XT3	BA7TASP003
*TOTAL TRACK 2												
				48.2	45,427	0		0	45,427			
3	CFP	23.0	24.0	1.0	500	0	M	0	500	96/11/14	15XT4	BA6TASP040
3	CFP	24.0	25.0	1.0	895	0	M	0	895	96/11/14	15XT4	BA6TASP040
3	CFP	25.0	26.0	1.0	808	0	M	0	808	96/11/14	15XT4	BA6TASP040
3	CFP	26.0	27.0	1.0	571	0	M	0	571	96/11/18	15XT4	BA6TASP040
3	CFP	27.0	28.0	1.0	677	0	M	0	677	96/11/18	15XT4	BA6TASP040
3	CFP	28.0	29.0	1.0	609	0	M	0	609	96/11/18	15XT4	BA6TASP040
3	CFP	29.0	29.7	.7	552	0	M	0	552	96/11/18	15XT4	BA6TASP040
3	CFP	29.7	30.0	.3	159	0	M	0	159	96/11/19	15XT4	BA6TASP040
3	CFP	34.0	35.0	1.0	1,124	0	M	0	1,124	96/11/19	15XT4	BA6TASP040
3	CFP	83.0	83.7	.7	450	0	M	0	450	96/11/20	15XT4	BA6TASP059
3	CFP	83.7	84.0	.3	388	0	M	0	388	96/11/21	15XT4	
3	CFP	84.0	85.0	1.0	984	0	M	0	984	96/11/21	15XT4	
3	CFP	85.0	86.0	1.0	1,005	0	M	0	1,005	96/11/21	15XT4	
3	CFP	86.0	86.5	.5	625	0	M	0	625	96/11/21	15XT4	
3	CFP	86.6	87.0	.4	435	0	M	0	435	96/11/22	15XT4	BA6TASP059
3	CFP	87.0	88.0	1.0	1,018	0	M	0	1,018	96/11/22	15XT4	BA6TASP059
3	CFP	88.0	89.0	1.0	947	0	M	0	947	96/11/22	15XT4	BA6TASP059
3	CFP	89.0	90.0	1.0	605	0	M	0	605	96/11/22	15XT4	BA6TASP059
*TOTAL TRACK 3												
				14.9	12,352	0		0	12,352			
*TOTAL PREF CFP												
				74.4	69,306	0		0	69,306			

Initial examination was made of the statistical mean of five GRMS output values:

- Unloaded Gage
- Loaded Gage
- Delta Gage (Loaded Gage – Unloaded Gage)
- Gage Widening Ratio (GWR)
- Projected Loaded Gage (PLG 24)

Appendix B presents the mean of all five of these parameters for the segment CFP MP 5 to CFP MP 37. It should be noted that the Projected Loaded Gage (PLG 24) corresponds closely to the loaded gage (see Appendix B), and combines both the tie lateral (gage) strength and the gage itself. It is thus sensitive to both wide gage and weakened track strength. The GWR corresponds closely to the Delta Gage (normalized for applied load) and is sensitive primarily to the track strength itself (by design it is not sensitive to wide gage).

Initial Data Analysis

During initial analysis of the August 1996 GRMS test data, there appeared to be some inconsistencies between the PLG24 and GWR data results. Subsequent analysis of the data used in the calculation of PLG24 and GWR (specifically loaded gauge and unloaded gauge, both of which were recorded directly by the GRMS) showed that the mean unloaded gage for the 1996 GRMS run was erratic and inconsistent. This can be seen clearly in Figure 1 which compares the 1998 run's mean unloaded gage with the 1996 mean unloaded gage. (Note, mean unloaded gage is the statistical mean or average of all the individual – one foot measurements taken on each mile. Thus Figure 1 corresponds to 105 miles, between MP 4 and MP 109.) As can be seen in this Figure, the 1998 data shows little variation in the mean unloaded gage for each of the 105 miles. This is to be expected since the actual gage is not expected to vary dramatically from mile to mile, for track with comparable traffic, geometry, and maintenance practices. However, the 1996 data shows significant variation in mean gage, with a maximum variation in mean (average) unloaded gage of 0.6 inches. This is totally inconsistent with the 1998 data and brings into question accuracy of the 1996 unloaded gage measurement. (Such behavior can be due to excessive noise in the data acquisition channel itself or in the transducer.)

Figure 2 presents the mean loaded gage for the two consecutive GRMS runs. Note how the two runs have very similar behavior. The difference in individual values is due to the degradation of the track strength (tie/fastener condition) in the two year period between measurement runs, or insertion of new ties.

Based on the above, the 1996 unloaded gage measurements should be used with caution. Note that the equations for PLG24 and GWR (Gage Widening Ratio) are:

$$PLG24 = UTG + A *(LTG - UTG)$$

And

$$GWR = (LTG- UTG)/L * 16000$$

Where

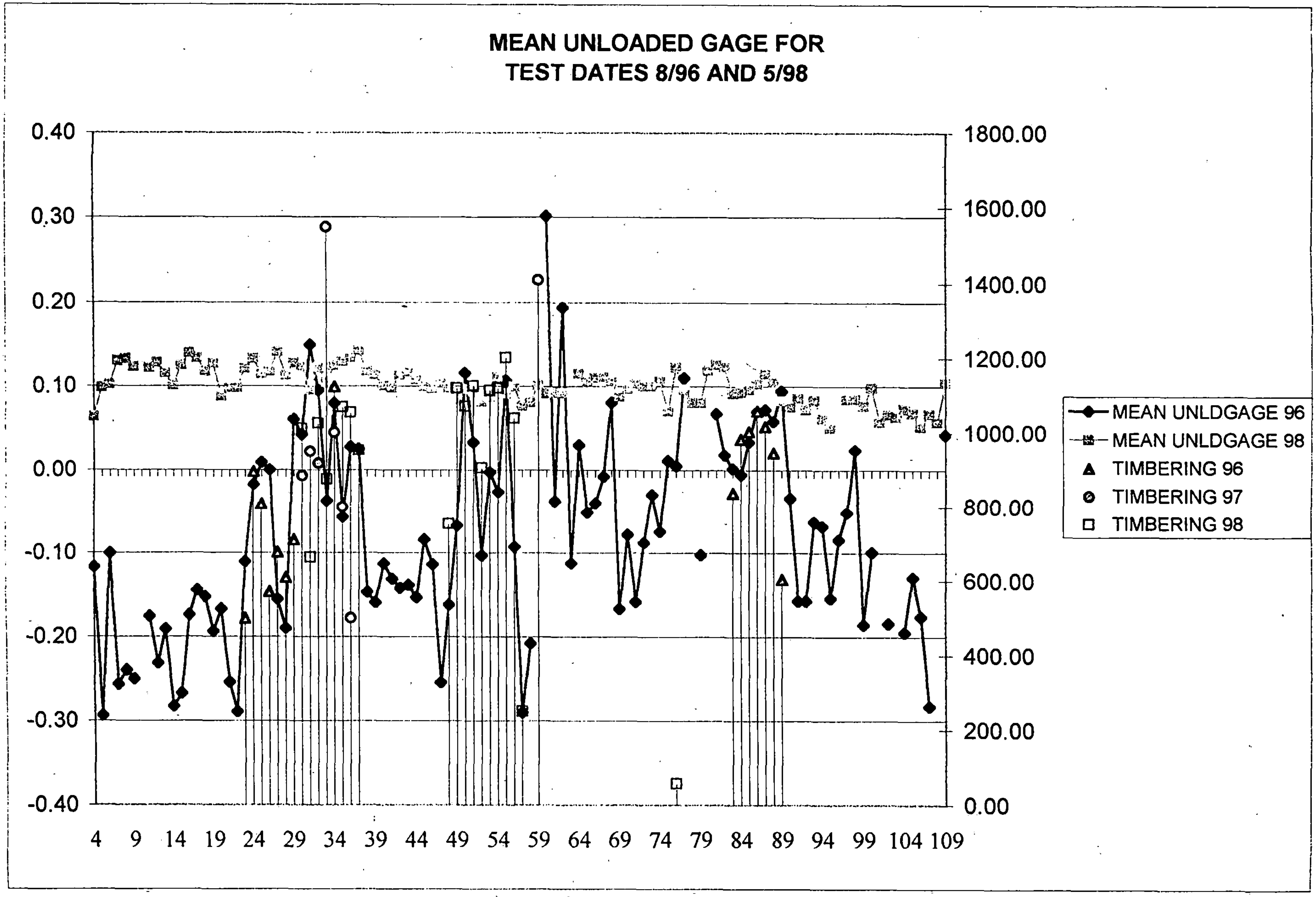
UTG is the unloaded gage

LTG is the loaded gage

A is a constant of the order of 1.6 for the GRMS vehicle

and L is the lateral load applied by the GRMS.

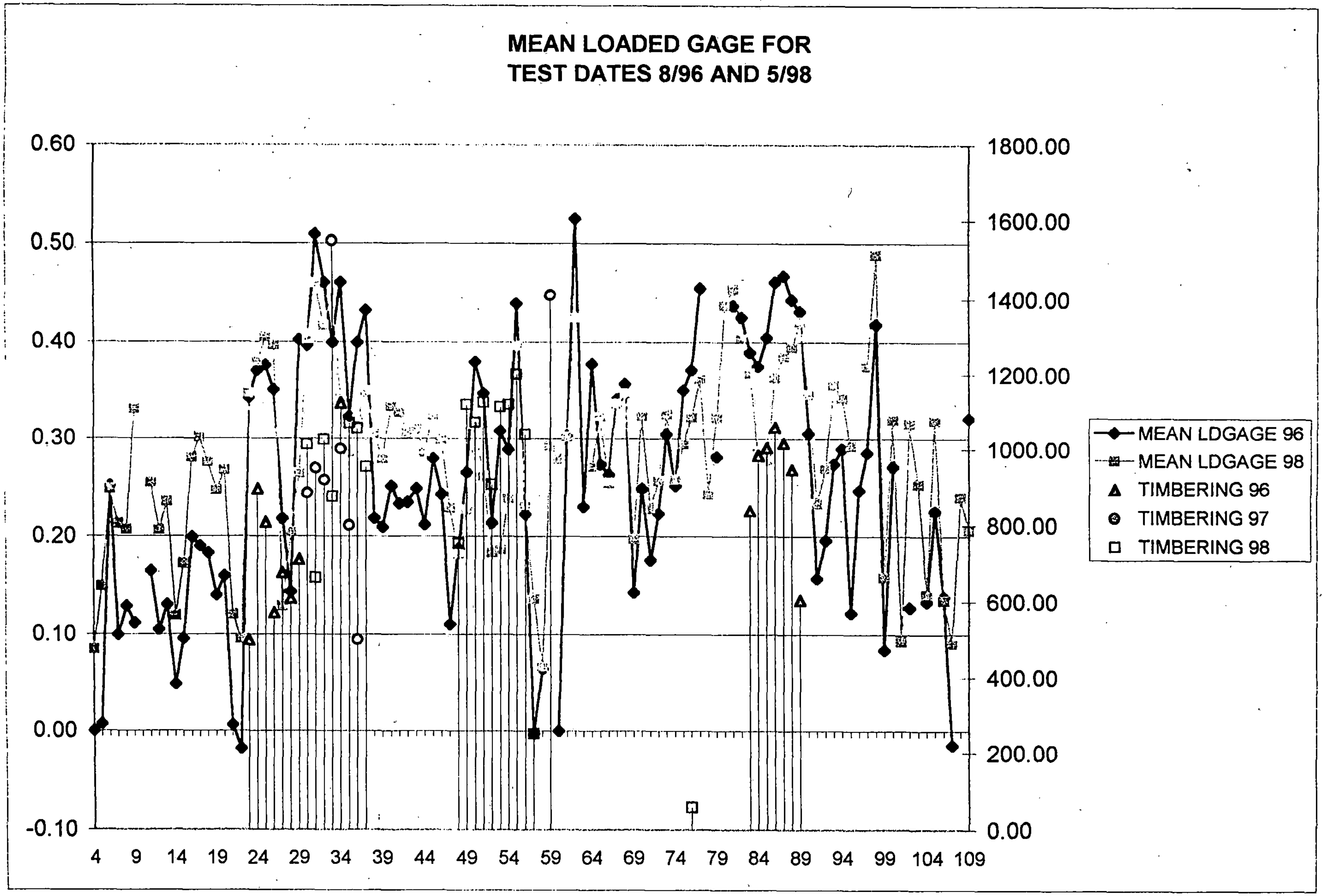
Figure 1



MEAN UNLOADED GAGE FOR
TEST DATES 8/96 AND 5/98
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
4 9 14 19 24 29 34 39 44 49 54 59 64 69 74 79 84 89 94 99 104 109
MEAN UNLDGAGE 96
MEAN UNLDGAGE 98
TIMBERING 96
TIMBERING 97
TIMBERING 98

11

Figure 2



MEAN LOADED GAGE FOR
TEST DATES 8/96 AND 5/98
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
4 9 14 19 24 29 34 39 44 49 54 59 64 69 74 79 84 89 94 99 104 109
MEAN LDGAGE 96
MEAN LDGAGE 98
TIMBERING 96
TIMBERING 97
TIMBERING 98

It can thus be seen that the Gage Widening Ratio is strongly dependent on the unloaded gage and thus the 1996 GWR values must be used with caution. The PLG24 value is less dependent on the unloaded gage and so is less effected by any problems associated with the unloaded gage measurements[6]. This explains the inconsistency in the February 1998 interim report between the two parameters where there was a distinct difference in sensitivity to the bad tie count for the same trackage.

Thus for the analysis presented here, the focus will be on the loaded gage directly (which is completely unaffected by the unloaded gage) and the PLG24 which is not as strongly effected by the observed problem with the data. GWR will not be a major focus here because of the problem noted above.

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[6] A ½" error in unloaded gage will result in a ½" error in GWR but only an approximate ¼" error in PLG24.

Comparison of August 1996 GRMS Data with CSX Tie Program

Initial evaluation of the TSQI data was performed using the August 1996 data in a mode corresponding to that of a maintenance planning officer, i.e. to help utilize the data for planning tie programs. As such this data is compared to the follow up CSX tie programs. Figure 3 presents the mean value of the PLG24 output for the segment CFP MP 5 to CFP MP 37, with the locations of the November 1996 tie program superimposed. Examination of this Figure indicates that the region between MP 23 and MP 37 shows significant higher mean PLG value than does the region between MP 5 and 22. Noting that according to the CSX roadmaster, MP 30 through 37 is scheduled for tie work in 1998, this data suggests an initial correlation between CSX timbering and GRMS PLG 24 measurements. However questions remain as to why MP 27 and 28 received ties while MP 31 did not. (Recent discussions with the CSX roadmaster indicated that based on his recollection, the miles that were timbered had the highest number of bad ties at the time and there was no other reason for the timbering on MP 27 and 28.)

Examination of the tie data for CFP MP 80 through 100 shows similar behavior. Examination of the mean PLG24 data (Figure 4) shows that the miles timbered had for the most part the highest PLG24 values, significantly higher than the adjacent miles 90 – 97 which were not timbered. This again suggests a good correlation between PLG measurements and actual tie counts (on which the timbering program was based). However, MP 81-82, which were not timbered, showed equally high PLG24 values to the miles that were timbered. (Note, there was no timbered mile in this segment that had a very low PLG24 value, as occurred in MP 5-37.)

Examination of the standard deviations for all five parameters together with the mean + standard deviation (mean + sigma) values show significantly less sensitivity to the actual tie program. This is clearly evident in Figure 5 which shows the standard deviation for the PLG24 values for all 32 miles. Note, MP 23 through 29 (and MP 30 – 37) do not stand out as clearly as they did in Figure 1. Appendix C presents the standard deviations for the different parameters together with the mean+standard deviation trends. Again the correlation is not as well defined as for the mean values presented in Figure 3.

Appendix D presents similar data for MP 80 through 100. Again note that the primary mean values appear to be the PLG24, and that the standard deviation of the parameters do not appear to present any additional information (that corresponds to the actual tie program performed).

Figure 3

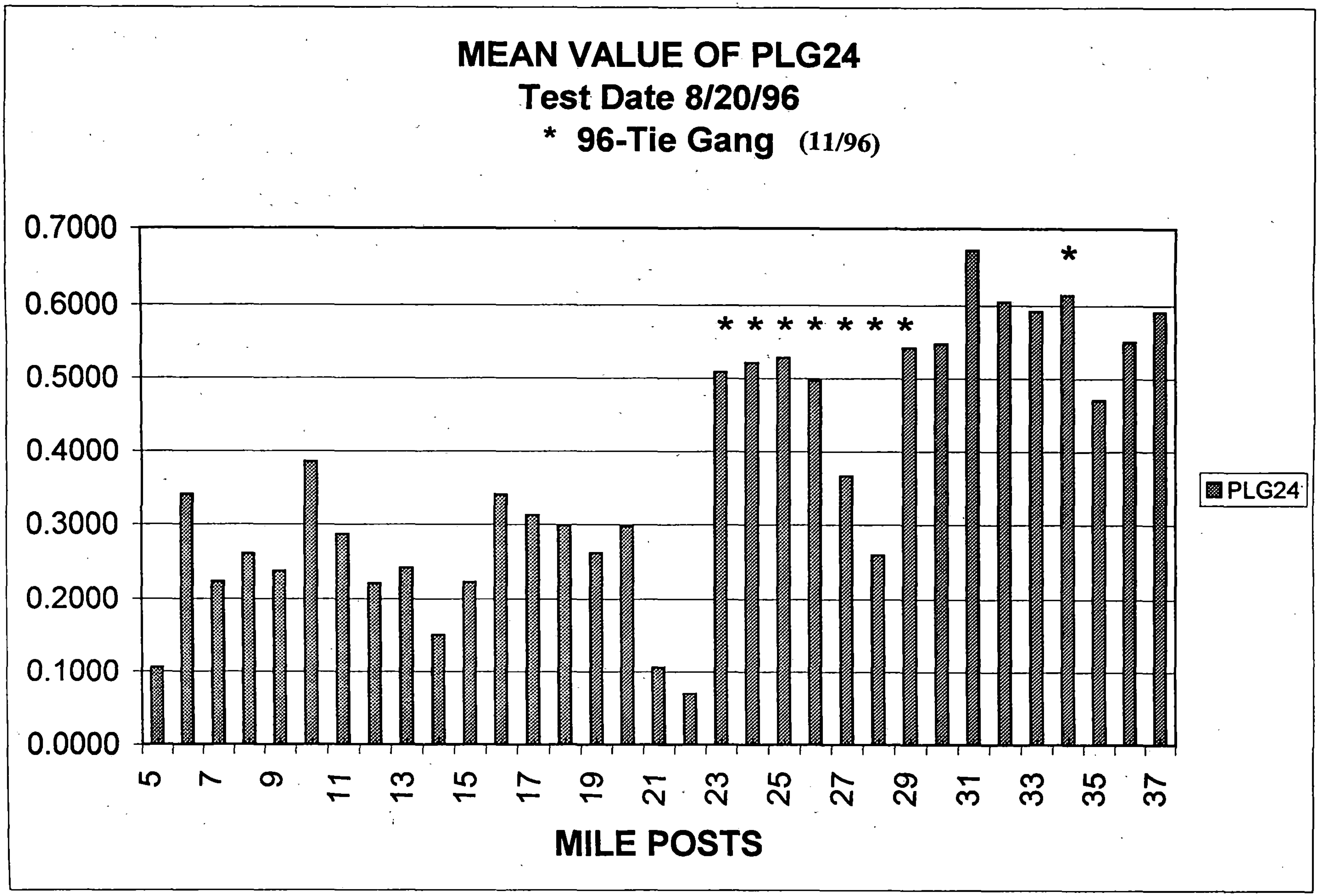

MEAN VALUE OF PLG24
Test Date 8/20/96
* 96-Tie Gang (11/96)
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
* * * * * * *
*
PLG24
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
MILE POSTS

Figure 4

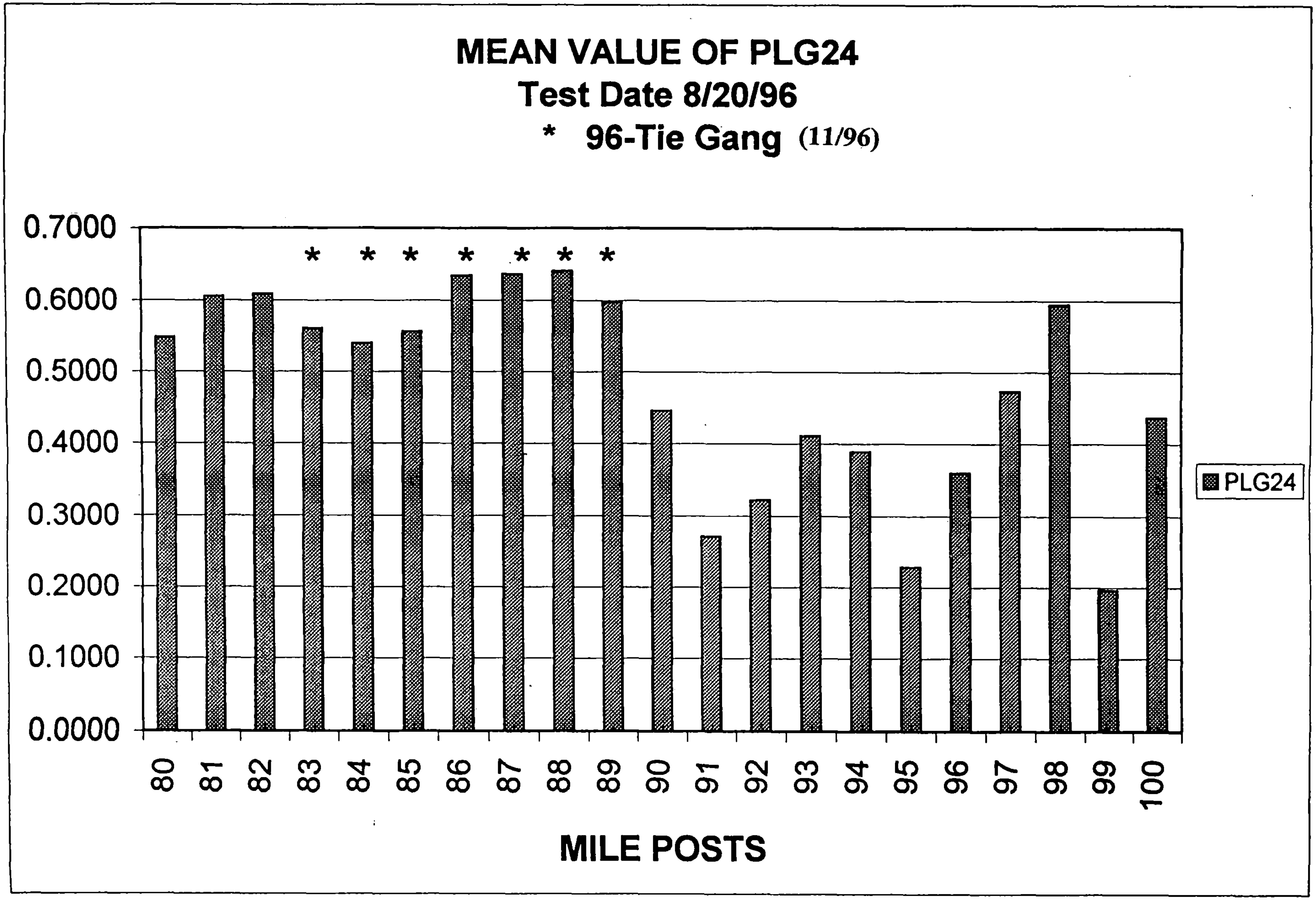
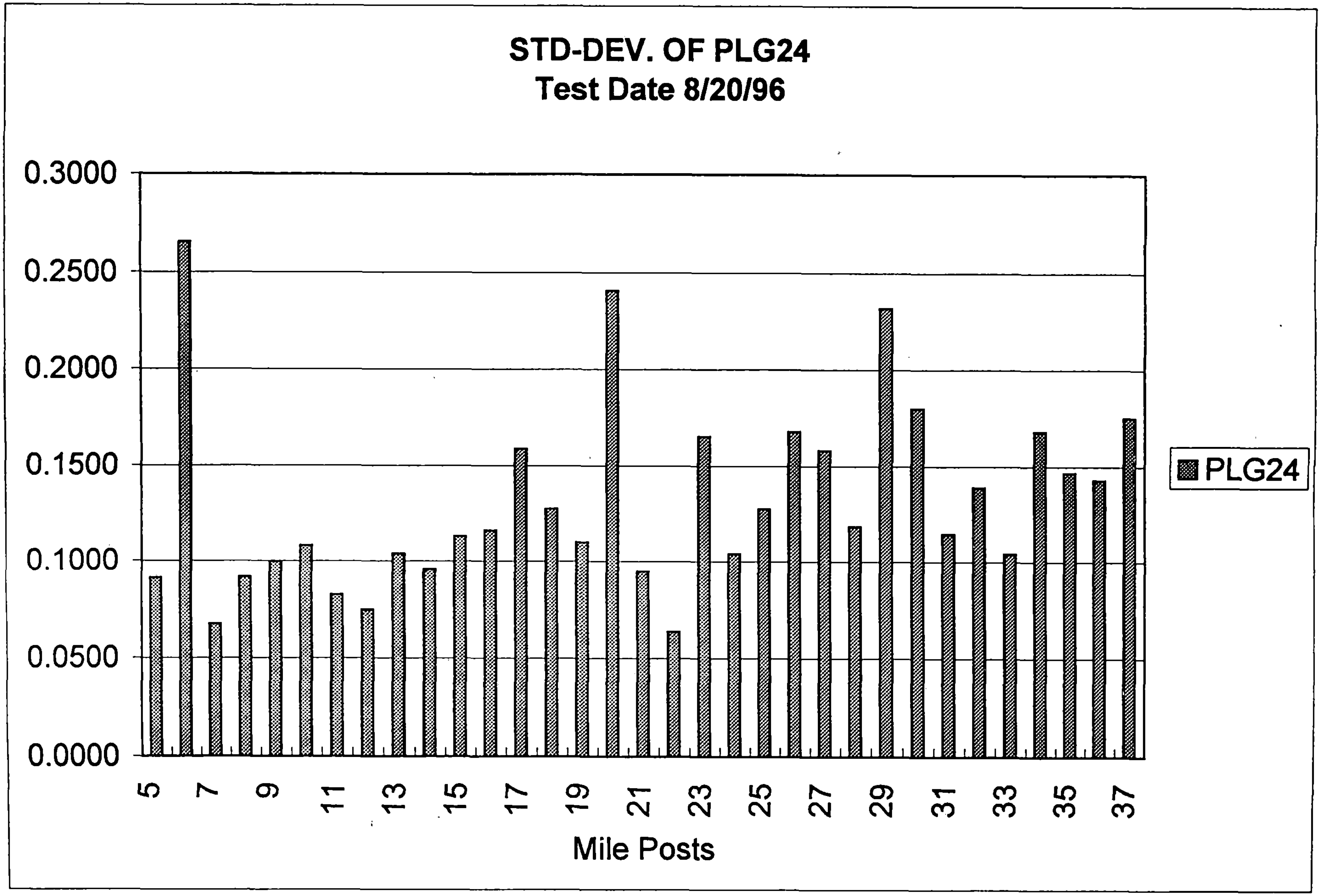

MEAN VALUE OF PLG24
Test Date 8/20/96
* 96-Tie Gang (11/96)
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
MILE POSTS
PLG24

Figure 5


STD-DEV. OF PLG24
Test Date 8/20/96
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
Mile Posts
PLG24

Use of Threshold Levels

As noted above, the use of summary statistics such as the mean values presented here represents a "top down" analysis approach. In order to attempt to achieve a better correlation with the actual CSX timbering program experience, a "bottom up" approach was also attempted. This analysis focused on the segment between MP 22 and MP 37, where the actual 1996 timbering program was carried out (and where the 1998 program is scheduled). This bottom up approach is based on a threshold approach comparable to that used for safety or immediate maintenance exceptions. However, while CSX current thresholds are 1.0" for PLG24[7] and 0.75" for the GWR[8], the maintenance values to be examined here will be at a reduced level.

Figure 6 presents the mean value of the PLG24 for this segment. Note, the miles timbered in 1996 are displayed in gray. As was already observed in Figure 3, there is no clear explanation for why MP 27 and 28 were included in this program. Figure 7 shows the number of feet exceeding a threshold of 0.5" (note CSX's on-board threshold is 1.0"). This graph closely parallels the mean PLG24 graph (Figure 6) except that it further accentuates the differences between the mileposts in question. Note, a threshold value of 0.75" was also examined however, it was too coarse and even further accentuated the differences. Table 2 and 3 (normalized by the actual footage per mile) summarizes these values in tabular form.

Figure 8 compares all five of these parameters in a normalized mode (see Table 3). In general, the mean values appear to show less differences than the bottom up exceedance values.

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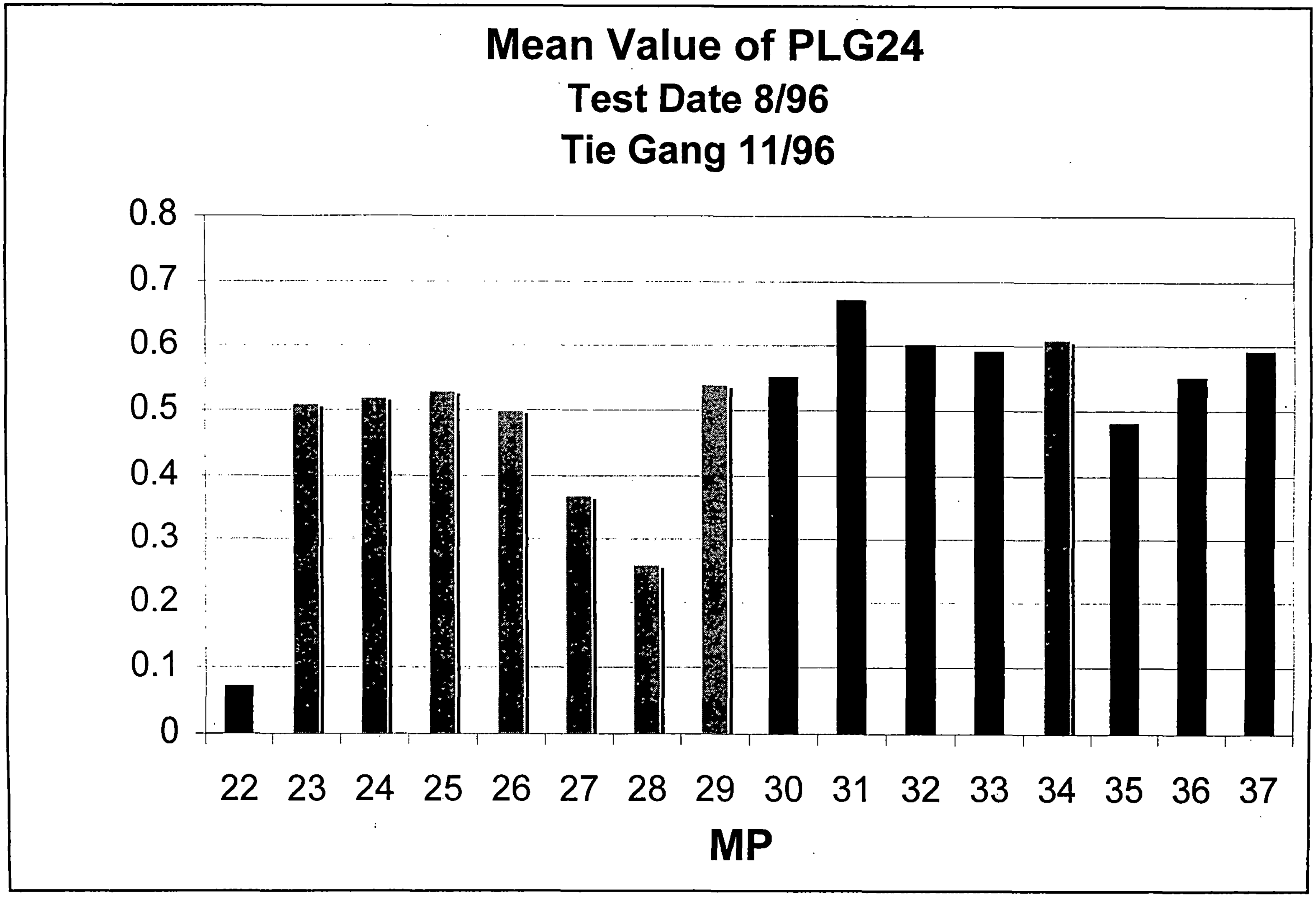
[7] As used here, the PLG24 value represents the value above nominal gage of 56 ½". Thus a PLG24 value of 1.0. would correspond to a value of 57 ½".

[8] While GWR was not used as a primary analysis tool here, some level of analysis was performed in order to determine the potential level of sensitivity of this parameter.

Figure 6


Mean Value of PLG24
Test Date 8/96
Tie Gang 11/96
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37
MP

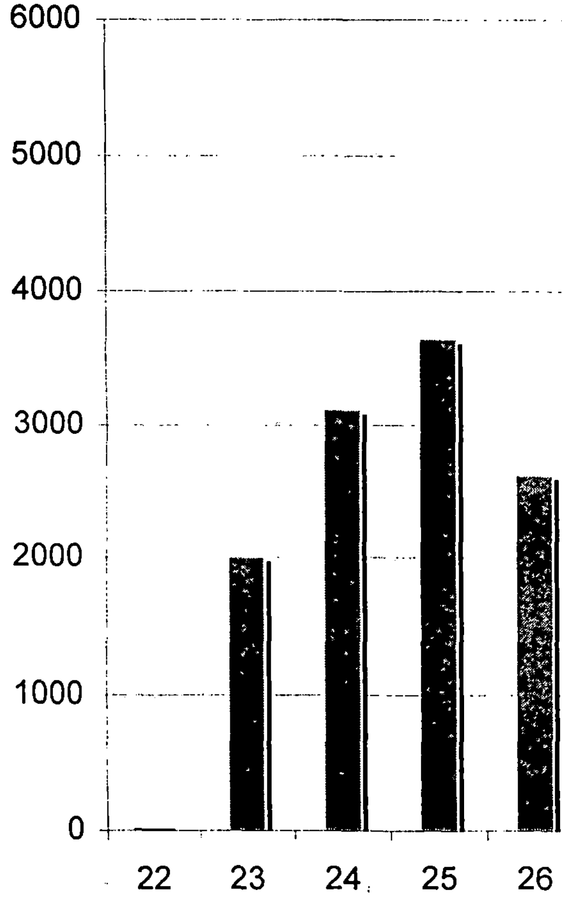

6000
5000
4000
3000
2000
1000
0
22
23
24
25
26

Figure 7

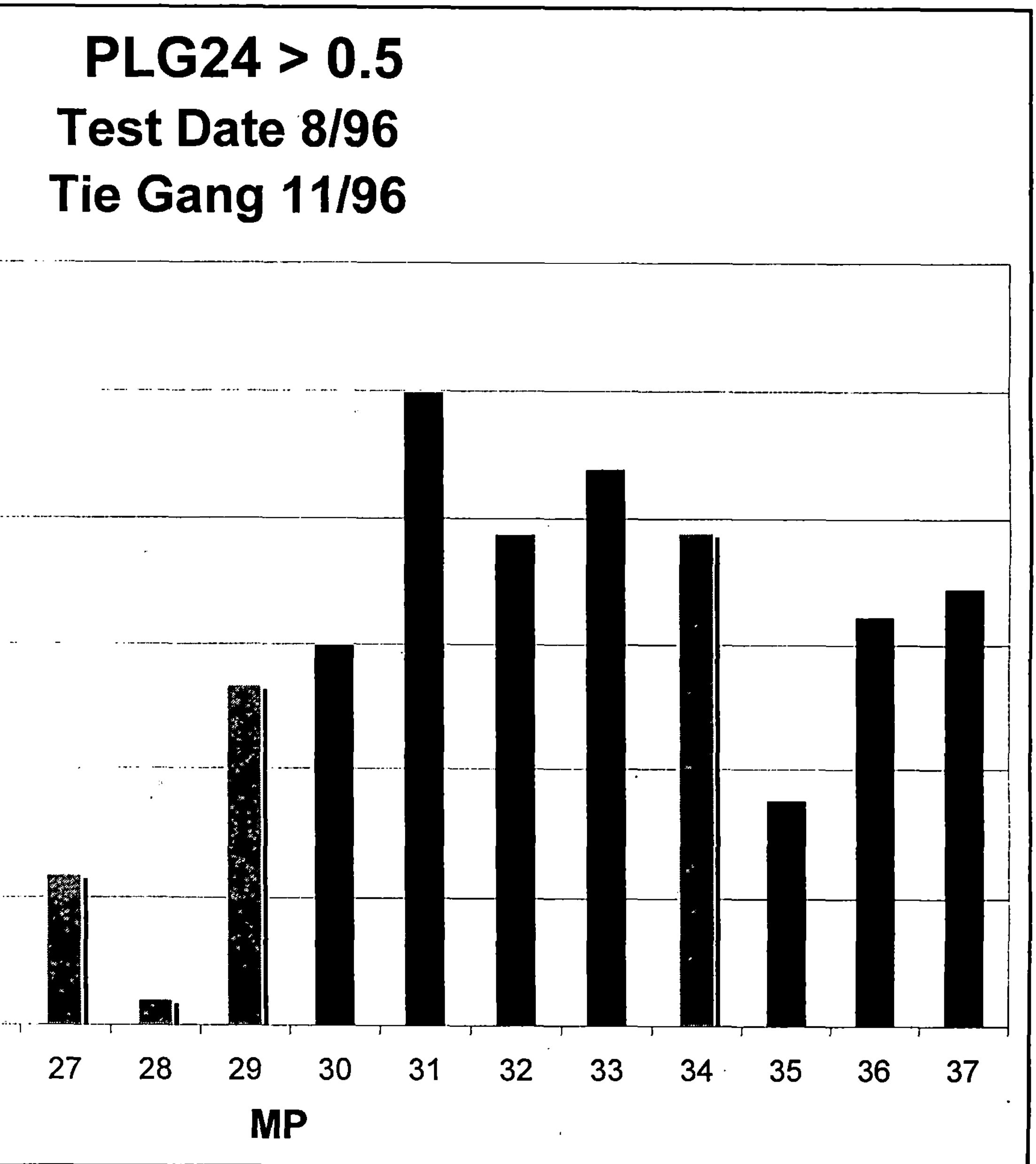

PLG24 > 0.5
Test Date 8/96
Tie Gang 11/96
27
28
29
30
31
32
33
34
35
36
37
MP

Figure 8

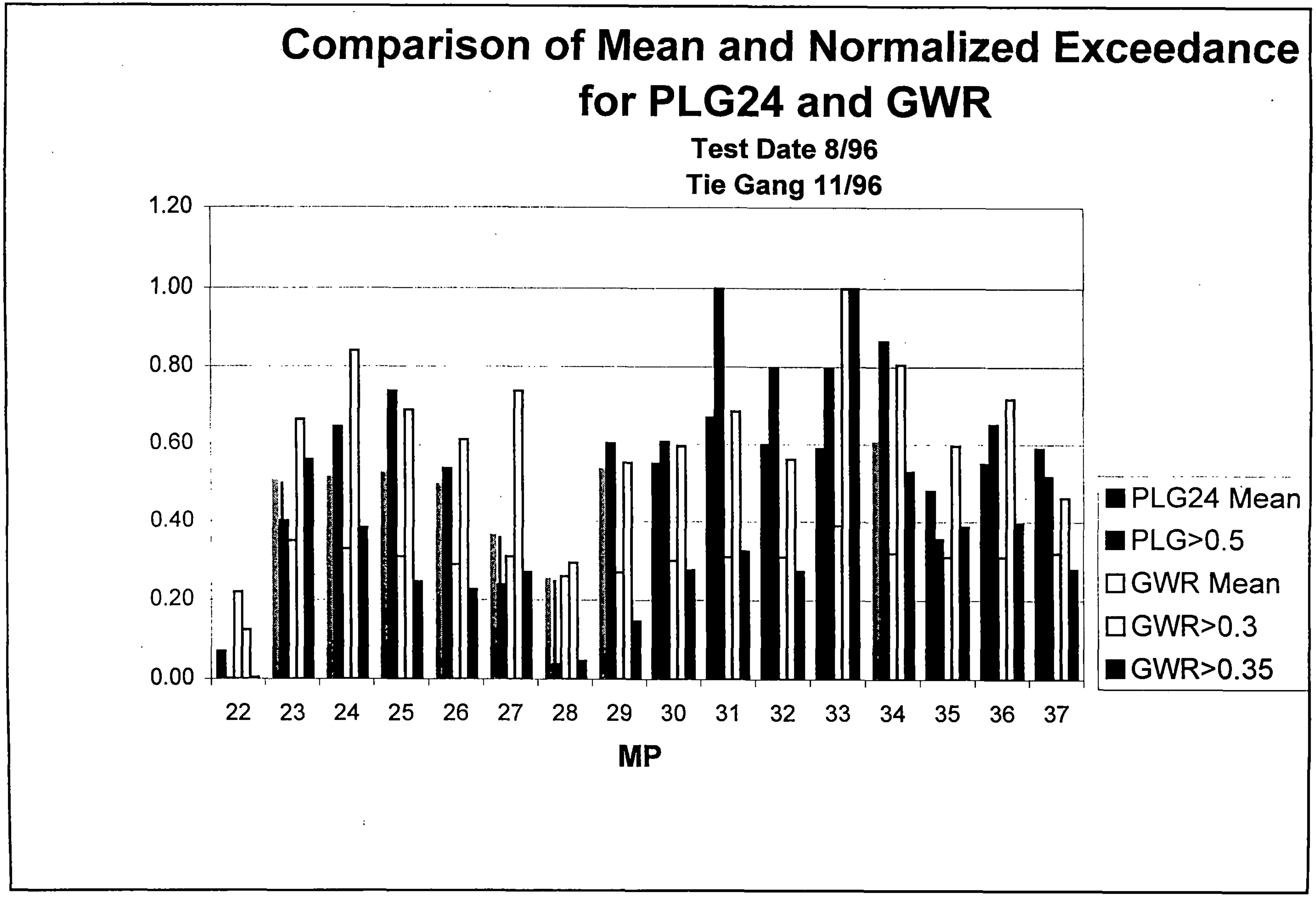

Comparison of Mean and Normalized Exceedance for PLG24 and GWR
Test Date 8/96
Tie Gang 11/96
1.20
1.00
0.80
0.60
0.40
0.20
0.00
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
MP
PLG24 Mean
PLG>0.5
GWR Mean
GWR>0.3
GWR>0.35

Table 2

"Bottom Up Analysis CSX RFP Track 3

MP	Tie Gang 11/96	feet per mile	PLG24 Mean	No. of feet PLG24>0.5	PLG24>0.75	GWR Mean
22		5280	0.07	3		
23	*	5200	0.51	1976		
24	*	5375	0.52	3177	105	
25	*	5246	0.53	3629	131	
26	*	5316	0.5	2640		
27	*	5275	0.37	1175		
28	*	4725	0.26	187	1	
29	*	5877	0.54	2966		
30		5305	0.55	2988		
31		5231	0.67	4923		
32		5379	0.6	3931		
33		4744	0.59	3928		
34	*	5781	0.61	4265		
35		5302	0.48	1748		
36		5279	0.55	3209		
37		3910	0.59	2544		

	No. of feet GWR > 0.3	GWR > 0.35	GWR > 0.4
0.22	535	100	7
0.35	2848	2059	1212
0.33	3605	1976	831
0.31	2956	1418	534
0.29	2621	1275	492
0.31	3170	1733	587
0.26	1264	387	100
0.27	2369	965	318
0.3	2553	1335	599
0.31	2943	1540	704
0.31	2409	1219	592
0.39	4291	3355	2166
0.32	3459	2095	1145
0.31	2558	1534	838
0.31	3081	1686	856
0.32	1983	1149	604

Table 3

1995 TONNAGE IN MGT
MP CFP 0 TO 999

FROM MP	TO MP	FROM STATION	TO STATION	ROUTE MILES	INC MP	DEC MP	TOTAL MGT
1.70	21.80	RICHMOND	DOSWELL	22	63.879674	32.407242	96.286917
.80	59.40	DOSWELL	FREDERICKSBURG	37	19.765449	20.948108	40.713558
.40	107.20	FREDERICKSBURG	POTOMAC YARD	49	19.667118	20.596245	40.263363
107.27	113.50	POTOMAC YARD	WASHINGTON	6	14.048228	13.384403	27.432631

1996 TONNAGE IN MGT
MP CFP 0 TO 999

FROM MP	TO MP	FROM STATION	TO STATION	ROUTE MILES	INC MP	DEC MP	TOTAL MGT
.70	21.80	RICHMOND	DOSWELL	22	72.570044	35.800570	108.370614
.80	59.40	DOSWELL	FREDERICKSBURG	37	25.867365	23.943583	49.810949
59.40	107.20	FREDERICKSBURG	POTOMAC YARD	49	25.266306	22.702336	47.968642
.27	113.50	POTOMAC YARD	WASHINGTON	6	20.781035	15.887991	36.669026

1997 TONNAGE IN MGT
MP CFP 0 TO 999

FROM MP	TO MP	FROM STATION	TO STATION	ROUTE MILES	INC MP	DEC MP	TOTAL MGT
1.70	21.80	RICHMOND	DOSWELL	22	56.756807	29.052228	85.809035
21.80	59.40	DOSWELL	FREDERICKSBURG	37	16.611495	19.147480	35.758975
.40	107.20	FREDERICKSBURG	POTOMAC YARD	49	16.314167	18.055918	34.370086
.27	113.50	POTOMAC YARD	WASHINGTON	6	12.429113	11.541406	23.970520

Initial Assessments

Examination of the 1996 GRMS data together with the follow on maintenance history data indicated that Track 3 had a good correlation of data between GRMS measurements and tie gang activity shortly after the GRMS inspection. This thus allowed for a comparison of the GRMS output results with the actual CSX tie replacement activities (based on a combination of factors to include local evaluation of tie condition, etc.). Table 1 presents the Track 3 tie program for this line segment. Note, tie replacement (timbering) was performed between CFP MP 23 and 35 during the period November 14-19, 1996, and between CFP MP 83 and 89 during the period November 20-22, 1996. Both tie replacement activities occurred approximately three months after the August 20, 1996 GRMS test run.

Initial comparison of the track strength data with the actual CSX timbering history shows a well defined correlation between high GRMS readings and miles actually timbered or scheduled for timbering in 1998. This is particularly true for the PLG24 data, but is also evident in the GWR data in spite of the data questions previously noted. Noting that the timbering programs are based on a number of factors to include local tie condition assessment, tie counts (and in recent years GRMS outputs as used within the CSX Track Management Program [TMP]), this correlation supports the use of GRMS data as a maintenance management tool. However, as noted in the analysis, the correlation is not completely "clean" with several miles that were timbered in 1996 showing lower (in some cases significantly lower) GRMS values than nearby miles that were not timbered in 1996.

At this point, it should be noted that the GRMS data examines the lateral gage holding strength of the cross-ties. It does not directly address the vertical condition of the ties, which is also a criterion for tie removal and replacement. This was seen in the *TieInspect* counts prepared by ZETA-TECH personnel, where the "bad" ties were separated between gage related and vertical conditions. When these counts were compared to the CSX bad tie counts, it was found that the total of the two matched the CSX bad tie count numbers (which were not separated based on failure mode or failure condition). Thus, while the correlation between GRMS data and tie counts (and tie replacement) is quite good, there may be discrepancies associated with ties that are deemed as "failed" because of their vertical support condition, which may not show up in a gage strength related GRMS measurement.

Analysis of 1998 and 1996 GRMS Data

The second stage in the analysis process was the evaluation of the 1998 GRMS data which was taken after the 1996, 1997, and part of the 1998 tie programs on the study line.

As noted previously, the focus of this analysis was on the track strength condition parameters, particularly:

- Mean Loaded Gage; the statistical mean (average) of all (every foot) loaded gage measurements in the mile. Calculated on a mile by mile basis from the GRMS loaded gage measurement.

- Mean PLG24; the statistical mean (average) of all (every foot) PLG24 measurements in the mile. Calculated on a mile by mile basis from the GRMS PLG24 calculated values.

The GWR values were deemed to be questionable because of the 1996 unloaded gage data and are not included in this analysis.

Table 4 and Appendix E present a mile by mile summary of the mean loaded gage and mean PLG24 for both the 1996 and 1998 GRMS runs together with the location of tie gang activity and the corresponding number of ties inserted between the two measurement cycles. Figure 9 presents this data graphically for the mean loaded gage showing both the areas of tie replacement and the areas where no tie replacement had occurred. Figure 10 presents the difference between these two sets of values (1998 mean loaded gage – 1996 mean loaded gage). Also presented in Figure 9 are the average mean loaded gage values for segments of track where ties were inserted and for segments where no ties were inserted. These values are as follows:

Zones where tie insertion occurred:

- For MP 23 through 37, the mean loaded gage for 1996 was 0.37. For 1998, the mean loaded gage was 0.34
- For MP 48 through 57, the mean loaded gage for 1996 was 0.24. For 1998, the mean loaded gage was 0.24
- For MP 83 through 89, the mean loaded gage for 1996 was 0.43. For 1998, the mean loaded gage was 0.36
- For all miles where ties have been inserted; the mean loaded gage for 1996 was 0.34. For 1998, the mean loaded gage was 0.31

Figure 9

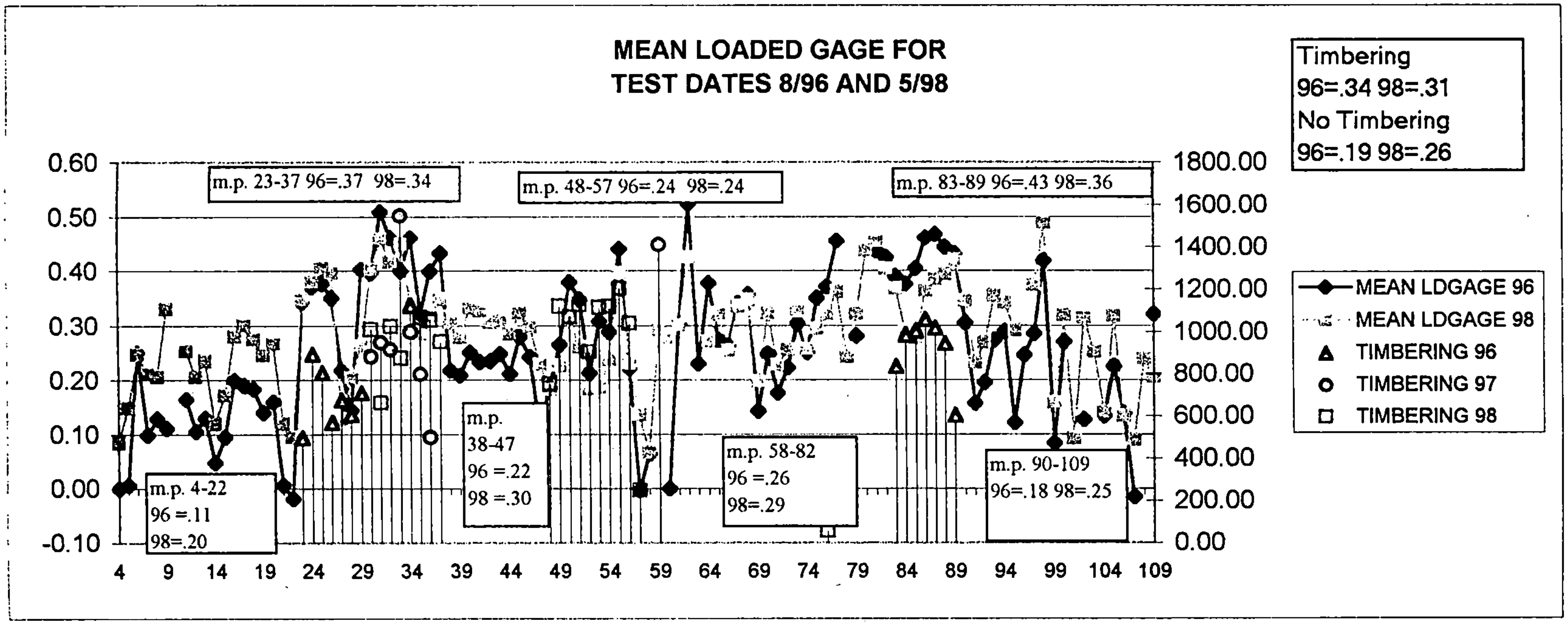

MEAN LOADED GAGE FOR
TEST DATES 8/96 AND 5/98
Timbering
96=.34 98=.31
No Timbering
96=.19 98=.26
m.p. 23-37 96=.37 98=.34
m.p. 48-57 96=.24 98=.24
m.p. 83-89 96=.43 98=.36
m.p. 4-22
96 =.11
98=.20
m.p.
38-47
96 =.22
98 =.30
m.p. 58-82
96 =.26
98=.29
m.p. 90-109
96=.18 98=.25
MEAN LDGAGE 96
MEAN LDGAGE 98
TIMBERING 96
TIMBERING 97
TIMBERING 98
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
4 9 14 19 24 29 34 39 44 49 54 59 64 69 74 79 84 89 94 99 104 109

Figure 10

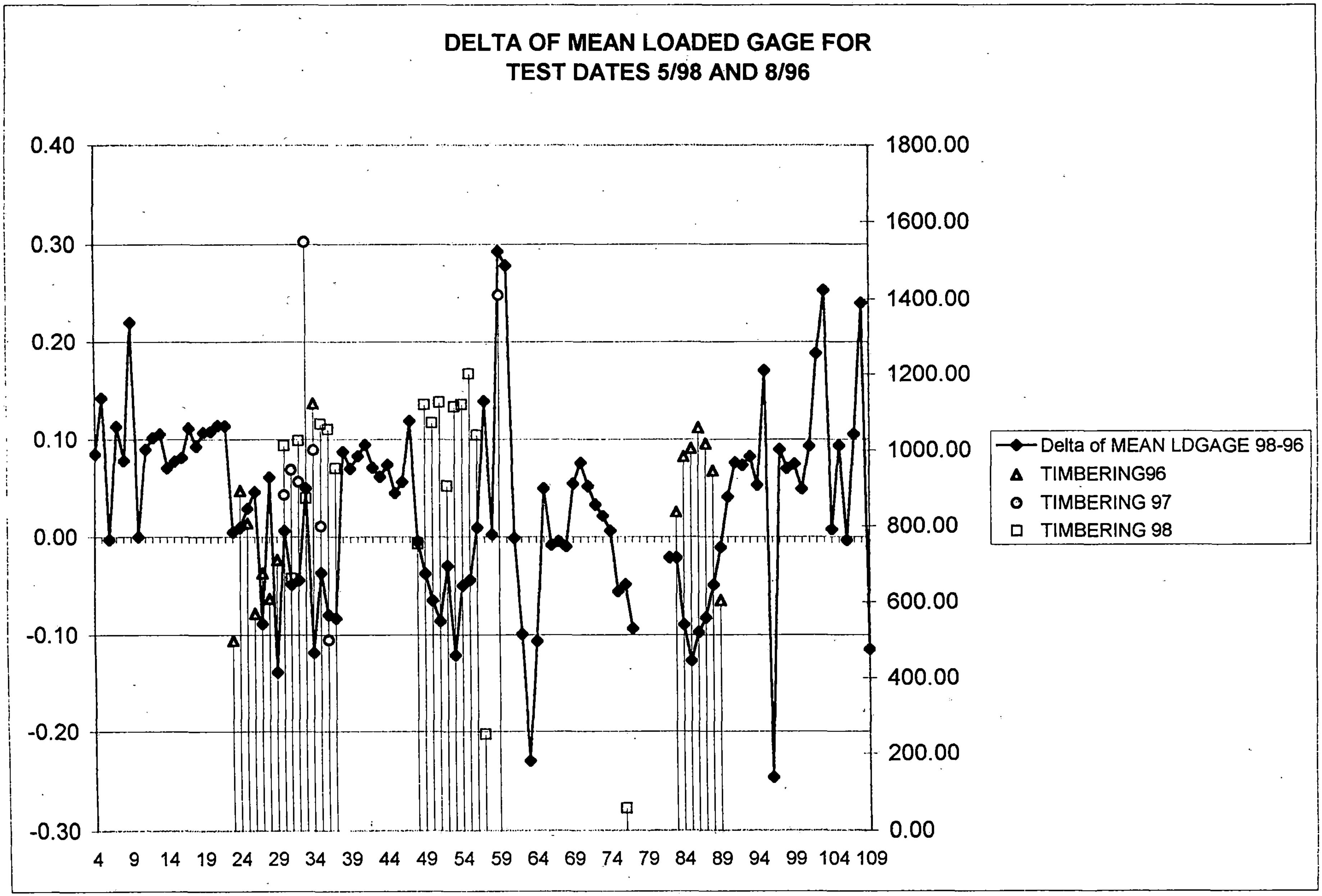

DELTA OF MEAN LOADED GAGE FOR
TEST DATES 5/98 AND 8/96
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
4 9 14 19 24 29 34 39 44 49 54 59 64 69 74 79 84 89 94 99 104 109
Delta of MEAN LDGAGE 98-96
TIMBERING96
TIMBERING 97
TIMBERING 98

Table 4

	96 test date					98 Test Date									
MilePost	Total Feet	MPLG24	MLDG	MULD	MDLG	Total Feet	MPLG24	MLDG	MULD	MDLG	Delta PLG24	Delta LdGage	96 Tie Gang # of Ties	97 Tie gang # of Ties	98 Tie Gang # of Ties
4	821	0.00	0.00	-0.12	0.00	5364	0.12	0.09	0.02	0.06	0.12	0.09			
5	5268	0.11	0.01	-0.29	0.30	6225	0.20	0.15	0.05	0.10	0.09	0.14			
6	5263	0.39	0.25	-0.10	0.35	9265	0.30	0.25	0.15	0.10	-0.10	0.00			
7	5295	0.22	0.10	-0.26	0.36	5330	0.28	0.21	0.08	0.13	0.05	0.11			
8	5293	0.26	0.13	-0.24	0.37	5300	0.27	0.21	0.07	0.13	0.01	0.08			
9	5283	0.24	0.11	-0.25	0.36	5274	0.40	0.33	0.21	0.12	0.16	0.22			
							0.39				0.39	0.00			
11	5281	0.29	0.16	-0.18	0.34	5216	0.32	0.25	0.13	0.12	0.03	0.09			
12	5231	0.22	0.11	-0.23	0.34	5281	0.27	0.21	0.08	0.13	0.05	0.10			
13	5305	0.24	0.13	-0.19	0.32	5339	0.29	0.24	0.12	0.12	0.05	0.11			
14	4974	0.16	0.05	-0.28	0.33	4956	0.17	0.12	0.02	0.10	0.01	0.07			
15	5662	0.22	0.10	-0.27	0.36	5679	0.24	0.17	0.05	0.13	0.01	0.08			
16	5347	0.34	0.20	-0.17	0.37	5414	0.36	0.28	0.14	0.14	0.02	0.08			
17	5222	0.31	0.19	-0.14	0.34	5172	0.37	0.30	0.17	0.13	0.06	0.11			
18	5273	0.30	0.18	-0.15	0.34	5302	0.34	0.28	0.16	0.12	0.04	0.09			
19	5312	0.26	0.14	-0.19	0.33	5353	0.31	0.25	0.12	0.13	0.05	0.11			
20	5275	0.30	0.16	-0.17	0.33	5261	0.32	0.27	0.18	0.09	0.02	0.11			
21	4093	0.10	0.01	-0.25	0.29	5296	0.17	0.12	0.02	0.10	0.07	0.11			
22	6495	0.08	-0.02	-0.29	0.30	5410	0.14	0.10	0.00	0.10	0.07	0.11			
23	5201	0.51	0.34	-0.11	0.41	5331	0.41	0.35	0.23	0.12	-0.10	0.00	500		
24	5376	0.52	0.37	-0.02	0.39	5321	0.45	0.38	0.25	0.13	-0.08	0.01	895		
25	5247	0.53	0.38	0.01	0.37	5318	0.47	0.41	0.29	0.11	-0.06	0.03	808		
26	5317	0.50	0.35	0.00	0.35	5255	0.46	0.40	0.28	0.12	-0.04	0.05	571		
27	5276	0.37	0.22	-0.16	0.37	5248	0.20	0.13	-0.01	0.14	-0.17	-0.09	677		
28	4726	0.26	0.14	-0.19	0.33	5295	0.26	0.21	0.09	0.11	0.00	0.06	609		
29	5878	0.54	0.40	0.06	0.33	5353	0.33	0.26	0.14	0.13	-0.21	-0.14	711		
30	5306	0.55	0.40	0.04	0.35	5342	0.47	0.40	0.28	0.12	-0.08	0.01		884	1012
31	5232	0.67	0.51	0.15	0.36	5264	0.52	0.46	0.36	0.10	-0.15	-0.05		950	663
32	5380	0.60	0.46	0.10	0.36	5400	0.49	0.42	0.30	0.12	-0.12	-0.04		918	1026
33	4745	0.59	0.40	-0.04	0.44	5264	0.51	0.45	0.35	0.10	-0.08	0.05		1550	875
34	5782	0.61	0.46	0.08	0.38	6247	0.41	0.34	0.22	0.12	-0.20	-0.12	1124	1001	
35	5303	0.47	0.32	-0.06	0.38	4738	0.36	0.29	0.16	0.13	-0.11	-0.04		800	1069
36	5290	0.55	0.40	0.03	0.37	5389	0.39	0.32	0.19	0.13	-0.16	-0.08		501	1055
37	3911	0.59	0.43	0.03	0.38	5875	0.43	0.35	0.21	0.14	-0.16	-0.08			953
38	6404	0.35	0.22	-0.15	0.36	5257	0.37	0.31	0.19	0.12	0.01	0.09			
39	5530	0.35	0.21	-0.16	0.37	5330	0.34	0.28	0.17	0.11	-0.01	0.07			
40	5283	0.41	0.25	-0.11	0.36	5290	0.39	0.33	0.23	0.10	-0.02	0.08			
41	5297	0.37	0.23	-0.13	0.36	5327	0.38	0.33	0.23	0.10	0.00	0.09			
42	5287	0.38	0.23	-0.14	0.38	5320	0.37	0.31	0.19	0.11	-0.01	0.07			
43	5196	0.40	0.25	-0.14	0.39	5330	0.37	0.31	0.19	0.12	-0.02	0.06			
44	5395	0.35	0.21	-0.15	0.36	5318	0.34	0.29	0.18	0.11	0.00	0.07			
45	5149	0.42	0.28	-0.08	0.36	5345	0.38	0.32	0.22	0.10	-0.04	0.05			
46	5424	0.37	0.24	-0.11	0.35	5320	0.35	0.30	0.20	0.10	-0.02	0.06			
47	515	0.24	0.11	-0.25	0.36	5324	0.28	0.23	0.13	0.10	0.05	0.12			
48	5289	0.32	0.19	-0.16	0.35	5308	0.23	0.18	0.08	0.10	-0.09	0.00			753
49	5289	0.40	0.26	-0.07	0.33	5259	0.27	0.23	0.14	0.09	-0.13	-0.04			1120
50	5193	0.50	0.38	0.12	0.29	5339	0.37	0.31	0.22	0.10	-0.13	-0.07			1072
51	5372	0.48	0.35	0.03	0.31	5316	0.31	0.26	0.17	0.09	-0.17	-0.09			1126
52	4788	0.34	0.21	-0.10	0.32	5316	0.23	0.18	0.10	0.08	-0.11	-0.03			906
53	5788	0.42	0.31	0.00	0.29	5298	0.24	0.19	0.10	0.09	-0.19	-0.12			1114
54	5270	0.42	0.29	-0.03	0.32	5299	0.30	0.24	0.13	0.11	-0.12	-0.05			1120
55	5279	0.57	0.44	0.11	0.31	5301	0.45	0.40	0.30	0.09	-0.12	-0.04			1201
56	5288	0.35	0.22	-0.09	0.31	5249	0.29	0.23	0.13	0.10	-0.06	0.01			1040
57	3678	0.09	0.00	-0.29	0.28	5307	0.18	0.14	0.06	0.08	0.09	0.14			250
58	6840	0.16	0.06	-0.21	0.28	5289	0.11	0.07	-0.01	0.08	-0.05	0.00			

Table 4 (continued)

	96 test date					98 Test Date									
MilePost	Total Feet	MPLG24	MLDG	MULD	MDLG	Total Feet	MPLG24	MLDG	MULD	MDLG	Delta PLG24	Delta LdGage	96 Tie Gang # of Ties	97 Tie gang # of Ties	98 Tie Gang # of Ties
						5291	0.35	0.29	0.19	0.10	0.35	0.29		1411	
60	721	0.00	0.00	0.30	0.00	5256	0.33	0.28	0.19	0.09	0.33	0.28			
61	4359	0.43	0.30	-0.04	0.34	5208	0.35	0.30	0.21	0.08	-0.08	0.00			
62	5256	0.67	0.52	0.19	0.33	5320	0.48	0.43	0.33	0.09	-0.19	-0.10			
63	5328	0.36	0.23	-0.11	0.34						-0.36	-0.23			
64	5234	0.52	0.38	0.03	0.35	10449	0.34	0.27	0.16	0.12	-0.18	-0.11			
65	5329	0.40	0.27	-0.05	0.32	5348	0.38	0.32	0.22	0.11	-0.01	0.05			
66	5279	0.37	0.26	-0.04	0.30	5167	0.32	0.25	0.14	0.11	-0.06	-0.01			
67	5294	0.49	0.34	-0.01	0.34	5226	0.40	0.34	0.22	0.11	-0.08	0.00			
68	5280	0.47	0.36	0.08	0.28	5248	0.41	0.35	0.24	0.11	-0.06	-0.01			
69	5282	0.26	0.14	-0.17	0.31	5273	0.25	0.20	0.11	0.09	-0.01	0.05			
70	5672	0.37	0.25	-0.08	0.33	5667	0.38	0.32	0.23	0.10	0.01	0.08			
71	4882	0.30	0.18	-0.16	0.33	4953	0.29	0.23	0.13	0.10	-0.01	0.05			
72	5288	0.34	0.22	-0.09	0.31	5334	0.31	0.26	0.16	0.10	-0.03	0.03			
73	5286	0.44	0.30	-0.03	0.33	5317	0.39	0.33	0.22	0.10	-0.05	0.02			
74	5282	0.38	0.25	-0.07	0.33	5334	0.32	0.26	0.15	0.11	-0.06	0.01			
75	5301	0.50	0.35	0.01	0.34	5321	0.34	0.29	0.22	0.07	-0.16	-0.06			
76	5293	0.52	0.37	0.00	0.37	5381	0.40	0.32	0.20	0.12	-0.12	-0.05			58
77	5287	0.60	0.46	0.11	0.34	5402	0.42	0.36	0.27	0.10	-0.18	-0.09			
						5346	0.29	0.24	0.16	0.08					
79	10785	0.43	0.28	-0.10	0.36	5462	0.37	0.32	0.24	0.08					
						5209	0.52	0.44	0.32	0.12					
81	10516	0.61	0.44	0.07	0.36	5138	0.54	0.45	0.33	0.13					
82	5269	0.61	0.43	0.02	0.40	5151	0.48	0.40	0.28	0.12	-0.13	-0.02			
83	5298	0.56	0.39	0.00	0.39	5337	0.42	0.37	0.28	0.09	-0.14	-0.02	838		
84	5340	0.54	0.38	-0.01	0.38	5256	0.34	0.29	0.19	0.09	-0.20	-0.09	984		
85	5234	0.56	0.40	0.03	0.37	5294	0.33	0.28	0.18	0.10	-0.23	-0.13	1005		
86	5313	0.63	0.46	0.07	0.38	5130	0.42	0.36	0.26	0.10	-0.21	-0.10	1060		
87	5209	0.64	0.47	0.07	0.40	5277	0.45	0.39	0.27	0.12	-0.19	-0.08	1018		
88	5313	0.64	0.44	0.06	0.39	5334	0.46	0.39	0.29	0.11	-0.18	-0.05	947		
89	5263	0.60	0.43	0.09	0.37	5236	0.47	0.42	0.34	0.08	-0.13	-0.01	605		
90	5220	0.45	0.31	-0.03	0.33	4376	0.39	0.35	0.27	0.08	-0.06	0.04			
91	5293	0.27	0.16	-0.16	0.31	5058	0.28	0.23	0.15	0.09	0.01	0.08			
92	5293	0.32	0.20	-0.16	0.33	5240	0.31	0.27	0.20	0.07	-0.01	0.07			
93	5270	0.41	0.27	-0.06	0.34	5244	0.40	0.36	0.27	0.08	-0.01	0.08			
94	5264	0.43	0.29	-0.07	0.34	5138	0.38	0.34	0.28	0.06	-0.05	0.05			
95	5284	0.23	0.12	-0.15	0.30	5200	0.32	0.29	0.24	0.05	0.10	0.17			
96	5298	0.36	0.25	-0.08	0.30						-0.36	-0.25			
97	5210	0.42	0.29	-0.05	0.33	10307	0.43	0.38	0.29	0.08	0.00	0.09			
98	5267	0.60	0.42	0.02	0.39	5283	0.54	0.49	0.40	0.09	-0.06	0.07			
99	5313	0.20	0.08	-0.19	0.30	5357	0.20	0.16	0.08	0.08	0.00	0.07			
100	4451	0.44	0.27	-0.10	0.37	5307	0.38	0.32	0.22	0.10	-0.06	0.05			
						5022	0.12	0.09	0.04	0.06	0.12	0.09			
102	11414	0.24	0.13	-0.18	0.31	5640	0.36	0.32	0.25	0.07	0.11	0.19			
						5336	0.29	0.25	0.19	0.06	0.29	0.25			
104	10558	0.25	0.13	-0.19	0.31	5311	0.18	0.14	0.07	0.07	-0.07	0.01			
105	5338	0.40	0.23	-0.13	0.37	5371	0.36	0.32	0.25	0.07	-0.05	0.09			
106	5213	0.27	0.14	-0.18	0.31	5160	0.16	0.13	0.08	0.05	-0.11	0.00			
107	5291	0.07	-0.01	-0.28	0.27	5491	0.12	0.09	0.02	0.07	0.05	0.11			
		0.64				5563	0.27	0.24	0.18	0.06	-0.37	0.24			
109	3062	0.45	0.32	0.04	0.29	5342	0.27	0.21	0.10	0.11	-0.18	-0.11			

Zones where no tie insertion occurred:

- For MP 4 through 22, the mean loaded gage for 1996 was 0.11. For 1998, the mean loaded gage was 0.20
- For MP 38 through 47, the mean loaded gage for 1996 was 0.22. For 1998, the mean loaded gage was 0.30
- For MP 58 through 82, the mean loaded gage for 1996 was 0.26. For 1998, the mean loaded gage was 0.29
- For MP 90 through 109, the mean loaded gage for 1996 was 0.18. For 1998, the mean loaded gage was 0.25
- For all miles where no ties have been inserted; the mean loaded gage for 1996 was 0.19. For 1998, the mean loaded gage was 0.26

Analysis of this data showed that in those zones where no ties were inserted (4 zones), the mean loaded gage increased in all cases, corresponding to a degradation of tie condition with time (2 years) and traffic (between 40 and 100+ MGT depending on MP, see Table 3). Furthermore, the zone with the greatest traffic density, MP 4 through 22, had the largest increase in mean loaded gage, an increase of 80%. Overall, for all zones, the loaded gage increased from 0.19 to 0.26, an increase of 37%. (Based on an average tonnage of 65 MGT over the two years, this corresponds to an increase in loaded gage of 0.0011 per MGT.)

Analysis of the zones where ties were inserted showed that in these cases, the average loaded gage decreased, corresponding to the improvement in track strength due to the new ties and fasteners. (The only exception to this was MP 48 through 57 where the mean loaded gage remained at 0.24. However, in this zone, the value of the mean loaded gage, which corresponded to the tie condition, was significantly lower than those of the adjacent two zones, which were of the order of 0.34 to 0.43, significantly higher.) Table 5 shows the correlation between the change in loaded gage (and PLG 24, which is presented in Figure 11) and the number of ties inserted. This will be discussed further, later in this report.

Finally, it should be noted that in general, the mean loaded gage for the miles that had ties inserted was measurably higher than those for which no ties had been inserted (with the exception of the track between MP 48 and 57). This is in agreement with the railroad practice of installing ties only in those miles where the track strength is inadequate and additional ties to upgrade the track strength is required. This was clearly the case for the zones MP 23 through 37 and 83 through 89.

Figure 11 presents the PLG24 data in the same format. As can be seen in Figure 11 (and Figure 12 which is a magnification of MP 4 through 57), those miles where ties were inserted had a measurable reduction in PLG24 with the average decreasing from 0.48 to 0.37. However, for the case of those miles where no ties were inserted, the data

Table 5

96 tie gang

	Delta PLG24	Delta LdGage	# of Ties
23	-0.10	0.00	500
24	-0.08	0.01	895
25	-0.06	0.03	808
26	-0.04	0.05	571
27	-0.17	-0.09	677
28	0.00	0.06	609
29	-0.21	-0.14	711
34	-0.20	-0.12	1124
83	-0.14	-0.02	838
84	-0.20	-0.09	984
85	-0.23	-0.13	1005
86	-0.21	-0.10	1060
87	-0.19	-0.08	1018
88	-0.18	-0.05	947
89	-0.13	-0.01	605

98 tie gang

	Delta PLG24	Delta LdGage	# of Ties
30	-0.08	0.01	1012
31	-0.15	-0.05	663
32	-0.12	-0.04	1026
33	-0.08	0.05	875
35	-0.11	-0.04	1069
36	-0.16	-0.08	1055
37	-0.16	-0.08	953
48	-0.09	0.00	753
49	-0.13	-0.04	1120
50	-0.13	-0.07	1072
51	-0.17	-0.09	1126
52	-0.11	-0.03	906
53	-0.19	-0.12	1114
54	-0.12	-0.05	1120
55	-0.12	-0.04	1201
56	-0.06	0.01	1040
57	0.09	0.14	250

Figure 11

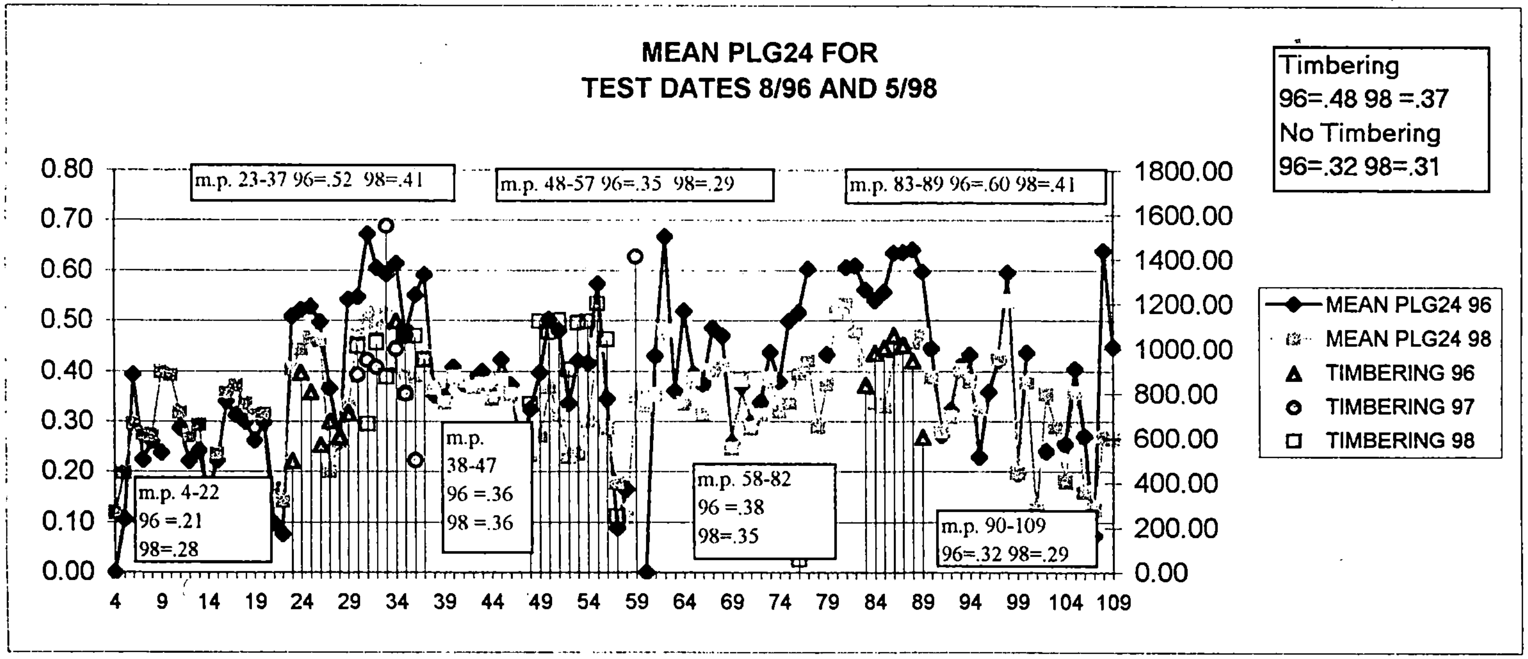
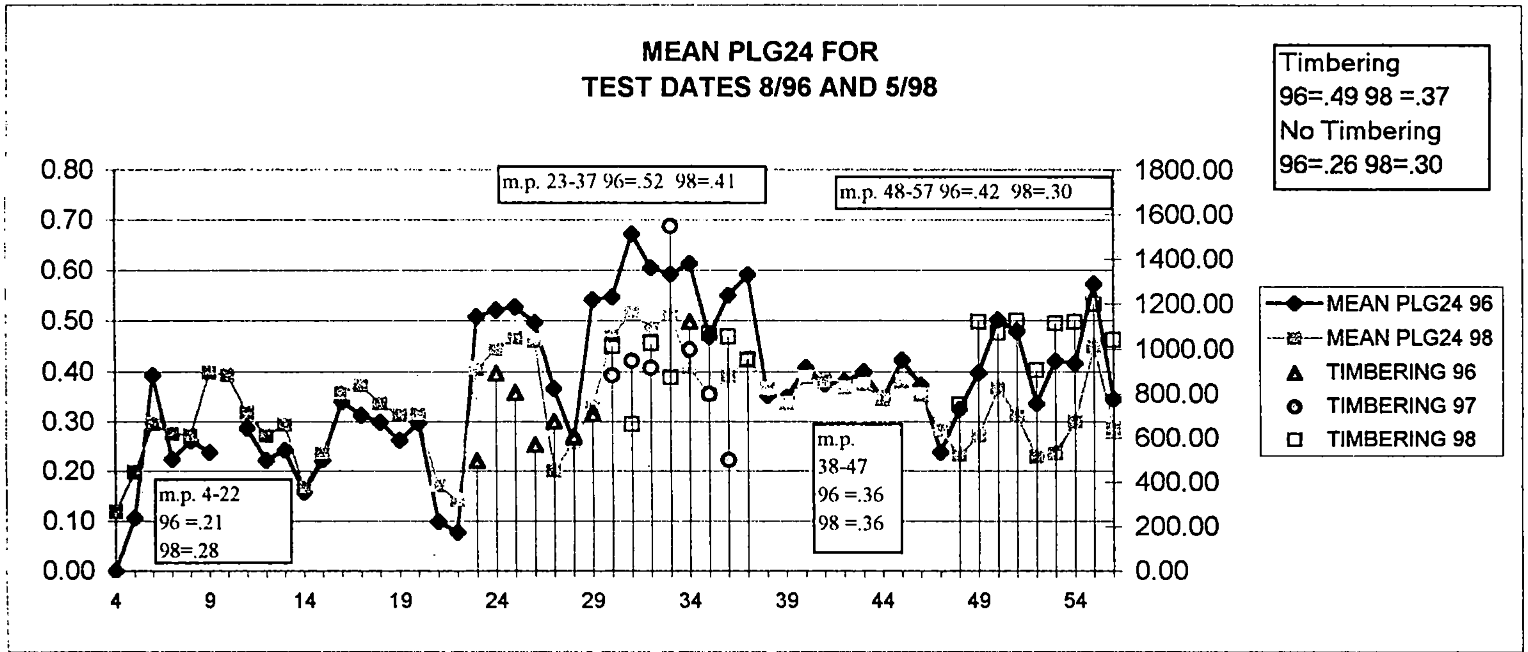

MEAN PLG24 FOR
TEST DATES 8/96 AND 5/98
m.p. 23-37 96=.52 98=.41
m.p. 48-57 96=.35 98=.29
m.p. 83-89 96=.60 98=.41
m.p. 4-22
96 =.21
98=.28
m.p.
38-47
96 =.36
98 =.36
m.p. 58-82
96 =.38
98=.35
m.p. 90-109
96=.32 98=.29
Timbering
96=.48 98 =.37
No Timbering
96=.32 98=.31
MEAN PLG24 96
MEAN PLG24 98
TIMBERING 96
TIMBERING 97
TIMBERING 98
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
4 9 14 19 24 29 34 39 44 49 54 59 64 69 74 79 84 89 94 99 104 109

Figure 12


MEAN PLG24 FOR
TEST DATES 8/96 AND 5/98
Timbering
96=.49 98 =.37
No Timbering
96=.26 98=.30
m.p. 23-37 96=.52 98=.41
m.p. 48-57 96=.42 98=.30
m.p. 4-22
96 =.21
98=.28
m.p.
38-47
96 =.36
98 =.36
MEAN PLG24 96
MEAN PLG24 98
TIMBERING 96
TIMBERING 97
TIMBERING 98
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
4
9
14
19
24
29
34
39
44
49
54

was more erratic. Figure 13 shows the difference between the 1998 and 1996 data directly.

Development of Correlation Equations

Noting the correlation between the change in indices and the number of ties installed presented in Table 5, it is possible to obtain a correlation between the Track Strength Quality Index parameters and the number of ties inserted. This correlation was obtained using statistical regression techniques.

Figure 14 and Table 6 present the results of the correlation between the change in loaded gage (Delta LDGAGE) and the ties inserted. This was performed for the entire data set. A separate analysis for each of the two insertion years was also performed to separate out the two year time change and associated change in track strength. (see Appendix F). As can be seen in the Figure and Table, good statistical correlation is obtained, with an R^2 of 0.36 obtained (the 1996 data had an R^2 of 0.38 and the more recent 1998 data an R^2 of 0.53). Furthermore, it should be noted that the slope of the relationship, corresponding to the rate of change of loaded gage with number of ties inserted, was virtually the same.

Thus, the relationship for the improvement in loaded gage with number of inserted ties is given by:

$$\text{LDGAGE (new)} = \text{LDGAGE (old)} + a^* \text{ TIES} + b$$

Where:

LDGAGE (new) is the predicted mean (per mile) loaded gage after ties are inserted

LDGAGE (old) is the measured mean (per mile) loaded gage prior to ties insertion

TIES is the number of ties inserted in the mile

a is a constant (slope) equal to –0.0002

b is a constant (intercept) equal to the additional degradation that occurs between the time of the first measurement (before) and the second measurement. Note, if the constant value of 0.11 is used, then the relationship is valid only for insertions greater than 600 ties per mile.

Figure 15 and Table 7 present the results of the correlation between the change in PLG24 (Delta PLG24) and the ties inserted. As with the case of loaded gage, this was

Figure 13

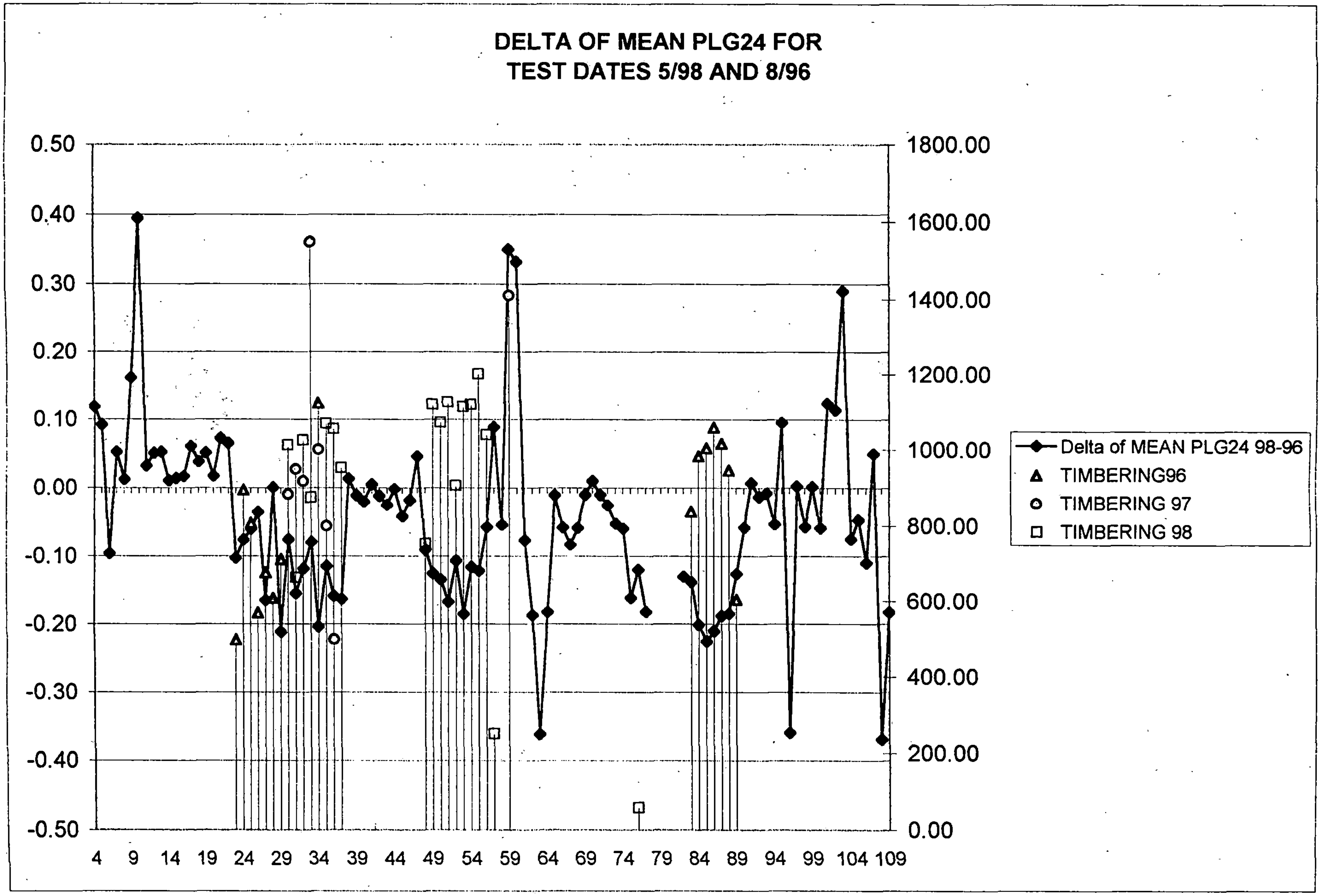
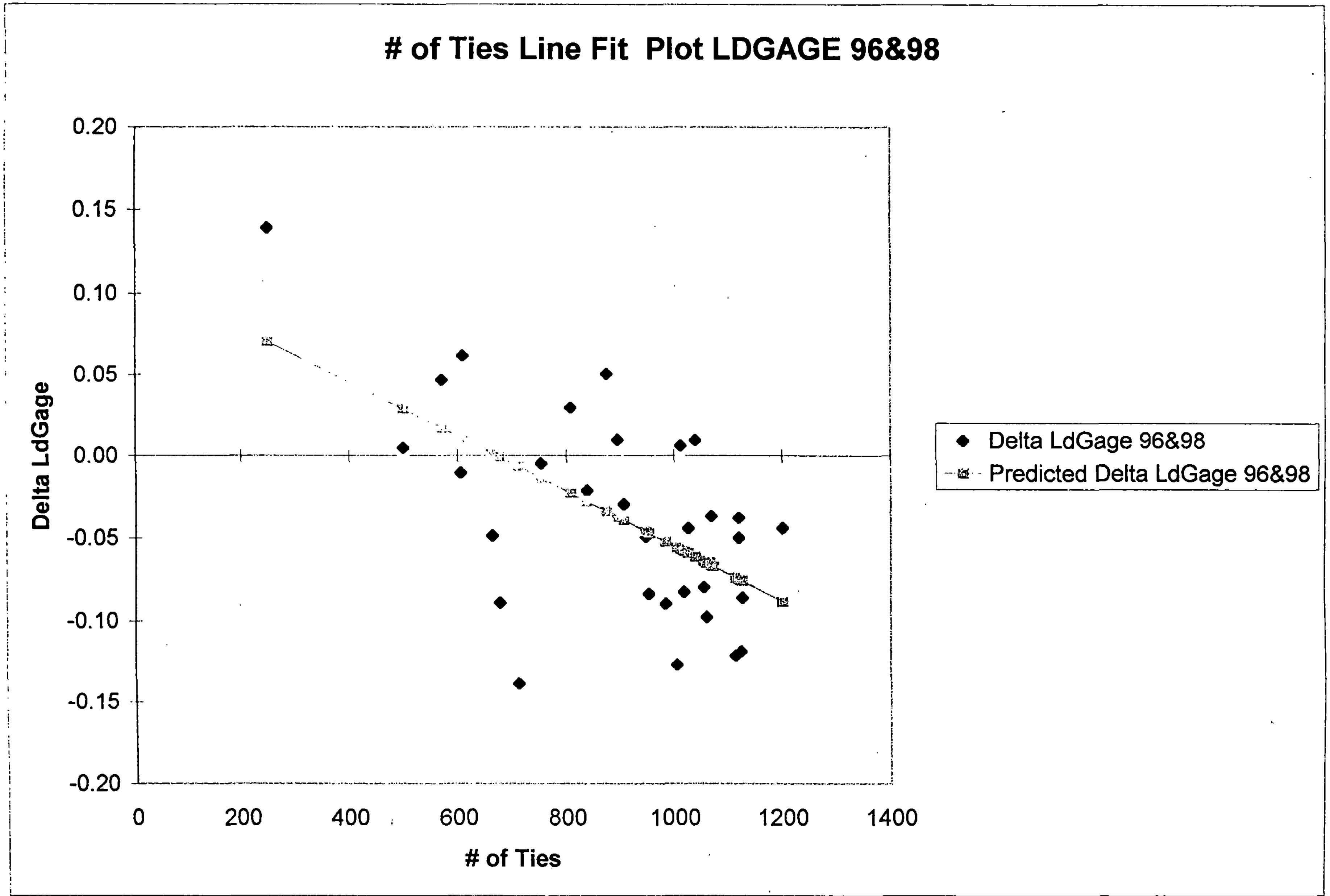

DELTA OF MEAN PLG24 FOR
TEST DATES 5/98 AND 8/96
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
4 9 14 19 24 29 34 39 44 49 54 59 64 69 74 79 84 89 94 99 104 109
Delta of MEAN PLG24 98-96
TIMBERING96
TIMBERING 97
TIMBERING 98

Figure 14



# of Ties Line Fit Plot LDGAGE 96&98
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
Delta LdGage
0
200
400
600
800
1000
1200
1400
# of Ties
Delta LdGage 96&98
Predicted Delta LdGage 96&98

36

Table 6

SUMMARY OUTPUT

didgage24 = 0.11216 - .000167* # of ties (96&98 timbering)

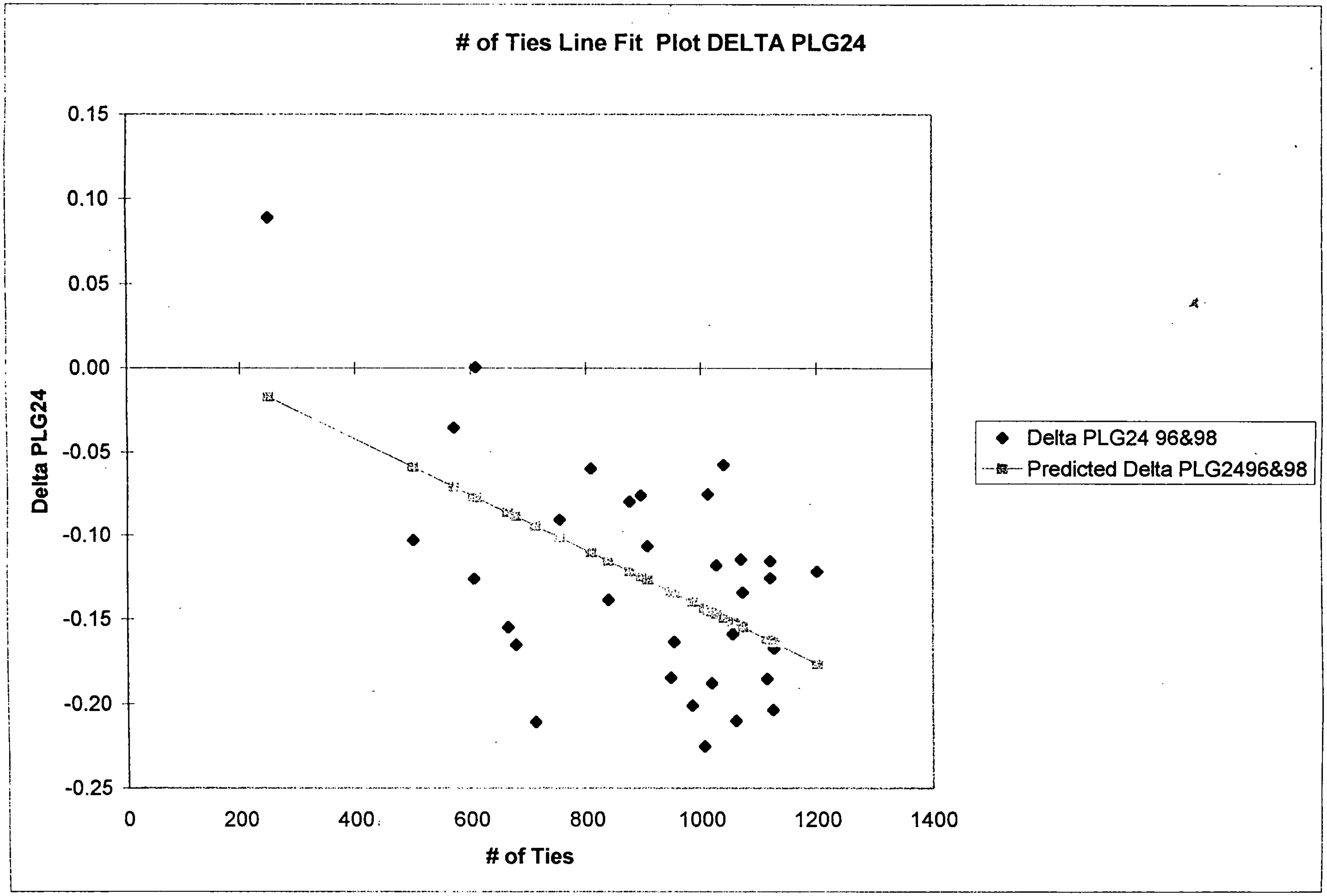
Regression Statistics	
Multiple R	0.600657529
R Square	0.360789467
Adjusted R Square	0.339482449
Standard Error	0.050679988
Observations	32

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.04349148	0.04349148	16.93289371	0.000278148
Residual	30	0.077053836	0.002568461		
Total	31	0.120545316			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.112160	0.037423	2.997055	0.005430	0.035731	0.188588
# of Ties	-0.000167	0.000041	-4.114960	0.000278	-0.000249	-0.000084

Figure 15



# of Ties Line Fit Plot DELTA PLG24
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
Delta PLG24
0
200
400
600
800
1000
1200
1400
# of Ties
Delta PLG24 96&98
Predicted Delta PLG2496&98

38

Table 7

SUMMARY OUTPUT

dplg24 = 0.02487 - .000167* # of ties (96&98 timbering)

Regression Statistics	
Multiple R	0.554898337
R Square	0.307912165
Adjusted R Square	0.28484257
Standard Error	0.05732968
Observations	32

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.043867806	0.04386781	13.3470991	0.000980284
Residual	30	0.098600765	0.00328669		
Total	31	0.142468572			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	0.024873	0.042334	0.587556	0.561227	-0.061583	0.111330
# of Ties	-0.000167	0.000046	-3.653368	0.000980	-0.000261	-0.000074

performed for the entire data set. (Appendix F again presents a corresponding regression performed separately for each of the two insertion years, to separate out the two year time change and associated change in track strength.). As can be seen in the Figure and Table, good statistical correlation is obtained, with an R^2 of 0.31 obtained for the combined data (the 1996 data had an R^2 of 0.30 and the 1998 data an R^2 of 0.51). It should likewise be noted that the slope of the relationship, corresponding to the rate of change of loaded gage with number of ties inserted, was again virtually the same.

Thus, the relationship for the improvement in PLG24 with number of inserted ties is given by:

$$PLG24\ (new) = PLG24\ (old) + a' * TIES + b'$$

Where:

PLG24 (new) is the predicted mean (per mile) PLG24 after ties are inserted

PLG24 (old) is the measured mean (per mile) PLG24 prior to ties insertion

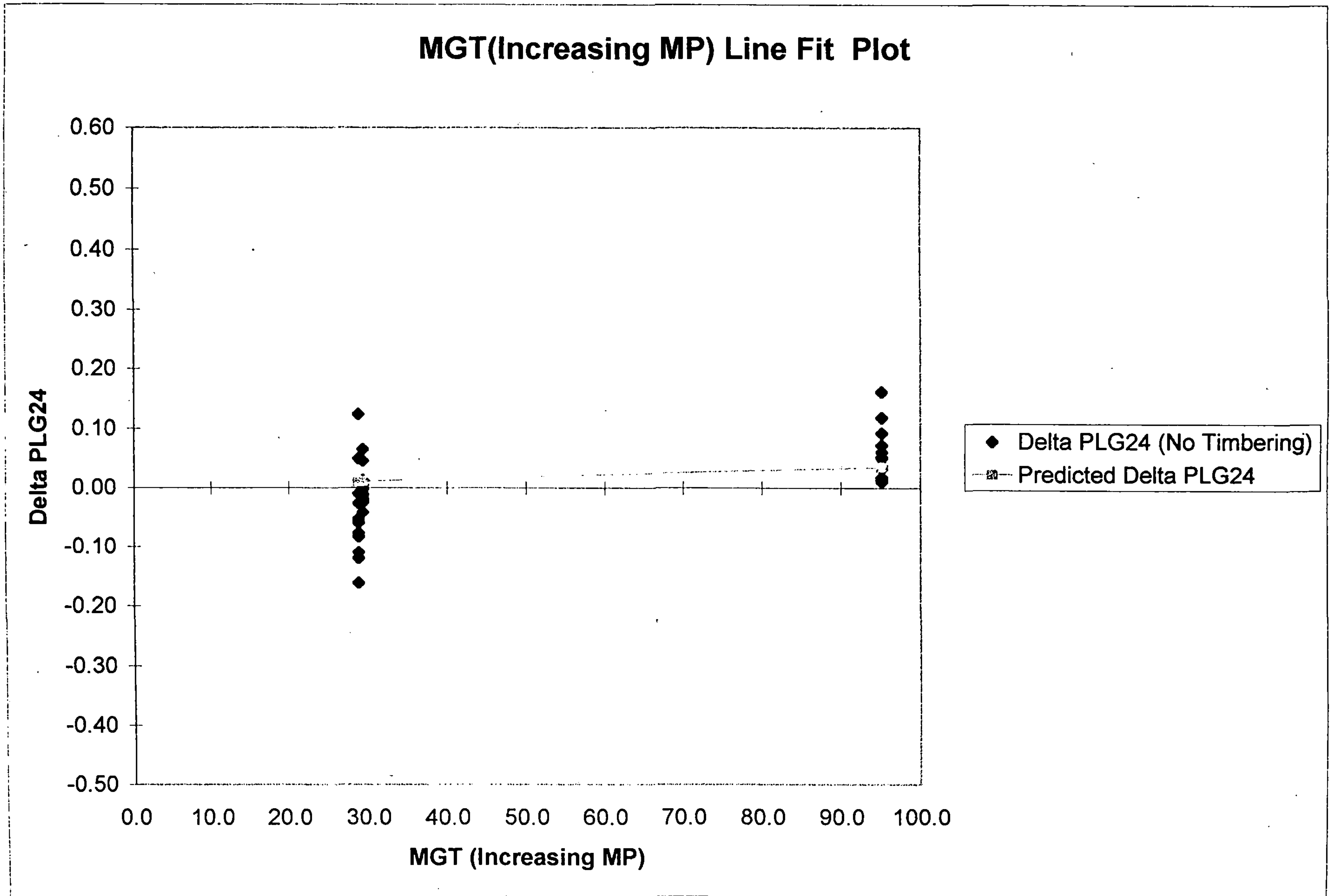
TIES is the number of ties inserted in the mile

a' is a constant (slope) equal to –0.0002

b' is a constant (intercept) equal to the additional degradation that occurs between the time of the first measurement (before) and the second measurement. Note, if the constant value of 0.025 is used, then the relationship is valid only for insertions greater than 35 ties per mile.

Thus, it appears that a relationship can be developed that relates changes in the TSQI with tie insertions. Also, a relationship can be obtained for the degradation of TSQI with tonnage. This was observed previously, for the loaded gage TSQI to be of the order of 0.0011 per MGT (corresponding to 0.11 per 100 MGT). Figure 16 presents the relationship for PLG24 which is of the form PLG24new = PLG24old +0.001*MGT.

Figure 16



MGT(Increasing MP) Line Fit Plot
0.60
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
-0.20
-0.30
-0.40
-0.50
Delta PLG24
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0
100.0
MGT (Increasing MP)
Delta PLG24 (No Timbering)
Predicted Delta PLG24

Analysis of *TieInspect* Data

In order to perform a "micro" correlation of the TSQI noted above and the actual tie condition, a detailed map of the tie condition was obtained from selected miles of Track 3 by ZETA-TECH personnel using the *TieInspect* hand held data collection unit (Appendix A). This unit allows for the recording of the condition of every tie, and the follow up analysis of tie clusters. The generated detailed map of bad tie clusters can then be correlated directly against the GRMS indices, particularly the GRMS threshold data (i.e. the GRMS readings that exceed a preset threshold). Such a correlation is presented in Attachments G and H for MP 30 and 32 respectively. This correlation is based on the 1996 GRMS data (note previous comments about the unloaded gage) and the March 1998 track inspection (which preceded both the 1998 tie gangs and the 1998 GRMS run).

Examination of the data directly (after correction for MP location which can be off by 25 or more feet in a moving inspection vehicle such as the GRMS), shows that a correlation does exist between the PLG24 and tie clusters (of two or more bad ties). This is further shown in Table 8 which indicates that there is a statistical correlation between two tie clusters (from *TieInspect* data) and the PLG24 data. The correlation is less clear in the GWR data (not surprising in light of the problem with the 1996 data). A similar statistical correlation was found in the November 1998 *TieInspect* track inspection (see Table 9.)

Appendix I presents the correlation between the 1998 TieInspect measurements and GRMS threshold data. Noting that the 1998 TieInspect measurements were taken after the completion of all of the tie programs, it can be seen that the overall tie condition is excellent, with only a very small number of bad ties reported by either TieInspect or GRMS. In fact, the TieInspect data showed virtually no clusters of bad ties greater than two, again correlating to the low level of the GRMS values, to include both mean GRMS values and exceedances beyond a defined threshold.

Table 8

M.P. 32

Tie Ranges	Bad+Marginal TIES >=2 Clst.	GWR >0.4 TIES	PLG24>0.6 TIES
301-600	71	20	277
601-900	65	18	237
901-1200	103	23	212
1201-1500	114	2	94
2101-2400	48	69	119
2401-2700	73	36	44
2701-3000	64	49	69
3001-3127	22	86	38
Total	560	303	1090

M.P. 32

	TIES >=2	GWR >0.4	PLG24>0.6
TIES >=2 Clst.	1.00		
GWR >0.4	-0.88	1.00	
PLG24>0.6	0.29	-0.54	1.00

Table 9

		M.P. 25 -98 GRMS DATA			
		CORELATION COEFF.			
	>=1 tie	*>=2 tie*	*PLG24>0.6*	*PLG24>0.7*	*PLG24>0.75*
>=1 tie	1.00				
>=2 tie	0.44	1.00			
PLG24>0.6	-0.04	0.13	1.00		
PLG24>0.7	0.00	0.16	0.76	1.00	
PLG24>0.75	-0.07	0.22	0.25	0.73	1.00

Analysis of Curve vs. Tangent Track Data

An additional set of analyses was performed to examine the effect of track curvature on tie degradation and strength behavior. The analysis divided the track into curved and non-curved segments. However, because CSX bad tie counts and tie inserted counts are based on mile units and are not divided between curve and tangent, it was necessary to do this analysis on a "per mile" basis (to avoid any pre-biased distribution of ties between curves and tangents). In order to accomplish this correlation analysis, the individual miles were designated as either a "curve" mile (which contains one or more curves within the mile) or a tangent mile (which contains no curves). Note, this is a "straight" section of railroad and as such had many miles of tangent only track.

Figures 17 and 18 present the mean loaded gage values (1998 and 1996) for "curve" and "tangent" miles respectively. In all cases, the mean loaded gage values behave as expected (and in accordance with the previously presented summary data), i.e. the track that had been timbered between GRMS runs showed a distinct reduction in mean loaded gage while the track with no timbering showed a distinct increase in mean loaded gage. Specifically:

For track that had timbering (tie gang) performed between GRMS runs:

- The curved miles showed an overall (average) reduction in mean loaded gage of 0.04; i.e. from 0.34 in 1996 to 0.30 in 1998.
- The tangent miles showed an overall (average) reduction in mean loaded gage of 0.04; i.e. from 0.38 in 1996 to 0.34 in 1998.

For track that had no timbering (no tie gang) performed between GRMS runs:

- The curved miles showed an overall (average) increase in mean loaded gage of 0.04; i.e. from 0.25 in 1996 to 0.29 in 1998. The corresponding rate of degradation was 0.0006 per MGT.[9]
- The tangent miles showed an overall (average) increase in mean loaded gage of 0.08; i.e. from 0.14 in 1996 to 0.22 in 1998. The corresponding rate of degradation was 0.001 per MGT.
- The overall strength level (loaded gage) of the tangent miles was noticeably lower than the curve miles.

Examination of the PLG24 data (Figures 19 and 20) showed, in general, similar behavior with the exception of one zone in the curved mile set of data (a no timbering zone

[9] Based on a total average tonnage over the two year period of 65 MGT

Figure 17

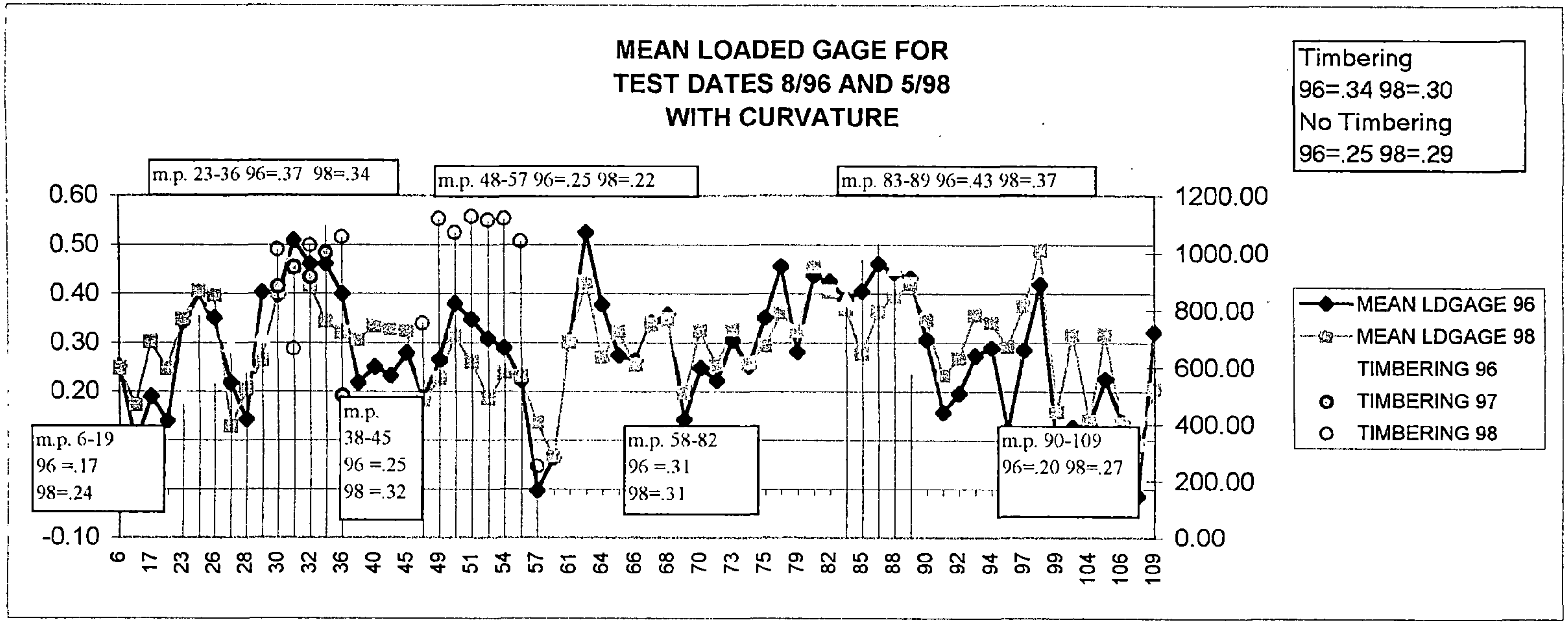

MEAN LOADED GAGE FOR
TEST DATES 8/96 AND 5/98
WITH CURVATURE
Timbering
96=.34 98=.30
No Timbering
96=.25 98=.29
m.p. 23-36 96=.37 98=.34
m.p. 48-57 96=.25 98=.22
m.p. 83-89 96=.43 98=.37
m.p. 6-19
96 =.17
98=.24
m.p.
38-45
96 =.25
98 =.32
m.p. 58-82
96 =.31
98=.31
m.p. 90-109
96=.20 98=.27
0.60
0.50
0.40
0.30
0.20
-0.10
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
6 17 23 26 28 30 32 36 40 45 49 51 54 57 61 64 66 68 70 73 75 79 82 85 88 90 92 94 97 99 104 106 109
MEAN LDGAGE 96
MEAN LDGAGE 98
TIMBERING 96
TIMBERING 97
TIMBERING 98

Figure 18

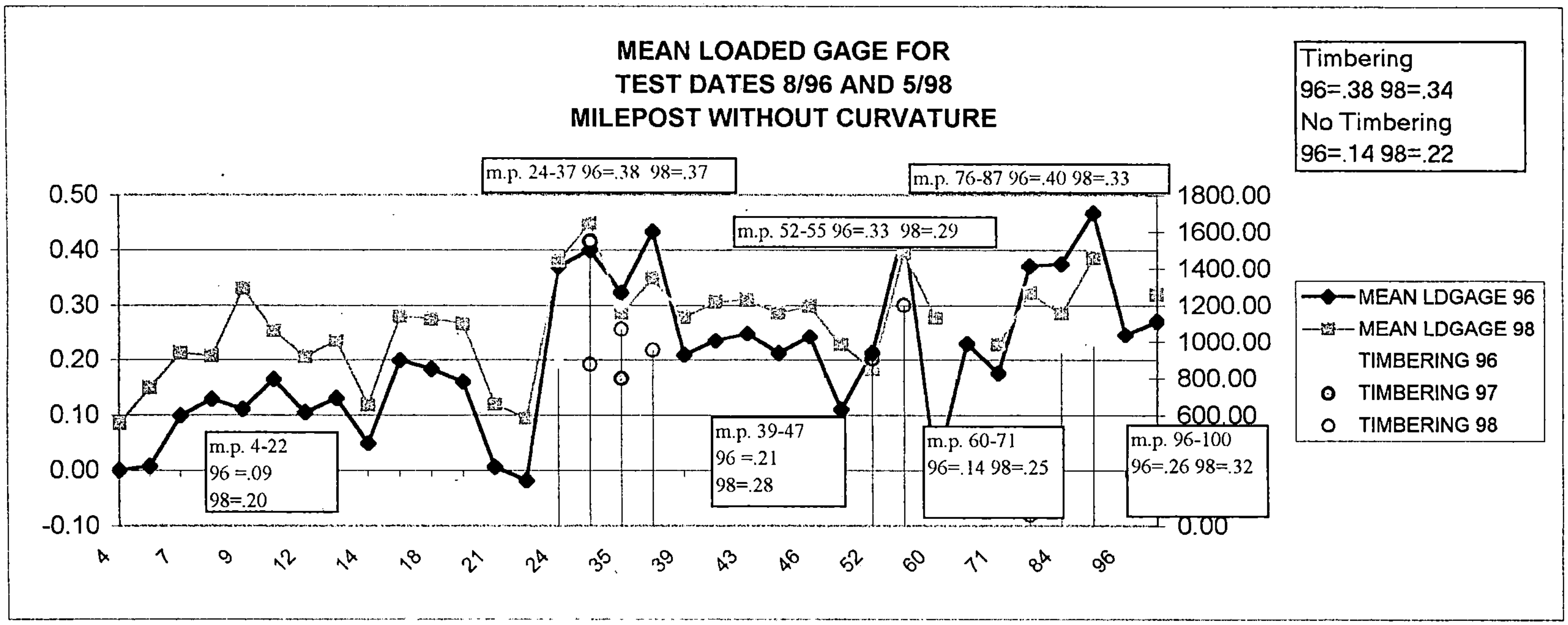

MEAN LOADED GAGE FOR
TEST DATES 8/96 AND 5/98
MILEPOST WITHOUT CURVATURE
Timbering
96=.38 98=.34
No Timbering
96=.14 98=.22
m.p. 24-37 96=.38 98=.37
m.p. 76-87 96=.40 98=.33
m.p. 52-55 96=.33 98=.29
m.p. 4-22
96 =.09
98=.20
m.p. 39-47
96 =.21
98=.28
m.p. 60-71
96=.14 98=.25
m.p. 96-100
96=.26 98=.32
MEAN LDGAGE 96
MEAN LDGAGE 98
TIMBERING 96
TIMBERING 97
TIMBERING 98
0.50
0.40
0.30
0.20
0.10
0.00
-0.10
1800.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
0.00
4
7
9
12
14
18
21
24
35
39
43
46
52
60
71
84
96

Figure 19

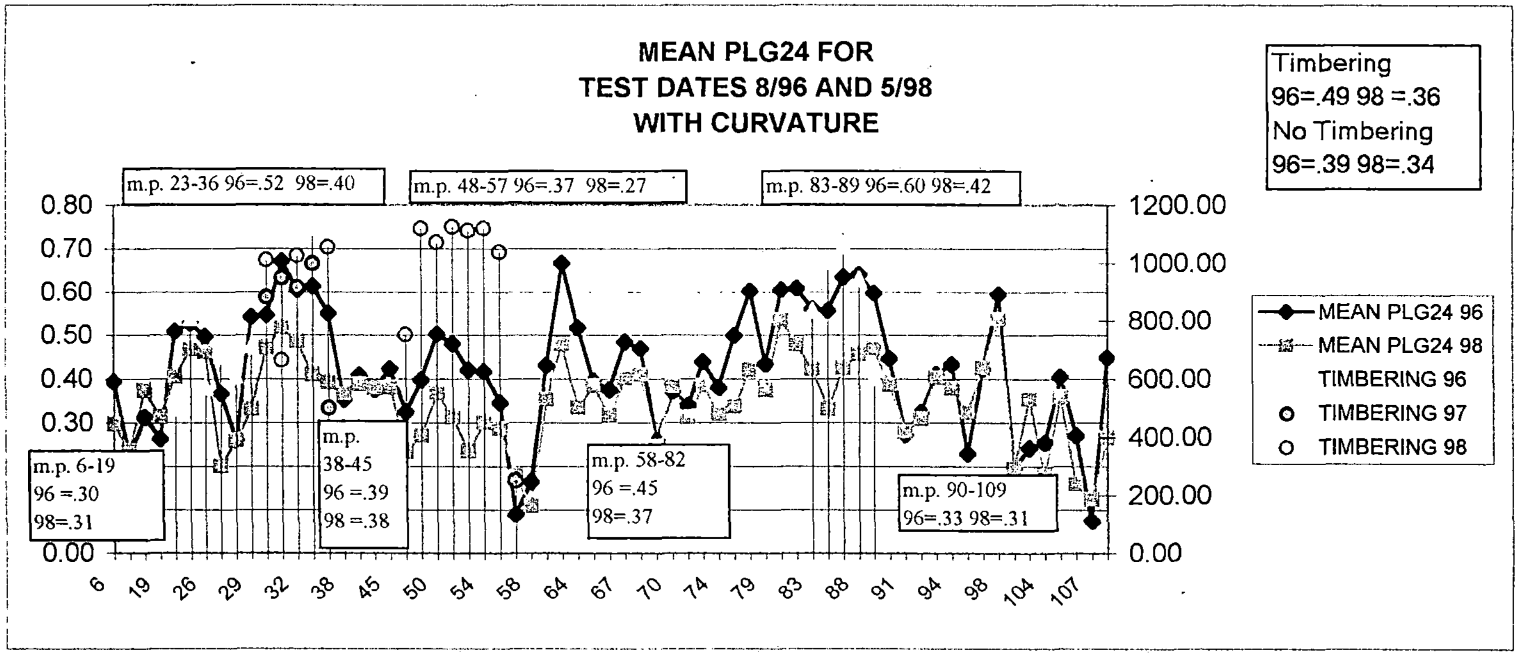
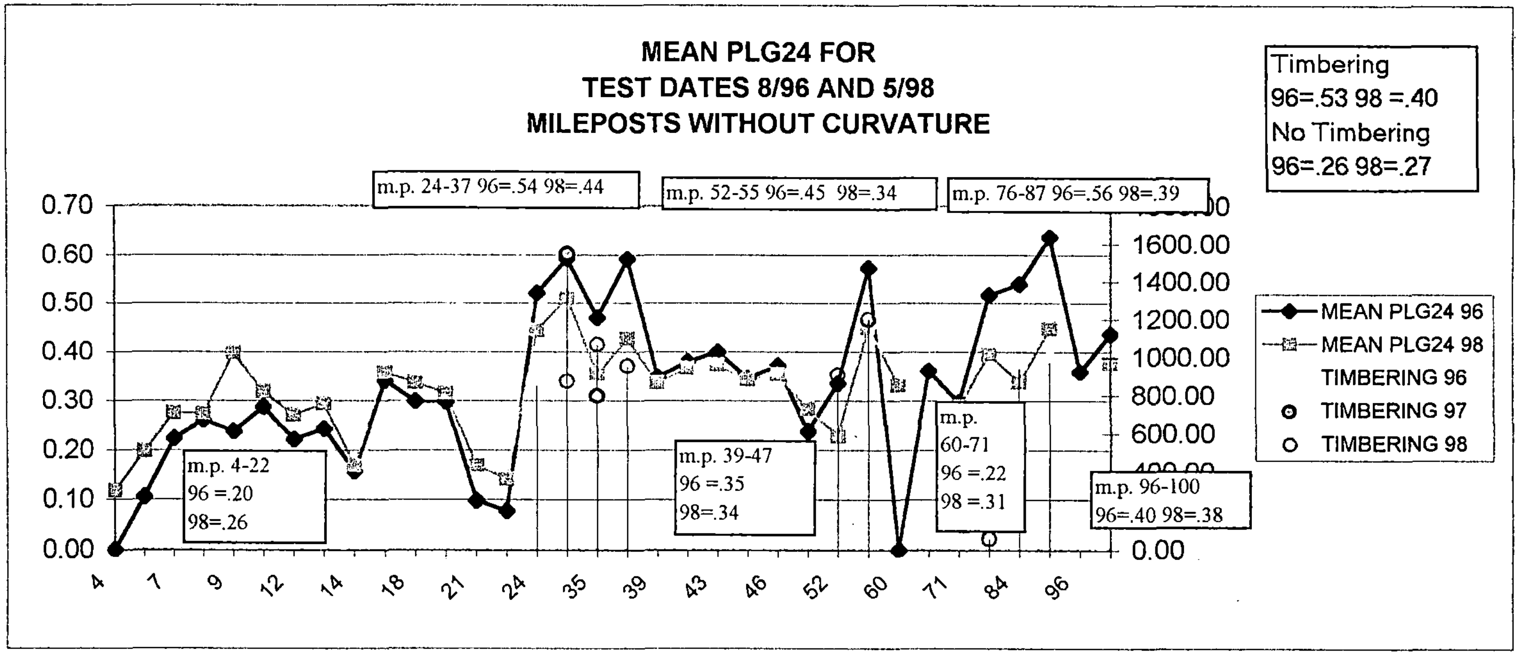

MEAN PLG24 FOR
TEST DATES 8/96 AND 5/98
WITH CURVATURE
Timbering
96=.49 98 =.36
No Timbering
96=.39 98=.34
m.p. 23-36 96=.52 98=.40
m.p. 48-57 96=.37 98=.27
m.p. 83-89 96=.60 98=.42
m.p. 6-19
96 =.30
98=.31
m.p.
38-45
96 =.39
98 =.38
m.p. 58-82
96 =.45
98=.37
m.p. 90-109
96=.33 98=.31
MEAN PLG24 96
MEAN PLG24 98
TIMBERING 96
TIMBERING 97
TIMBERING 98
0.80
0.70
0.60
0.50
0.40
0.30
0.00
1200.00
1000.00
800.00
600.00
400.00
200.00
0.00
6 19 26 29 32 38 45 50 54 58 64 67 70 74 79 83 88 91 94 98 104 107

Figure 20



MEAN PLG24 FOR
TEST DATES 8/96 AND 5/98
MILEPOSTS WITHOUT CURVATURE
Timbering
96=.53 98 =.40
No Timbering
96=.26 98=.27
m.p. 24-37 96=.54 98=.44
m.p. 52-55 96=.45 98=.34
m.p. 76-87 96=.56 98=.39
m.p. 4-22
96 =.20
98=.26
m.p. 39-47
96 =.35
98=.34
m.p.
60-71
96 =.22
98 =.31
m.p. 96-100
96=.40 98=.38
MEAN PLG24 96
MEAN PLG24 98
TIMBERING 96
TIMBERING 97
TIMBERING 98
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
1600.00
1400.00
1200.00
1000.00
800.00
600.00
0.00
4
7
9
12
14
18
21
24
35
39
43
46
52
60
71
84
96

between MP 58 and 82) which showed a reduction in PLG24 with tonnage (i.e. between 1996 and 1998).

Thus, based on *the data presented here*, there did not appear to be any apparent differences in degradation behavior between the tangent and curved sections, except that the average values (both loaded gage and PLG24) for the tangent miles (no timbering) was significantly lower that that of the curved miles, suggesting a higher level of lateral loading for the curved track, as expected.

Figures 21 through 24 present a correlation analysis, for both tangent and curve miles, of the change in loaded gage (Delta Loaded Gage) as a function of ties inserted. As can be seen in these Figures, the two classes of track behave quite similarly (and similar to the overall behavior reported previously). Both generate degradation relationships of the form:

LDGAGE (new) = LDGAGE (old) + a* TIES + b

Where:

LDGAGE (new) is the predicted mean (per mile) loaded gage after ties are inserted

LDGAGE (old) is the measured mean (per mile) loaded gage prior to ties insertion

Note; Delta LdGage = LDGAGE(new) - LDGAGE(old)

TIES is the number of ties inserted in the mile

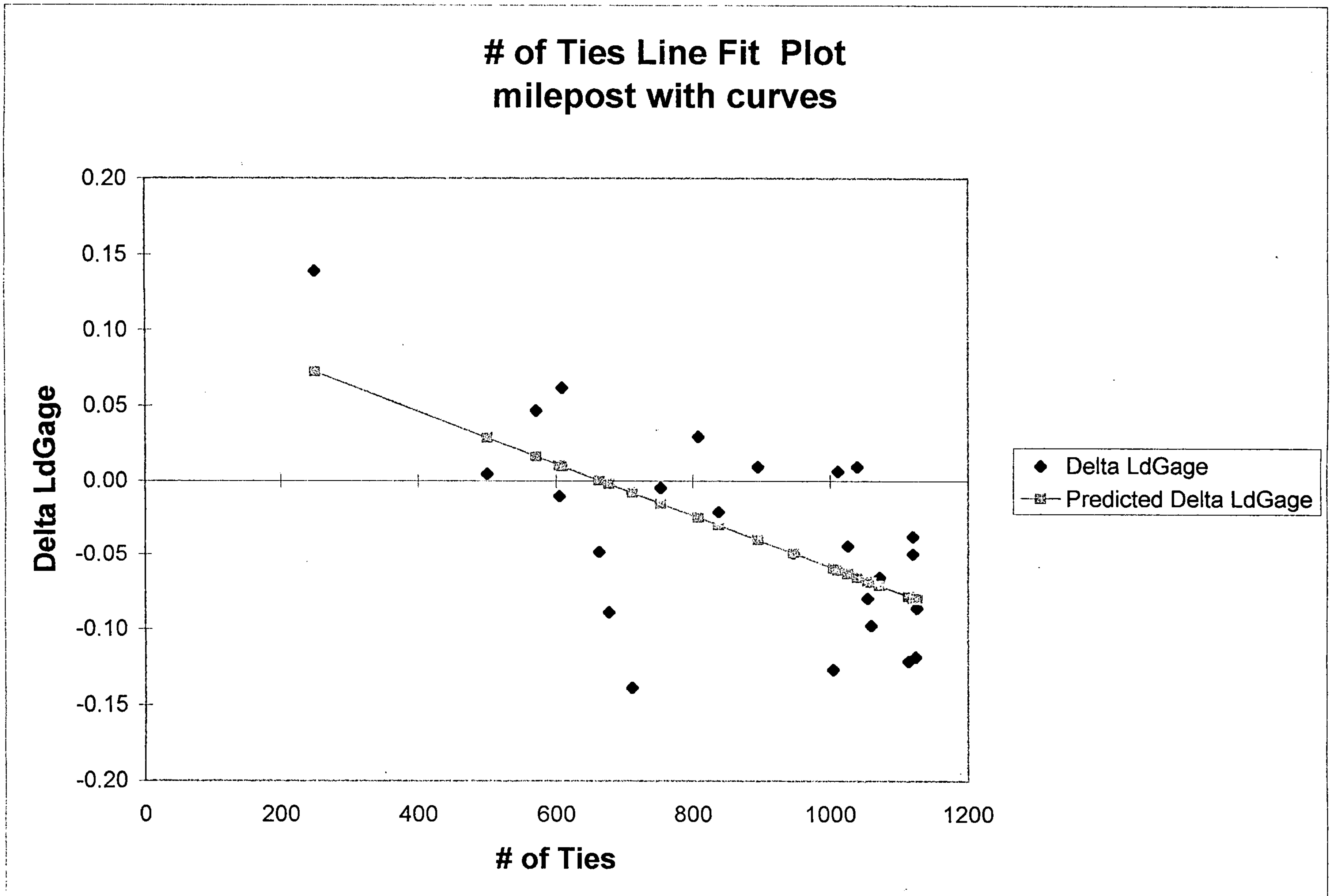
a is a constant (slope) equal to –0.0002

b is a constant (intercept) equal to the additional degradation that occurs between the time of the first measurement (before) and the second measurement.

Finally, analysis of the rate of degradation of the Loaded Gage, as a function of MGT (with no intervening timbering programs), likewise shows a similar behavior to that reported previously. Figure 25 shows the tangent miles rate of degradation (with a slope of 0.001). Figure 26 shows the curve miles with a slope of 0.0007. [Note, the slopes correspond to the rate of degradation already noted above.]

Again, the differences between the tangent and curved miles are not well defined in this data set. However, this may be due to the fact that most of the curves in this line segment are relatively shallow and, in general, the variation between traffic types and speeds is limited. Other locations with more severe curvature and larger traffic variations may show more pronounced differences.

Figure 21



# of Ties Line Fit Plot
milepost with curves
Delta LdGage
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
0
200
400
600
800
1000
1200
# of Ties
Delta LdGage
Predicted Delta LdGage

Figure 22

SUMMARY OUTPUT

with curves
dldgage = 0.115848 - .000174* # of ties (96&98 timbering)

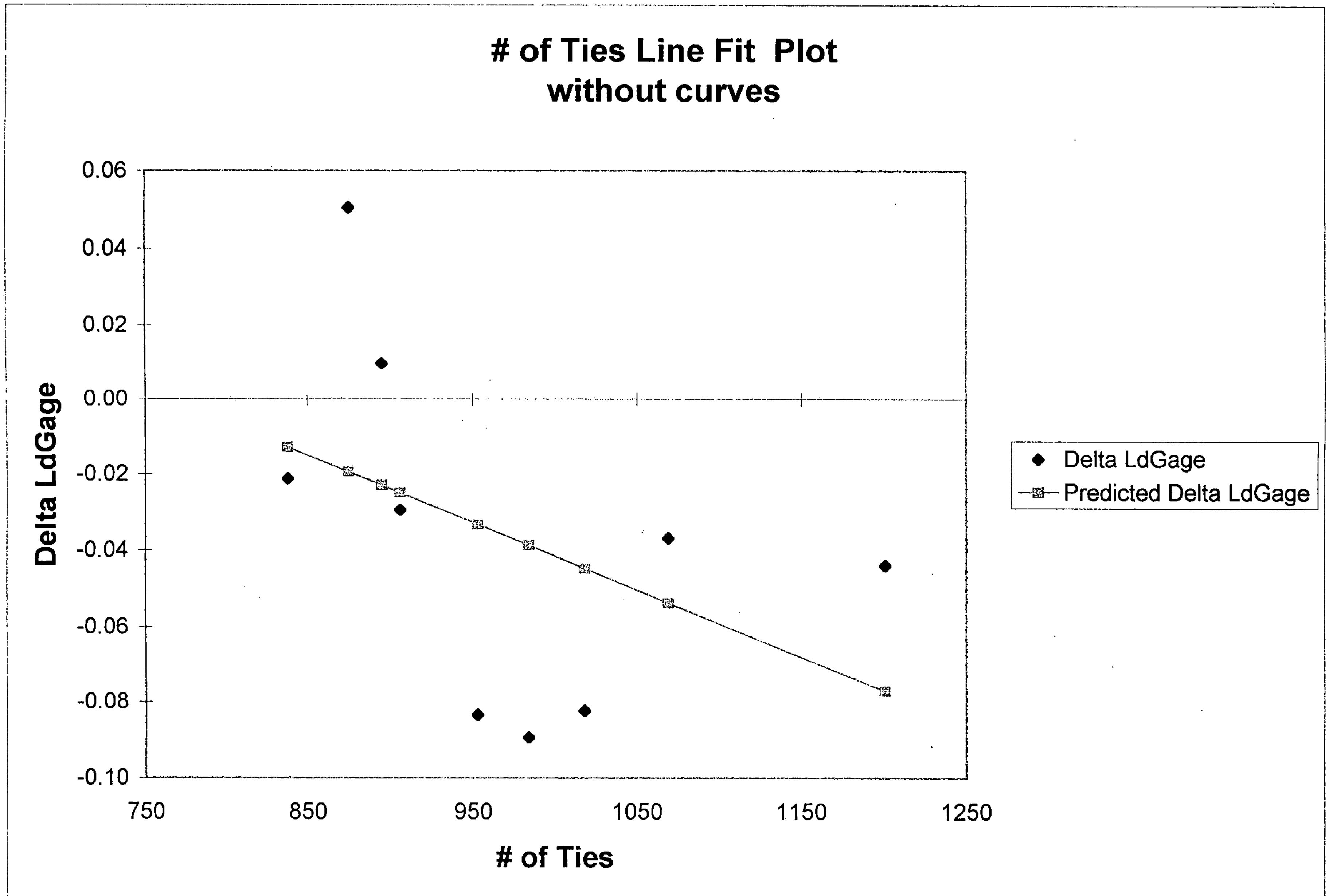
Regression Statistics	
Multiple R	0.632436116
R Square	0.399975441
Adjusted R Square	0.373887416
Standard Error	0.052528712
Observations	25

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.04230441	0.04230441	15.33176432	0.000693602
Residual	23	0.063463109	0.002759266		
Total	24	0.10576752			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*
Intercept	0.1158478	0.039985675	2.89723255	0.008123805	0.033131241	0.19856436	0.033131241
# of Ties	-0.000174032	4.4446E-05	-3.915579691	0.000693602	-0.000265975	-8.20884E-05	-0.000265975

Figure 23



# of Ties Line Fit Plot
without curves
0.06
0.04
0.02
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
Delta LdGage
750
850
950
1050
1150
1250
# of Ties
Delta LdGage
Predicted Delta LdGage

Figure 24

SUMMARY OUTPUT

without curves
dldgage = 0.13551 - .000177* # of ties (96&98 timbering)

Regression Statistics	
Multiple R	0.432168284
R Square	0.186769425
Adjusted R Square	0.070593629
Standard Error	0.044591279
Observations	9

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.003196612	0.003196612	1.60764489	0.245365741
Residual	7	0.013918675	0.001988382		
Total	8	0.017115288			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*
Intercept	0.1355074	0.136310163	0.994110762	0.3532826	-0.186814687	0.457829488	-0.186814687
# of Ties	-0.000176932	0.000139544	-1.267929371	0.245365741	-0.000506901	0.000153037	-0.000506901

Figure 25

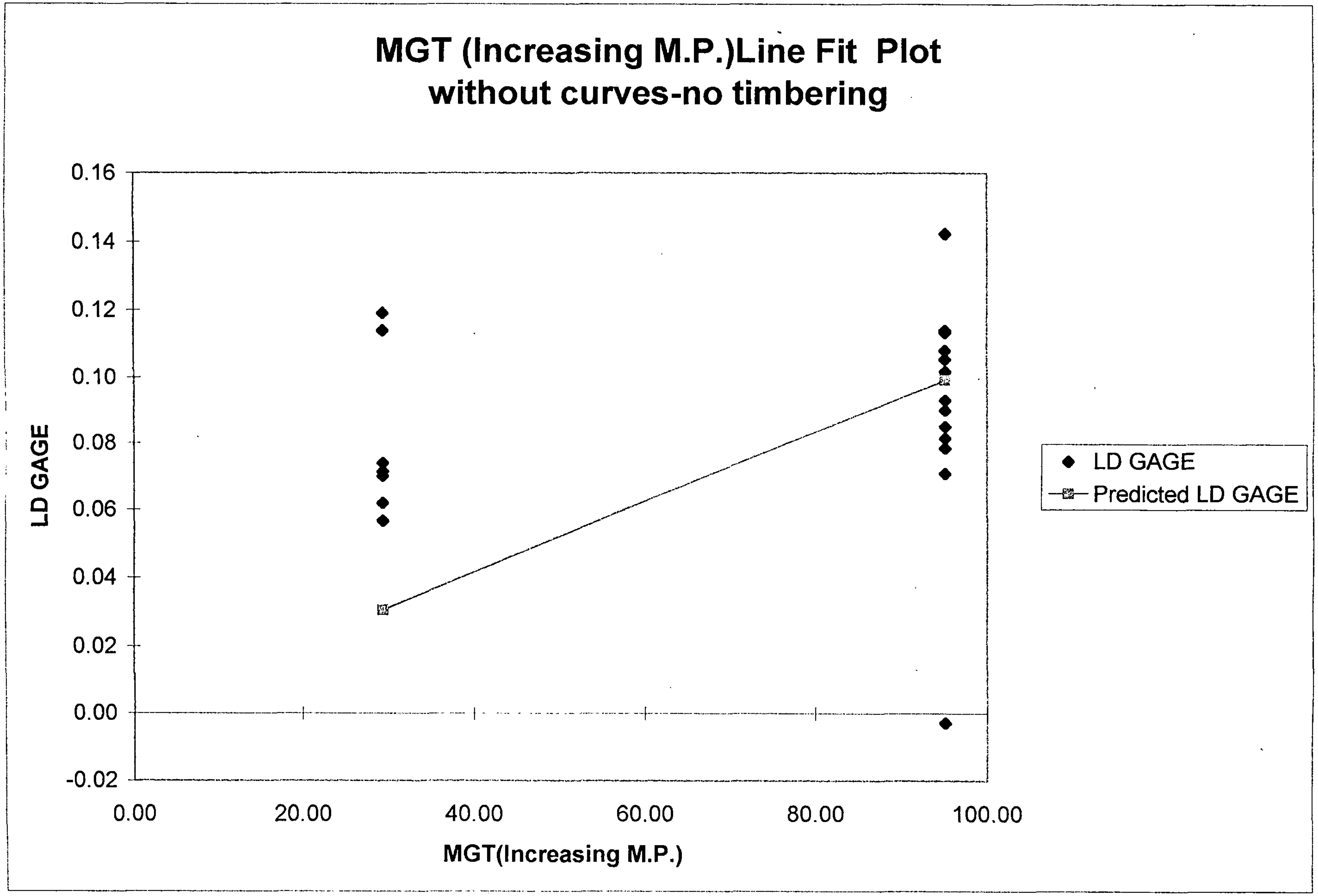
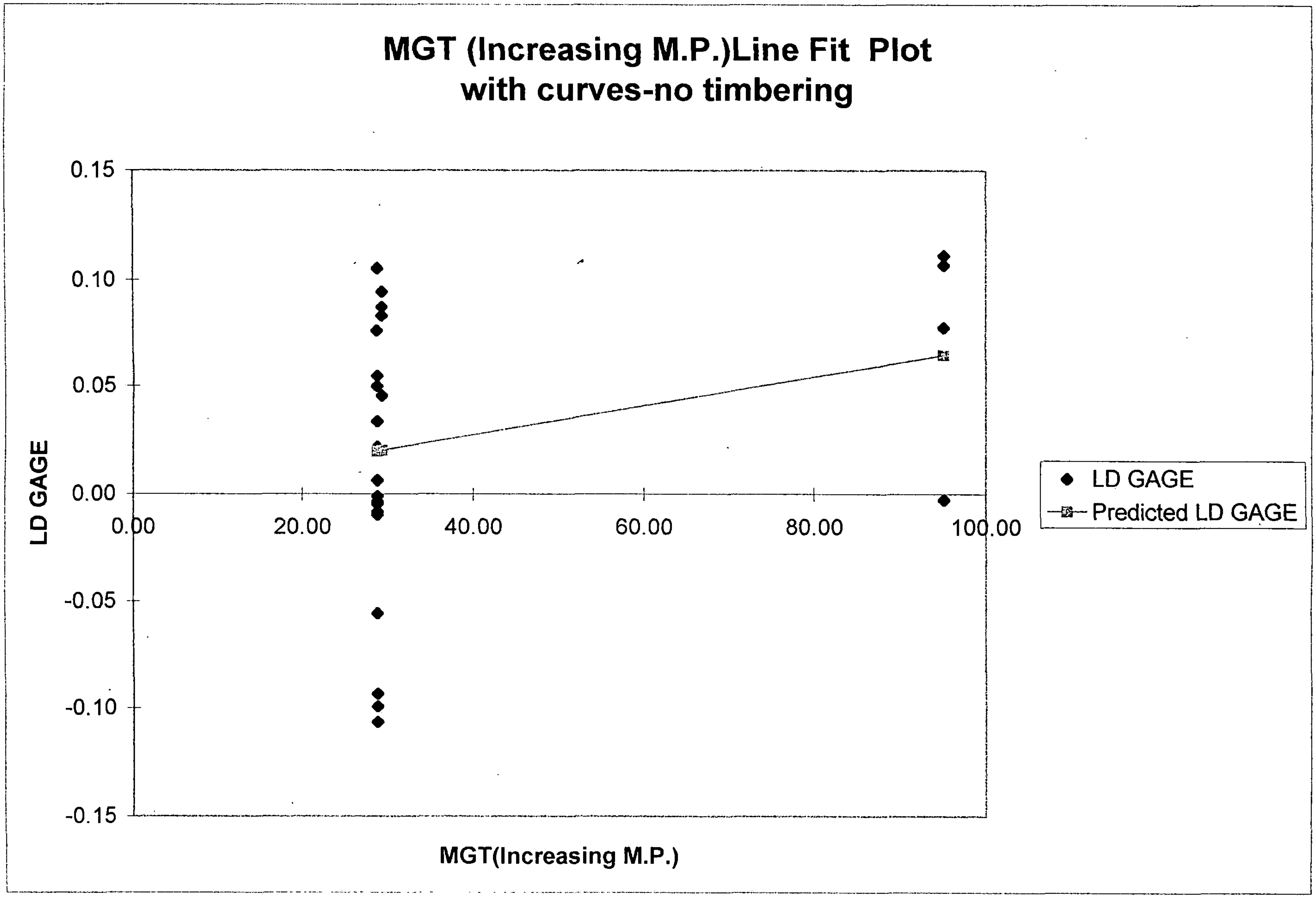

MGT (Increasing M.P.)Line Fit Plot
without curves-no timbering
LD GAGE
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
-0.02
0.00
20.00
40.00
60.00
80.00
100.00
MGT(Increasing M.P.)
LD GAGE
Predicted LD GAGE

Figure 26


MGT (Increasing M.P.)Line Fit Plot
with curves-no timbering
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
LD GAGE
0.00
20.00
40.00
60.00
80.00
100.00
MGT(Increasing M.P.)
LD GAGE
Predicted LD GAGE

Correlation of Track Strength data with Anticipated Load Environment

The final question that must be addressed is the definition of proper TSQI values for the maintenance of track for the range of equipment under consideration. This includes the freight traffic, for which the line is currently being maintained, and future high speed passenger traffic.

Figure 27 presents previous TSC sponsored tests of track strength which indicates that a GWR of 0.52 represents weak cut spike track, a value of 0.32 represents good wood tie track, and a value of 0.15 represents good concrete tie track. While reliable GWR values for poor track are not available (due to the problems with the unloaded gage in the 1996 GRMS run), the data presented in the February interim 1998 report[10] indicated that mean GWR values of 0.25 to 0.38 corresponded to track that CSX determined as needing ties (Figure 28). Note, that the data in Figure 27 corresponds to a spot (local) measurement while Figure 28 corresponds to a per mile mean. The latter is necessary in order to utilize this information in a planning mode, rather than in a safety inspection mode.

Based on this data, it appears that a "first" cut estimate for a "per mile" mean TSQI value is 50 to 75% of the "spot" TSQI value.

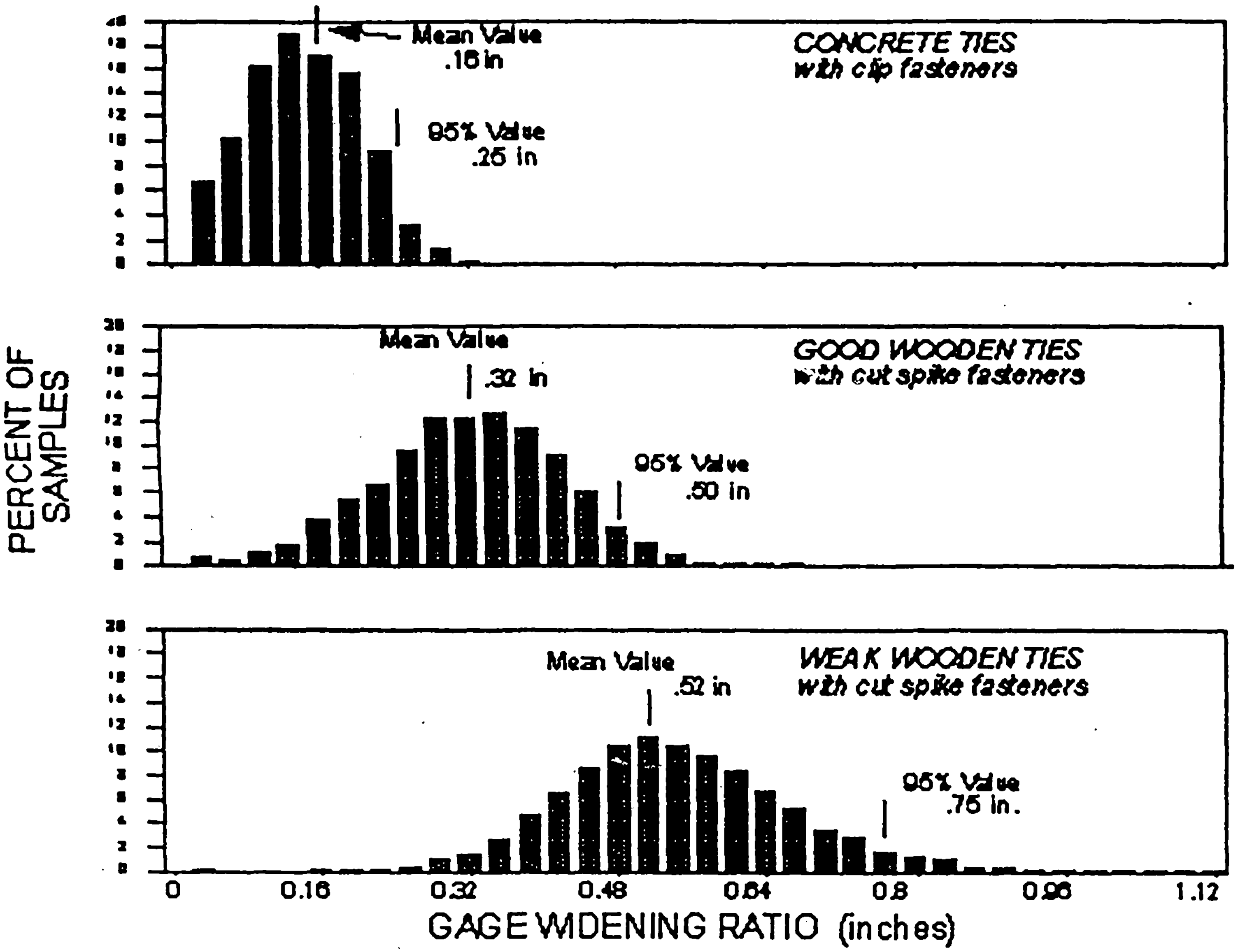
In the case of PLG24, Figure 11 shows that the range of mean PLG24 for track requiring timbering (based on CSX standards for freight traffic) is of the order of 0.35 to 0.70 with an average value of 0.48. The corresponding range of mean loaded gage for track requiring timbering (based on CSX standards for freight traffic) is of the order of 0.24 to 0.50 with an average value of 0.34.

The new FRA standards require the following gage widening restrictions:

Class of Track	Maximum Speed (mph) Freight	Passenger	Maximum Gage Widening[11]
Class 3	40	60	1.25"
Class 4	60	80	1.00"
Class 5	80	90	1.00"
Class 6	N/A	110	0.75"[12]

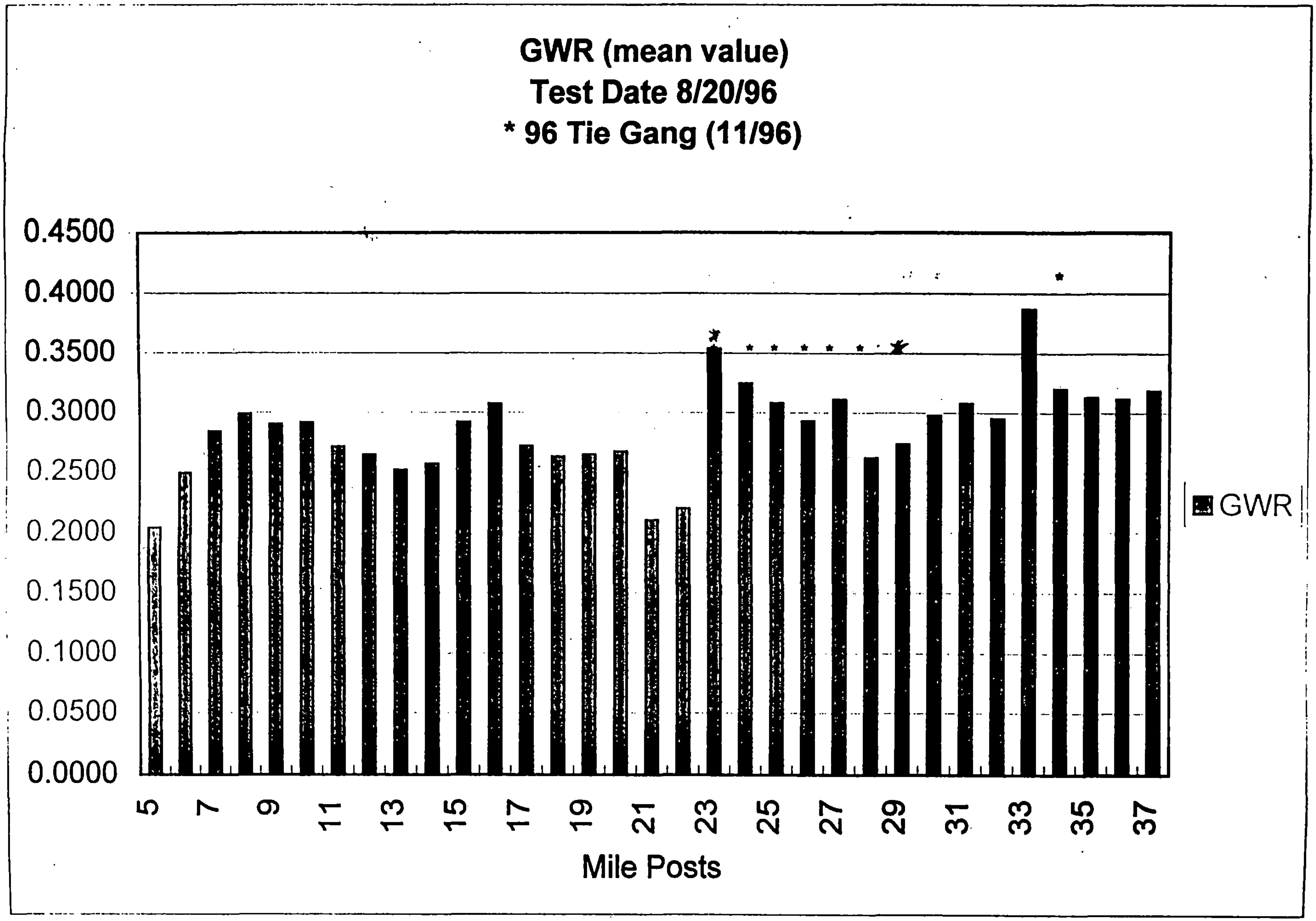
[10] "Demonstration of High Speed Track Maintenance Using Objective Gage Strength Data", Interim Report by ZETA-TECH Associates to the FRA, February 5, 1998.
[11] from nominal gage of 4' 8 ½"
[12] maximum change of 0.5" within 31 feet

Figure 27



Mean Value
.16 in
95% Value
.25 in
CONCRETE TIES
with clip fasteners
Mean Value
.32 in
95% Value
.50 in
GOOD WOODEN TIES
with cut spike fasteners
Mean Value
.52 in
95% Value
.75 in.
WEAK WOODEN TIES
with cut spike fasteners
PERCENT OF
SAMPLES
0
0.16
0.32
0.48
0.64
0.8
0.96
1.12
GAGE WIDENING RATIO (inches)

Figure 28


GWR (mean value)
Test Date 8/20/96
* 96 Tie Gang (11/96)
0.4500
0.4000
0.3500
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
Mile Posts
GWR

These are for "spot" inspection, as such they are too restrictive for a maintenance planning index (TSQI). However, taking 50% of this spot value (the bottom of the range noted above), a corresponding per mile mean limit for PLG24 (the "maintenance" PLG24) would now be as follows:

	"Maintenance" PLG24
Low Speed Freight (Class 3)	0.625
Moderate/High Speed Track (Class 4)	0.5
Passenger (Class 6)	0.375

Note; the limit of 0.5 corresponds to the measured average of the mean PLG24 on the track that was actually timbered by CSX (thus determined by the railroad inspectors as requiring ties).

These limits allow for the determination of the number of ties to be inserted per mile, by calculating the difference between the "actual" (measured) mean PLG24 for the mile and the above defined limit. This difference is then divided by the "slope" of the PLG24 degradation equation presented previously to calculate the number of ties to be inserted, as follows:

$$TIES' = \frac{PLG24_{EXISTING} - PLG24_{THRESHOLD}}{|a'|}$$

Where: $TIES'$ = number or ties to be installed

$PLG24_{EXISTING}$ = the current measurement mean (per mile) PLG24

$PLG24_{THRESHOLD}$ = the railroad defined maintenance threshold for PLG24

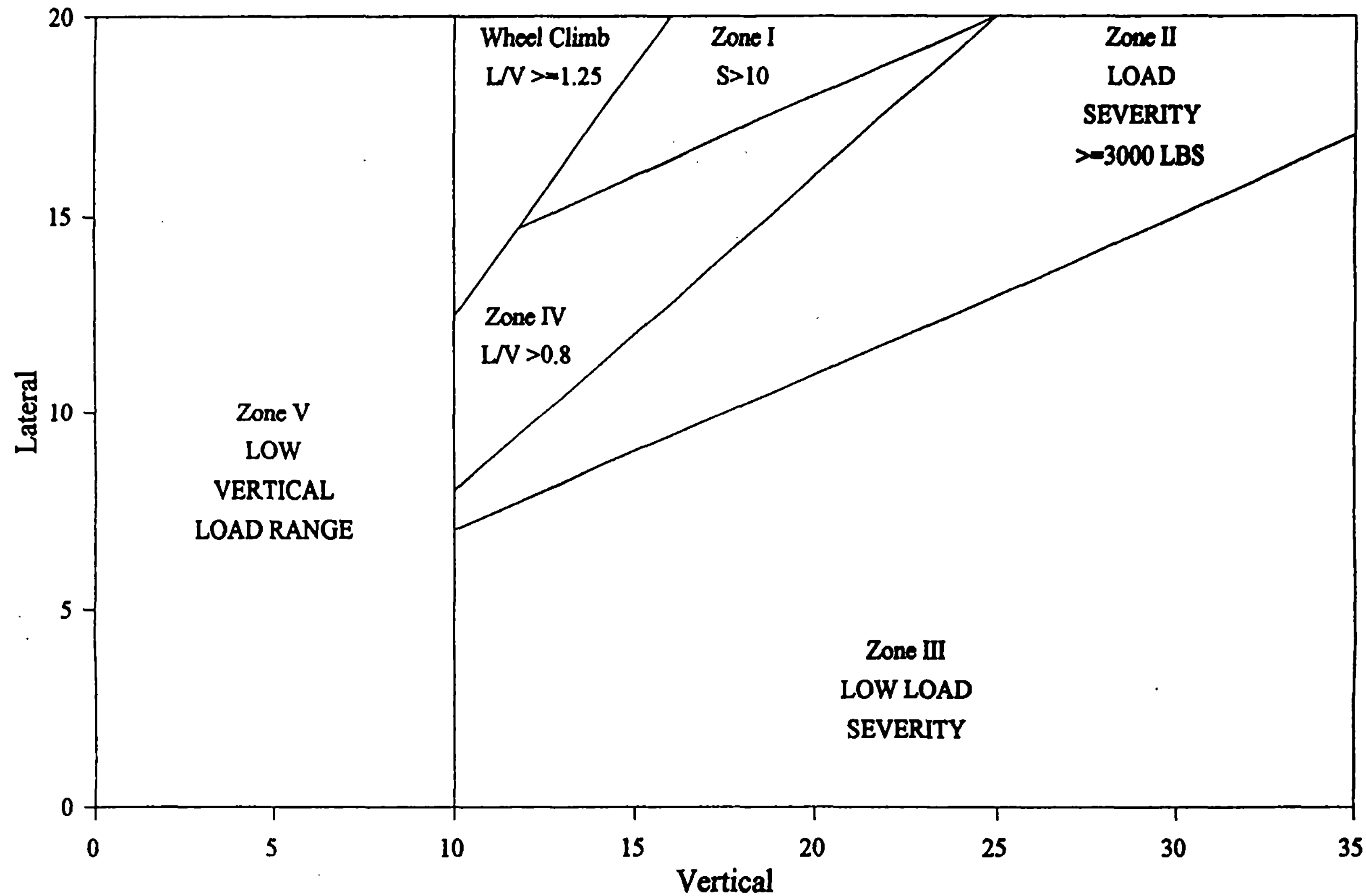
And

$|a'|$ = the absolute value of the slope of the PLG24 equation (equal to 0.0002 for the data presented on pager 16)

Finally, it should be noted that the most effective GRMS loading levels are a combination of Lateral (L) and Vertical (V) loads such that the load severity of the combined load is of sufficient magnitude as to cause a measurable displacement of the rail head (Zone II of Figure 29). The GRMS load levels are L= 14 Kips and V = 21 Kips, which fall within this zone. This range of loading is well above average lateral load levels (and load severity) as measured on both passenger and freight rail operations. These levels however are representative of the low probability high magnitude loads that occur infrequently (less than 1%), and which represent potential safety problems. Thus they are appropriate for use as a spot or safety parameter and are "conservative" in their application to the maintenance planning approach presented here-in (provided that the maintenance limits are appropriately selected, as discussed previously.)

Figure 29

GRMS Forces vs. Recommended Practices



Determination of "Minimum Number of Ties Required to Maintain "Satisfactory" Track

Using the tools and analysis techniques presented in this report, it is possible to examine the relationship between actual number of crossties installed by CSX on the study route and the number of crossties **required** to maintain a satisfactory[13] level of track condition (from a maintenance as well as safety point of view).

Figure 30 shows the mean PLG24 (calculated from the 8/96 GRMS test run) for Mileposts 5 through 37, together with those miles where a tie gang was used in late 1996 (after the GRMS measurement run). Table 10 presents the calculated mean PLG24 values for those miles, for which ties were inserted. The presented PLG24 values correspond to the "before ties " condition (1996 GRMS) and the "after tie installation" condition (1998 GRMS). The number of ties inserted is also presented (together with the equivalent number of ties per mile). As can be seen, these range from between 500 and 1,124 ties installed in late 1996.

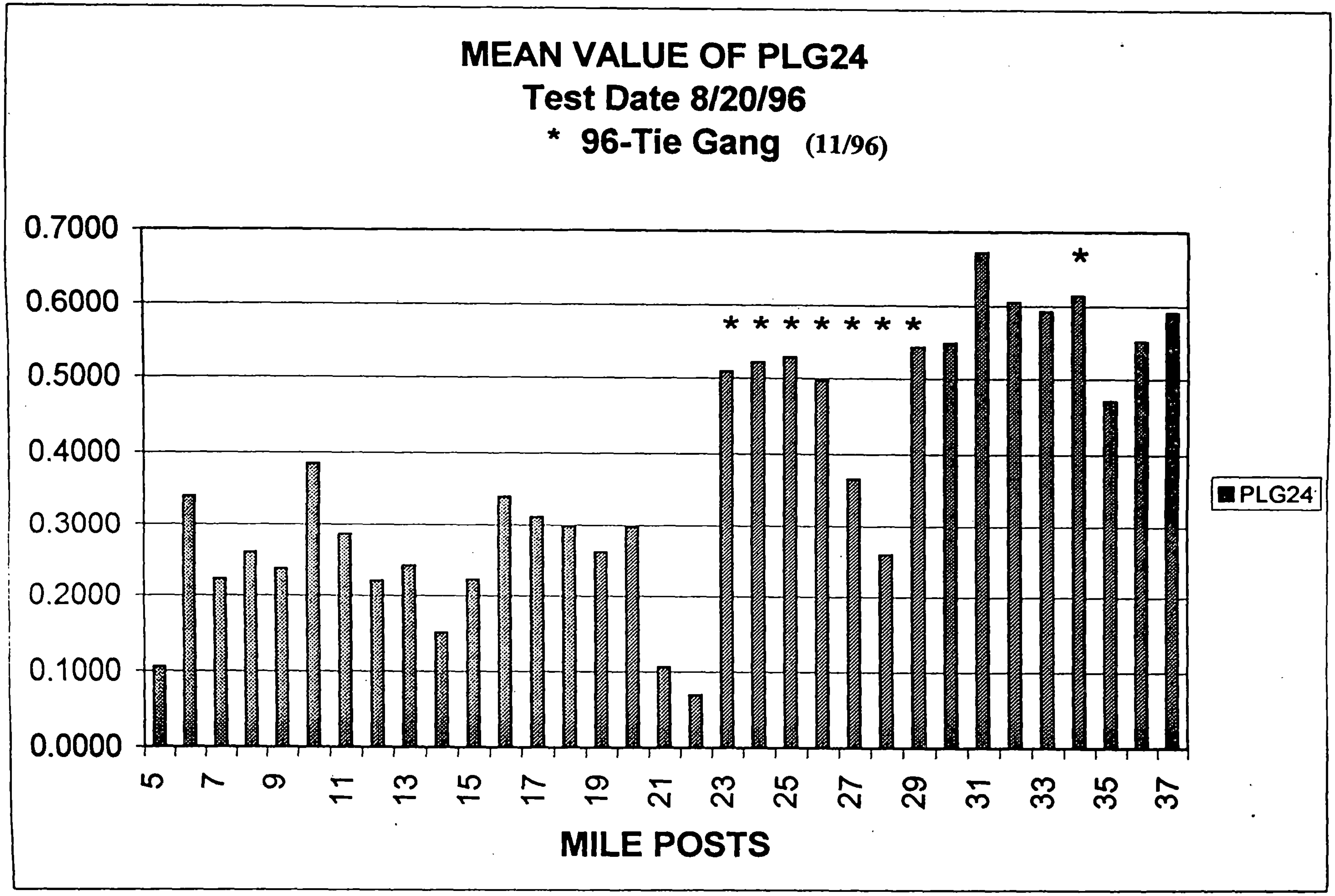
Note that for all mileposts except 27 and 28, the before mean GRMS value is greater than the required 0.5 value (corresponding to 57" for track with a nominal gage of 56 ½") identified previously for this class of track. (Mileposts 27 and 28 show mean GRMS values that are significantly lower and thus may not require additional ties at all, unless the ties are for vertical support purposes which are not identified by the GRMS data). In all cases, the "after" mean GRMS values are less than 0.50 with the maximum mean GRMS value being 0.47.

Table 11 and Figure 31 present the number of ties, for each mile, that exceeds a defined individual GRMS value. (Note, this is the "safety" standard which examines track strength on an individual foot basis). As can be seen from this Table, there are very few ties that exceed a PLG24 of 0.8 (the railroad uses a value of 1.0 for a safety threshold), with increasing numbers of ties to be replaced as the threshold is lowered. At the 0.50 level, most of the mileposts (except 25 and 26) need fewer ties than were actually installed. For example, for the milepost with the greatest number of ties installed, Milepost 34, only 65% of the actual ties installed are needed at the PLG24 = 0.5 level (on a per tie basis). *For all of the mileposts, only 88% of the actual ties installed are needed at the PLG24 = 0.50 level.* Furthermore, the removal of all individual ties with PLG24 > 0.50 will result in a mean PLG24 that is *significantly* less than 0.50 (because the measurement data indicates a variation in individual tie strength, as measured by the PLG24, with many of the ties having a significantly lower PLG24 value than this 0.50 threshold).

---

[13] It should be noted that this is based on lateral track strength , i.e. gage strength, as measured by the GRMS only. It further does not account for any additional factors of safety introduced by maintenance officers in anticipation of non-uniform future maintenance (e.g. periods of potential deferred maintenance). Thus there may be a "gap" between the theoretical minimum number of ties needed for maintaining the track on an ongoing basis, and the number of ties that are installed in anticipation of future fluctuations in budget and maintenance focus.

Figure 30

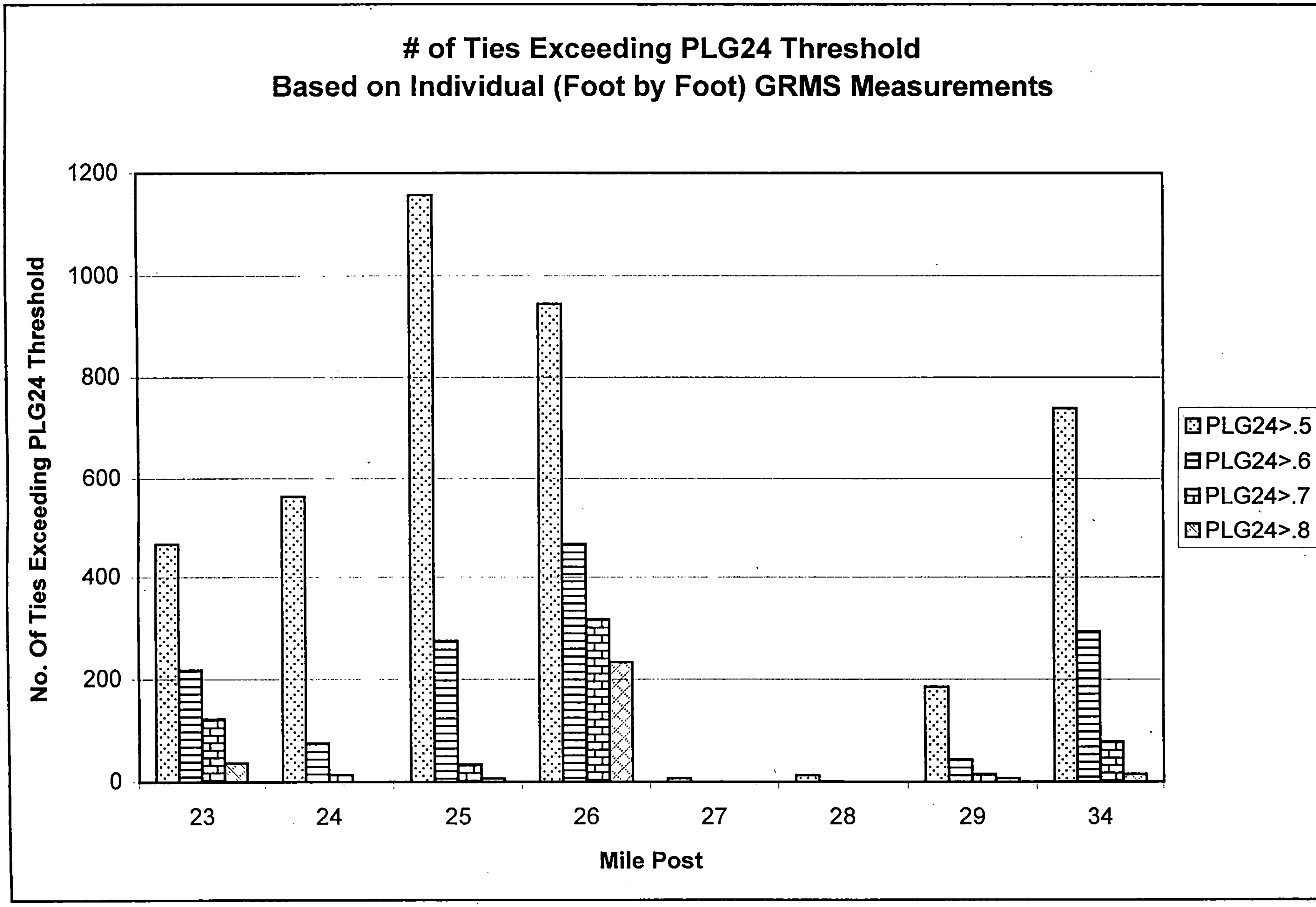

MEAN VALUE OF PLG24
Test Date 8/20/96
* 96-Tie Gang (11/96)
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
MILE POSTS
PLG24

MilePost	96 GRMS MEAN PLG24
23	0.51
24	0.52
25	0.53
26	0.50
27	0.37
28	0.26
29	0.54
34	0.61

Table 10

98 GRMS MEAN PLG24	Total Equ. Ties	# of Ties Installed
0.41	3198	500
0.45	3192	895
0.47	3190	808
0.46	3152	571
0.20	3148	677
0.26	3176	609
0.33	3211	711
0.41	3147	1124

Figure 31



# of Ties Exceeding PLG24 Threshold
Based on Individual (Foot by Foot) GRMS Measurements
No. Of Ties Exceeding PLG24 Threshold
1200
1000
800
600
400
200
0
23
24
25
26
27
28
29
34
Mile Post
PLG24>.5
PLG24>.6
PLG24>.7
PLG24>.8

Table 11

MilePost	96 GRMS MEAN PLG24	98 GRMS MEAN PLG24	Total Equ. Ties	# of Ties Installed		GRMS Ties PLG24>.3	PLG24>.4	PLG24>.5	PLG24>.6	PLG24>.7	PLG24>.8
23	0.51	0.41	3198	500		2268	1452	467	218	123	37
24	0.52	0.45	3192	895		3126	2290	564	76	14	0
25	0.53	0.47	3190	808		2939	2355	1157	274	34	7
26	0.50	0.46	3152	571		2661	1817	944	467	316	233
27	0.37	0.20	3148	677		501	66	7	0	0	0
28	0.26	0.26	3176	609		881	175	13	1	0	0
29	0.54	0.33	3211	711		1759	629	186	44	15	7
34	0.61	0.41	3147	1124		2402	1458	739	292	79	15
			Total	5895	Total	16537	10242	4077	1372	581	299
					% of actual installed	281%	174%	69%	23%	10%	5%
			Total (w/o 27,28)	4609	Total (w/o 27,28)	15155	10001	4057	1371	581	299
					% of actual installed	329%	217%	88%	30%	13%	6%

Table 12 presents the number of ties, for each mile, necessary to achieve the "maximum desired" mean (per mile) PLG24 level (based on a linear interpolation of the mean GRMS values and the actual number of ties installed). Thus, for a mean PLG24 level of 0.47, corresponding to the highest "acceptable" level actually achieved by the railroad tie installation program (at MP 25), only 66% of actual ties installed were really needed. (Note, this is exclusive of MP 27 and 28 which were already well below this PLG24 level even before the tie installations.) For a mean PLG24 level of 0.46, a higher level of track strength corresponding to the next highest "acceptable" level actually achieved by the railroad tie installation program (at MP 26), only 78% of actual ties installed were really needed. Based on this analysis, the railroad in fact, could have installed 1561 fewer ties at the PLG24 = 0.47 level and 1010 fewer ties at the PLG24 = 0.46 level.

Looking at this data from the point of view of improvement in mean PLG24, using the regression equation presented previously, Tables 13[14] and 14[15] present the projected improved PLG24, based on a tie insertion rate corresponding to the PLG24 levels presented in Table 11. Thus, for example, if ties were installed that exceeded the individual PLG24 = 0.5 level only , then for MP 23, 24, 29 and 34 , significantly fewer ties were required to achieve an acceptable level of mean PLG24 (e.g. for MP 34, 65% of the actual ties installed project to a mean PLG24 level of 0.49, below the PLG24 = .50 threshold- see Table 13.) In fact, Table 13 shows that for all of the mileposts that had initially high PLG24 levels (greater than 0.5), a reduction to an acceptable level (i.e. below 0.49) can be achieved with the installation of significantly fewer ties than were actually installed.

Using the results and methodology presented here-in, it is possible to extrapolate the results forward to examine the potential for maintenance for high speed track. Noting that the "Maintenance" PLG24 for high speed (Class 6) track was set at 0.375" (corresponding to 56 7/8"), the previously defined equation can be used to determine the number of ties necessary to bring the track to the higher strength standard associated with high speed operations. The results of such an analysis is presented in Table 15 which shows, for the selected mileposts, the number of ties that would have to be installed to reach the more restrictive PLG24 level required for high speed track. (Note, these values are based on the regression equation presented previously). Thus, for the case of MP 34, 1431 ties would be required (as opposed to the 1124 ties actually inserted which brought the track to a level of 0.41).

---

[14] Based on the slope of the PLG24 vs. tie inserted equation presented previously (with the intercept set equal to zero).

[15] Based on the slope and intercept of the PLG24 vs. ties inserted equation presented previously.

Table 12

MilePost	96 GRMS MEAN PLG24	98 GRMS MEAN PLG24	Total Equ. Ties	# of Ties Installed	Threshold Mean PLG24= Required Change in PLG24
23	0.51	0.41	3198	500	0.04
24	0.52	0.45	3192	895	0.05
25	0.53	0.47	3190	808	0.06
26	0.50	0.46	3152	571	0.03
27	0.37	0.20	3148	677	0.00
28	0.26	0.26	3176	609	0.00
29	0.54	0.33	3211	711	0.07
34	0.61	0.41	3147	1124	0.14
			Total	5895	Total
			Total (w/o 27,28)	4609	Total (w/o 27,28)

0.47		Threshold Mean PLG24=	0.46	
Ties Require	% actual	Required Change in PLG24	Ties Require	% actual
189	38%	0.05	238	48%
606	68%	0.06	724	81%
781	97%	0.07	915	113%
440	77%	0.04	602	105%
0	0%	0.00	0	0%
-0	-0%	0.00	-0	-0%
237	33%	0.08	271	38%
795	71%	0.15	850	76%
3048	52%	Total	3599	61%
3048	66%	Total (w/o 27,28)	3599	78%

MilePost	96 GRMS MEAN PLG24	98 GRMS MEAN PLG24	Total Equ. Ties
23	0.51	0.41	3198
24	0.52	0.45	3192
25	0.53	0.47	3190
26	0.50	0.46	3152
27	0.37	0.20	3148
28	0.26	0.26	3176
29	0.54	0.33	3211
34	0.61	0.41	3147

Table 13

Predicted PLG24 W/O Constatnt					
PLG24>.3	PLG24>.4	PLG24>.5	PLG24>.6	PLG24>.7	PLG24>.8
0.13	0.27	0.43	0.47	0.49	0.50
0.00	0.14	0.43	0.51	0.52	0.52
0.04	0.13	0.33	0.48	0.52	0.53
0.05	0.19	0.34	0.42	0.44	0.46
0.28	0.36	0.37	0.37	0.37	0.37
0.11	0.23	0.26	0.26	0.26	0.26
0.25	0.44	0.51	0.53	0.54	0.54
0.21	0.37	0.49	0.57	0.60	0.61

Table 14

MilePost	96 GRMS MEAN PLG24	98 GRMS MEAN PLG24	Total Equ. Ties	Predicted PLG24 PLG24>.3	PLG24>.4	PLG24>.5	PLG24>.6	PLG24>.7	PLG24>.8	Predicted PLG24 at # of ties Installed
23	0.51	0.41	3198	0.16	0.29	0.46	0.50	0.51	0.53	0.45
24	0.52	0.45	3192	0.02	0.16	0.45	0.53	0.54	0.55	0.40
25	0.53	0.47	3190	0.06	0.16	0.36	0.51	0.55	0.55	0.42
26	0.50	0.46	3152	0.08	0.22	0.36	0.44	0.47	0.48	0.43
27	0.37	0.20	3148	0.31	0.38	0.39	0.39	0.39	0.39	0.28
28	0.26	0.26	3176	0.14	0.26	0.28	0.28	0.28	0.28	0.18
29	0.54	0.33	3211	0.27	0.46	0.54	0.56	0.56	0.57	0.45
34	0.61	0.41	3147	0.24	0.40	0.52	0.59	0.63	0.64	0.45

Table 15

MilePost	96 GRMS MEAN PLG24	98 GRMS MEAN PLG24	Total Equ. Ties	GRMS Ties PLG24>.4	PLG24>.5	PLG24>.6	PLG24>.7	PLG24>.8	# of Ties Installed	Predicted PLG24 W/O Constatnt PLG24>.4	PLG24>.5	PLG24>.6	PLG24>.7	PLG24>.8	# of Ties (Equation) Mean PLG24 = .375
23	0.51	0.41	3198	1452	467	218	123	37	500	0.27	0.43	0.47	0.49	0.50	802
24	0.52	0.45	3192	2290	564	76	14	0	895	0.14	0.43	0.51	0.52	0.52	877
25	0.53	0.47	3190	2355	1157	274	34	7	808	0.13	0.33	0.48	0.52	0.53	916
26	0.50	0.46	3152	1817	944	467	316	233	571	0.19	0.34	0.42	0.44	0.46	732
27	0.37	0.20	3148	66	7	0	0	0	677	0.36	0.37	0.37	0.37	0.37	0
28	0.26	0.26	3176	175	13	1	0	0	609	0.23	0.26	0.26	0.26	0.26	0
29	0.54	0.33	3211	629	186	44	15	7	711	0.44	0.51	0.53	0.54	0.54	1000
34	0.61	0.41	3147	1458	739	292	79	15	1124	0.37	0.49	0.57	0.60	0.61	1431

Noting the above results, it can be seen that all three of these analyses[16] indicate that the number of ties that are required to achieve a defined level of track strength (as defined by the PLG24) can be determined using this methodology. This, in turn, supports the approach of an analytical methodology to define "mean" track strength and corresponding tie insertion requirements, based on that strength. Furthermore, the above strongly indicates that *the use of the GRMS data as part of the tie installation decision making process can result in a significant reduction of ties needed to be installed in order to achieve an acceptable level of track strength*[17] *from both the safety and maintenance points of view.*

[16] The individual (tie by tie) PLG24 measurements (Table B), the linear interpolation of actual PLG24 data (Tables C) and the results of the predictive equations, based on the regression of actual tie insertions vs. mean PLG24 (Tables D and E).
[17] Note, this does not necessarily include ties needed for vertical support, which may not be identified by the GRMS data.

Results

The results of this activity indicates that Track Strength Quality Indices, TSQIs, can be developed which relate the GRMS output data to the general condition of the tie-fastener system. Furthermore, these TSQIs can be correlated to the number of ties installed, to develop a predictive relationship between improvements in TSQIs and ties installed. The TSQI can also be used as part of the tie installation decision making process with a potentially significant reduction of ties needed to be installed in order to achieve an acceptable level of track strength[18] from both the safety and maintenance points of view.

The TSQI parameters that were found to be most meaningful in representing the track condition were "mean" values, calculated over a mile length of track, of the following key GRMS outputs:

- Loaded Gage
- Projected Loaded Gage (PLG 24)
- Delta Gage (Loaded Gage – Unloaded Gage)[19]
- Gage Widening Ratio (GWR)[9]

In addition, meaningful correlations were also obtained by summing the number of feet per mile (or number of ties per mile which was calculated by dividing length by tie spacing) exceeding a defined PLG24 or GWR threshold.

Analysis of the CSX tie insertion data shows a good correlation between mean PLG 24 (specifically mean PLG24 > 0.5) and mean GWR (GWR > 0.30) and actual tie insertions performed by a production tie gang. Furthermore, analysis of the number of feet of track, per mile, exceeding these thresholds, likewise shows a correlation with the tie insertions, though the variation in this parameter is significantly greater than for the mean value itself. (This larger variation also appeared in the analysis of the individual GRMS data, which suggests that the mean value acts as a smoothing function, which would be of value in defining general behavior trends as well as for planning purposes.) This correlation supports the use of GRMS data as a maintenance management tool.

[18] Note, this does not necessarily include ties needed for vertical support, which may not be identified by the GRMS data. It further does not account for any additional factors of safety introduced by maintenance officers in anticipation of non-uniform future maintenance (e.g. periods of potential deferred maintenance). Thus there may be a "gap" between the theoretical minimum number of ties needed for maintaining the track on an ongoing basis, and the number of ties that are installed in anticipation of future fluctuations in budget and maintenance focus.

[19] Note; only limited results were obtained from these parameters due to an apparent data problem with the unloaded gage measurements taken from the August 1996 GRMS run.

Analysis of the GRMS degradation data (between the 1996 and 1998 GRMS runs) showed that in those zones where no ties were inserted (4 zones), the mean loaded gage increased in all cases, corresponding to a degradation of tie condition with time and traffic. Furthermore, the zone with the greatest traffic density, MP 4 through 22, had the largest increase in mean loaded gage, an increase of 80%. Overall, for all zones, the loaded gage increased from 0.19 to 0.26, an increase of 37%. Based on an average tonnage of 65 MGT over the two years, this corresponds to an increase in loaded gage of 0.0011 per MGT. The corresponding degradation relationship for PLG24 is given by:

PLG24new = PLG24old +0.001*MGT.

Analysis of the GRMS data for the zones where ties were inserted showed that in these cases, the average loaded gage decreased, corresponding to the improvement in track strength due to the new ties and fasteners. Using statistical regression techniques, this data resulted in the development of a correlation between the Track Strength Quality Index parameters and the number of ties inserted.

The resulting relationship for the improvement in PLG24 as a function of the number of inserted ties is given by:

PLG24 (new) = PLG24 (old) + A'* TIES + b'

Where:

PLG24 (new) is the predicted mean (per mile PLG24 after ties are inserted)

PLG24 (old) is the measured mean (per mile PLG24 prior to ties insertion)

TIES is the number of ties inserted in the mile

A' is a constant (slope) equal to –0.0002

b' is a constant (intercept) equal to 0.025 (for insertions greater than 35 ties per mile)

A similar relationship was obtained for Loaded Gage.

Based on the results of the measurements and data collected on this line, together with earlier FRA and TSC test data for track strength values, a set of maintenance thresholds for the TSQI planning index were developed. These per mile mean limit for PLG24 (the "maintenance" PLG24) were set as follows:

	"Maintenance" PLG24	
Low Speed Freight (Class 3)	0.625	57 1/8"
Moderate/High Speed Track (Class 4)	0.5	57"
Passenger (Class 6)	0.375	56 7/8"

Note: the limit of 0.5 (57") corresponds to the measured average of the mean PLG24 on the track that was actually timbered by CSX (thus determined by the railroad inspectors as requiring ties).

These limits allow for the determination of the number of ties to be inserted per mile, by calculating the difference between the "actual" (measured) mean PLG24 for the mile and the above defined limit. This difference is then divided by the "slope" of the PLG24 degradation equation presented previously to calculate the number of ties to be inserted.

Application of these limits to the study track showed that for current operations (Moderate Class 4 track), the above defined mean PLG24 limits can be reached with between 50% and 80% of the actual ties installed (based on obtaining an equivalent mean average PLG24 comparable to what was actually achieved, which was of the order of 0.47). *For high speed track, with the more restrictive PLG24 limit noted above (.375" corresponding to 56 7/8"), the above defined equation can be used to determine the number of ties necessary to bring the track to the higher strength standard associated with high speed operations.* The results of such an analysis is presented in Table 16 which shows, for several specific mileposts, the number of ties that would have to be installed to reach the more restrictive PLG24 level required for high speed track.

Thus, based on the presented results, it appears that the GRMS data, when developed in the form of TSQI values, on a mile by mile or segment by segment[20] basis, can be used as part of the maintenance planning process as well as a predictor of crosstie replacement requirements.

[20] The TSQI presented in this report can be applied on a segment by segment basis, such as either mile length of track, curve vs. tangent lengths, or other lengths as appropriate.

Table 16: Example Tie Insertion Analysis

Milepost	Mean PLG24 8/96	Actual Ties Inserted 5/98	Actual Ties Inserted 11/96	Ties Required for PLG24[21] 0.47[22]	Ties Required for PLG24[21] 0.375
23	0.51	0.41	500	233	802
29	0.54	0.33	711	431	1000
34	0.61	0.41	1124	862	1431

[21] Based on analysis
[22] Corresponding to values actually achieved by the tie gang

Recommendations for Further Investigation

The results presented above, indicate that the GRMS data can be used to more effectively plan tie maintenance activities by developing objective criteria for the determination of the number of ties to be installed and a corresponding level of track strength that must be achieved. This is different than the current "safety" based application which uses a local strength limit to locate weak track spots.

While the results to date strongly support the TSQI approach, these results are based on only one line segment at one traffic level. They do not represent the range of conditions found in North America to include high curvature, high tonnage lines with significantly greater rates of track strength degradation. Therefore, it is recommended that the results of this analysis be extended to a broader range of track and traffic conditions to determine if the relationships developed here-in remain the same, or if the shape of the relationships or the relationship parameters (e.g. constants) change. In particular, a severe curvature line should be investigated. Such an analysis would also further examine the differences in track strength behavior between tangent and curved track segments.

In the longer horizon, it is necessary to determine and demonstrate whether such a track strength based approach to tie replacement provides a more economical means, on a life cycle basis, to upgrade and maintain track. This is to include conventional track and track with mixed heavy freight and high speed operations. The objective of such an activity is to determine if this track strength approach allows for the most cost effective installation of ties, and to determine where to install the ties, on what schedule, and how many to install. Note, this approach can also be used as part of an "upgrade" approach in which track can be upgraded to a higher standard, e.g. to support high speed passenger operations.

In order to validate these results, however, it is necessary to perform a comparison of maintenance activities performed using this approach as compared to the conventional "bad tie count" approach currently used. In order to perform this next step evaluation, the following activities are recommended:

- Conduct a "side by side" comparison of alternate tie maintenance techniques.

In this comparison, a selected segment of track, corresponding to approximately 10 to 20 miles, with homogeneous traffic, track, and topography, is divided into two to three zones corresponding to the maintenance approach desired. The following maintenance approaches have been suggested.

- GRMS based tie maintenance
- Out of face upgrade and spot tie replacement (using GRMS to locate spot ties)

- Conventional bad tie count planning and cyclic tie maintenance

Note, the 1st and 3rd represent a direct comparison of alternate maintenance approaches (GRMS vs. conventional). The 2nd approach is an option which can be included if resources permit.

In this comparison, the GRMS maintenance based test zone would be upgraded, using the criteria presented in this report, to a defined level of TSQI. The test zone would then be maintained, using GRMS data, on an ongoing basis to keep a minimum TSQI level.

The resulting number of ties inserted would be compared to that used in the conventional approach.

Note, this approach can also be used for track upgrade, such as for the introduction of high speed passenger operations on a freight only line.

In addition, in order to determine the economic viability of these approaches, it is necessary to conduct a life cycle cost analysis comparing the alternate approaches:

- GRMS based tie maintenance
- Out of face upgrade and spot tie replacement (using GRMS to locate spot ties)
- Conventional bad tie count planning and cyclic tie maintenance

This economic analysis can be conducted using an appropriate life cycle tie maintenance tool such as the Railway Tie Association's *SelecTie* model. Such an analysis is recommended here as part of the next step assessment of tie maintenance practices.

Appendix A

ZETA-TECH's *TieInspect*
Tie Inspection And Planning System

Introduction

TieInspect is a comprehensive computerized crosstie inspection system designed to accurately and efficiently collect tie condition data based on a tie inspector's assessment of condition. This revolutionary unit aids the tie inspector by providing an easy to use mechanism that allows for the complete collection and storage of valuable tie condition data. Tie condition data can be stored for each and every tie inspected, providing a complete database of historical and current tie condition. In addition, offline analysis software is provided for viewing and analyzing the collected data.

The system is outfitted with a handgrip input device which is connected to a palmtop computer via an RS-232 interface. The palmtop computer is conveniently held in a belt pouch, which also contains a rechargeable battery good for hours of continued inspection. All inspection data is stored on the palmtop and can be downloaded to a desktop PC for analysis and reporting. All acquisition and offline analysis software is provided with the system.

General Features

The general features of the system provide the tie inspector with an easy to use, digital tie inspection and recording device. The inspection unit provides the tie inspector with an ergonomic input device for conveniently cataloging tie condition (good, marginal, or bad), milepost changes (next milepost), tie type (crosstie, turnout, bridge, or grade crossing), tie material (wood, concrete, steel, or other), and curvature (tangent, mild, moderate, or severe).

The palmtop computer records the tie inspectors inputs from the handgrip. In addition, the inspector has the ability to fill in certain fields within the software on the palmtop including, division, subdivision, inspection direction, fasteners, comment, and others. The inspector can quickly evaluate how many good, marginal, bad, and total ties were counted for any given milepost while in the field. A complete record of all inputs is kept on the palmtop until downloaded to the host software.

The system provides two primary modes of inspection capability, a detailed identification of the condition of every tie, and a bad tie only count by milepost. The inspector can choose which configuration to use based on their individual requirements.

The *TieInspect* host software provides the user with the ability to upload the inspection information and creates a historical database of the inspection data. This data can then be viewed for several mileposts in both a summary and detailed format, showing the analyst the distribution and counts of good, marginal, and bad ties. In addition, bad tie clusters and FRA defects (optional) are listed by location to aid in maintenance planning.

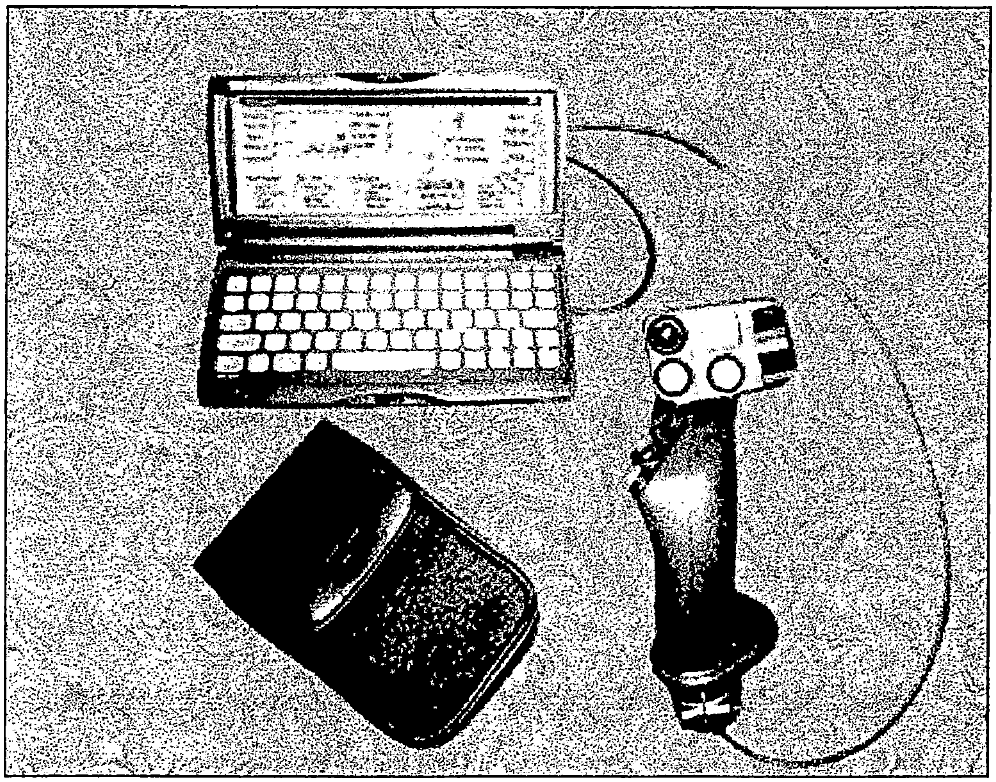
Inspection Process

The inspection process utilizes the input device and the palmtop computer along with the data collection software for cataloging the complete distribution of tie condition data. The data collection software on the palmtop computer allows the tie inspector to specify the initial parameters of the inspection including the following:

- Division	- Fastener Type
- Subdivision	- FRA Class
- Track	- Inspector
- Starting Milepost	- Weather
- Ending Milepost	- Tie Spacing
- Inspection Direction	- Inspection Mode
- Comments	- RS-232 Port Settings

Once the initial parameters are set they can be changed at any time during the inspection and will hold constant until changed again. The palmtop computer can be placed in the belt-pouch and inspection can commence.

For the detailed tie inspection, every tie is graded as good, marginal or bad. The handgrip provides input buttons for each of these conditions. Pressing the good tie button will store a good tie in the system. Each tie is graded and the appropriate button clicked. Note that each time the bad tie button is pressed, a beep will sound from the palmtop providing the user with positive feedback that the bad tie button was clicked.



For the bad ties only inspection mode, the bad tie button is clicked for each bad tie encountered. In addition, whenever a tie cluster is located (as defined by the inspector), the tie cluster button is clicked (same as good tie button in every tie mode).

A milepost input button is provided for inputting the milepost marker when it is encountered. The milepost will increment or decrement based on inspection direction as initially defined.

There is a backup button on the handgrip, which allows the user to backup one tie at a time, should it be necessary.

When the tie material, tie type or curvature changes, one of three toggle switches can be used to change the appropriate tie characteristics. Pushing the toggle up sets the characteristics to its default, while pushing it down cycles it through the three alternative choices. These features can be changed at will, and every tie inspected after a change is made will have the characteristics defined by the setting.
In addition to the handgrip input device, the inspector can open the palmtop at any time and make changes to any of the inputs. This includes comments. Should the user wish to enter a comment, it will be stored at the appropriate milepost and tie location in the data file. These comments can later be viewed along with the data using the offline software.

A summary review is provided such that the user can view the total number of ties, as well as the number of good, marginal, and bad tie for any milepost inspected on any given day for which the data resides on the palmtop computer.

The inspector can end a session and start a session at any time during the working day. The data is stored in a file for each day of inspection, which continually appends the days work. It is these daily files that are downloaded to the host analysis software.

The daily inspection files are downloaded to a desktop PC using a RS-232 interface and communication software provided by the palmtop manufacturer. Once the files have been uploaded by the desktop PC, they can be imported into the host analysis software.

The host analysis software allows the user to specify any track location within the database (a contiguous range) and view the summary inspection results (good, marginal, bad, and total tie counts), as well as the detailed distribution of ties for any given mile for a historically defined time frame. The detailed distribution is analyzed to provide the user with number of tie clusters, defined as continuous counts of 2 to 10 (or more) bad ties in a row. This provides the analyst with the ability to estimate how many ties are required to breakup tie clusters and insure safety.

In addition, the host software has an optional FRA analysis package, which provides the user with a graphical and tabular representation of FRA defects as defined by track class. A moving window analysis allows the user to define the number of ties required to eliminate FRA defined defects.

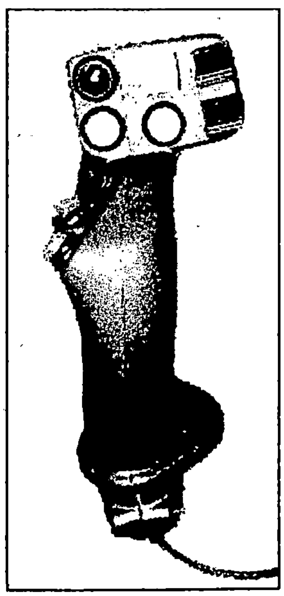
Hardware

The hardware for the *TieInspect* system consists of the handgrip input device, palmtop computer and manufacturer supplied accessories, belt-pouch, lead-acid batteries, and communications and power harness.

Handgrip

The handgrip is an ergonomically designed hard plastic grip designed for right-handed use. The grip is used as the primary data entry device while the user is inspecting and rating ties. The grip has a green LED to indicate battery power and five push button switches and three thumb actuators used for data entry:

- red push button
  "Bad" tie
- green push button
  "Good" tie
- yellow push button
  "Marginal" tie
- orange push button
  Milepost
- black push button
  Backup
- toggle, upper center
  Tie Type
- toggle, upper right
  Tie Material
- toggle, lower right
  Curvature



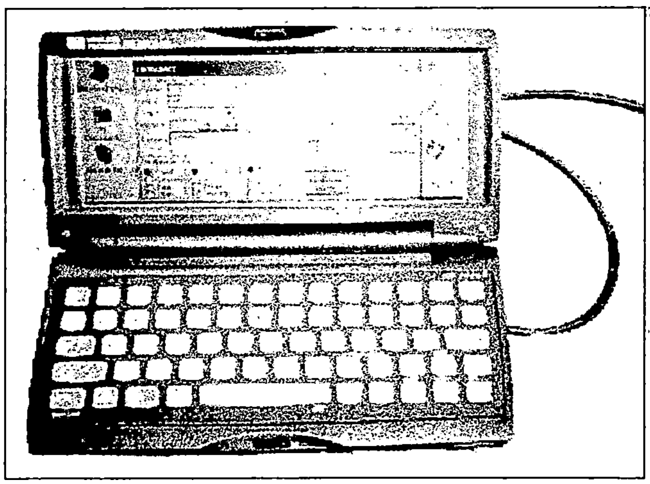
The grip is constructed of black impact-resistant plastic for durability and is sealed against moisture and water to protect against rain, snow and other precipitation. The grip is not protected against immersion.

The grip is powered by a six-volt sealed lead-acid battery that is carried in the pouch at all times.

The grip communicates with the palm-top computer via an RS-232 communications cable.

Palmtop Computer and Manufacturer-Supplied Accessories

Note that due to the rapid changes in the marketplace, the palm-top computer is subject to change based on the availability from the manufacturer. The computer described here is one model provided with *TieInspect*. It may not be the model provided with every order.



- HP 360 LX Palmtop with Windows CE 2.0 and 8 MB RAM
- Rechargeable NiMH batteries
- Battery Charger
- Docking station
- Synchronizing cable
- Software applications provided by the Manufacturer (Operating System)

Belt Pouch for Palmtop Computer and Battery

The belt pouch includes a hook to carry the grip while the user is entering data to the palm-top via the keyboard or while the user is walking to the site to be inspected.

Two Sealed Lead-Acid 6.0 volt 1.2 amp-hour Batteries and Charger

Each battery will provide up to 14 hours of testing on a single charge and can be used to provide power to the grip and/or the palm-top computer. The external battery will supplement the batteries internal to the palm-top. Each battery will fully recharge in 6-8 hours with the charger provided.

Communications and Power Cable Harness

This harness is used to connect the palm-top computer, the grip and the battery while data is gathered. This harness includes the synchronization cable provided by the computer manufacturer.

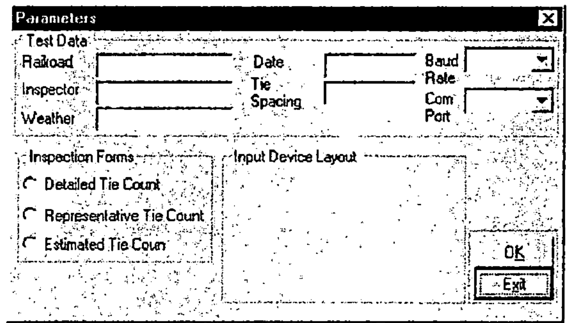
Palmtop Software

The palmtop software is the control system that allows the user to input, collect, and store tie condition data in an easy and intuitive manner. The palmtop computer uses the Windows CE operating system and is compatible with Windows 95.

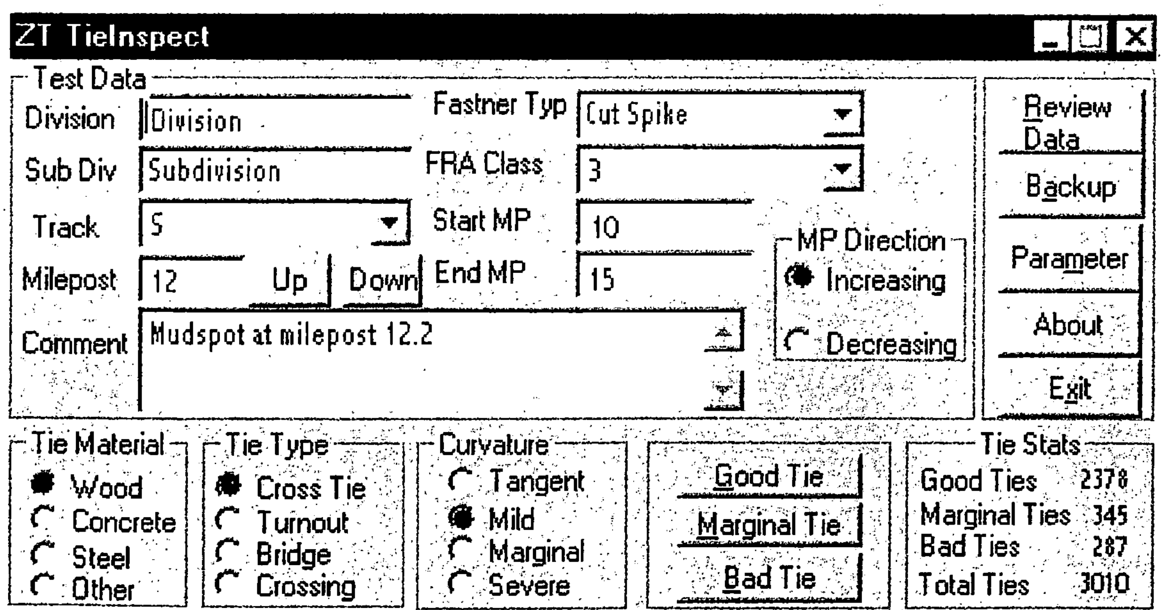
The software allows the user to input information using intuitive controls such as drop-down list boxes, radio buttons, and input text boxes.

The main access screen provides the user with feedback of the current state of the primary input variables. These variables can be changed as necessary during inspection by removing the palmtop from the case and initiating changes. In addition, the current tie status (wood, crosstie, curvature) and tie counts (good, marginal, bad) for the milepost being inspected are available to the user when viewing the palmtop screen. It is this screen that is used when the inspector wishes to enter a comment at any time during the inspection.

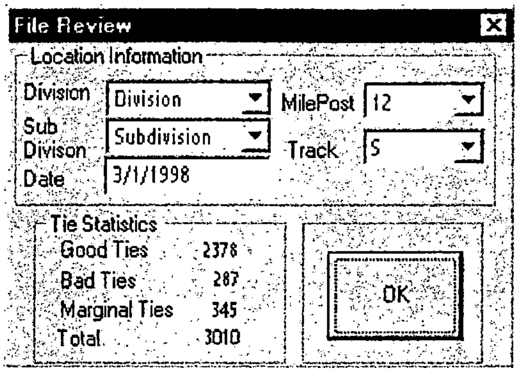
Less used parameters can be edited by pressing the parameters button and editing those parameters on the form that pops up. These include the inspector, weather, and RS-232 connection parameters.



It is here that the inspector can change the mode of inspection between every tie and bad ties only. In addition, the inspector has the ability to define whether they are inspecting the entire milepost or are only inspecting a representative portion, for which the information collected can be applied to a longer stretch of track.



The inspector has access to summary information for any given milepost that they can retrieve by pressing the Review Data button. Doing this will prompt the user for the file to review (files saved by date). The review screen will then allow the user to select any inspected milepost and view the tie counts accordingly.



Offline Analysis Software

The offline analysis software allows the user to upload the inspection data into a comprehensive database for later retrieval, viewing and analysis.

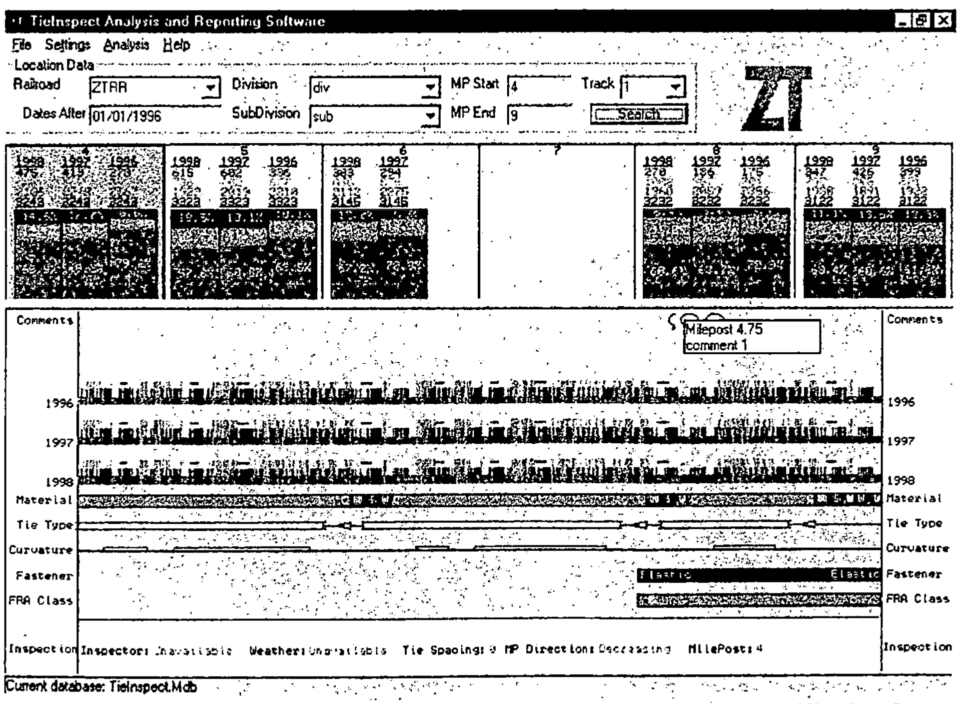
Utilities are provided for uploading the *TieInspect* field collected data files. These utilities parse the incoming data and create a database (Microsoft Access Compatible) for use with the analysis and reporting features.

The user can select the boundaries of a segment of track and a bar chart will show the summary data for each milepost in that segment for each date an inspection occurred. The summary data includes the tie count and percentage of ties in each condition category.

By clicking on a milepost, a detailed graphical representation of the tie inspection data will appear for each date of inspection. This intuitively identifies to the user the location of bad tie clusters, as well as all of the other information collected during inspection.

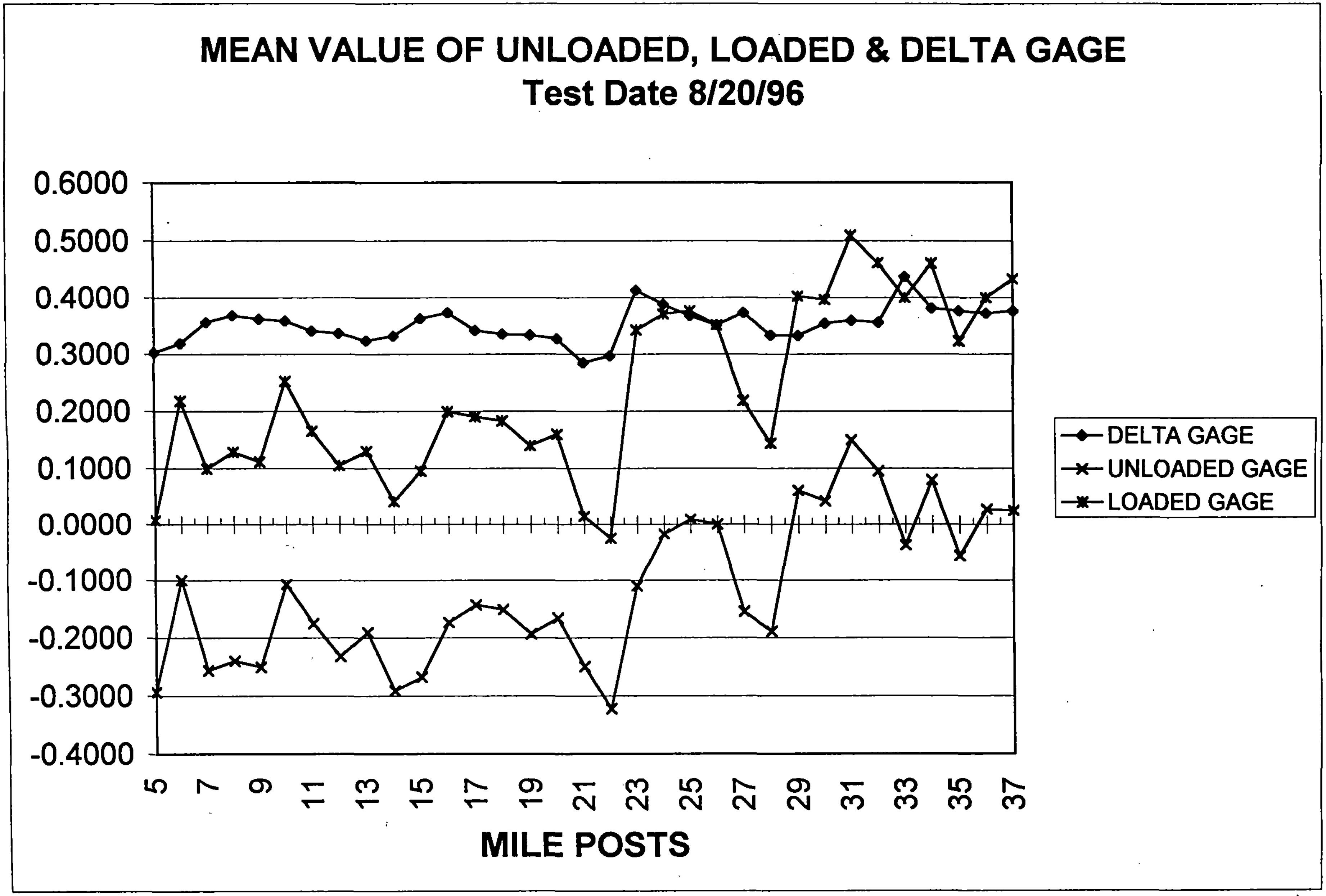
The locations of curvature, track class, and tie type and material are shown as well as the general inspection parameters entered by the user. In addition, any comments entered appear as "balloons" at the milepost where they were entered. The actual comment can be viewed by moving the mouse over top of the icon.

Lists of clusters and FRA defects (optional) can be reviewed and printed. Also, the summary data can be printed for a defined section of track.



ZETA-TECH Associates, Inc., 900 Kings Highway North, Suite 208, Cherry Hill, New Jersey 08034
(609) 779-7795; fax (609) 779-7436; email: TieInspect@zetatech.com

Appendix B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0.4000
0.3000
0.2000
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0.0000
-0.1000
-0.2000
-0.3000
-0.4000
5
7
9
11
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31
33
35
37
MILE POSTS
DELTA GAGE
UNLOADED GAGE
LOADED GAGE

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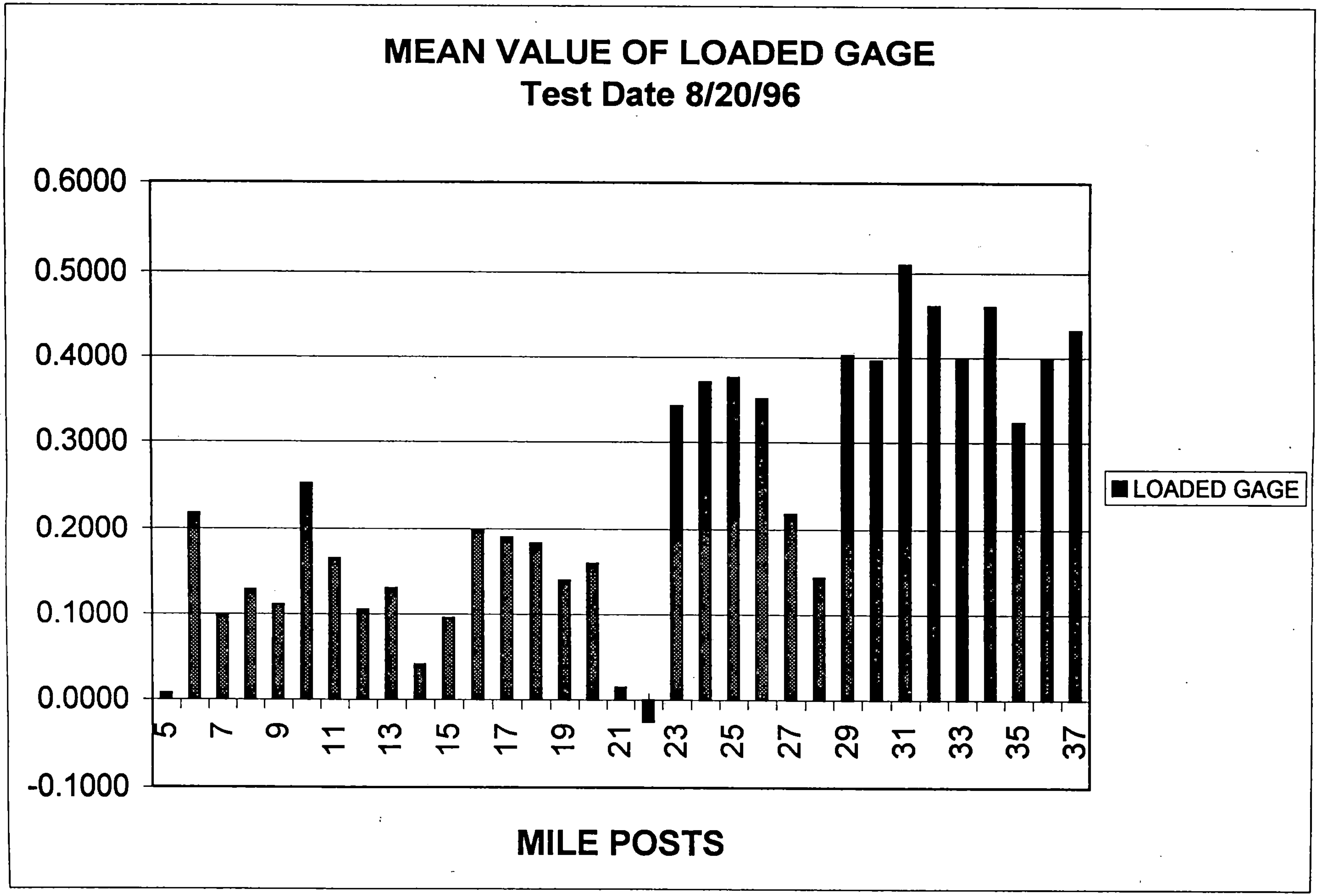
MEAN VALUE OF LOADED GAGE
Test Date 8/20/96
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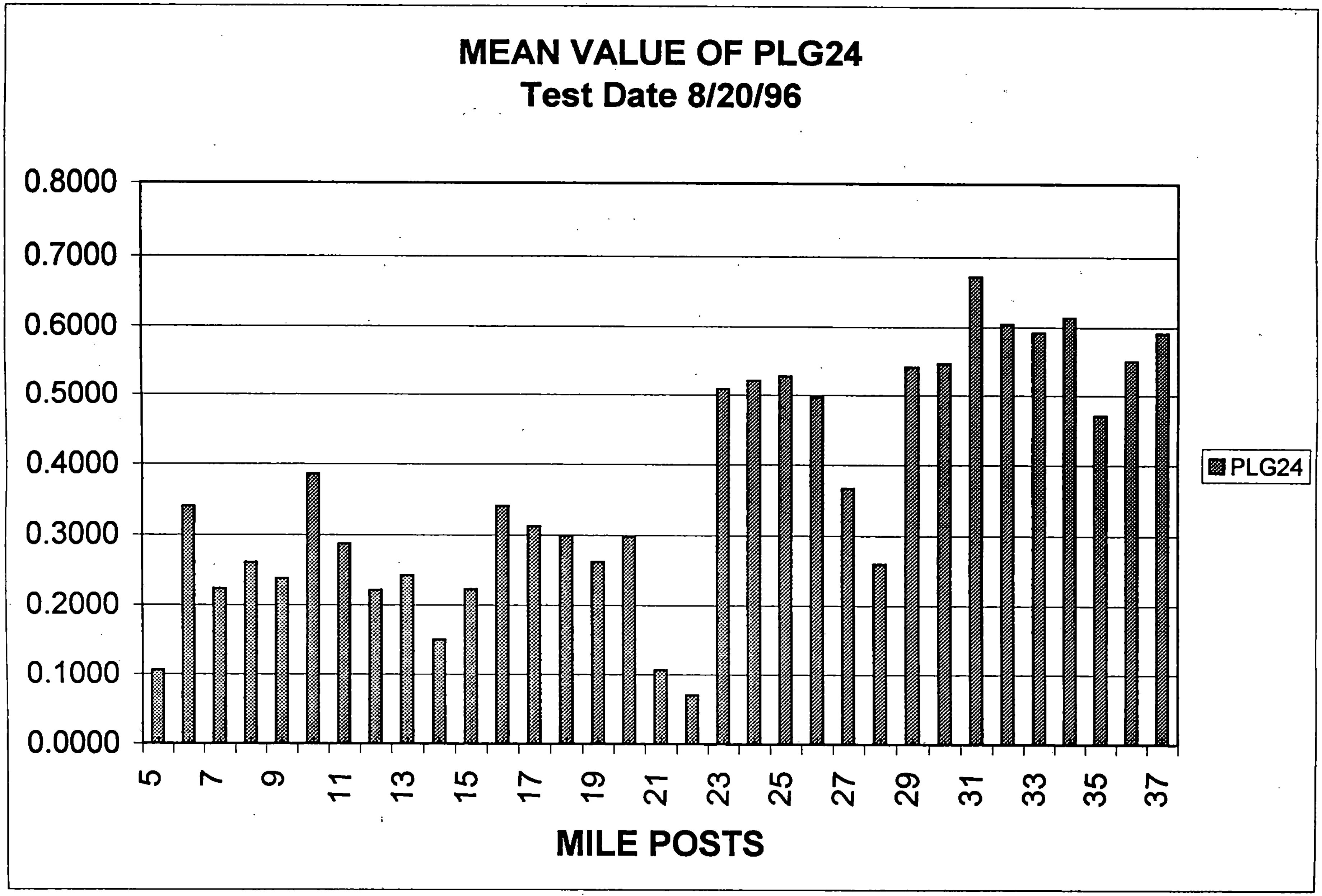
LOADED GAGE
MILE POSTS


MEAN VALUE OF PLG24
Test Date 8/20/96
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0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
5
7
9
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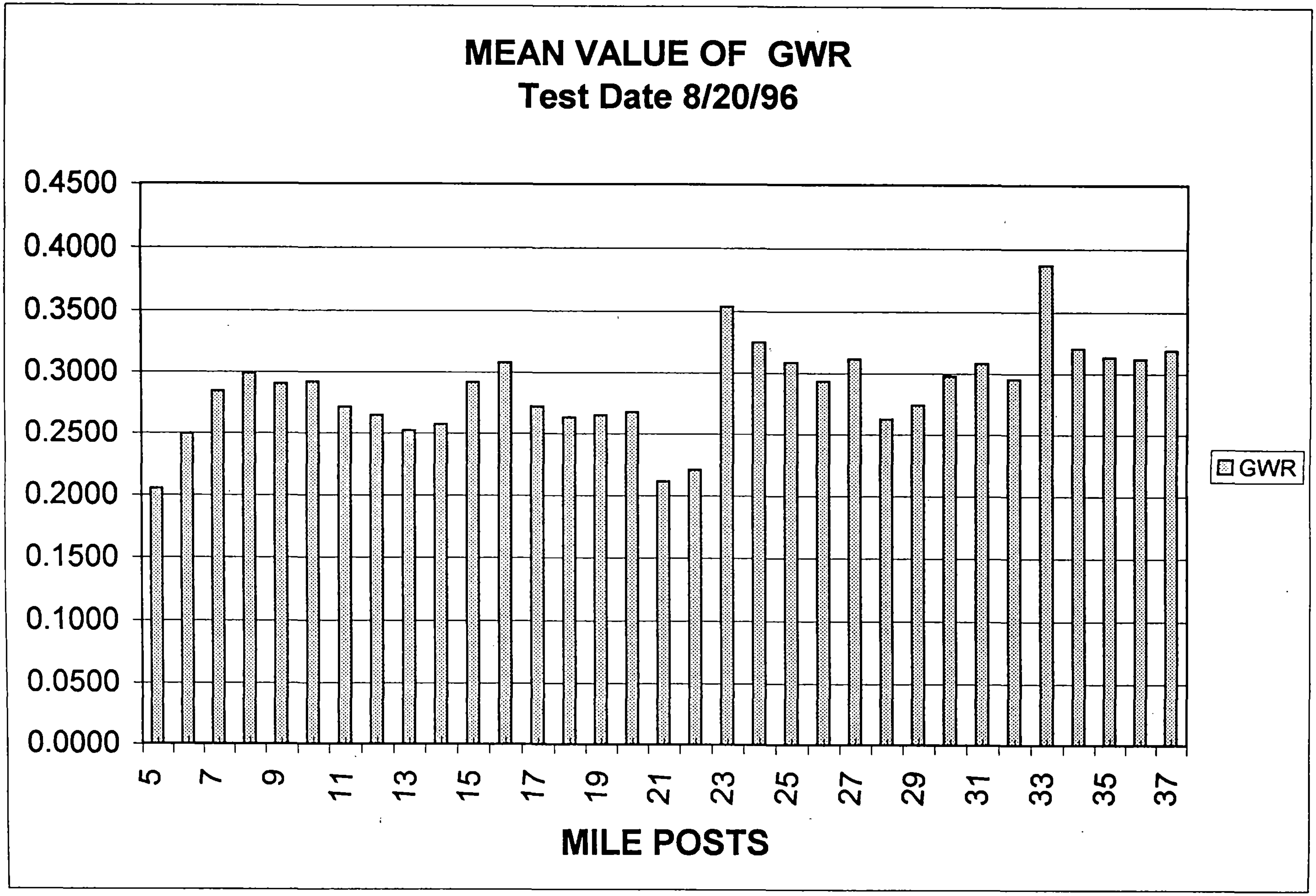
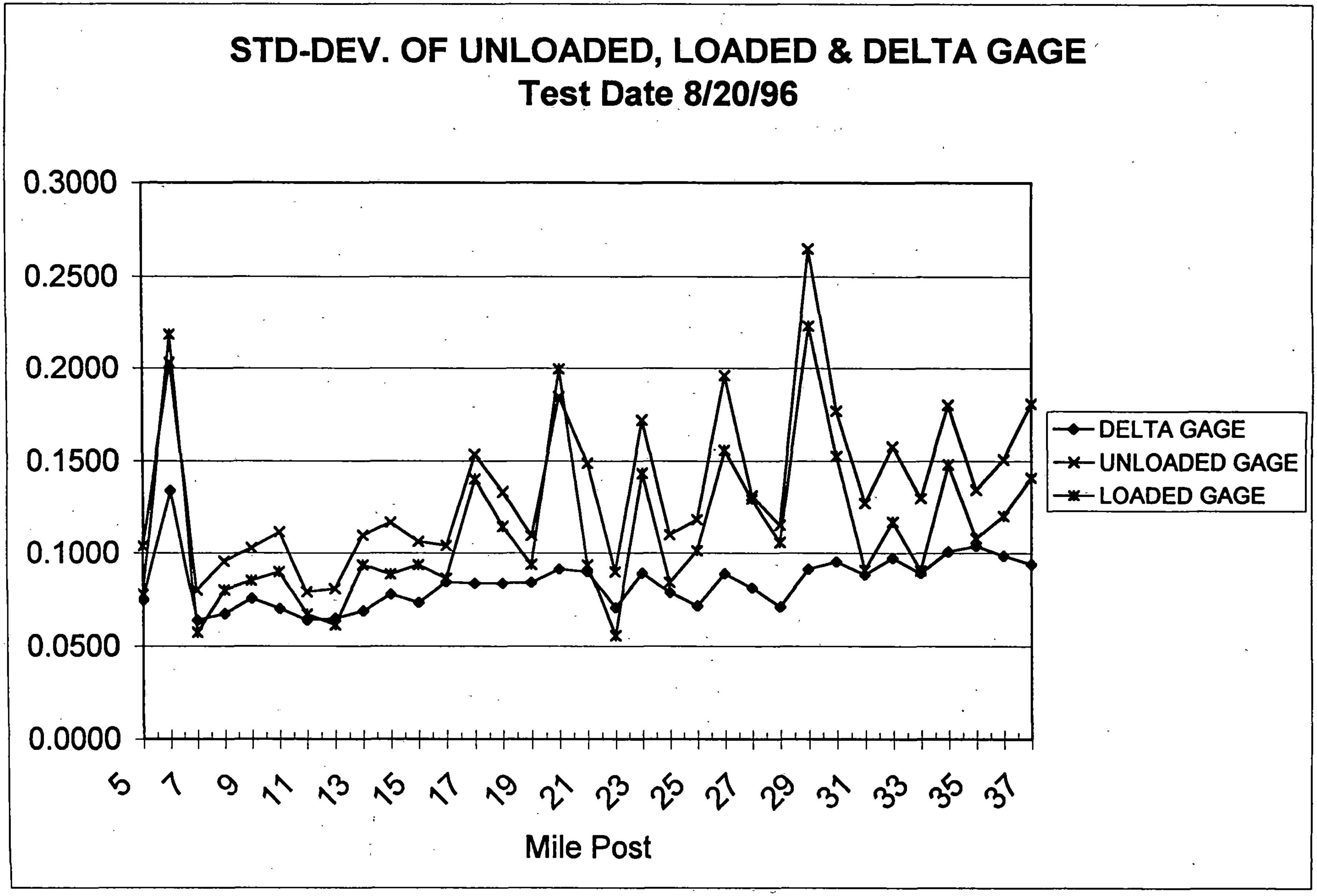
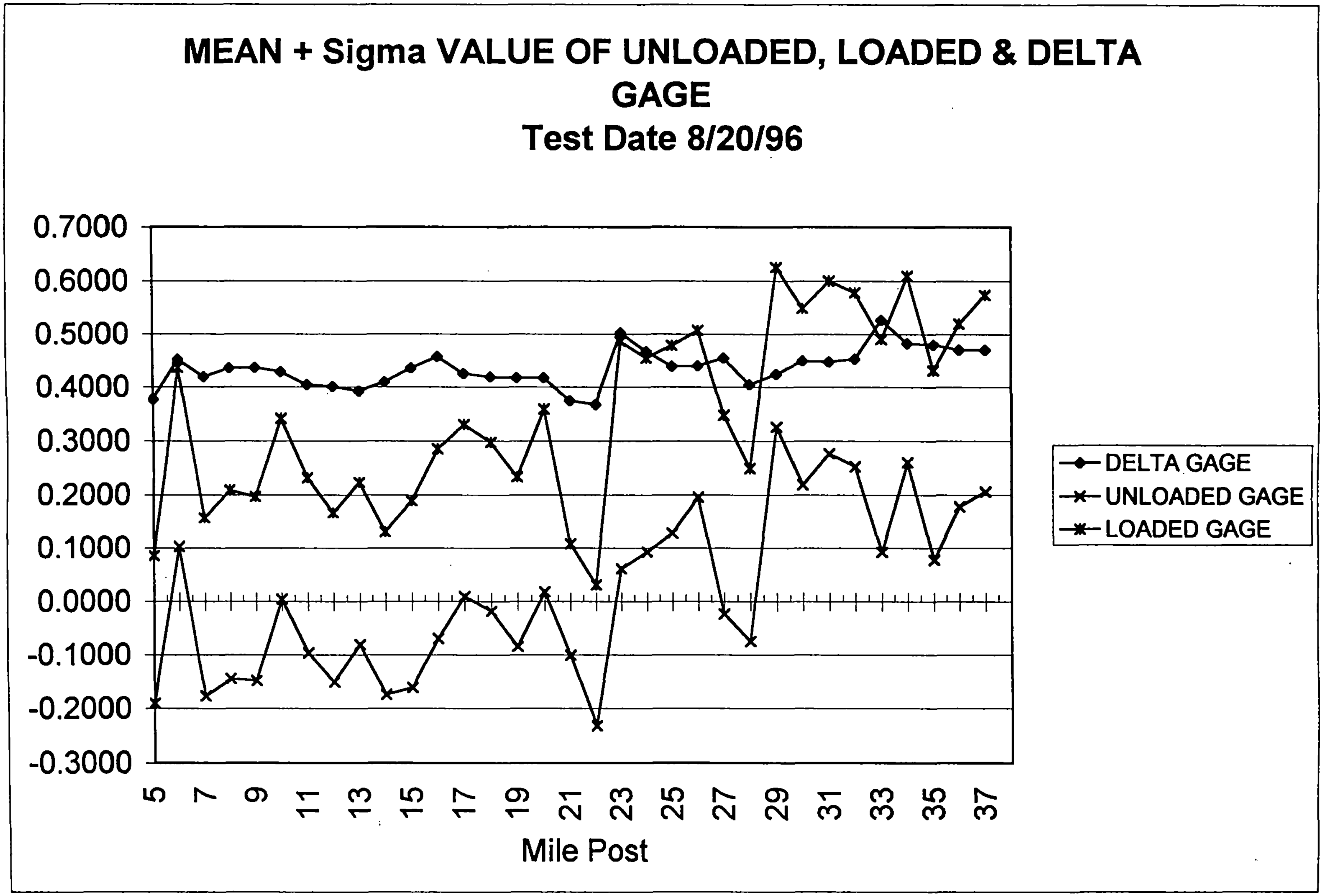
37
MILE POSTS
PLG24



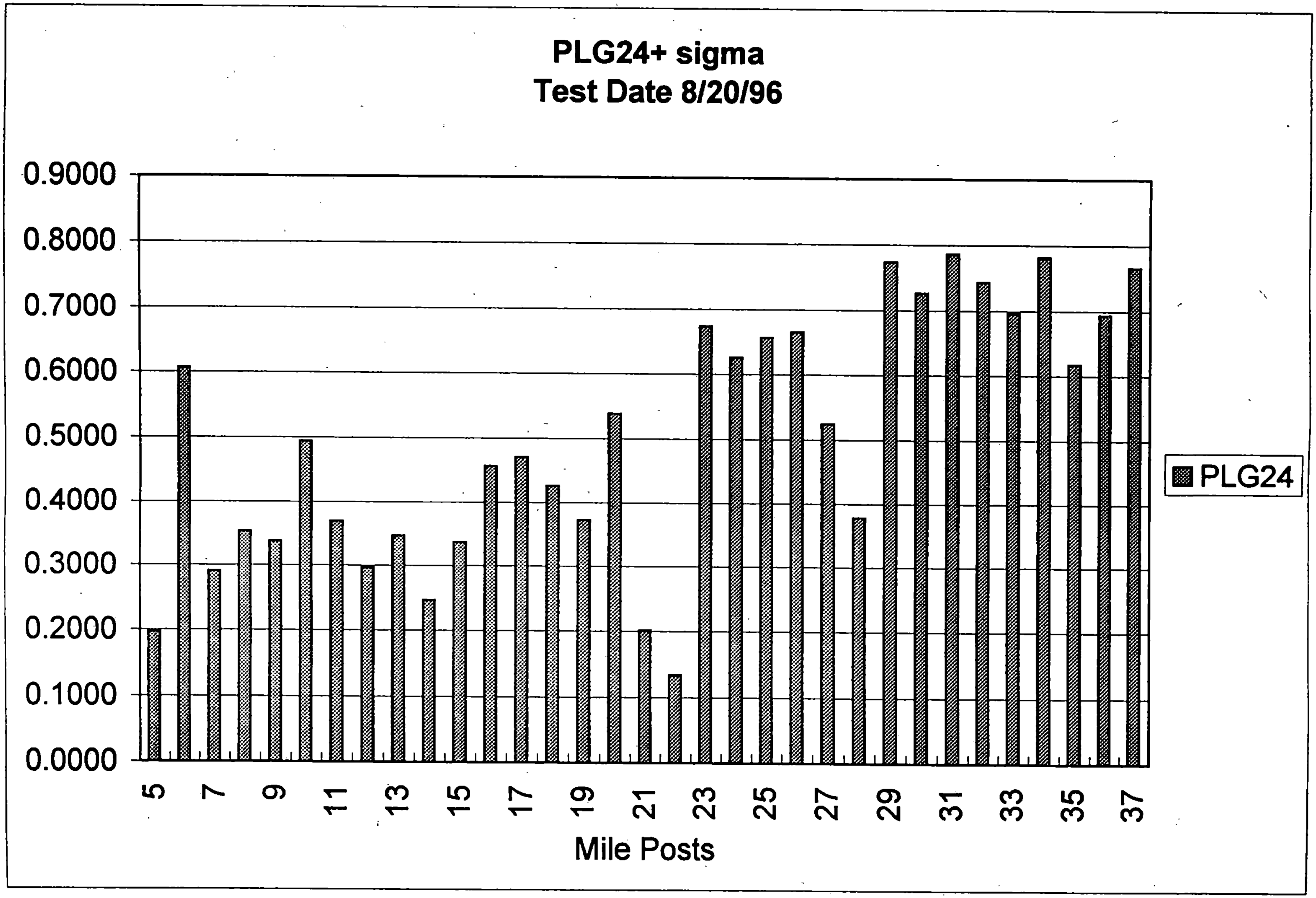
MEAN VALUE OF GWR
Test Date 8/20/96
0.4500
0.4000
0.3500
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
MILE POSTS
GWR

Appendix C

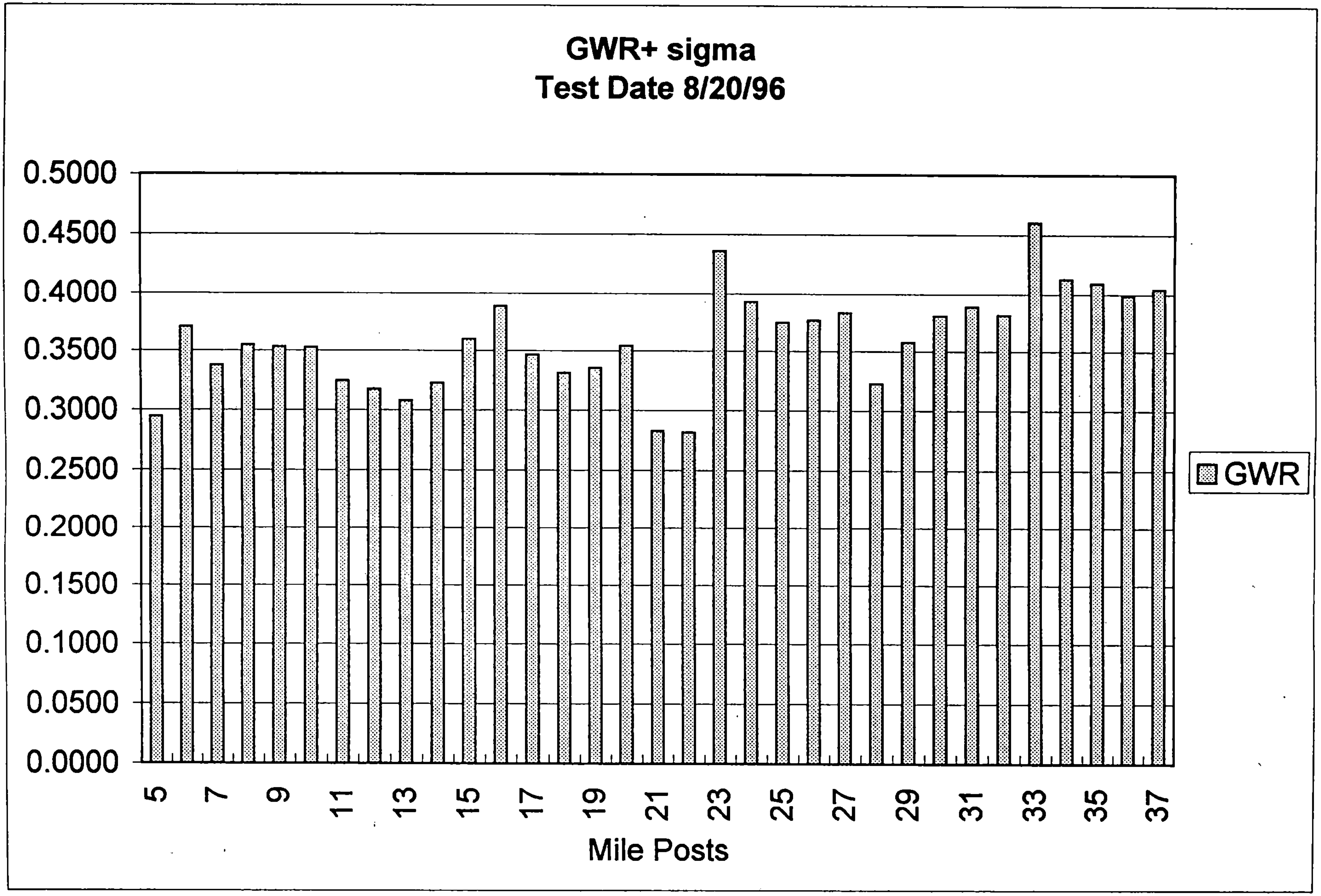

STD-DEV. OF UNLOADED, LOADED & DELTA GAGE
Test Date 8/20/96
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
Mile Post
DELTA GAGE
UNLOADED GAGE
LOADED GAGE



MEAN + Sigma VALUE OF UNLOADED, LOADED & DELTA GAGE
Test Date 8/20/96
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
-0.1000
-0.2000
-0.3000
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
Mile Post
DELTA GAGE
UNLOADED GAGE
LOADED GAGE

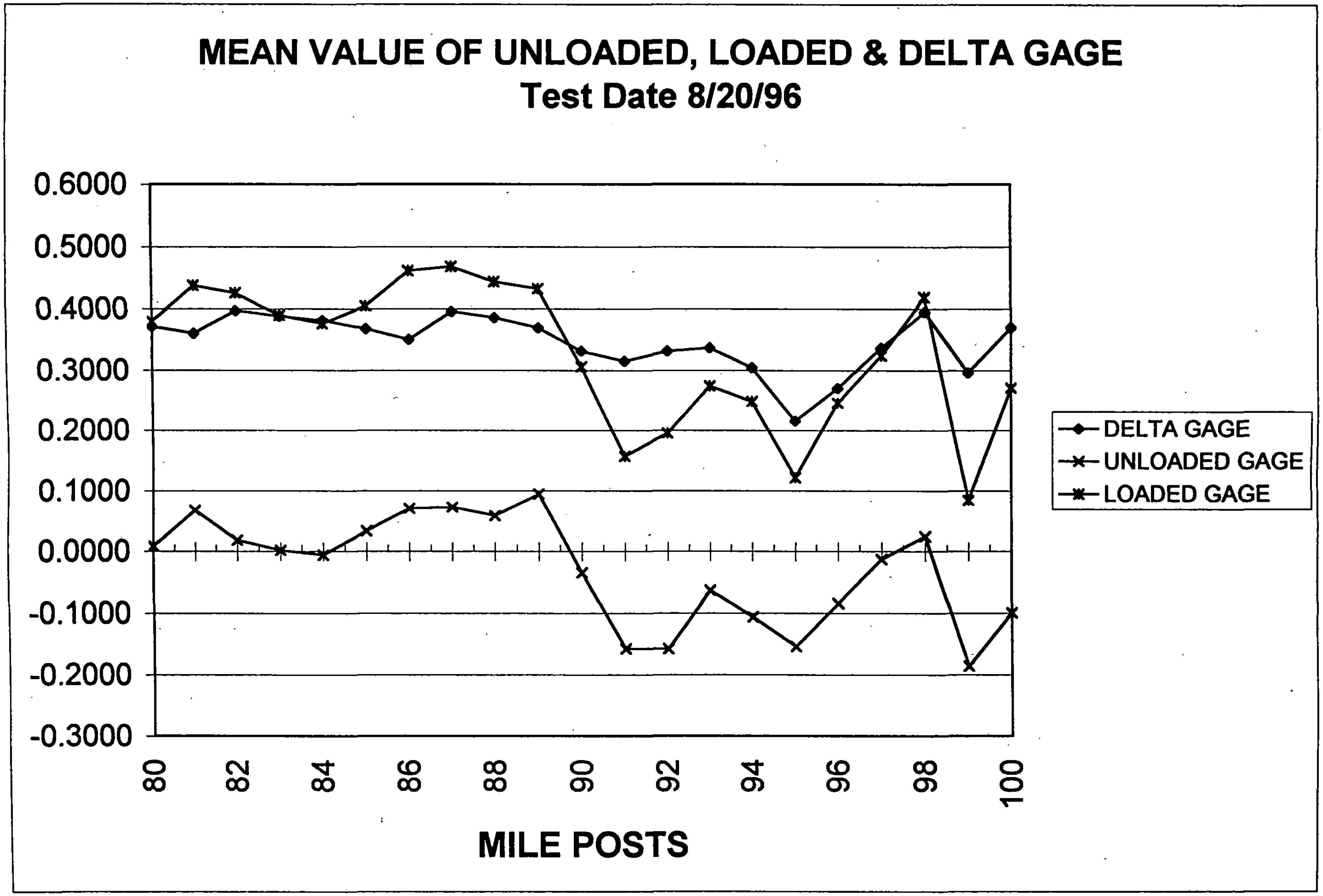


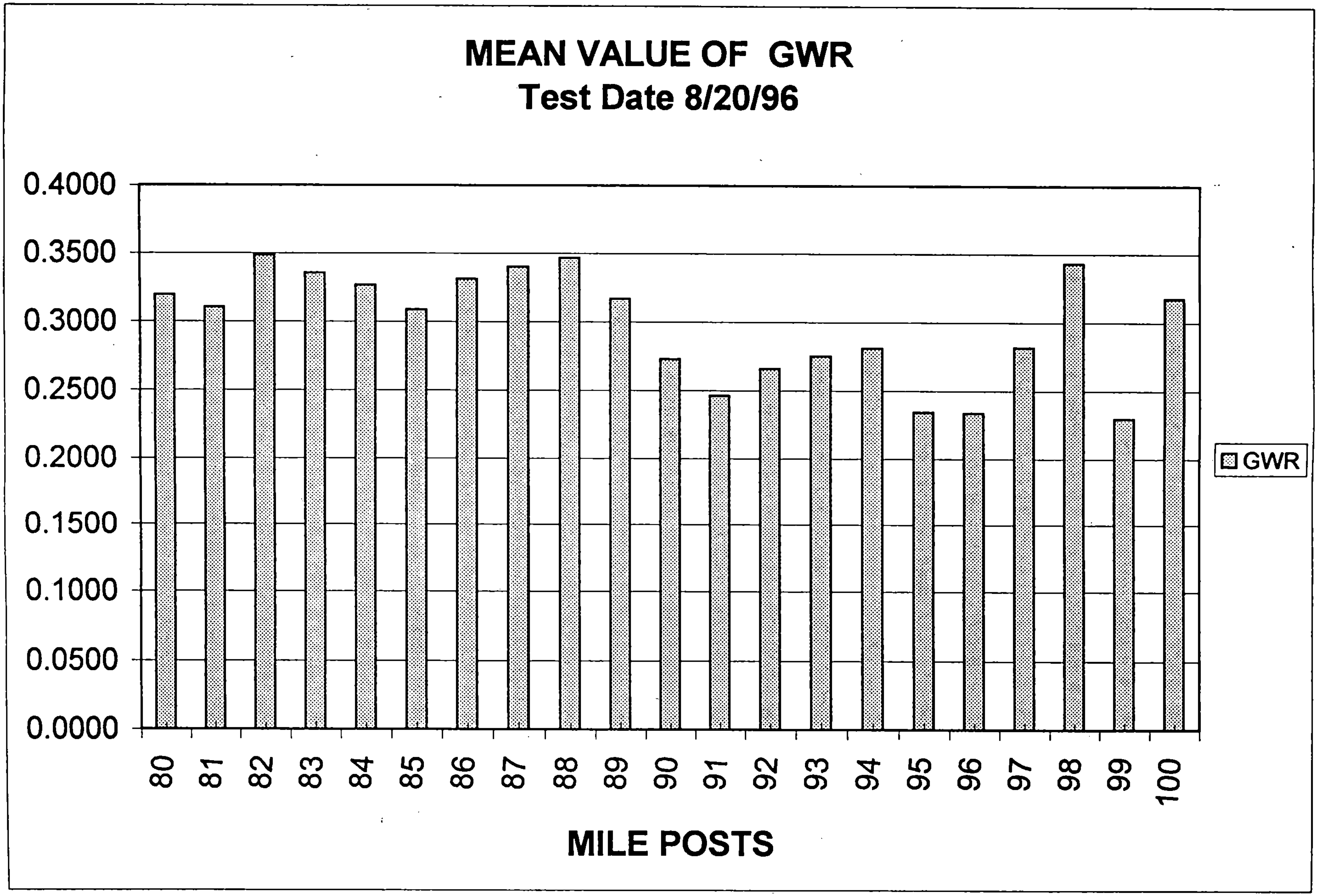
PLG24+ sigma
Test Date 8/20/96
0.9000
0.8000
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
Mile Posts
PLG24



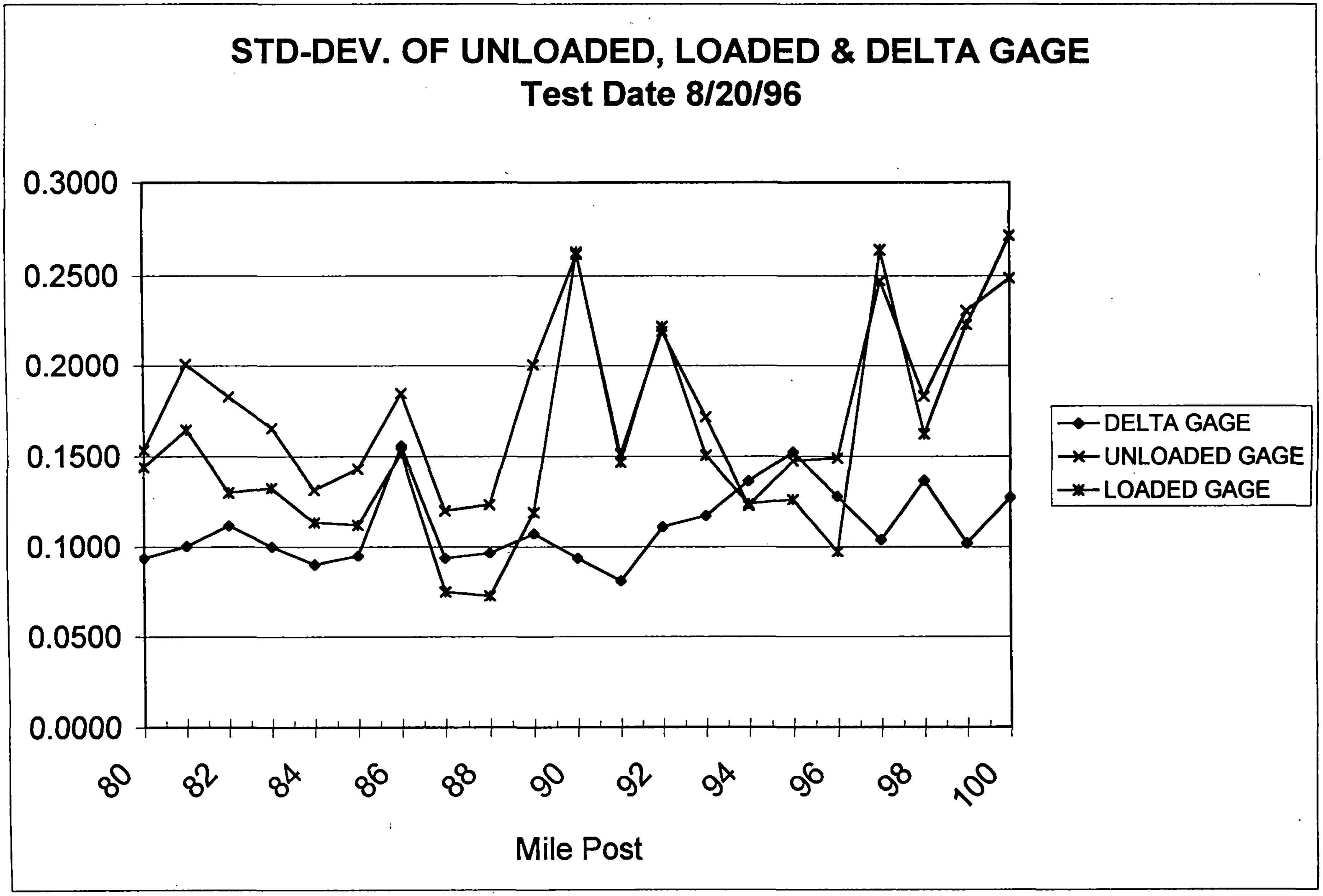
GWR+ sigma
Test Date 8/20/96
0.5000
0.4500
0.4000
0.3500
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
5
7
9
11
13
15
17
19
21
23
25
27
29
31
33
35
37
Mile Posts
GWR

Appendix D

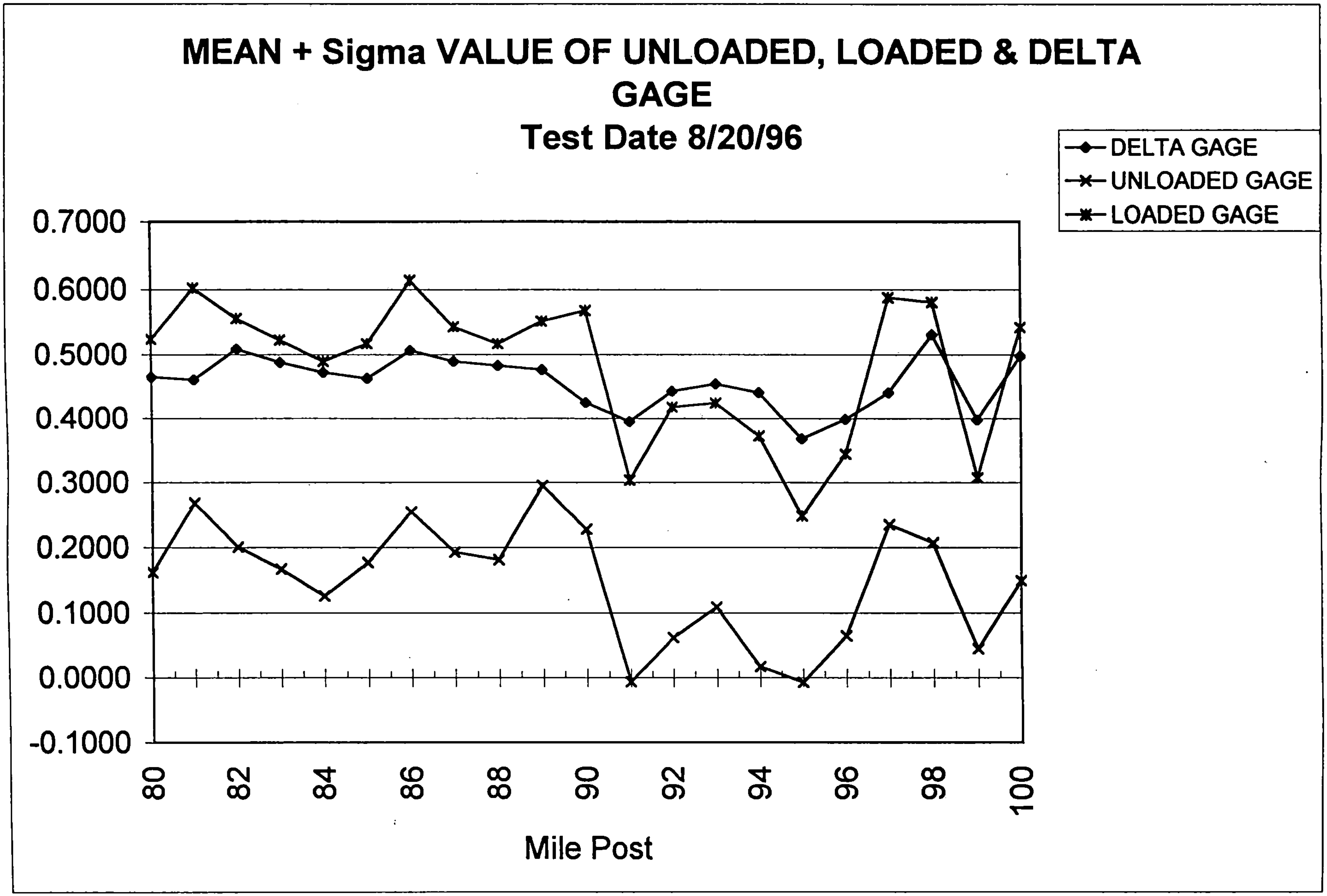

MEAN VALUE OF UNLOADED, LOADED & DELTA GAGE
Test Date 8/20/96
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
-0.1000
-0.2000
-0.3000
80
82
84
86
88
90
92
94
96
98
100
MILE POSTS
DELTA GAGE
UNLOADED GAGE
LOADED GAGE

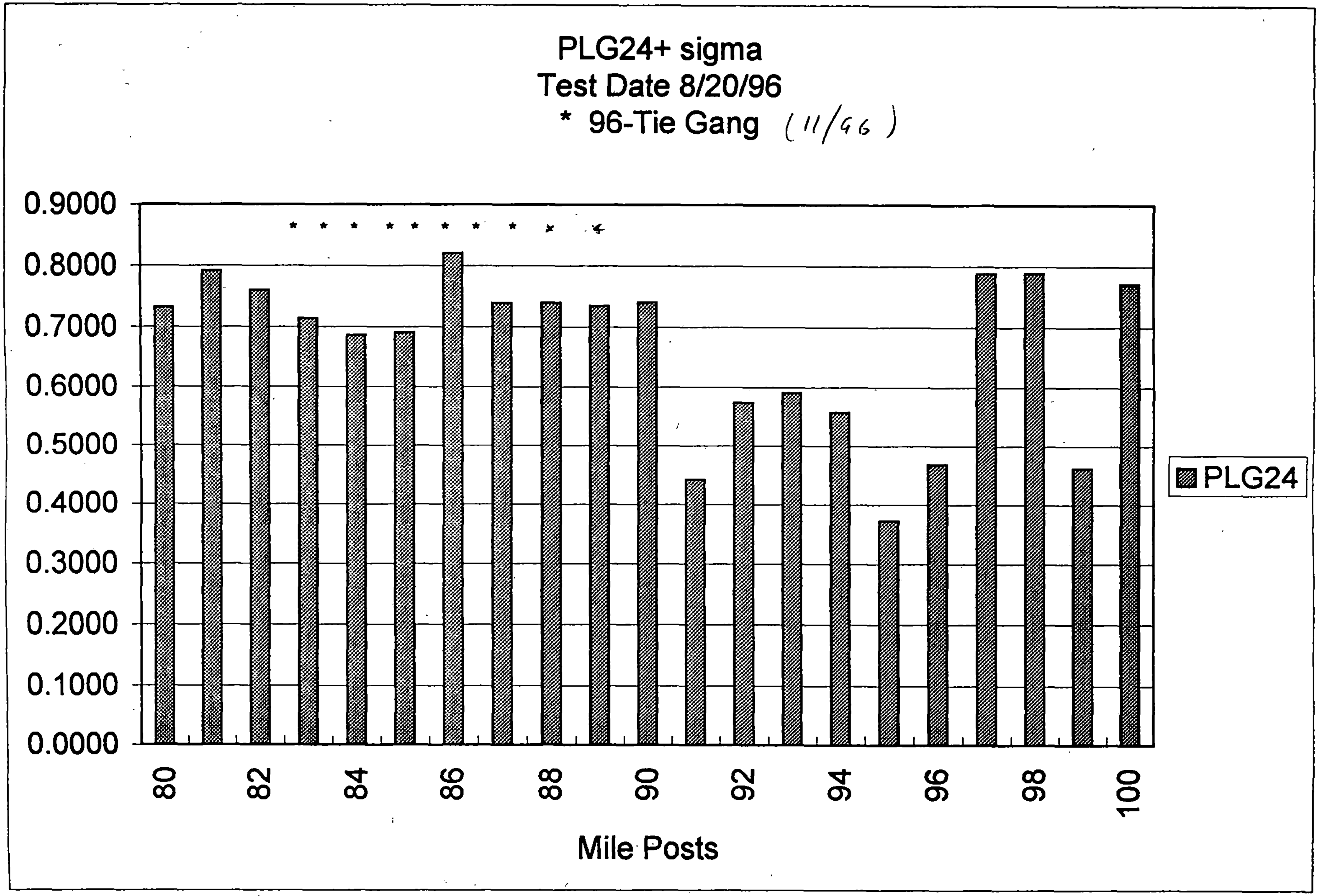


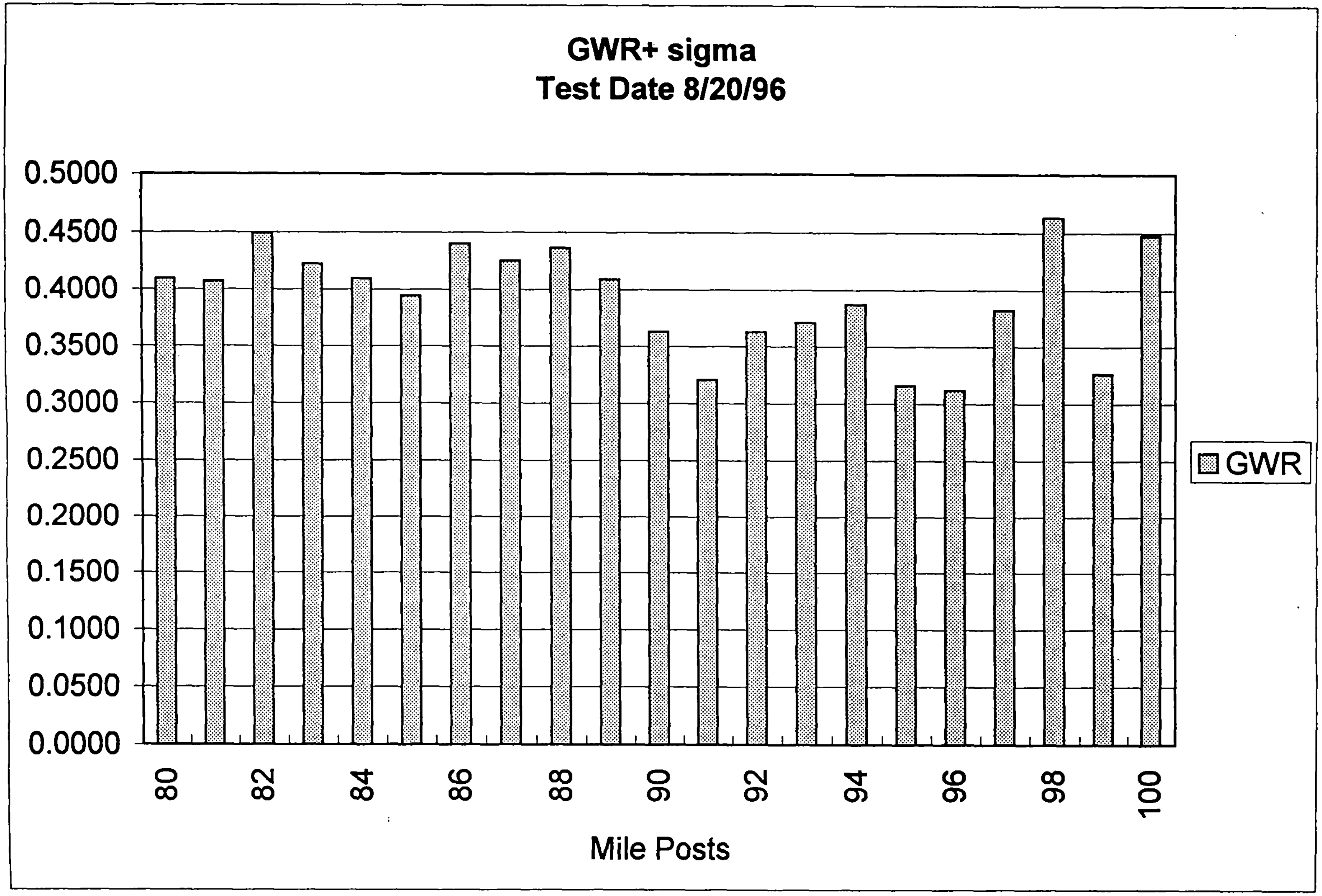
MEAN VALUE OF GWR
Test Date 8/20/96
0.4000
0.3500
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
80
81
82
83
84
85
86
87
88
89
90
91
92
93
94
95
96
97
98
99
100
MILE POSTS
GWR



STD-DEV. OF UNLOADED, LOADED & DELTA GAGE
Test Date 8/20/96
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
80
82
84
86
88
90
92
94
96
98
100
Mile Post
DELTA GAGE
UNLOADED GAGE
LOADED GAGE


MEAN + Sigma VALUE OF UNLOADED, LOADED & DELTA GAGE
Test Date 8/20/96
DELTA GAGE
UNLOADED GAGE
LOADED GAGE
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
-0.1000
80
82
84
86
88
90
92
94
96
98
100
Mile Post


PLG24+ sigma
Test Date 8/20/96
* 96-Tie Gang (11/96)
0.9000
0.8000
0.7000
0.6000
0.5000
0.4000
0.3000
0.2000
0.1000
0.0000
80
82
84
86
88
90
92
94
96
98
100
Mile Posts
PLG24


GWR+ sigma
Test Date 8/20/96
0.5000
0.4500
0.4000
0.3500
0.3000
0.2500
0.2000
0.1500
0.1000
0.0500
0.0000
80
82
84
86
88
90
92
94
96
98
100
Mile Posts
GWR

Appendix E

TEST DATE 8/20/96

MilePost	Total Feet	MEAN LD GAGE	MEAN GWR	MEAN PLG24	#. OF TIES GWR>0.4	#. OF TIES PLG24>.6	M
4	821	0.00	0.00	0.00	0	0	
5	5268	0.01	0.23	0.11	23	1	
6	5263	0.25	0.29	0.39	178	696	
7	5295	0.10	0.28	0.22	43	1	
8	5293	0.13	0.30	0.26	116	36	
9	5283	0.11	0.29	0.24	105	26	
10							
11	5281	0.16	0.27	0.29	31	15	
12	5231	0.11	0.27	0.22	19	3	
13	5305	0.13	0.25	0.24	25	18	
14	4974	0.05	0.26	0.16	62	2	
15	5662	0.10	0.29	0.22	191	6	
16	5347	0.20	0.31	0.34	327	98	
17	5222	0.19	0.27	0.31	117	111	
18	5273	0.18	0.26	0.30	70	111	
19	5312	0.14	0.27	0.26	87	1	
20	5275	0.16	0.27	0.30	140	369	
21	4093	0.01	0.21	0.10	1	0	
22	6495	-0.02	0.22	0.08	3	2	
23	5201	0.34	0.35	0.51	613	606	
24	5376	0.37	0.33	0.52	369	681	
25	5247	0.38	0.31	0.53	247	1027	
26	5317	0.35	0.29	0.50	234	830	
27	5276	0.22	0.31	0.37	268	254	
28	4726	0.14	0.26	0.26	49	18	
29	5878	0.40	0.27	0.54	132	1605	
30	5306	0.40	0.30	0.55	306	1124	
31	5232	0.51	0.31	0.67	352	2330	
32	5380	0.46	0.30	0.60	304	1577	
33	4745	0.40	0.39	0.59	1137	1310	
34	5782	0.46	0.32	0.61	589	1881	
35	5303	0.32	0.31	0.47	447	496	
36	5290	0.40	0.31	0.55	415	1061	
37	3911	0.43	0.32	0.59	313	1060	
38	6404	0.22	0.30	0.35	173	206	
39	5530	0.21	0.30	0.35	262	111	
40	5283	0.25	0.31	0.41	366	603	
41	5297	0.23	0.30	0.37	294	183	
42	5287	0.23	0.31	0.38	385	39	
43	5196	0.25	0.33	0.40	431	87	
44	5395	0.21	0.30	0.35	252	25	
45	5149	0.28	0.30	0.42	141	332	
46	5424	0.24	0.28	0.37	89	42	
47	515	0.11	0.29	0.24	1	0	
48	5289	0.19	0.29	0.32	103	118	
49	5289	0.26	0.27	0.40	139	982	
50	5193	0.38	0.23	0.50	56	1304	
51	5372	0.35	0.26	0.48	138	1153	
52	4788	0.21	0.25	0.34	82	335	
53	5788	0.31	0.22	0.42	120	1238	
54	5270	0.29	0.25	0.42	89	634	
55	5279	0.44	0.25	0.57	186	1827	

TEST DATE 5/7/98

ilePost	Total Feet	MEAN LD GAGE	MEAN GWR	MEAN PLG24	#. OF TIES GWR>0.4	#. OF TIES PLG24>.6
4	5364	0.09	0.08	0.12	0	0
5	6225	0.15	0.11	0.20	0	15
6	9265	0.25	0.12	0.30	0	70
7	5330	0.21	0.15	0.28	0	2
8	5300	0.21	0.15	0.27	1	6
9	5274	0.33	0.14	0.40	1	36
10	11		0.11	0.39	0	0
11	5216	0.25	0.14	0.32	0	14
12	5281	0.21	0.14	0.27	2	9
13	5339	0.24	0.13	0.29	0	13
14	4956	0.12	0.12	0.17	0	2
15	5679	0.17	0.14	0.24	0	0
16	5414	0.28	0.16	0.36	12	115
17	5172	0.30	0.15	0.37	2	165
18	5302	0.28	0.14	0.34	3	94
19	5353	0.25	0.15	0.31	1	4
20	5261	0.27	0.10	0.32	0	110
21	5296	0.12	0.11	0.17	0	0
22	5410	0.10	0.11	0.14	0	0
23	5331	0.35	0.14	0.41	0	222
24	5321	0.38	0.15	0.45	0	78
25	5318	0.41	0.13	0.47	0	286
26	5255	0.40	0.14	0.46	0	480
27	5248	0.13	0.16	0.20	1	0
28	5295	0.21	0.13	0.26	0	1
29	5353	0.26	0.15	0.33	2	46
30	5342	0.40	0.14	0.47	0	650
31	5264	0.46	0.11	0.52	0	564
32	5400	0.42	0.14	0.49	0	355
33	5264	0.45	0.12	0.51	0	1014
34	5247	0.34	0.14	0.41	2	295
35	4738	0.29	0.15	0.36	0	19
36	5389	0.32	0.15	0.39	2	108
37	5875	0.35	0.16	0.43	1	295
38	5257	0.31	0.13	0.37	0	108
39	5330	0.28	0.13	0.34	5	55
40	5290	0.33	0.12	0.39	0	215
41	5327	0.33	0.11	0.38	0	123
42	5320	0.31	0.13	0.37	0	10
43	5330	0.31	0.14	0.37	2	46
44	5318	0.29	0.13	0.34	0	18
45	5345	0.32	0.12	0.38	0	87
46	5320	0.30	0.12	0.35	0	36
47	5324	0.23	0.12	0.28	0	8
48	5308	0.18	0.11	0.23	0	0
49	5259	0.23	0.10	0.27	0	119
50	5339	0.31	0.11	0.37	0	446
51	5316	0.26	0.11	0.31	1	108
52	5316	0.18	0.10	0.23	0	3
53	5298	0.19	0.10	0.24	0	0
54	5299	0.24	0.13	0.30	1	246
55	5301	0.40	0.11	0.45	0	807

MilePost	Total Feet	MEAN LD GAGE	MEAN GWR	MEAN PLG24	#. OF TIES GWR>0.4	#. OF TIES PLG24>.6	MilePost	Total Feet	MEAN LD GAGE	MEAN GWR	MEAN PLG24	#. OF TIES GWR>0.4	#. OF TIES PLG24>.6
56	5288	0.22	0.25	0.35	151	750	56	5249	0.23	0.12	0.29	0	460
57	3678	0.00	0.21	0.09	9	9	57	5307	0.14	0.09	0.18	0	109
58	6840	0.06	0.21	0.16	50	305	58	5289	0.07	0.10	0.11	0	1
59							59	5291	0.29	0.12	0.35	0	510
60	721	0.00	0.00	0.00	0	0	60	5256	0.28	0.11	0.33	0	670
61	4359	0.30	0.27	0.43	158	543	61	5208	0.30	0.11	0.35	0	155
62	5256	0.52	0.27	0.67	241	1972	62	5320	0.43	0.11	0.48	0	628
63	5328	0.23	0.27	0.36	224	782	63						
64	5234	0.38	0.29	0.52	287	1519	64	10449	0.27	0.13	0.34	0	850
65	5329	0.27	0.26	0.40	101	190	65	5348	0.32	0.12	0.38	0	62
66	5279	0.26	0.24	0.37	111	657	66	5167	0.25	0.13	0.32	0	18
67	5294	0.34	0.29	0.49	267	890	67	5226	0.34	0.13	0.40	0	180
68	5280	0.36	0.22	0.47	114	1407	68	5248	0.35	0.13	0.41	0	849
69	5282	0.14	0.24	0.26	68	410	69	5273	0.20	0.10	0.25	0	161
70	5672	0.25	0.26	0.37	100	197	70	5667	0.32	0.12	0.38	2	82
71	4882	0.18	0.26	0.30	109	20	71	4953	0.23	0.12	0.29	1	10
72	5288	0.22	0.25	0.34	95	272	72	5334	0.26	0.12	0.31	2	25
73	5286	0.30	0.27	0.44	225	695	73	5317	0.33	0.12	0.39	1	244
74	5282	0.25	0.26	0.38	111	495	74	5334	0.26	0.13	0.32	0	54
75	5301	0.35	0.28	0.50	206	969	75	5321	0.29	0.09	0.34	0	39
76	5293	0.37	0.30	0.52	562	817	76	5381	0.32	0.15	0.40	1	144
77	5287	0.46	0.29	0.60	305	1741	77	5402	0.36	0.12	0.42	0	361
78							78	5346	0.24	0.10	0.29	0	9
79	10785	0.28	0.30	0.43	842	1072	79	5452	0.32	0.10	0.37	6	478
80							80	5209	0.44	0.14	0.52	14	926
81	10516	0.44	0.31	0.61	913	3329	81	5138	0.45	0.15	0.54	5	1032
82	5269	0.43	0.35	0.61	805	1447	82	5151	0.40	0.15	0.48	6	538
83	5298	0.39	0.34	0.56	635	1312	83	5337	0.37	0.11	0.42	0	709
84	5340	0.38	0.33	0.54	583	1207	84	5256	0.29	0.11	0.34	0	49
85	5234	0.40	0.31	0.56	382	1192	85	5294	0.28	0.11	0.33	0	17
86	5313	0.46	0.33	0.63	704	2005	86	5130	0.36	0.12	0.42	0	206
87	5209	0.47	0.34	0.64	641	1951	87	5277	0.39	0.13	0.45	0	71
88	5313	0.44	0.35	0.64	823	2047	88	5334	0.39	0.12	0.46	0	70
89	5263	0.43	0.32	0.60	338	879	89	5236	0.42	0.10	0.47	5	280
90	5220	0.31	0.27	0.45	226	1122	90	4376	0.35	0.09	0.39	2	578
91	5293	0.16	0.25	0.27	92	92	91	5058	0.23	0.10	0.28	1	46
92	5293	0.20	0.27	0.32	167	444	92	5240	0.27	0.09	0.31	0	342
93	5270	0.27	0.28	0.41	283	458	93	5244	0.36	0.10	0.40	0	274
94	5264	0.29	0.28	0.43	298	506	94	5138	0.34	0.08	0.38	0	265
95	5284	0.12	0.23	0.23	46	23	95	5200	0.29	0.07	0.32	0	63
96	5298	0.25	0.23	0.36	25	23	96						
97	5210	0.29	0.27	0.42	292	1009	97	10307	0.38	0.10	0.43	4	1012
98	5267	0.42	0.34	0.60	1022	1935	98	5283	0.49	0.11	0.54	0	1400
99	5313	0.08	0.23	0.20	171	393	99	5357	0.16	0.09	0.20	0	47
100	4451	0.27	0.32	0.44	722	1208	100	5307	0.32	0.12	0.38	10	1028
101							101	5022	0.09	0.07	0.12	0	7
102	11414	0.13	0.24	0.24	337	242	102	5640	0.32	0.09	0.36	0	188
103							103	5336	0.25	0.08	0.29	0	130
104	10558	0.13	0.25	0.25	171	234	104	5311	0.14	0.09	0.18	3	22
105	5338	0.23	0.33	0.40	401	288	105	5371	0.32	0.08	0.36	1	338
106	5213	0.14	0.25	0.27	244	692	106	5160	0.13	0.06	0.16	0	0
107	5291	-0.01	0.19	0.07	6	0	107	5491	0.09	0.08	0.12	0	0
108	2339		0.35	0.64	362	686	108	5563	0.24	0.07	0.27	0	489

MilePost	Total Feet	MEAN LD GAGE	MEAN GWR	MEAN PLG24	#. OF TIES GWR>0.4	#. OF TIES PLG24>.6	MilePost	Total Feet	MEAN LD GAGE	MEAN GWR	MEAN PLG24	#. OF TIES GWR>0.4	#. OF TIES PLG24>.6
109	3062	0.32	0.24	0.45	40	656	109	5342	0.21	0.12	0.27	3	172

96 test date

MilePost	Total Feet	MPLG24	MLDG	MULD	MDLG	NGWR
4	821	0.00	0.00	-0.12	0.00	0
5	5268	0.11	0.01	-0.29	0.30	465
6	5263	0.39	0.25	-0.10	0.35	1970
7	5295	0.22	0.10	-0.26	0.36	1841
8	5293	0.26	0.13	-0.24	0.37	2355
9	5283	0.24	0.11	-0.25	0.36	2054
11	5281	0.29	0.16	-0.18	0.34	1324
12	5231	0.22	0.11	-0.23	0.34	1149
13	5305	0.24	0.13	-0.19	0.32	783
14	4974	0.16	0.05	-0.28	0.33	1094
15	5662	0.22	0.10	-0.27	0.36	2271
16	5347	0.34	0.20	-0.17	0.37	2580
17	5222	0.31	0.19	-0.14	0.34	1204
18	5273	0.30	0.18	-0.15	0.34	1359
19	5312	0.26	0.14	-0.19	0.33	1502
20	5275	0.30	0.16	-0.17	0.33	1846
21	4093	0.10	0.01	-0.25	0.29	308
22	6495	0.08	-0.02	-0.29	0.30	439
23	5201	0.51	0.34	-0.11	0.41	2741
24	5376	0.52	0.37	-0.02	0.39	3373
25	5247	0.53	0.38	0.01	0.37	2663
26	5317	0.50	0.35	0.00	0.35	2383
27	5276	0.37	0.22	-0.16	0.37	2952
28	4726	0.26	0.14	-0.19	0.33	1066
29	5878	0.54	0.40	0.06	0.33	2117
30	5306	0.55	0.40	0.04	0.35	2339
31	5232	0.67	0.51	0.15	0.36	2719
32	5380	0.60	0.46	0.10	0.36	2217
33	4745	0.59	0.40	-0.04	0.44	4193
34	5782	0.61	0.46	0.08	0.38	3251
35	5303	0.47	0.32	-0.06	0.38	2399
36	5290	0.55	0.40	0.03	0.37	2870
37	3911	0.59	0.43	0.03	0.38	1859
38	6404	0.35	0.22	-0.15	0.36	2840
39	5530	0.35	0.21	-0.16	0.37	2664
40	5283	0.41	0.25	-0.11	0.36	2568
41	5297	0.37	0.23	-0.13	0.36	2390
42	5287	0.38	0.23	-0.14	0.38	2827
43	5196	0.40	0.25	-0.14	0.39	3057
44	5395	0.35	0.21	-0.15	0.36	2457
45	5149	0.42	0.28	-0.08	0.36	2468
46	5424	0.37	0.24	-0.11	0.35	1655
47	515	0.24	0.11	-0.25	0.36	217
48	5289	0.32	0.19	-0.16	0.35	2050
49	5289	0.40	0.26	-0.07	0.33	1692
50	5193	0.50	0.38	0.12	0.29	942
51	5372	0.48	0.35	0.03	0.31	1719
52	4788	0.34	0.21	-0.10	0.32	1319
53	5788	0.42	0.31	0.00	0.29	779
54	5270	0.42	0.29	-0.03	0.32	1325
55	5279	0.57	0.44	0.11	0.31	1410
56	5288	0.35	0.22	-0.09	0.31	1125
57	3678	0.09	0.00	-0.29	0.28	333
58	6840	0.16	0.06	-0.21	0.28	636
60	721	0.00	0.00	0.30	0.00	0
61	4359	0.43	0.30	-0.04	0.34	1432
62	5256	0.67	0.52	0.19	0.33	1865
63	5328	0.36	0.23	-0.11	0.34	1592
64	5234	0.52	0.38	0.03	0.35	2111
65	5329	0.40	0.27	-0.05	0.32	1421
66	5279	0.37	0.26	-0.04	0.30	1006
67	5294	0.49	0.34	-0.01	0.34	2049

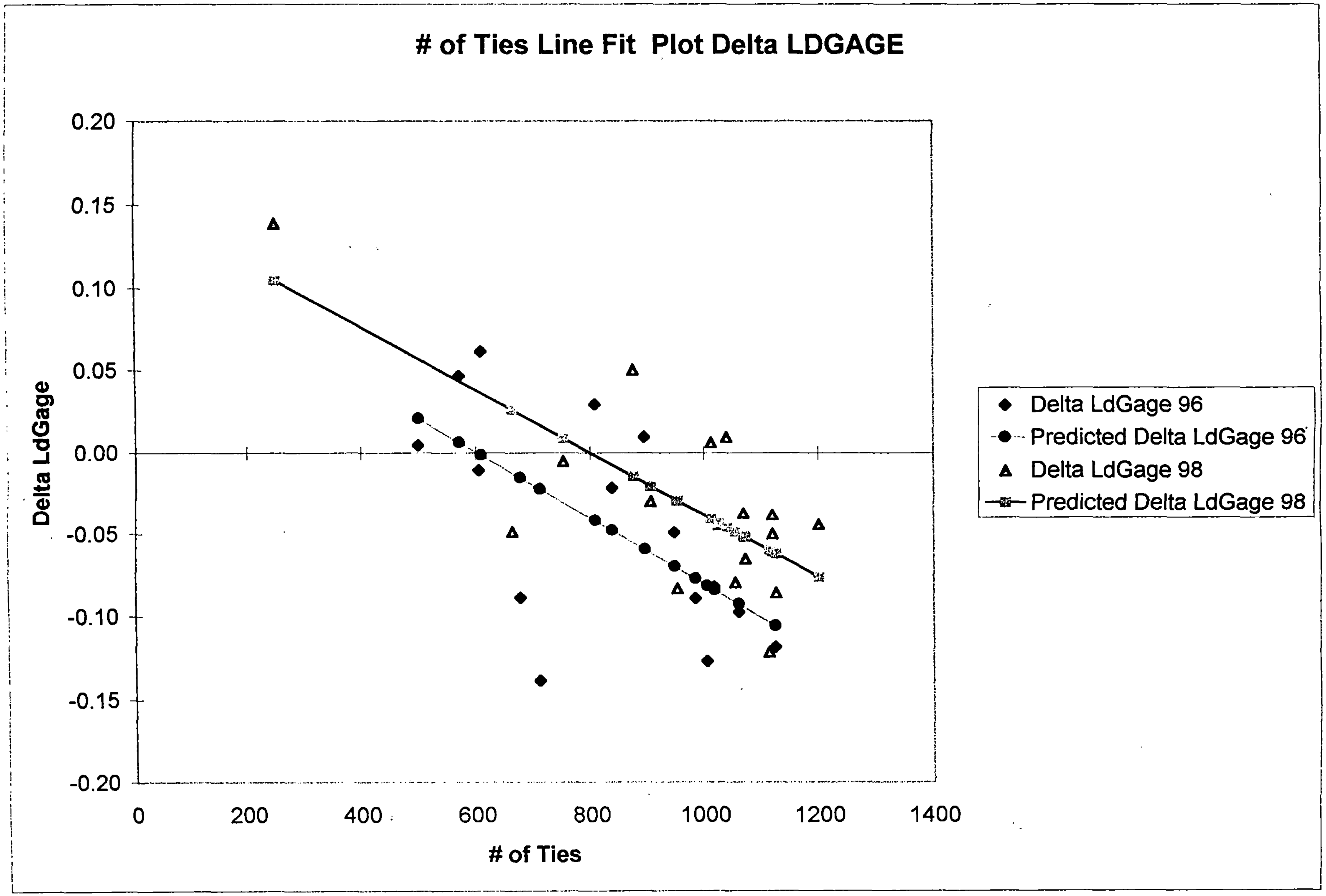
98 Test Date

MilePost	Total Feet	MPLG24	MLDG	MULD	MDLG	96 Tie Gang # of Ties	97 Tie gang # of Ties	98 Tie Gang # of Ties
4	5364	0.12	0.09	0.02	0.06			
5	6225	0.20	0.15	0.05	0.10			
6	9265	0.30	0.25	0.15	0.10			
7	5330	0.28	0.21	0.06	0.13			
8	5300	0.27	0.21	0.07	0.13			
9	5274	0.40	0.33	0.21	0.12			
10		0.39						
11	5216	0.32	0.25	0.13	0.12			
12	5281	0.27	0.21	0.08	0.13			
13	5339	0.29	0.24	0.12	0.12			
14	4956	0.17	0.12	0.02	0.10			
15	5679	0.24	0.17	0.05	0.13			
16	5414	0.36	0.28	0.14	0.14			
17	5172	0.37	0.30	0.17	0.13			
18	5302	0.34	0.28	0.16	0.12			
19	5353	0.31	0.25	0.12	0.13			
20	5261	0.32	0.27	0.18	0.09			
21	5296	0.17	0.12	0.02	0.10			
22	5410	0.14	0.10	0.00	0.10			
23	5331	0.41	0.35	0.23	0.12	500		
24	5321	0.45	0.38	0.25	0.13	895		
25	5318	0.47	0.41	0.29	0.11	808		
26	5255	0.46	0.40	0.28	0.12	571		
27	5248	0.20	0.13	-0.01	0.14	677		
28	5295	0.26	0.21	0.09	0.11	609		
29	5353	0.33	0.26	0.14	0.13	711		
30	5342	0.47	0.40	0.28	0.12		884	1012
31	5264	0.52	0.46	0.36	0.10		950	863
32	5400	0.49	0.42	0.30	0.12		918	1026
33	5264	0.51	0.45	0.35	0.10		1550	875
34	5247	0.41	0.34	0.22	0.12	1124	1001	
35	4738	0.36	0.29	0.16	0.13		800	1069
36	5389	0.39	0.32	0.19	0.13		501	1055
37	5875	0.43	0.35	0.21	0.14			953
38	5257	0.37	0.31	0.19	0.12			
39	5330	0.34	0.28	0.17	0.11			
40	5290	0.39	0.33	0.23	0.10			
41	5327	0.38	0.33	0.23	0.10			
42	5320	0.37	0.31	0.19	0.11			
43	5330	0.37	0.31	0.19	0.12			
44	5318	0.34	0.29	0.18	0.11			
45	5345	0.38	0.32	0.22	0.10			
46	5320	0.35	0.30	0.20	0.10			
47	5324	0.28	0.23	0.13	0.10			
48	5308	0.23	0.18	0.08	0.10			753
49	5259	0.27	0.23	0.14	0.09			1120
50	5339	0.37	0.31	0.22	0.10			1072
51	5316	0.31	0.26	0.17	0.09			1126
52	5316	0.23	0.18	0.10	0.08			906
53	5298	0.24	0.19	0.10	0.09			1114
54	5299	0.30	0.24	0.13	0.11			1120
55	5301	0.45	0.40	0.30	0.09			1201
56	5249	0.29	0.23	0.13	0.10			1040
57	5307	0.18	0.14	0.06	0.08			250
58	5289	0.11	0.07	-0.01	0.08			
59	5291	0.35	0.29	0.19	0.10		1411	
60	5256	0.33	0.28	0.19	0.09			
61	5208	0.35	0.30	0.21	0.09			
62	5320	0.48	0.43	0.33	0.09			
64	10449	0.34	0.27	0.16	0.12			
65	5348	0.38	0.32	0.22	0.11			
66	5167	0.32	0.25	0.14	0.11			
67	5226	0.40	0.34	0.22	0.11			

68	5280	0.47	0.36	0.08	0.28	864
69	5282	0.26	0.14	-0.17	0.31	984
70	5672	0.37	0.25	-0.08	0.33	1527
71	4882	0.30	0.18	-0.18	0.33	1407
72	5288	0.34	0.22	-0.09	0.31	1102
73	5286	0.44	0.30	-0.03	0.33	1625
74	5282	0.38	0.25	-0.07	0.33	1299
75	5301	0.50	0.35	0.01	0.34	1876
76	5293	0.52	0.37	0.00	0.37	2501
77	5287	0.60	0.46	0.11	0.34	2182
79	10785	0.43	0.28	-0.10	0.36	3809
81	10516	0.61	0.44	0.07	0.36	5142
82	5269	0.61	0.43	0.02	0.40	3334
83	5298	0.56	0.39	0.00	0.39	3368
84	5340	0.54	0.38	-0.01	0.38	3150
85	5234	0.56	0.40	0.03	0.37	2588
86	5313	0.63	0.46	0.07	0.38	2833
87	5209	0.64	0.47	0.07	0.40	3374
88	5313	0.64	0.44	0.06	0.39	3615
89	5263	0.60	0.43	0.09	0.37	1758
90	5220	0.45	0.31	-0.03	0.33	1783
91	5293	0.27	0.16	-0.16	0.31	1007
92	5293	0.32	0.20	-0.16	0.33	1212
93	5270	0.41	0.27	-0.06	0.34	1953
94	5264	0.43	0.29	-0.07	0.34	1736
95	5284	0.23	0.12	-0.15	0.30	505
96	5298	0.36	0.25	-0.08	0.30	730
97	5210	0.42	0.29	-0.05	0.33	1532
98	5267	0.60	0.42	0.02	0.39	3334
99	5313	0.20	0.08	-0.19	0.30	847
100	4451	0.44	0.27	-0.10	0.37	2367
102	11414	0.24	0.13	-0.18	0.31	2921
104	10558	0.25	0.13	-0.19	0.31	2098
105	5338	0.40	0.23	-0.13	0.37	2281
106	5213	0.27	0.14	-0.18	0.31	1277
107	5291	0.07	-0.01	-0.28	0.27	229
		0.64				
109	3062	0.45	0.32	0.04	0.29	527

68	5248	0.41	0.35	0.24	0.11	
69	5273	0.25	0.20	0.11	0.09	
70	5667	0.38	0.32	0.23	0.10	
71	4953	0.29	0.23	0.13	0.10	
72	5334	0.31	0.26	0.16	0.10	
73	5317	0.39	0.33	0.22	0.10	
74	5334	0.32	0.26	0.15	0.11	
75	5321	0.34	0.29	0.22	0.07	
76	5381	0.40	0.32	0.20	0.12	
77	5402	0.42	0.36	0.27	0.10	
78	5346	0.29	0.24	0.16	0.08	
79	5452	0.37	0.32	0.24	0.08	
80	5209	0.52	0.44	0.32	0.12	
81	5138	0.54	0.45	0.33	0.13	
82	5151	0.48	0.40	0.28	0.12	
83	5337	0.42	0.37	0.28	0.09	838
84	5256	0.34	0.29	0.19	0.09	984
85	5294	0.33	0.28	0.18	0.10	1005
86	5130	0.42	0.36	0.26	0.10	1060
87	5277	0.45	0.39	0.27	0.12	1018
88	5334	0.46	0.39	0.29	0.11	947
89	5236	0.47	0.42	0.34	0.08	605
90	4376	0.39	0.35	0.27	0.08	
91	5058	0.28	0.23	0.15	0.09	
92	5240	0.31	0.27	0.20	0.07	
93	5244	0.40	0.36	0.27	0.08	
94	5138	0.38	0.34	0.28	0.06	
95	5200	0.32	0.29	0.24	0.05	
97	10307	0.43	0.38	0.29	0.08	
98	5283	0.54	0.49	0.40	0.09	
99	5357	0.20	0.16	0.08	0.08	
100	5307	0.38	0.32	0.22	0.10	
101	5022	0.12	0.09	0.04	0.08	
102	5640	0.36	0.32	0.25	0.07	
103	5336	0.29	0.25	0.19	0.06	
104	5311	0.18	0.14	0.07	0.07	
105	5371	0.36	0.32	0.25	0.07	
106	5160	0.16	0.13	0.08	0.05	
107	5491	0.12	0.09	0.02	0.07	
108	5563	0.27	0.24	0.18	0.06	
109	5342	0.27	0.21	0.10	0.11	

Appendix F



# of Ties Line Fit Plot Delta LDGAGE
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
Delta LdGage
0
200
400
600
800
1000
1200
1400
# of Ties
Delta LdGage 96
Predicted Delta LdGage 96
Delta LdGage 98
Predicted Delta LdGage 98

SUMMARY OUTPUT

didgage = 0.15248 - .000191* # of ties (98 timbering)

Regression Statistics	
Multiple R	0.732551534
R Square	0.53663175
Adjusted R Square	0.505740533
Standard Error	0.042226012
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.030974298	0.030974298	17.37166117	0.000824654
Residual	15	0.026745541	0.001783036		
Total	16	0.057719839			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.152484	0.045168	3.375903	0.004158	0.056210
# of Ties	-0.000191	0.000046	-4.167932	0.000825	-0.000288

SUMMARY OUTPUT

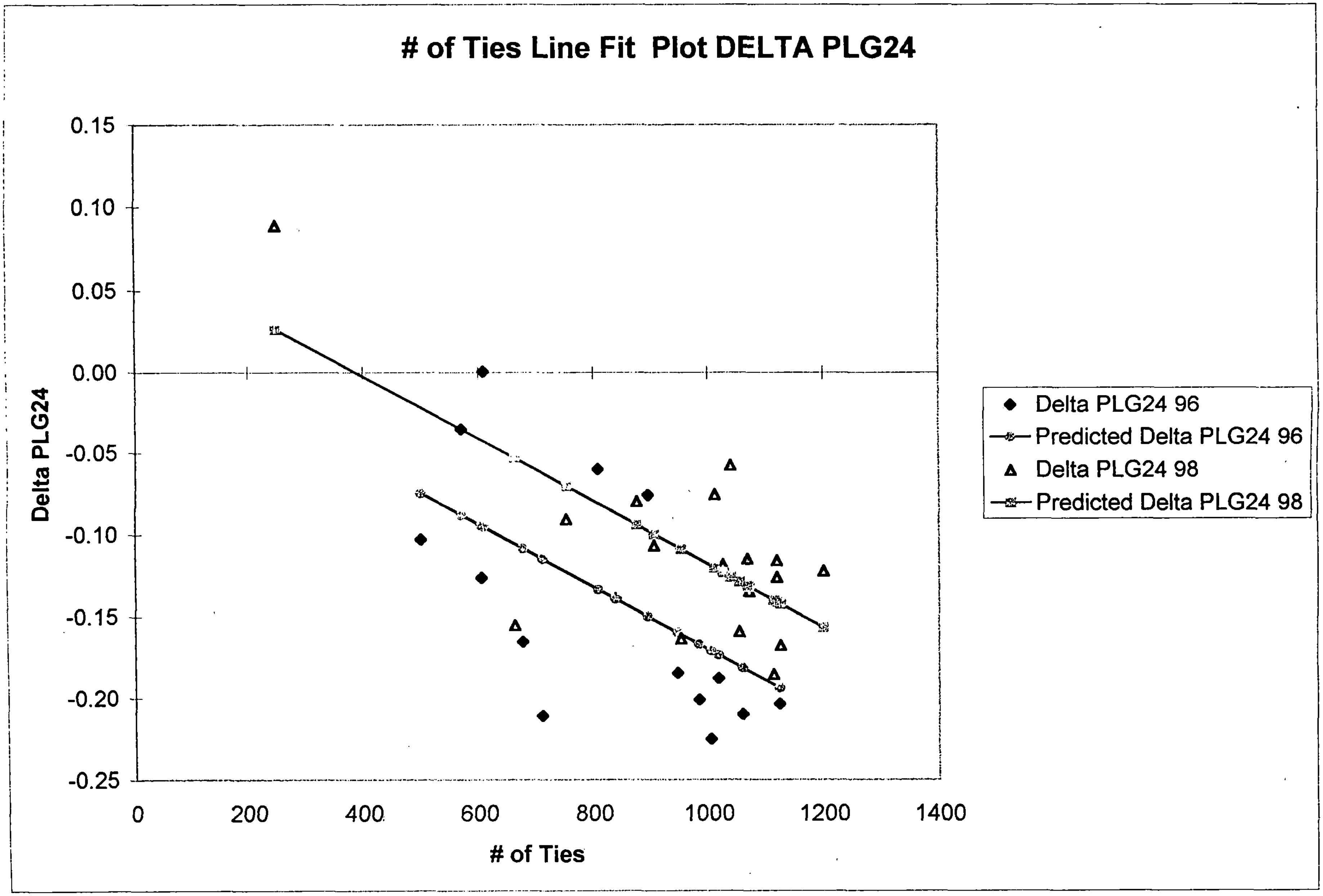
dldgage = 0.12256 - .00020* # of ties (96 timbering)

Regression Statistics	
Multiple R	0.613786754
R Square	0.376734179
Adjusted R Square	0.328790655
Standard Error	0.054211888
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.023093732	0.023093732	7.857874068	0.014938226
Residual	13	0.038206074	0.002938929		
Total	14	0.061299807			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.122536662	0.061282413	1.999540419	0.066895384	-0.009855917
# of Ties	-0.000203099	7.24528E-05	-2.803189981	0.014938226	-0.000359623



# of Ties Line Fit Plot DELTA PLG24
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
Delta PLG24
0
200
400
600
800
1000
1200
1400
# of Ties
Delta PLG24 96
Predicted Delta PLG24 96
Delta PLG24 98
Predicted Delta PLG24 98

SUMMARY OUTPUT

dplg24 = 0.074526 - .000193* # of ties (98 timbering)

Regression Statistics	
Multiple R	0.71316698
R Square	0.508607142
Adjusted R Square	0.475847618
Standard Error	0.045117065
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.031602873	0.031602873	15.52547415	0.001309299
Residual	15	0.030533244	0.00203555		
Total	16	0.062136117			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.074526	0.048261	1.544224	0.143367	-0.028340
# of Ties	-0.000193	0.000049	-3.940238	0.001309	-0.000297

SUMMARY OUTPUT

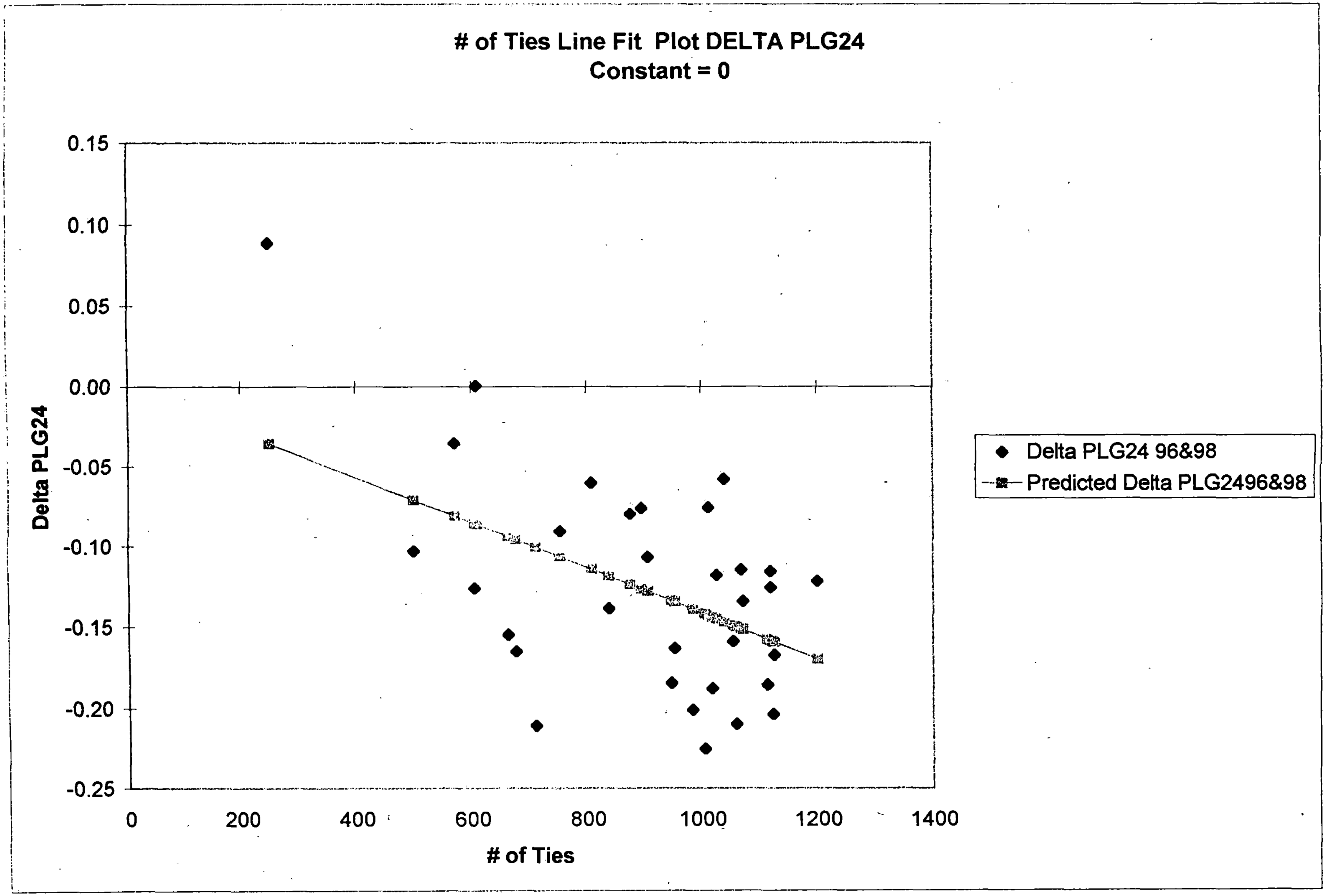
dplg24 = 0.02075-.000191* # of ties (96 timbering)

Regression Statistics	
Multiple R	0.543422792
R Square	0.295308331
Adjusted R Square	0.24110128
Standard Error	0.061085715
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.020328215	0.020328215	5.44778443	0.036288395
Residual	13	0.04850904	0.003731465		
Total	14	0.068837255			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.020756	0.069053	0.300582	0.768486	-0.128423
# of Ties	-0.000191	0.000082	-2.334049	0.036288	-0.000367



# of Ties Line Fit Plot DELTA PLG24
Constant = 0
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
Delta PLG24
0
200
400
600
800
1000
1200
1400
# of Ties
Delta PLG24 96&98
Predicted Delta PLG2496&98

SUMMARY OUTPUT

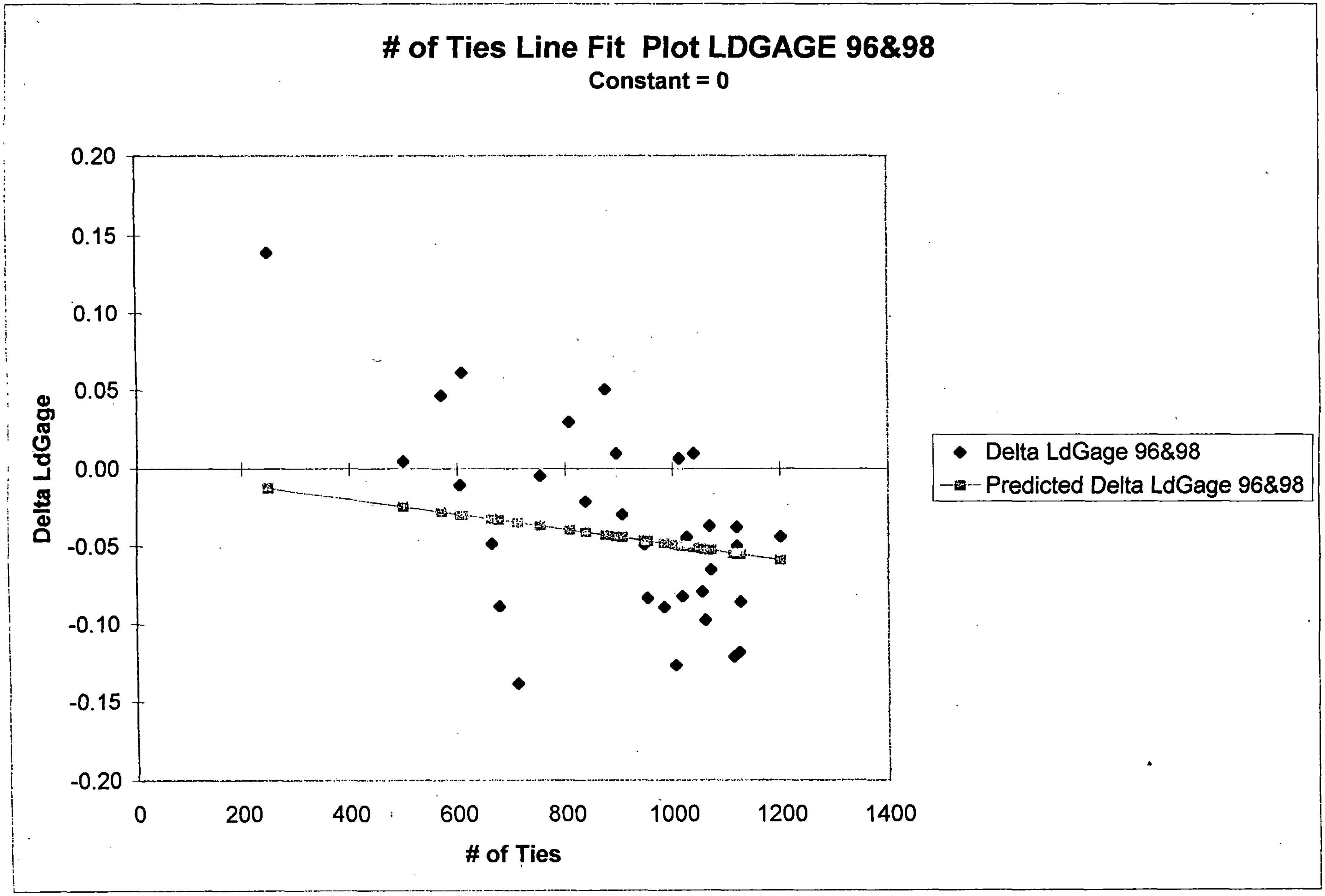
dlplg24 = - .00014125* # of ties (96&98 timbering)

Regression Statistics	
Multiple R	0.54767511
R Square	0.299948026
Adjusted R Square	0.267689961
Standard Error	0.056720994
Observations	32

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.042733167	0.042733167	13.28242636	0.001003909
Residual	31	0.099735405	0.003217271		
Total	32	0.142468572			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A
# of Ties	-0.00014125	1.08521E-05	-13.0159109	4.19848E-14	-0.000163383



# of Ties Line Fit Plot LDGAGE 96&98
Constant = 0
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
Delta LdGage
0
200
400
600
800
1000
1200
1400
# of Ties
Delta LdGage 96&98
Predicted Delta LdGage 96&98

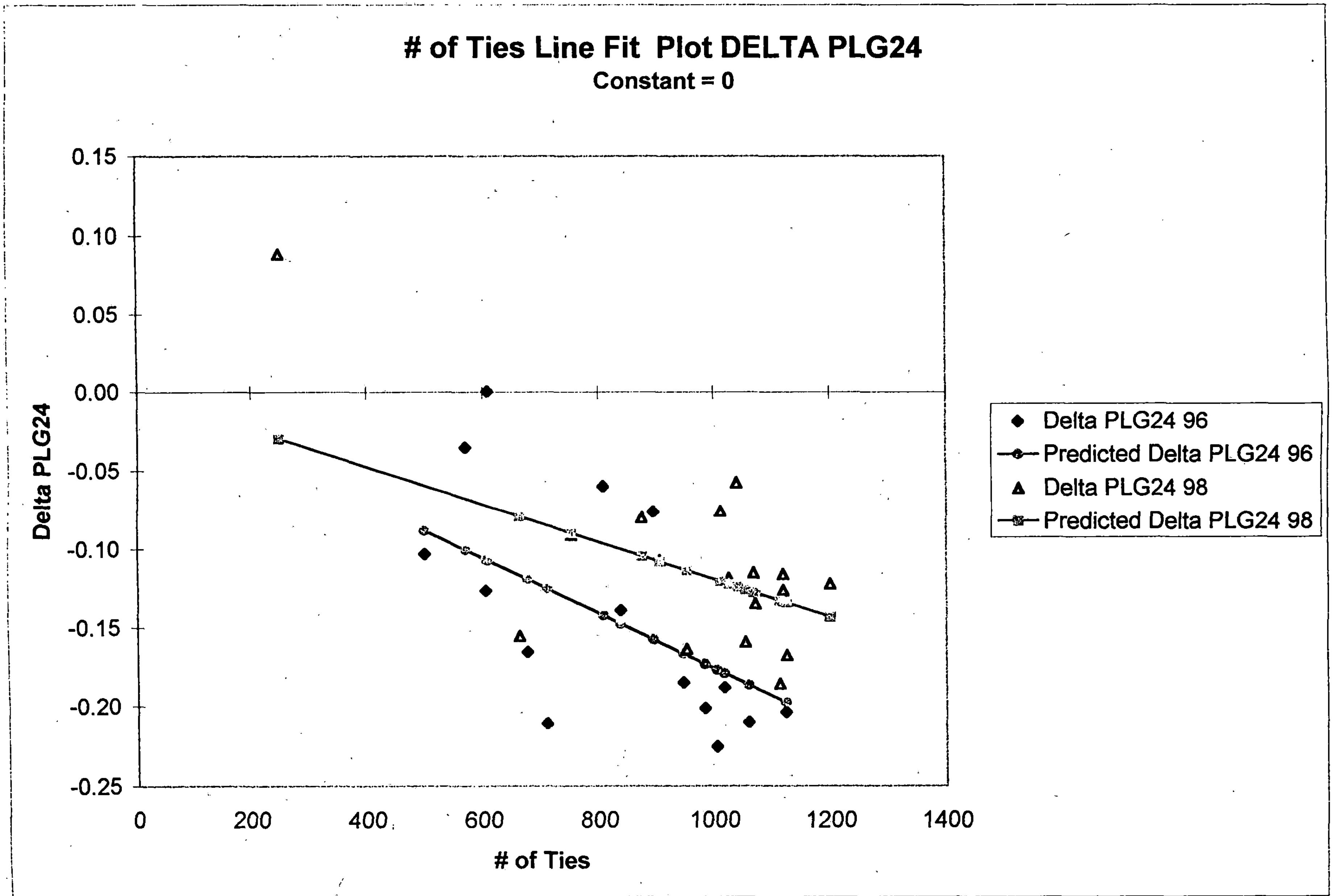
SUMMARY OUTPUT **dldgage = - .000049* # of ties (96&98 timbering)**

Regression Statistics	
Multiple R	0.411585463
R Square	0.169402593
Adjusted R Square	0.137144529
Standard Error	0.056831564
Observations	32

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.020420689	0.020420689	6.322534047	0.017515805
Residual	31	0.100124627	0.003229827		
Total	32	0.120545316			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%
Intercept	0.000000	#N/A	#N/A	#N/A	#N/A
# of Ties	-0.000049	0.000011	-4.488832	0.000092	-0.000071



# of Ties Line Fit Plot DELTA PLG24
Constant = 0
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
-0.25
Delta PLG24
0
200
400
600
800
1000
1200
1400
# of Ties
Delta PLG24 96
Predicted Delta PLG24 96
Delta PLG24 98
Predicted Delta PLG24 98

SUMMARY OUTPUT

dplg24 = - .000176* # of ties (96 timbering)

Regression Statistics	
Multiple R	0.63310055
R Square	0.400816306
Adjusted R Square	0.329387735
Standard Error	0.055739626
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.029096552	0.029096552	9.365121816	0.009118369
Residual	14	0.043496683	0.003106906		
Total	15	0.072593235			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.000000	#N/A	#N/A	#N/A	#N/A
# of Ties	-0.000176	0.000017	-10.320072	0.000000	-0.000212

SUMMARY OUTPUT

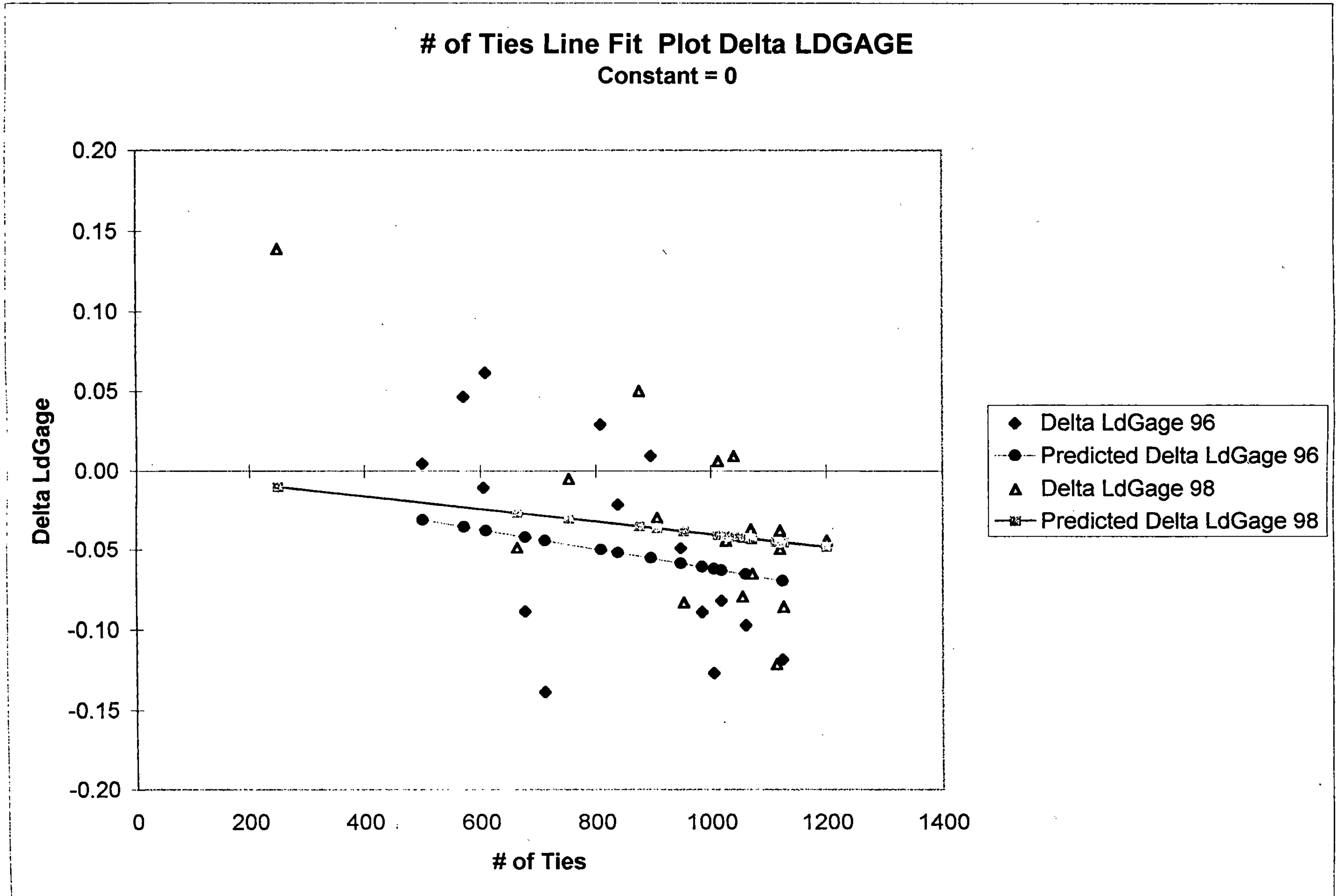
dplg24 = - .000119* # of ties (98 timbering)

Regression Statistics	
Multiple R	0.656115756
R Square	0.430487885
Adjusted R Square	0.367987885
Standard Error	0.047028762
Observations	17

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.026748845	0.026748845	12.09422236	0.003374643
Residual	16	0.035387271	0.002211704		
Total	17	0.062136117			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0	#N/A	#N/A	#N/A	#N/A
# of Ties	-0.000119029	1.15472E-05	-10.30800189	1.79812E-08	-0.000143508


# of Ties Line Fit Plot Delta LDGAGE
Constant = 0
Delta LdGage
0.20
0.15
0.10
0.05
0.00
-0.05
-0.10
-0.15
-0.20
0
200
400
600
800
1000
1200
1400
# of Ties
Delta LdGage 96
Predicted Delta LdGage 96
Delta LdGage 98
Predicted Delta LdGage 98

SUMMARY OUTPUT

dldgage = - .000062* # of ties (96 timbering)

Regression Statistics	
Multiple R	0.430172298
R Square	0.185048206
Adjusted R Square	0.113619635
Standard Error	0.059735361
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.011343419	0.011343419	3.17893022	0.097946193
Residual	14	0.049956388	0.003568313		
Total	15	0.061299807			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.000000	#N/A	#N/A	#N/A	#N/A
# of Ties	-0.000062	0.000018	-3.403148	0.004286	-0.000101

SUMMARY OUTPUT **dldgage = - .000040* # of ties (98 timbering)**

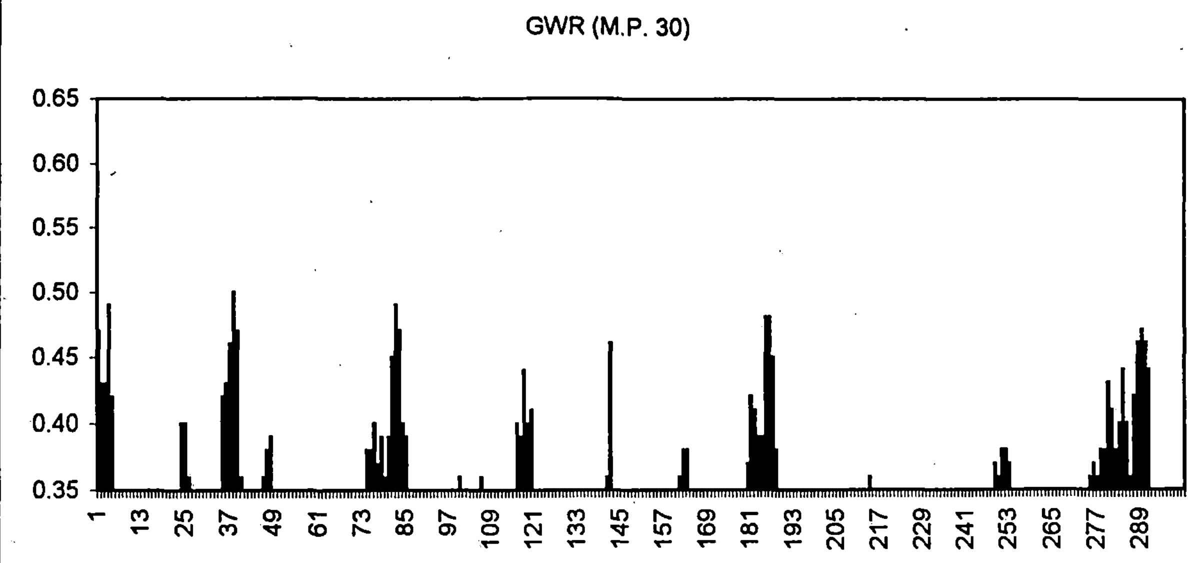
Regression Statistics	
Multiple R	0.429619754
R Square	0.184573133
Adjusted R Square	0.122073133
Standard Error	0.054236927
Observations	17

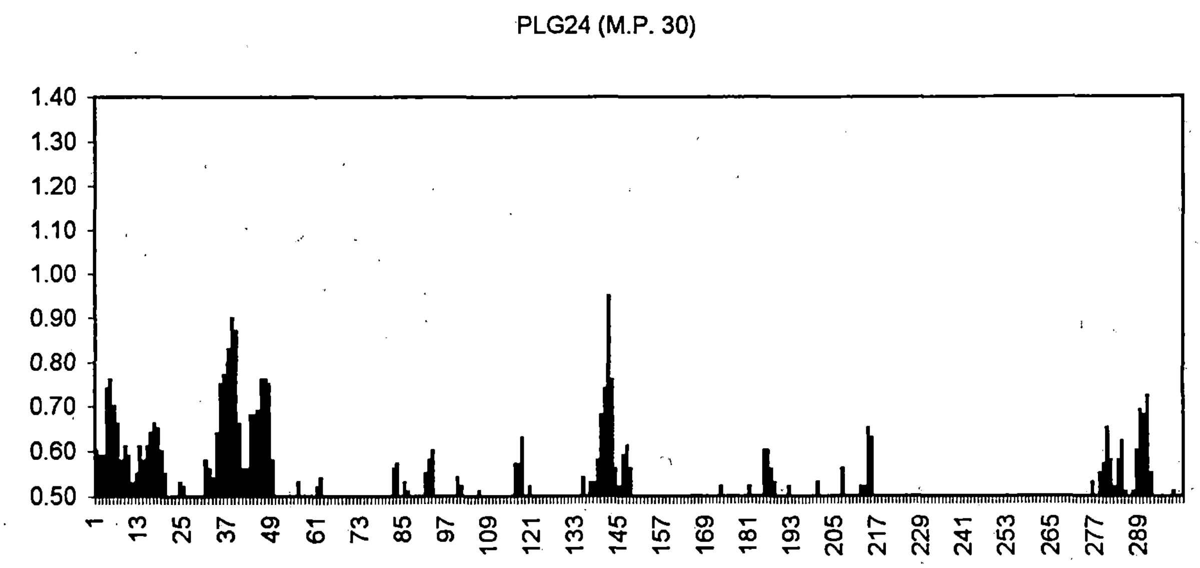
ANOVA

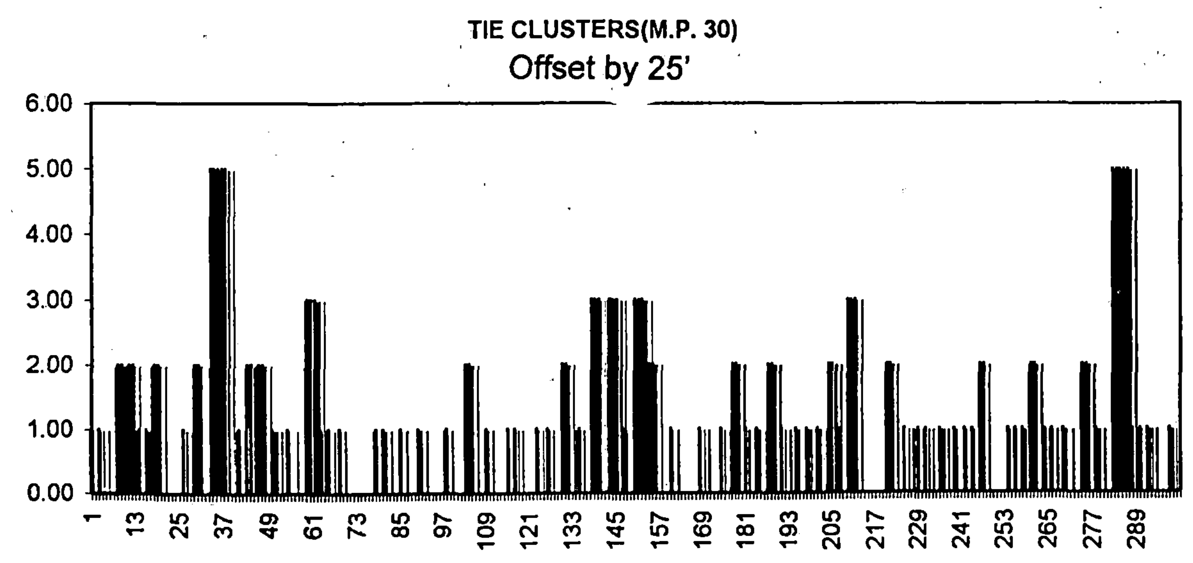
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.010653531	0.010653531	3.621624753	0.076404805
Residual	16	0.047066307	0.002941644		
Total	17	0.057719839			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*
Intercept	0.000000	#N/A	#N/A	#N/A	#N/A
# of Ties	-0.000040	0.000013	-3.021496	0.008107	-0.000068

Appendix G


GWR (M.P. 30)
0.65
0.60
0.55
0.50
0.45
0.40
0.35
1 13 25 37 49 61 73 85 97 109 121 133 145 157 169 181 193 205 217 229 241 253 265 277 289


PLG24 (M.P. 30)
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
1 13 25 37 49 61 73 85 97 109 121 133 145 157 169 181 193 205 217 229 241 253 265 277 289


TIE CLUSTERS(M.P. 30)
Offset by 25'
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5.00
4.00
3.00
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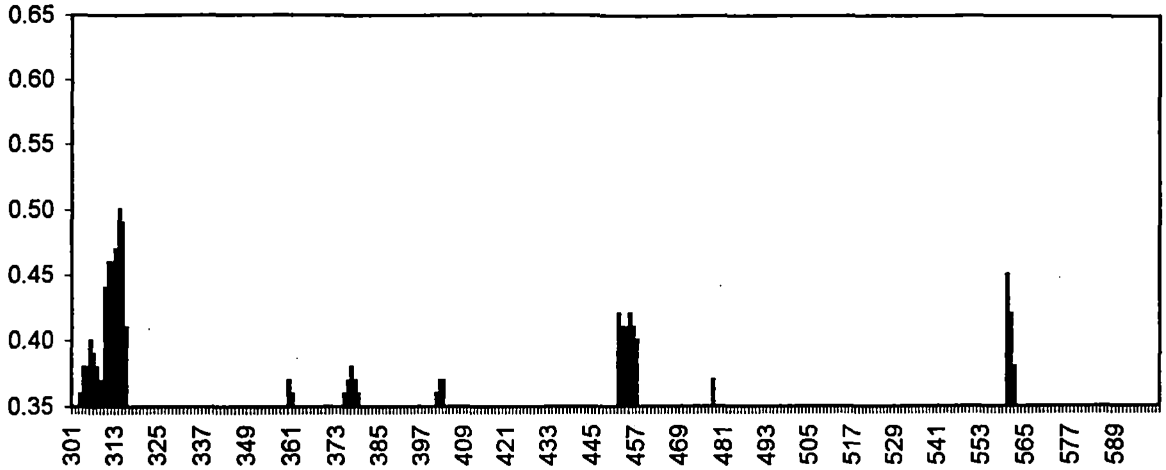
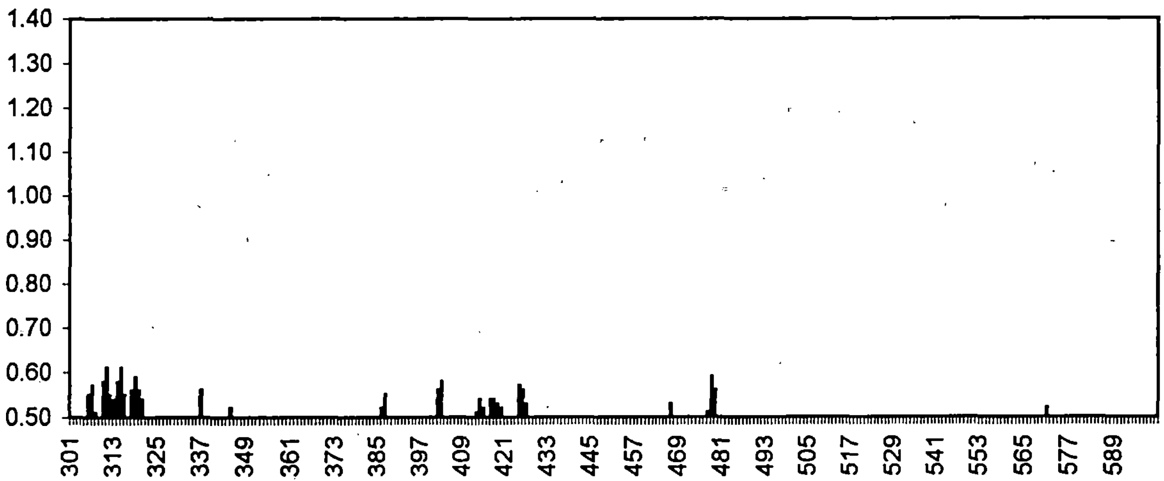
1.00
0.00
1 13 25 37 49 61 73 85 97 109 121 133 145 157 169 181 193 205 217 229 241 253 265 277 289

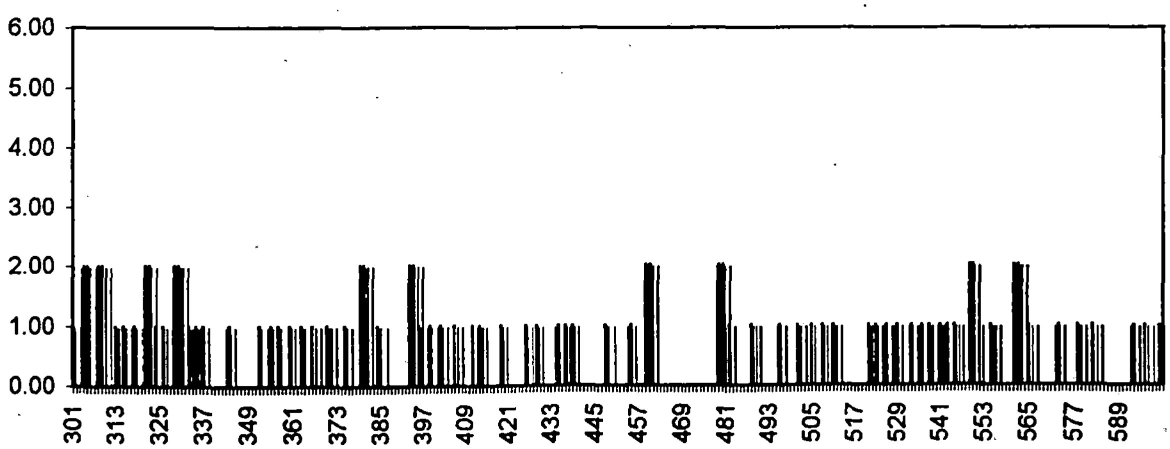
GWR (M.P. 30)

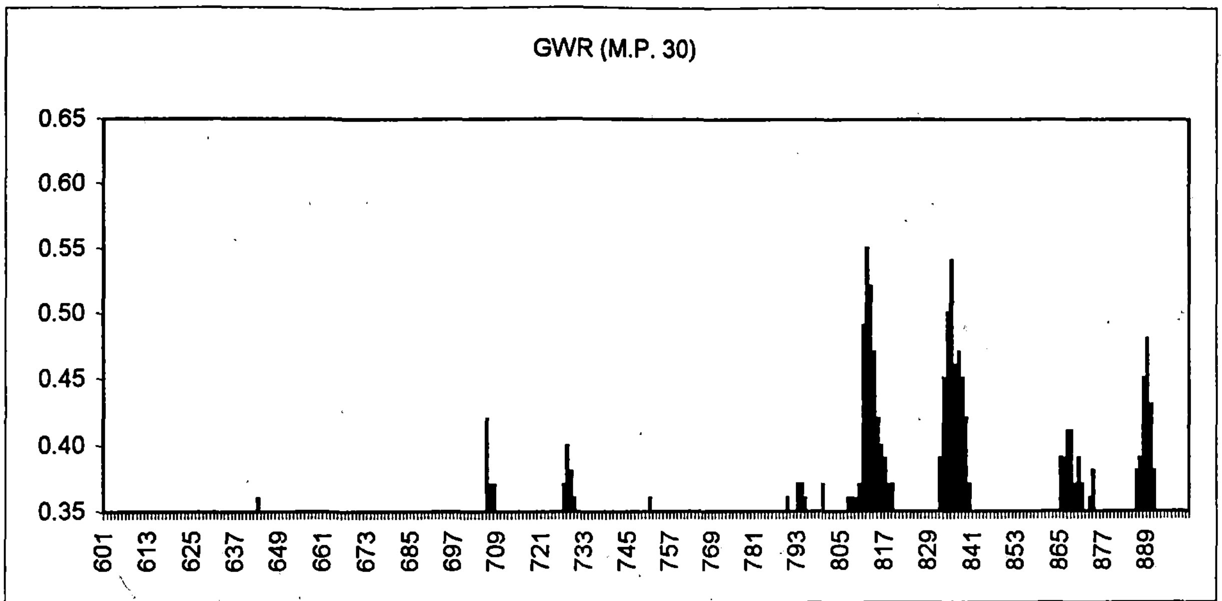


PLG24 (M.P. 30)



TIE CLUSTERS(M.P. 30)
Offset of 25 Ties




GWR (M.P. 30)
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0.55
0.50
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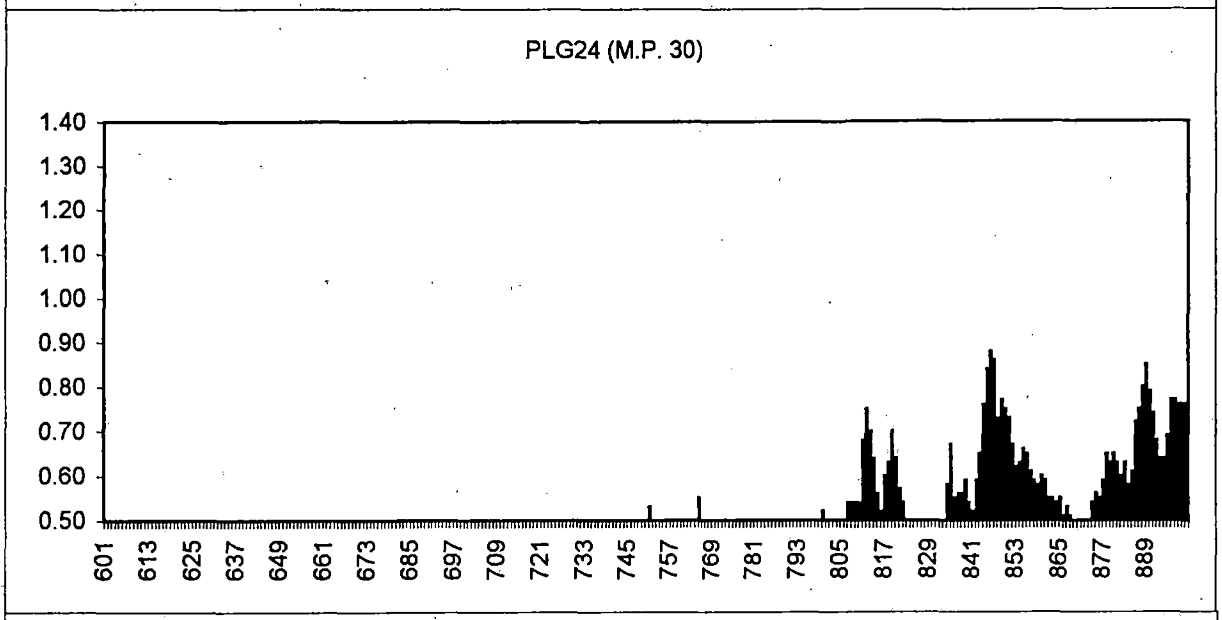
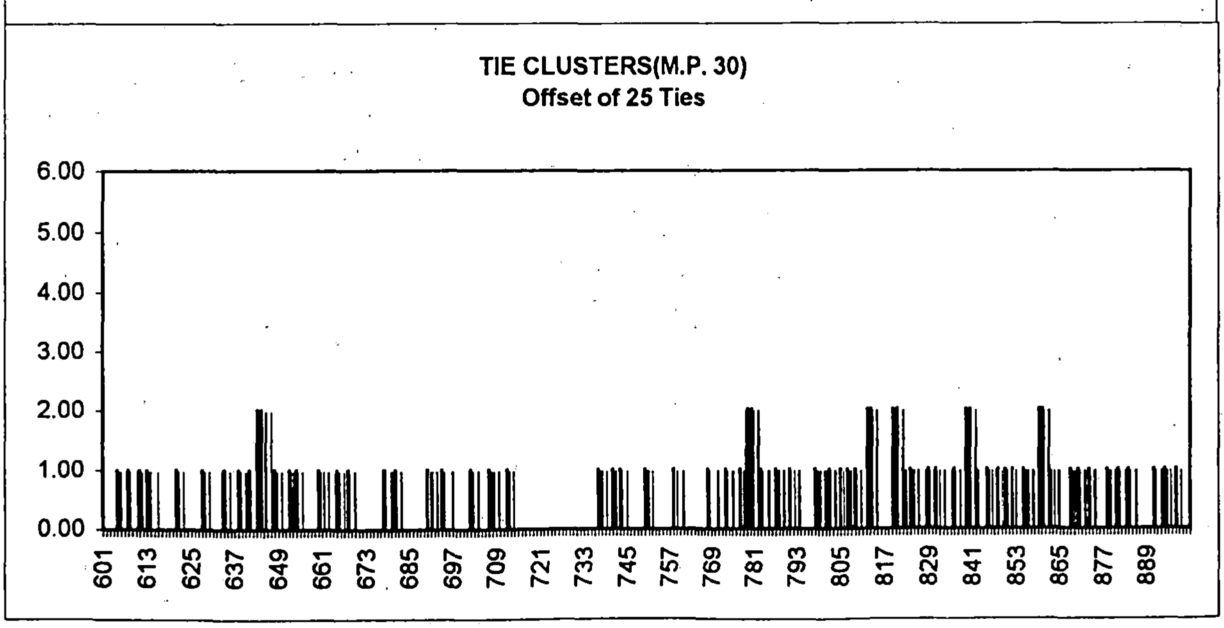

PLG24 (M.P. 30)
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
601 613 625 637 649 661 673 685 697 709 721 733 745 757 769 781 793 805 817 829 841 853 865 877 889


TIE CLUSTERS(M.P. 30)
Offset of 25 Ties
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5.00
4.00
3.00
2.00
1.00
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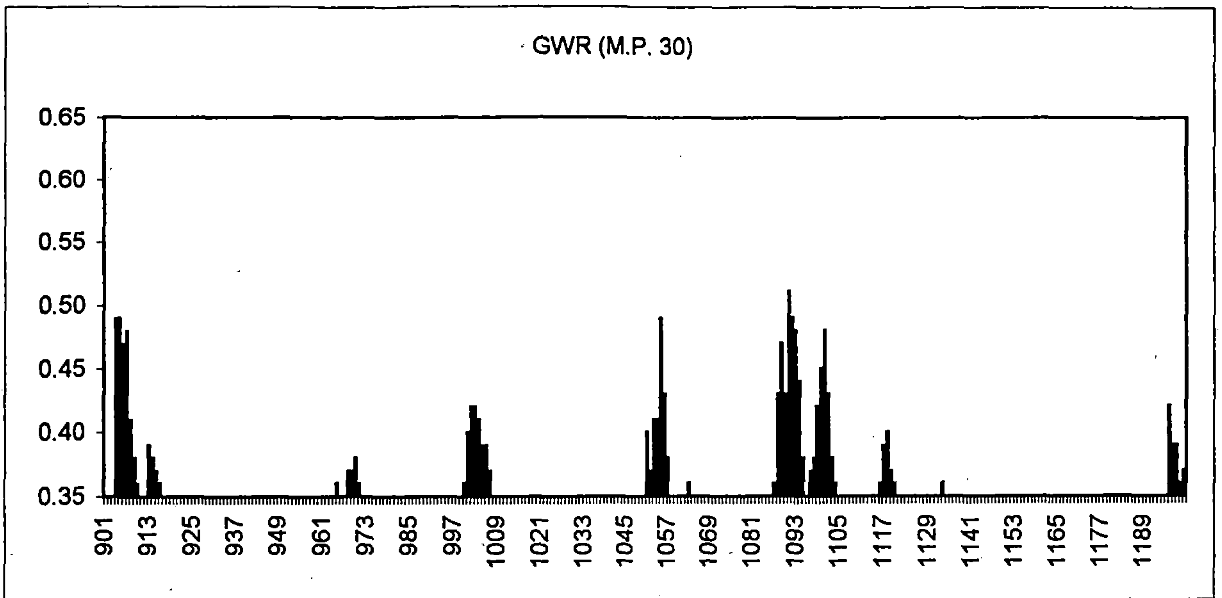
GWR (M.P. 30)
0.65
0.60
0.55
0.50
0.45
0.40
0.35
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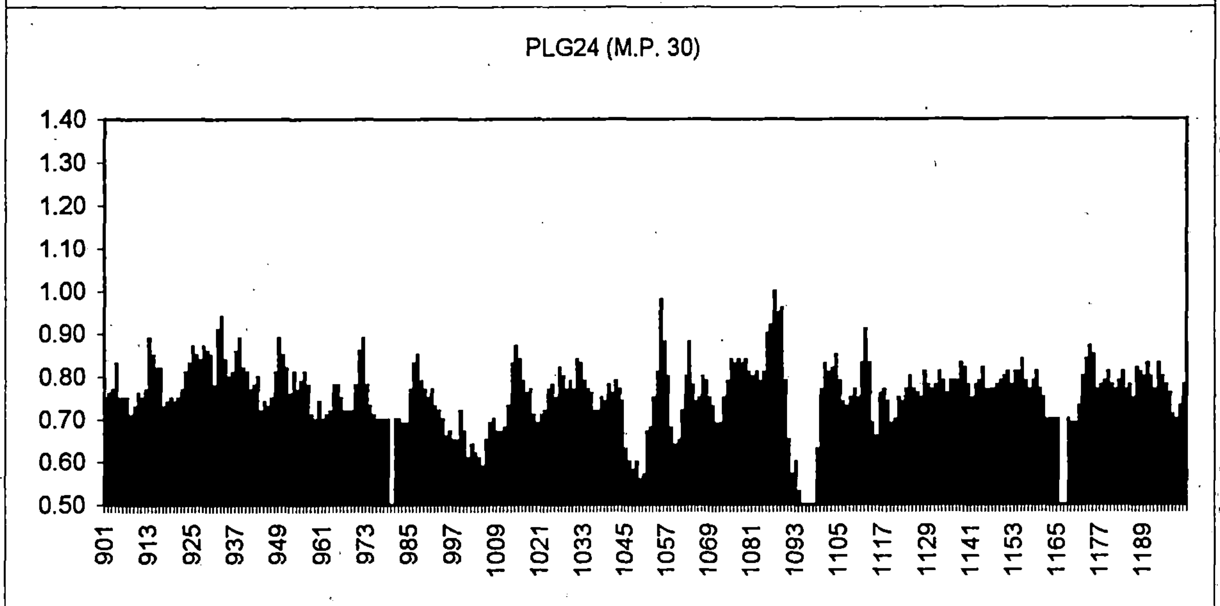
PLG24 (M.P. 30)
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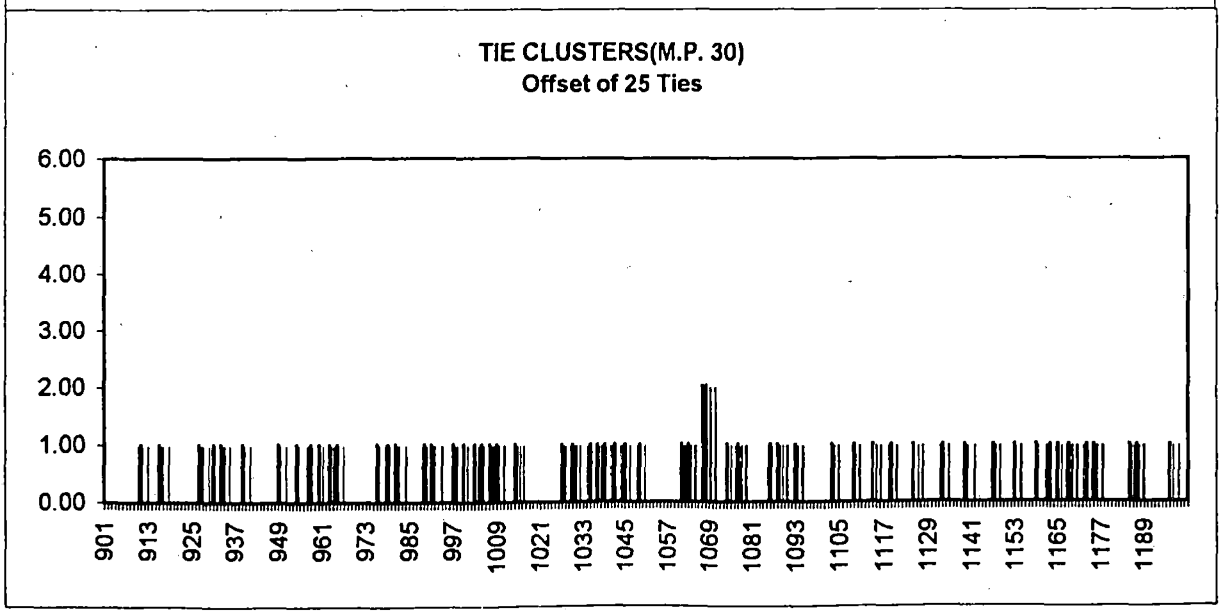
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
901 913 925 937 949 961 973 985 997 1009 1021 1033 1045 1057 1069 1081 1093 1105 1117 1129 1141 1153 1165 1177 1189


TIE CLUSTERS(M.P. 30)
Offset of 25 Ties
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4.00
3.00
2.00
1.00
0.00
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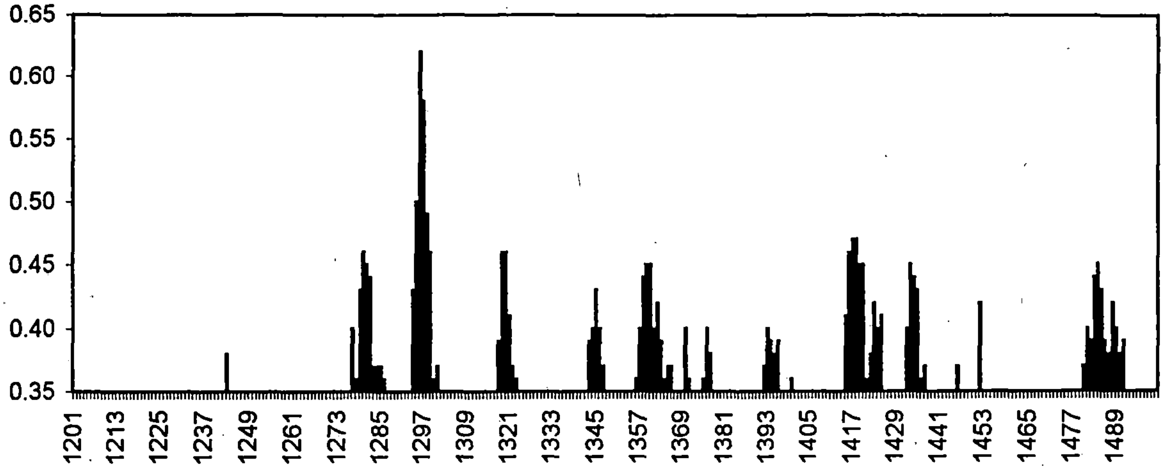
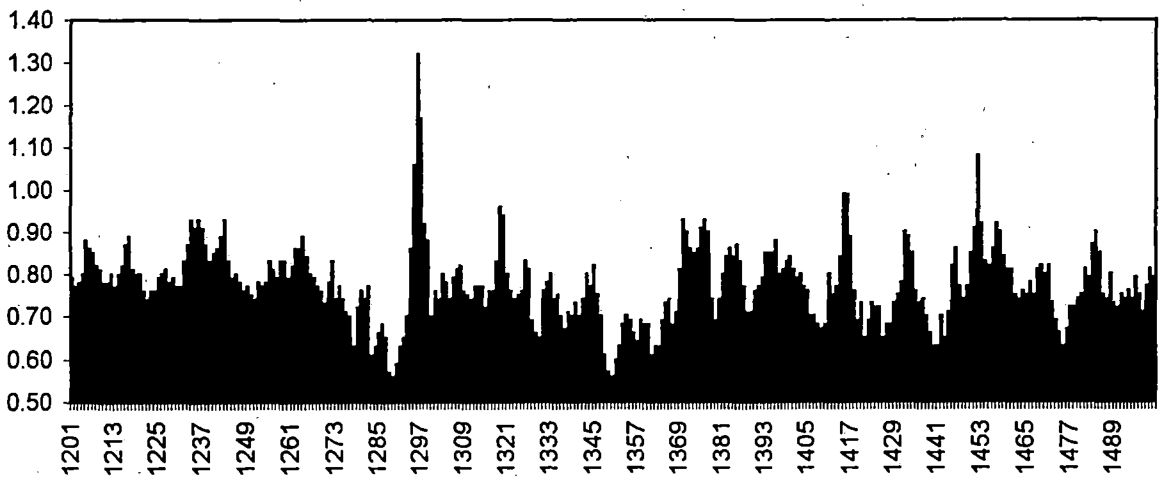
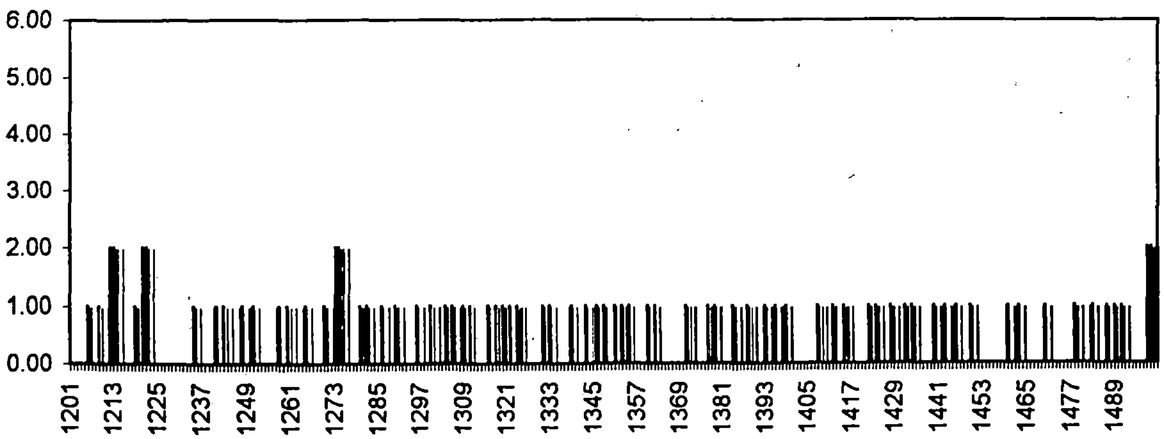
GWR (M.P. 30)

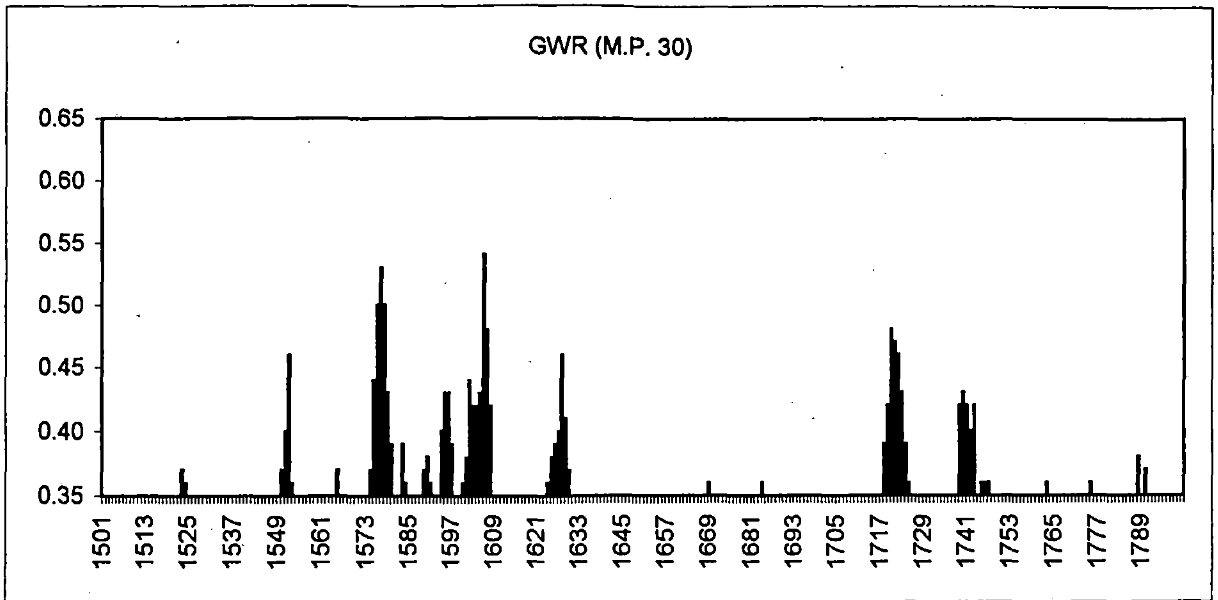


PLG24 (M.P. 30)



TIE CLUSTERS(M.P. 30)
Offset of 25 Ties




GWR (M.P. 30)
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0.60
0.55
0.50
0.45
0.40
0.35
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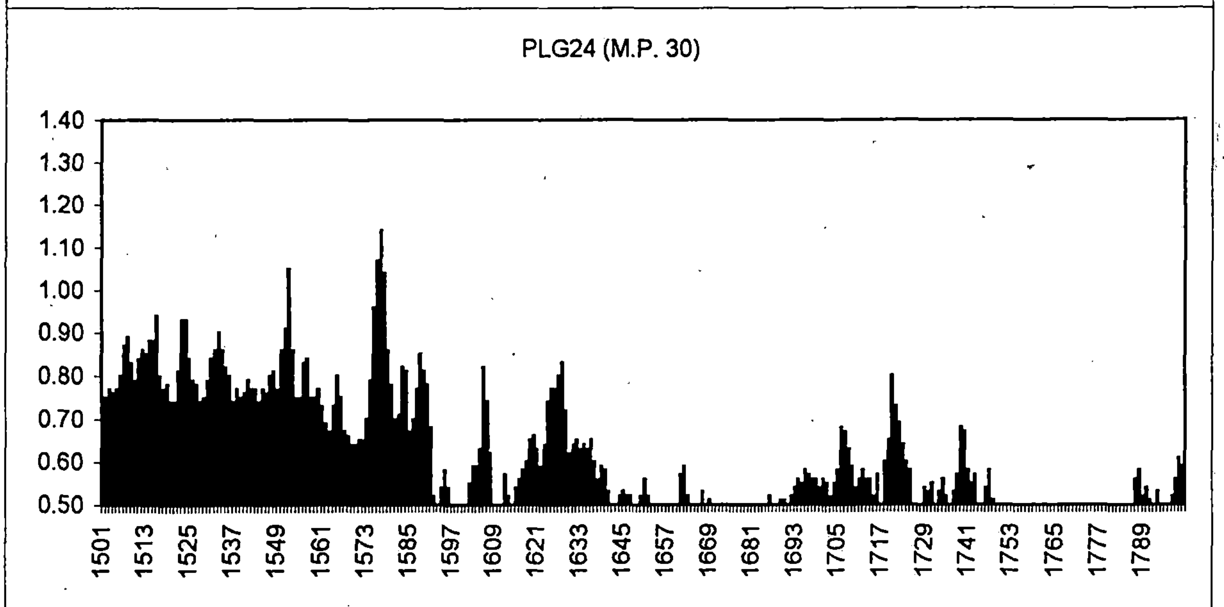
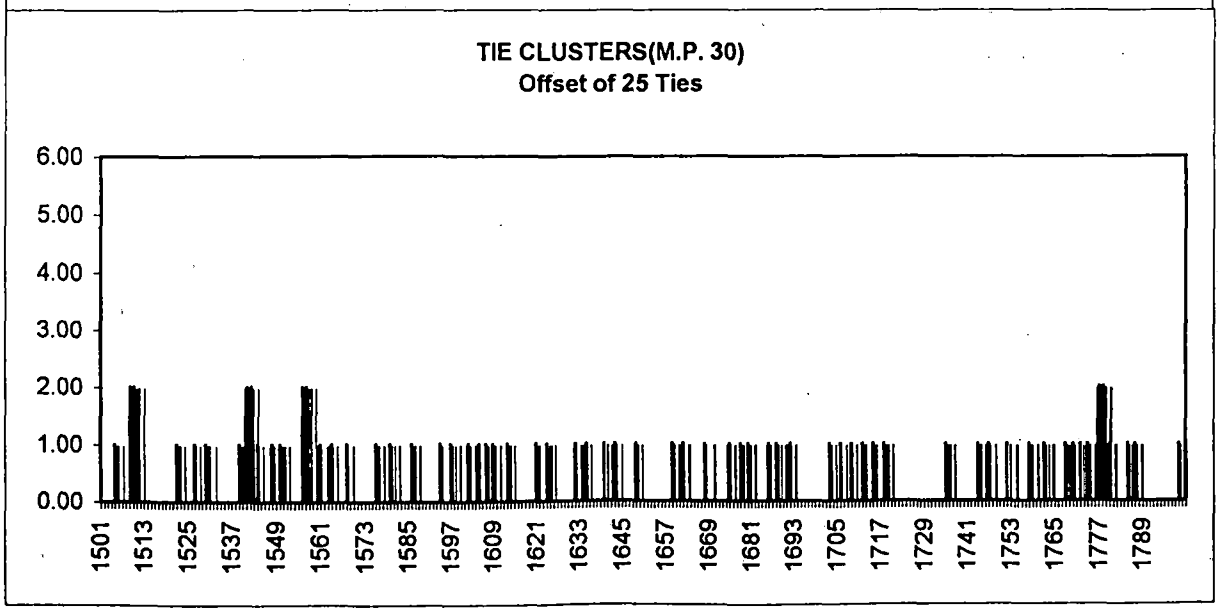

PLG24 (M.P. 30)
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
1501 1513 1525 1537 1549 1561 1573 1585 1597 1609 1621 1633 1645 1657 1669 1681 1693 1705 1717 1729 1741 1753 1765 1777 1789


TIE CLUSTERS(M.P. 30)
Offset of 25 Ties
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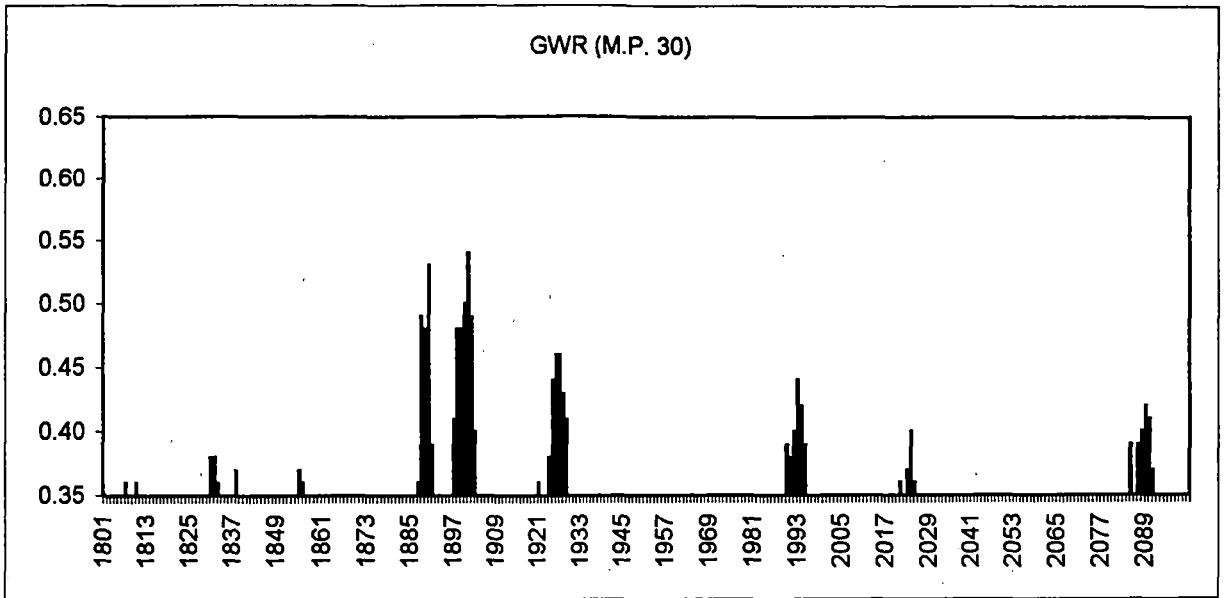
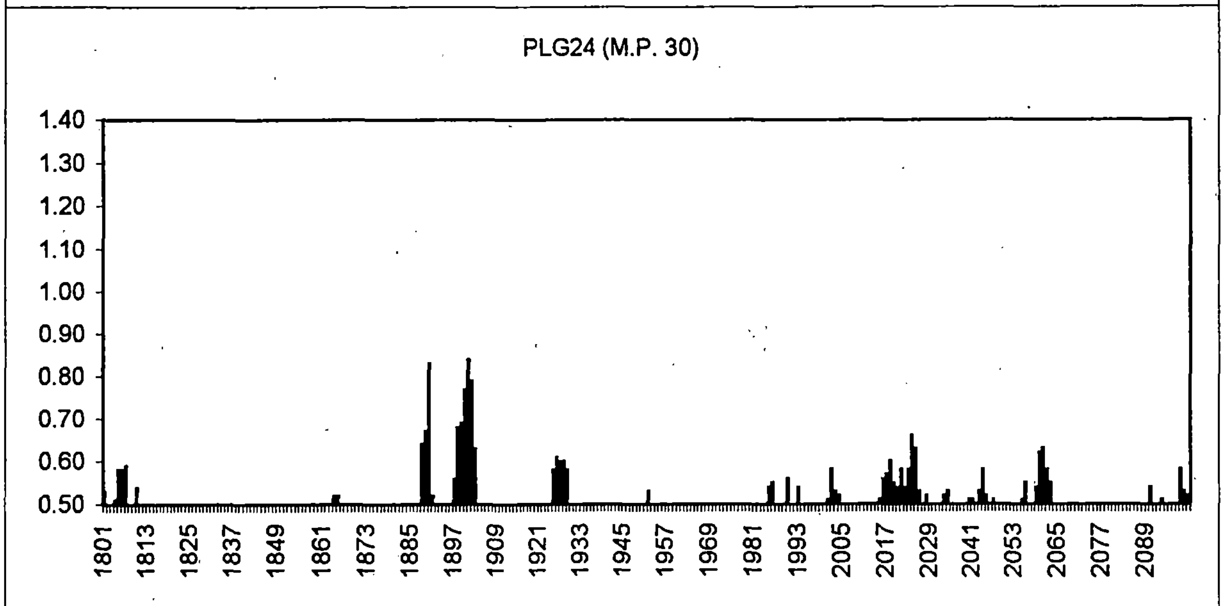
5.00
4.00
3.00
2.00
1.00
0.00
1501 1513 1525 1537 1549 1561 1573 1585 1597 1609 1621 1633 1645 1657 1669 1681 1693 1705 1717 1729 1741 1753 1765 1777 1789


GWR (M.P. 30)
0.65
0.60
0.55
0.50
0.45
0.40
0.35
1801
1813
1825
1837
1849
1861
1873
1885
1897
1909
1921
1933
1945
1957
1969
1981
1993
2005
2017
2029
2041
2053
2065
2077
2089


PLG24 (M.P. 30)
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
1801
1813
1825
1837
1849
1861
1873
1885
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1945
1957
1969
1981
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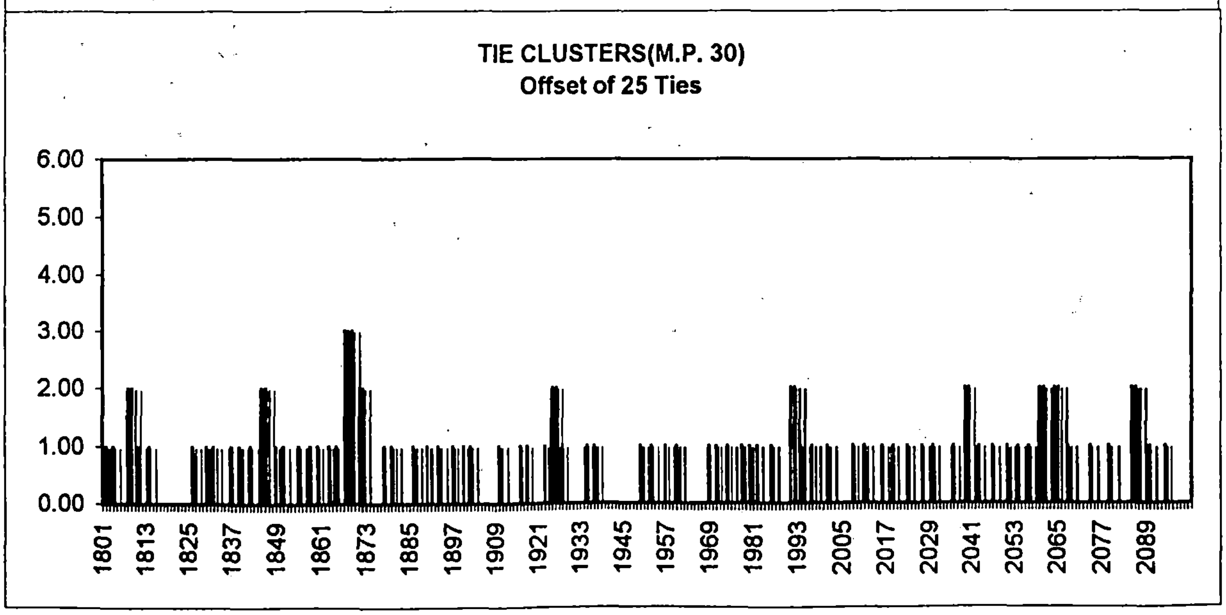
TIE CLUSTERS(M.P. 30)
Offset of 25 Ties
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5.00
4.00
3.00
2.00
1.00
0.00
1801
1813
1825
1837
1849
1861
1873
1885
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1981
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2029
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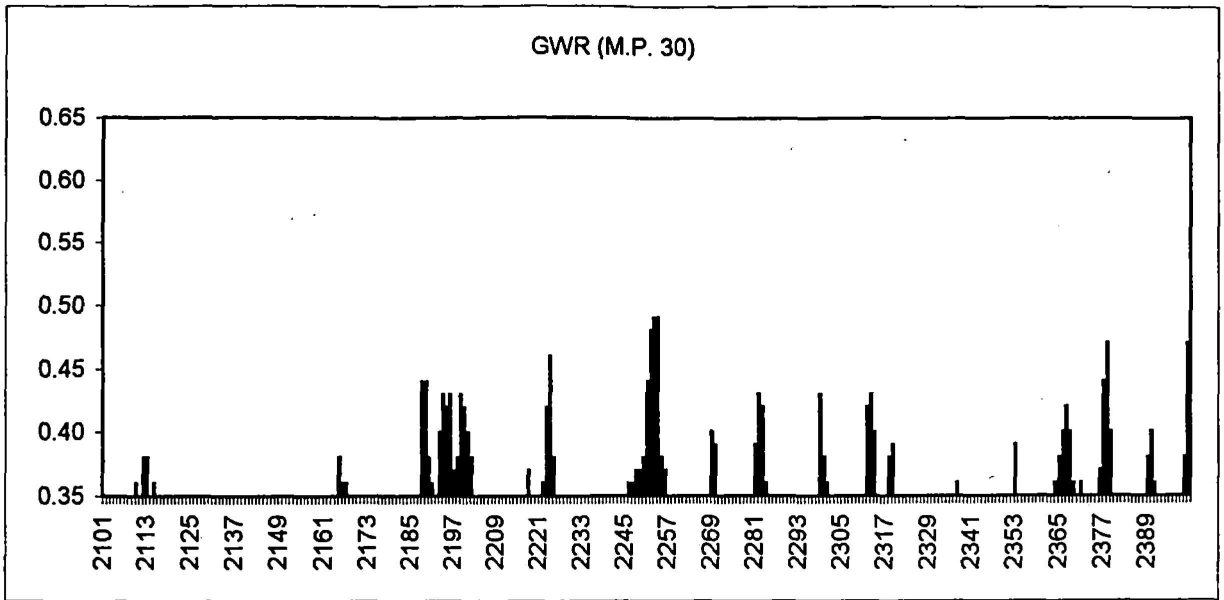
2065
2077
2089


GWR (M.P. 30)
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0.50
0.45
0.40
0.35
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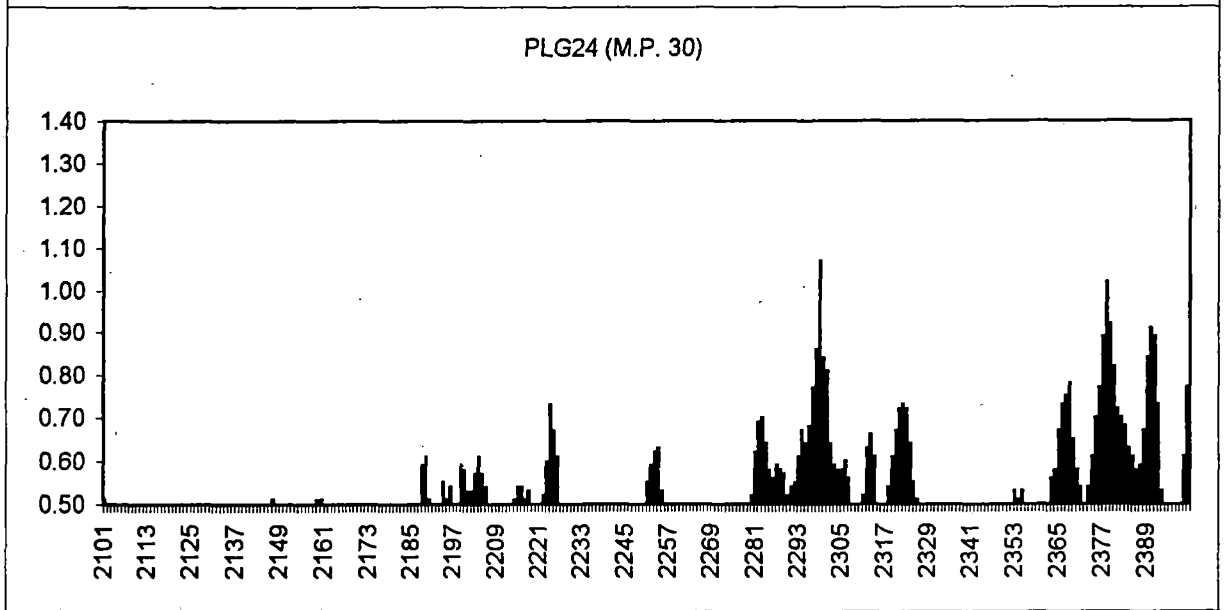
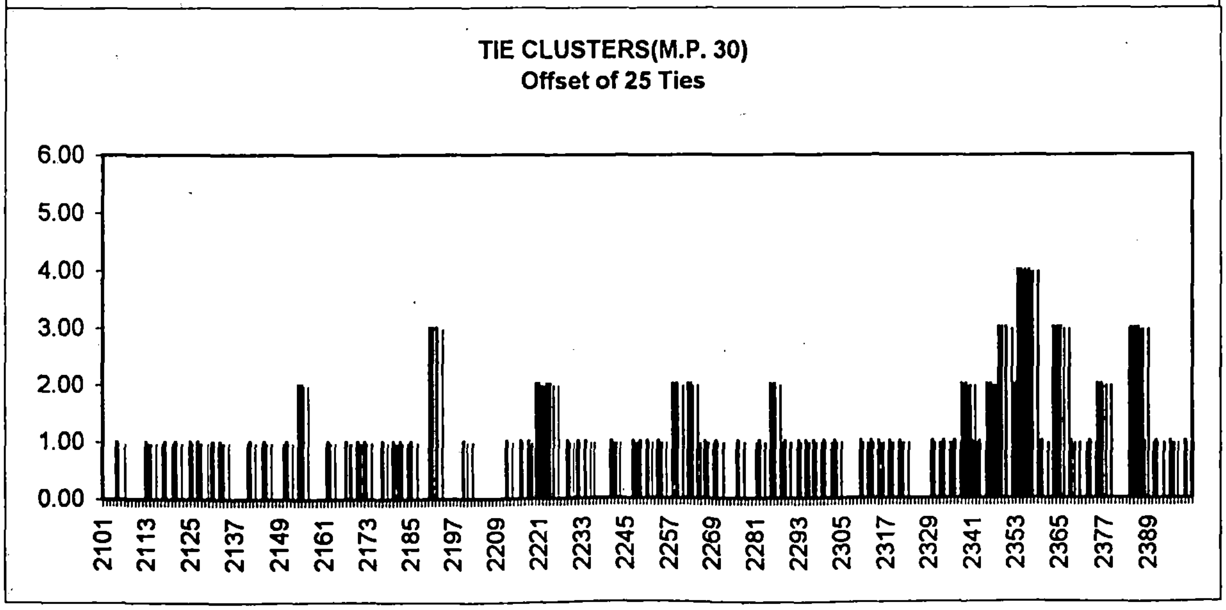

PLG24 (M.P. 30)
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
2101 2113 2125 2137 2149 2161 2173 2185 2197 2209 2221 2233 2245 2257 2269 2281 2293 2305 2317 2329 2341 2353 2365 2377 2389


TIE CLUSTERS(M.P. 30)
Offset of 25 Ties
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4.00
3.00
2.00
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0.00
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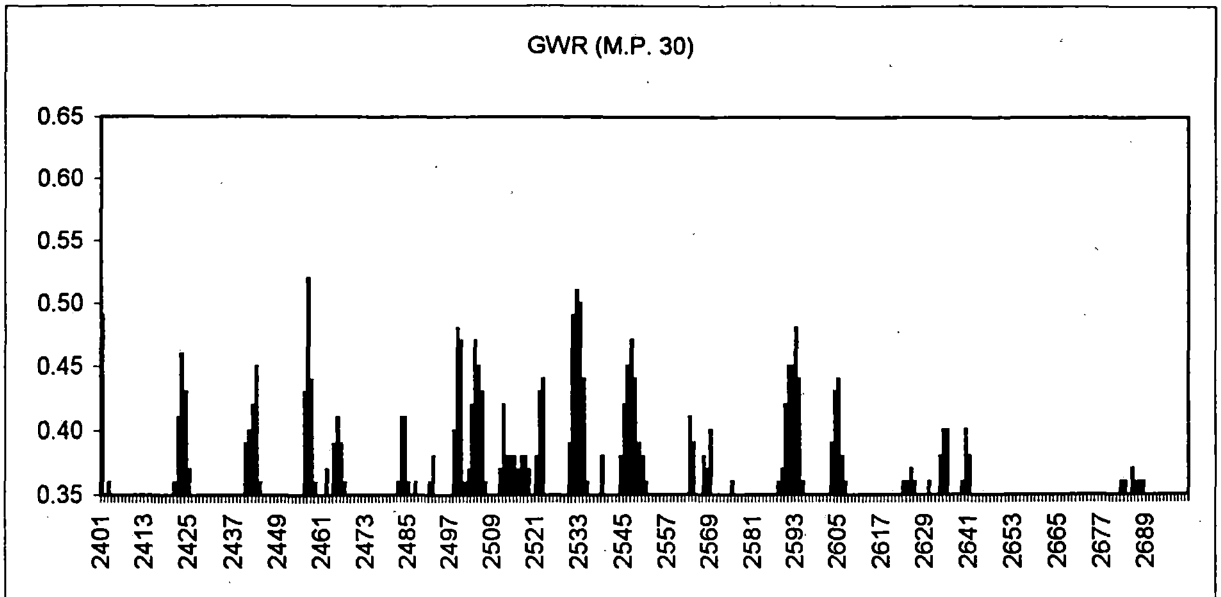
GWR (M.P. 30)
0.65
0.60
0.55
0.50
0.45
0.40
0.35
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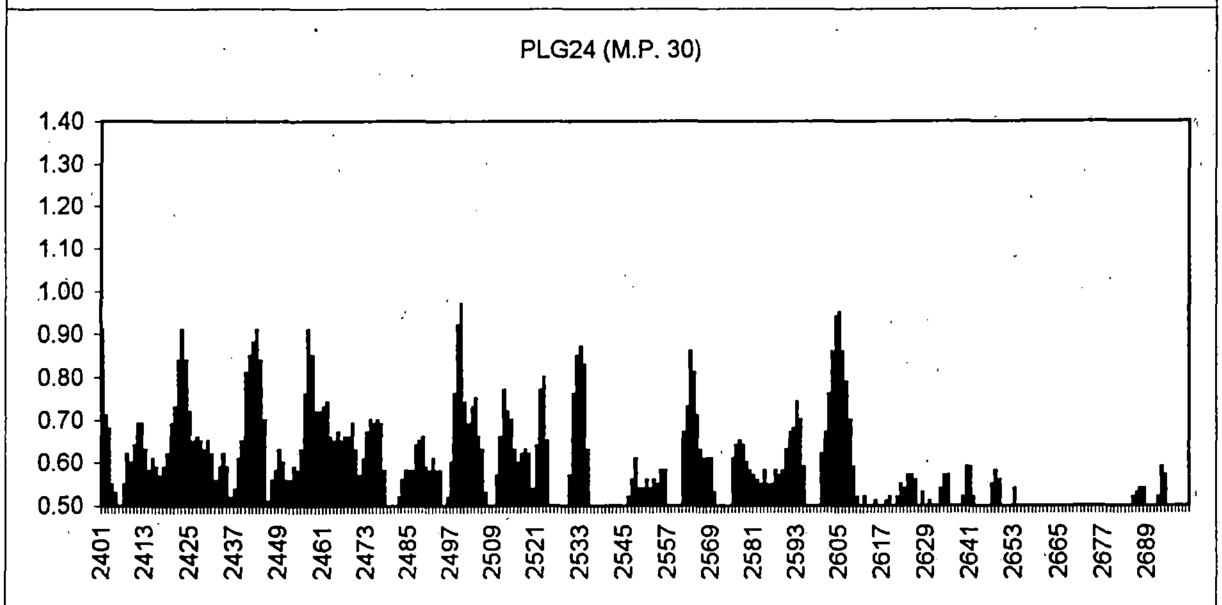
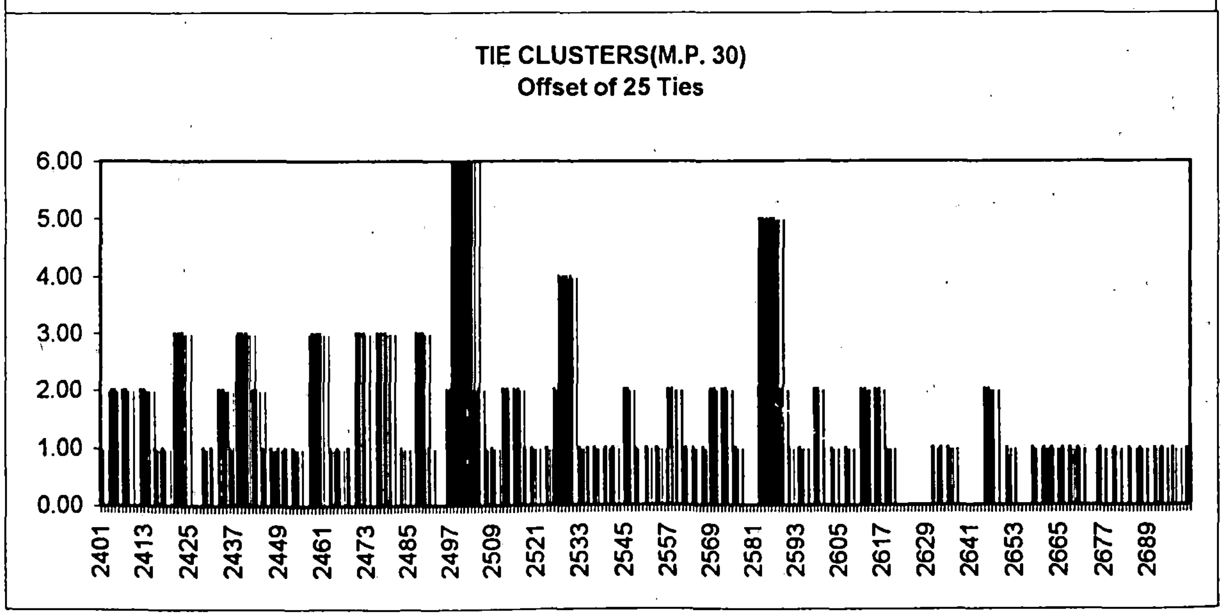

PLG24 (M.P. 30)
1.40
1.30
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
2401 2413 2425 2437 2449 2461 2473 2485 2497 2509 2521 2533 2545 2557 2569 2581 2593 2605 2617 2629 2641 2653 2665 2677 2689


TIE CLUSTERS(M.P. 30)
Offset of 25 Ties
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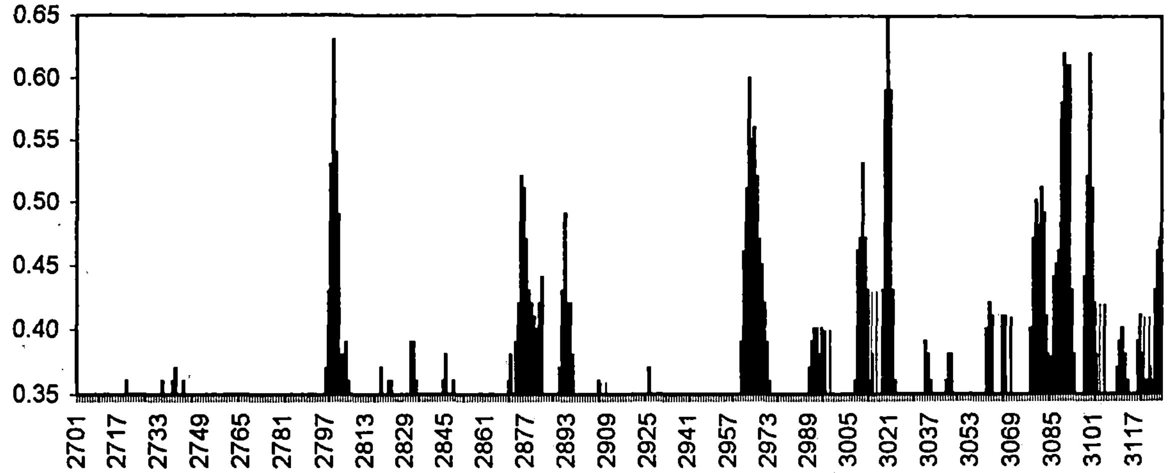
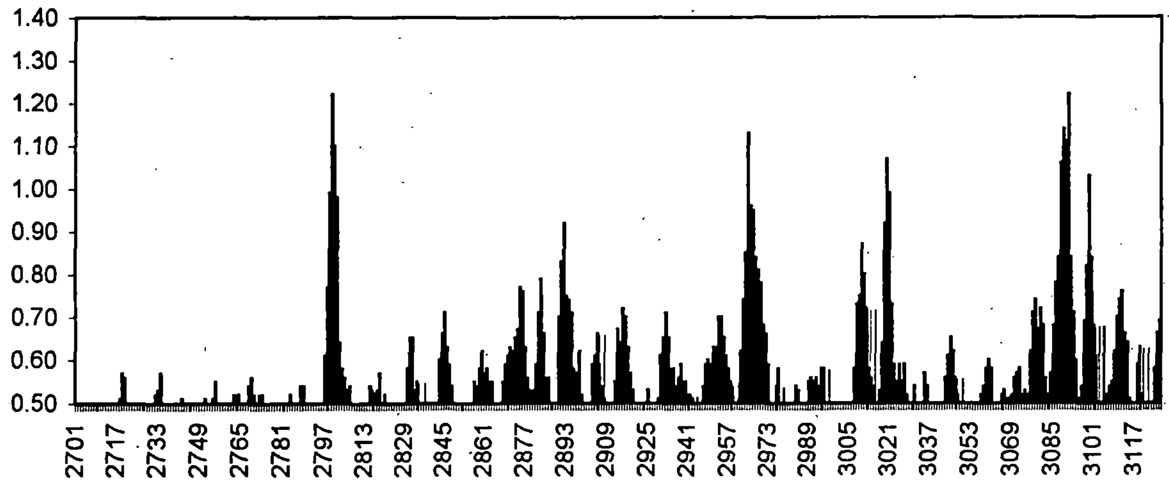
4.00
3.00
2.00
1.00
0.00
2401 2413 2425 2437 2449 2461 2473 2485 2497 2509 2521 2533 2545 2557 2569 2581 2593 2605 2617 2629 2641 2653 2665 2677 2689

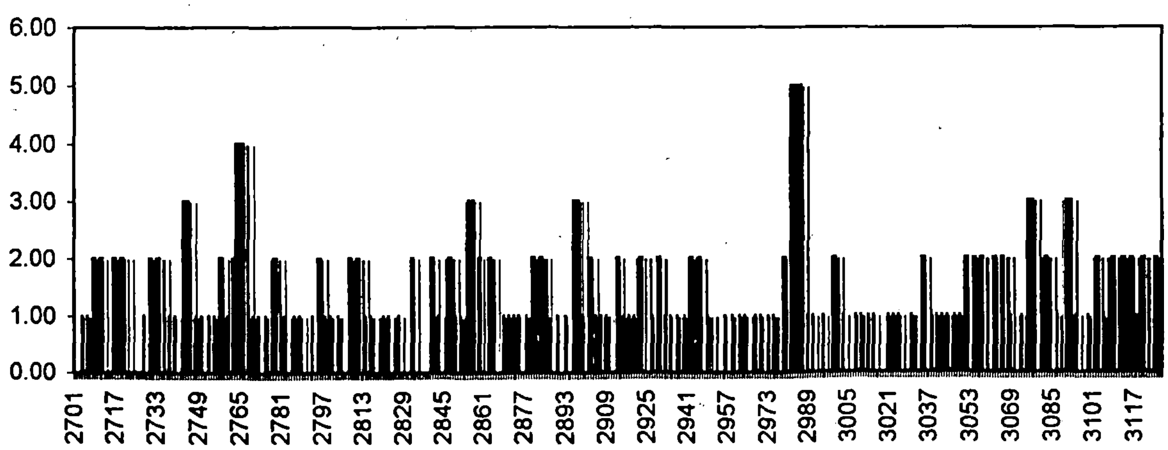
GWR (M.P. 30)



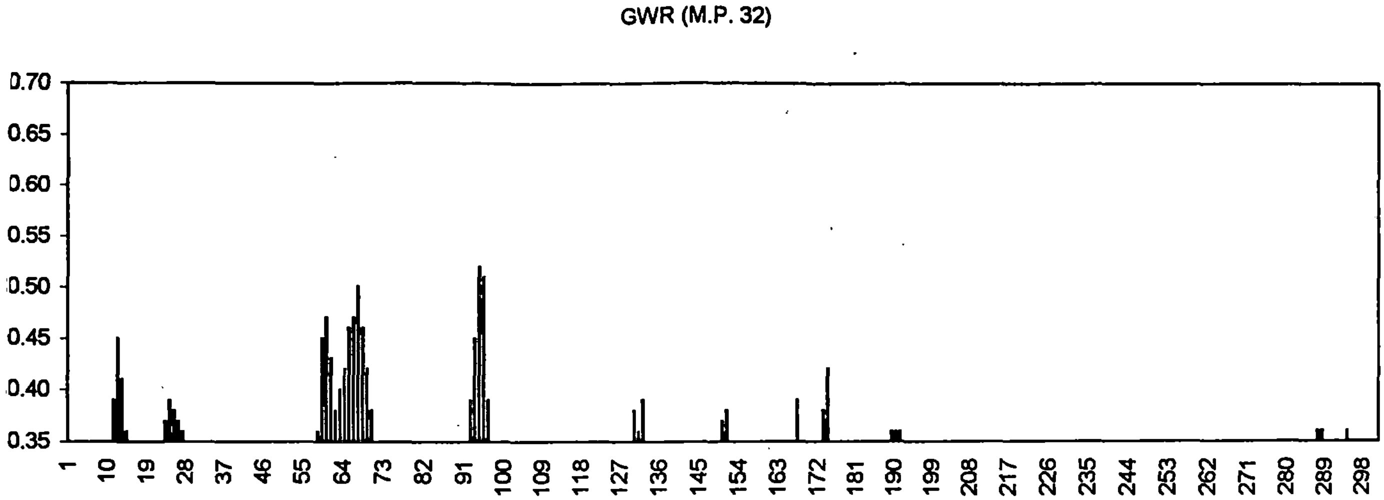
PLG24 (M.P. 30)



TIE CLUSTERS(M.P. 30)
Offset of 25 Ties



Appendix H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0.60
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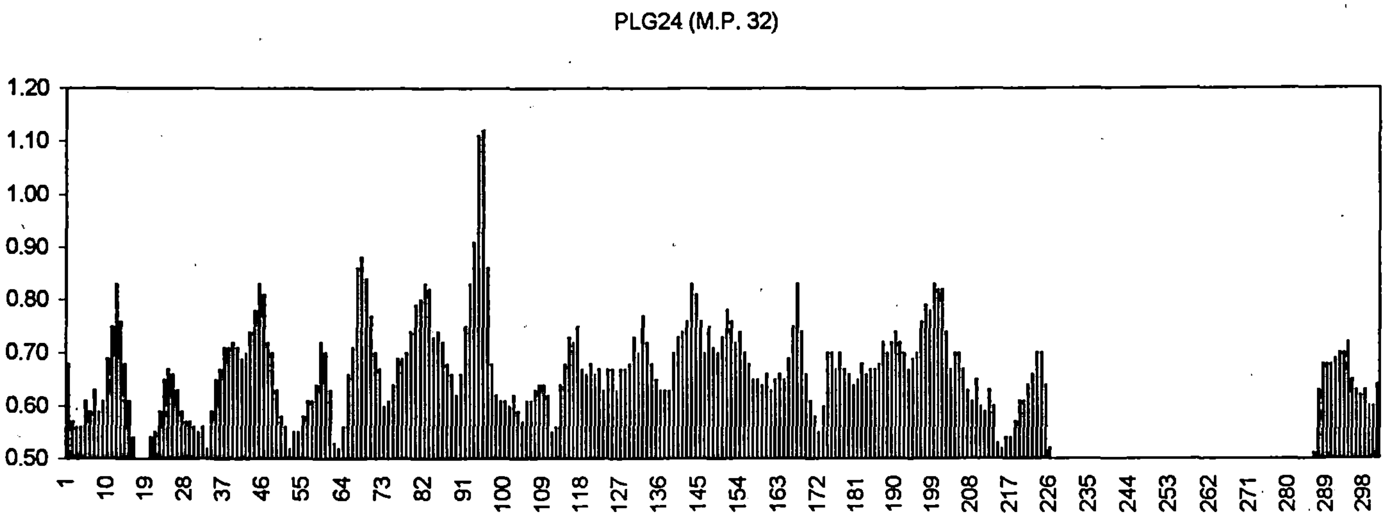
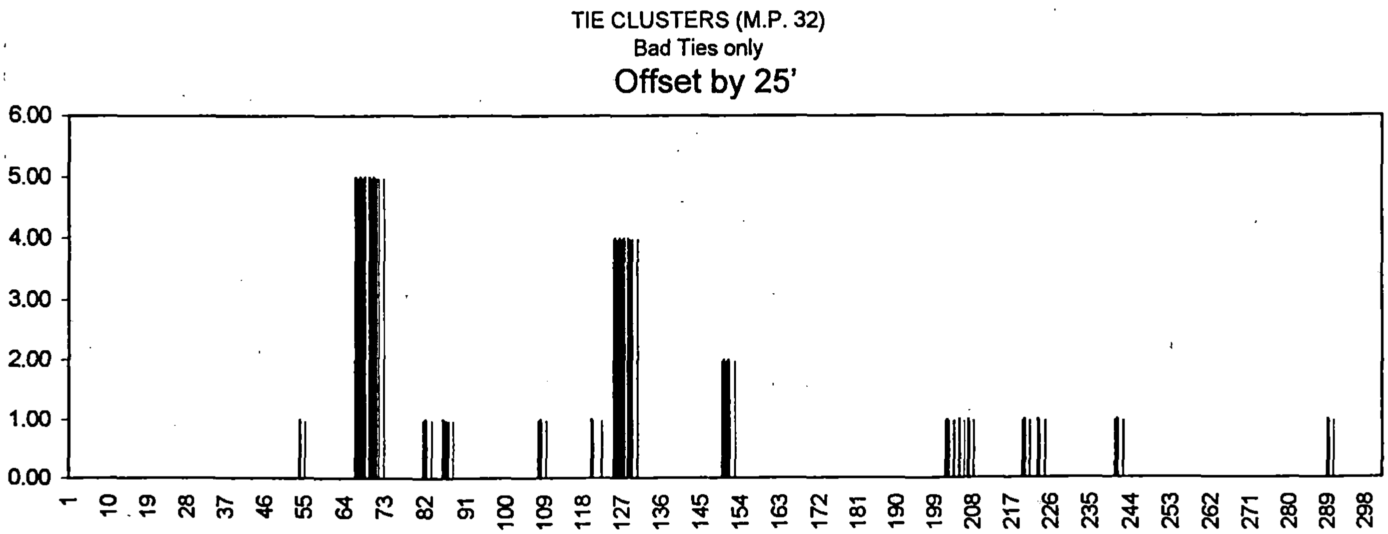

PLG24 (M.P. 32)
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145 154 163 172 181 190 199 208 217 226 235 244 253 262 271 280 289 298


TIE CLUSTERS (M.P. 32)
Bad Ties only
Offset by 25'
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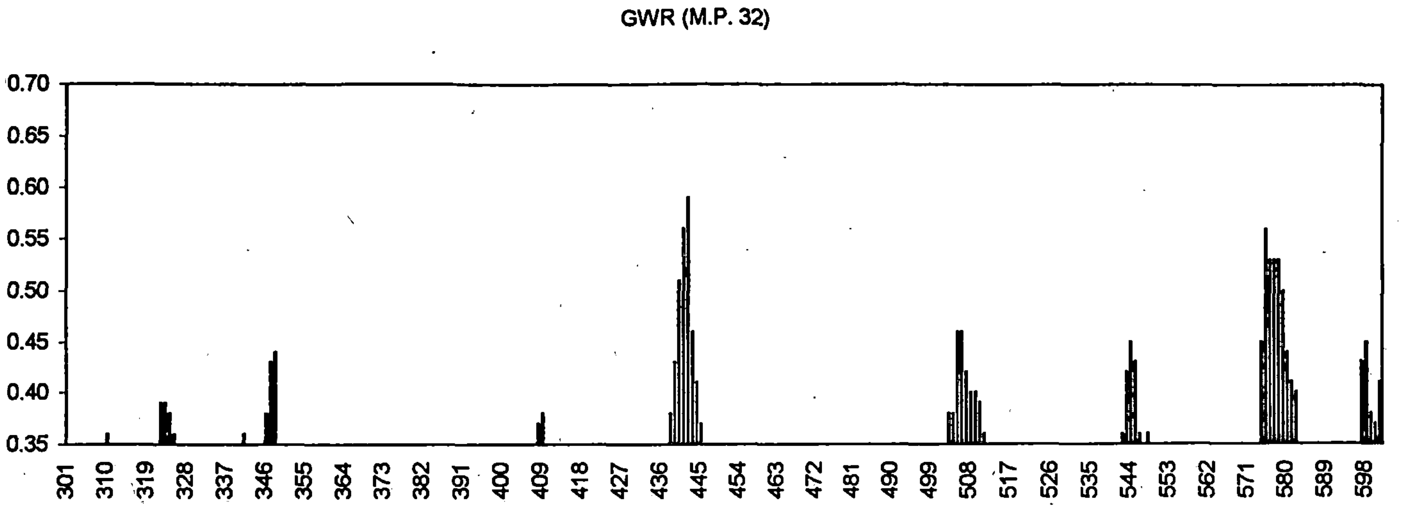
3.00
2.00
1.00
0.00
1 10 19 28 37 46 55 64 73 82 91 100 109 118 127 136 145 154 163 172 181 190 199 208 217 226 235 244 253 262 271 280 289 298


GWR (M.P. 32)
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0.65
0.60
0.55
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0.40
0.35
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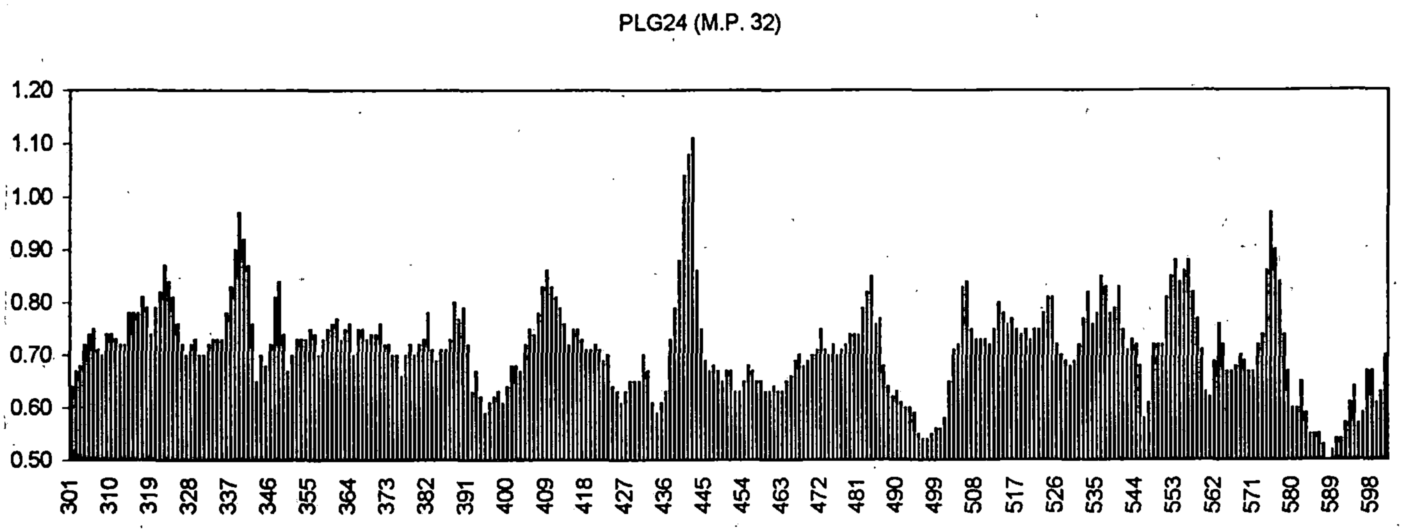
PLG24 (M.P. 32)
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1.10
1.00
0.90
0.80
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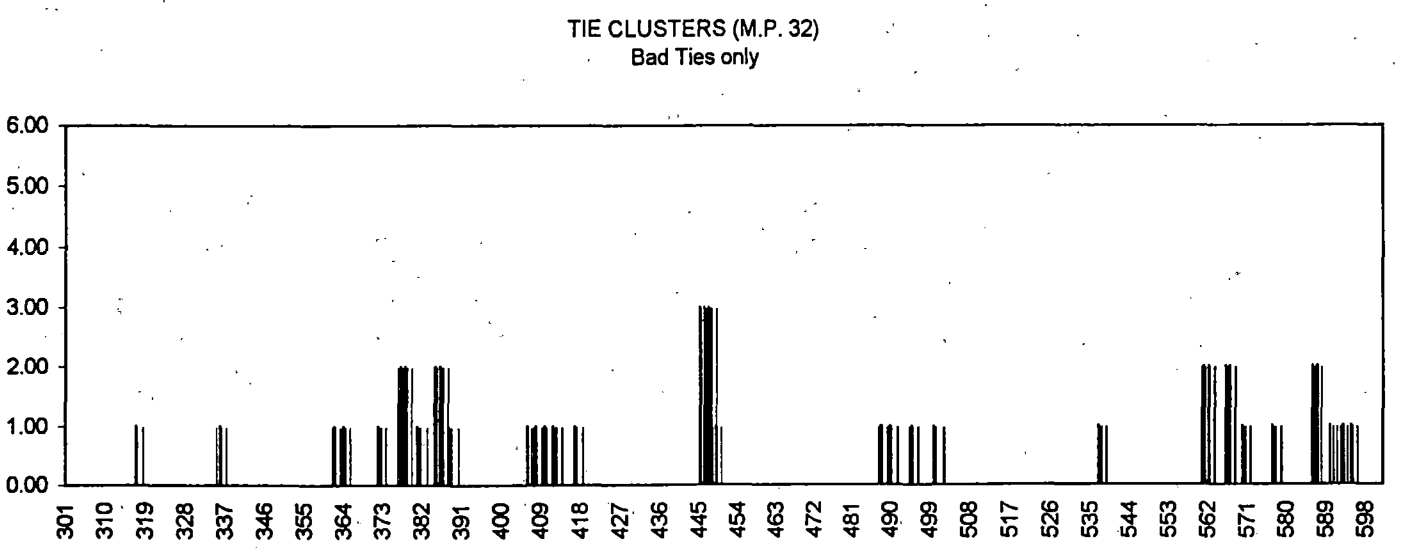
0.60
0.50
301 310 319 328 337 346 355 364 373 382 391 400 409 418 427 436 445 454 463 472 481 490 499 508 517 526 535 544 553 562 571 580 589 598


TIE CLUSTERS (M.P. 32)
Bad Ties only
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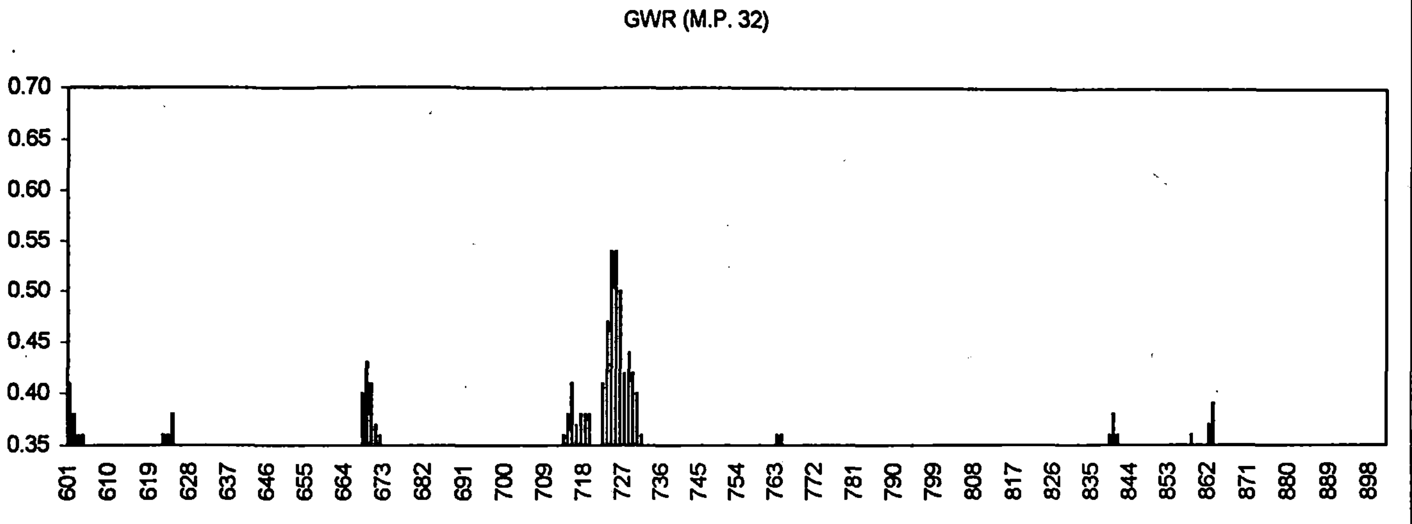
5.00
4.00
3.00
2.00
1.00
0.00
301 310 319 328 337 346 355 364 373 382 391 400 409 418 427 436 445 454 463 472 481 490 499 508 517 526 535 544 553 562 571 580 589 598


GWR (M.P. 32)
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
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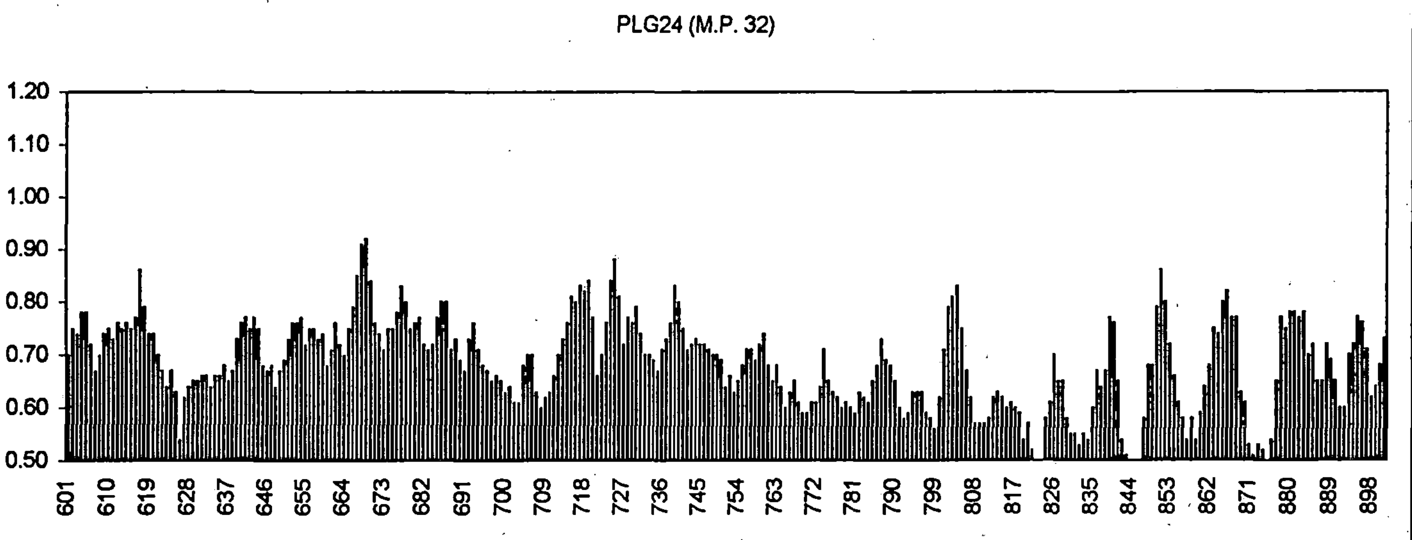
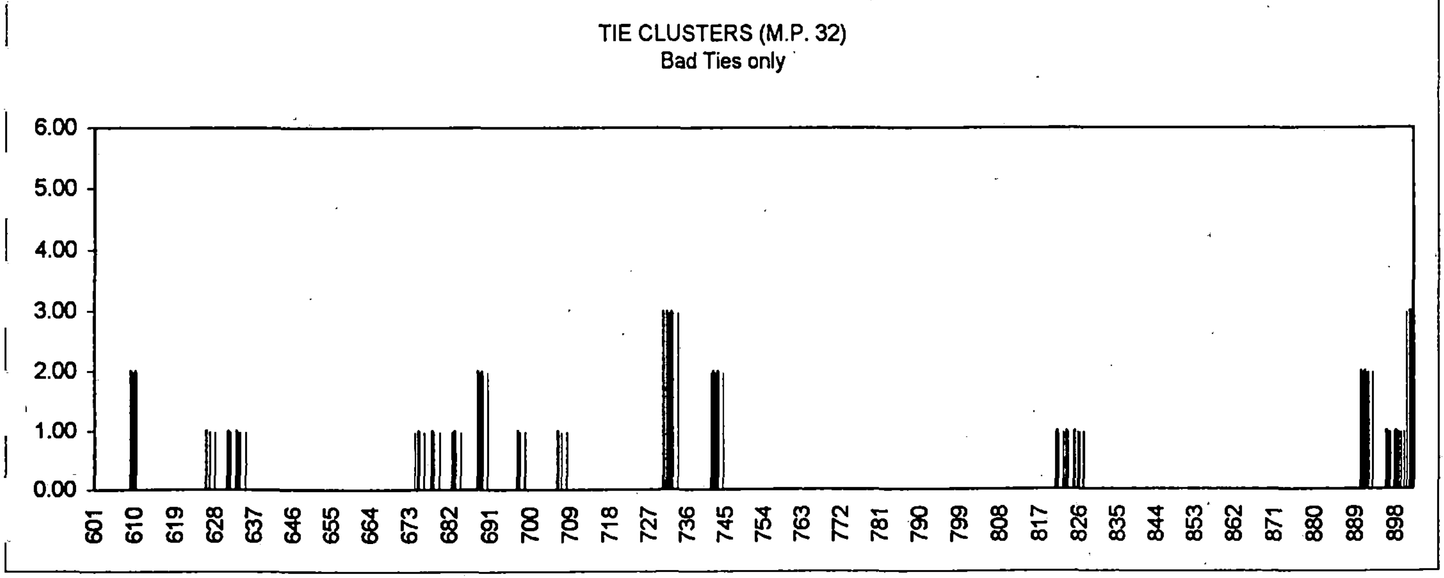

PLG24 (M.P. 32)
1.20
1.10
1.00
0.90
0.80
0.70
0.60
0.50
601 610 619 628 637 646 655 664 673 682 691 700 709 718 727 736 745 754 763 772 781 790 799 808 817 826 835 844 853 862 871 880 889 898


TIE CLUSTERS (M.P. 32)
Bad Ties only
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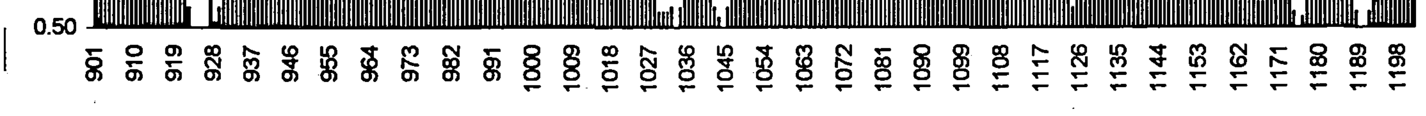
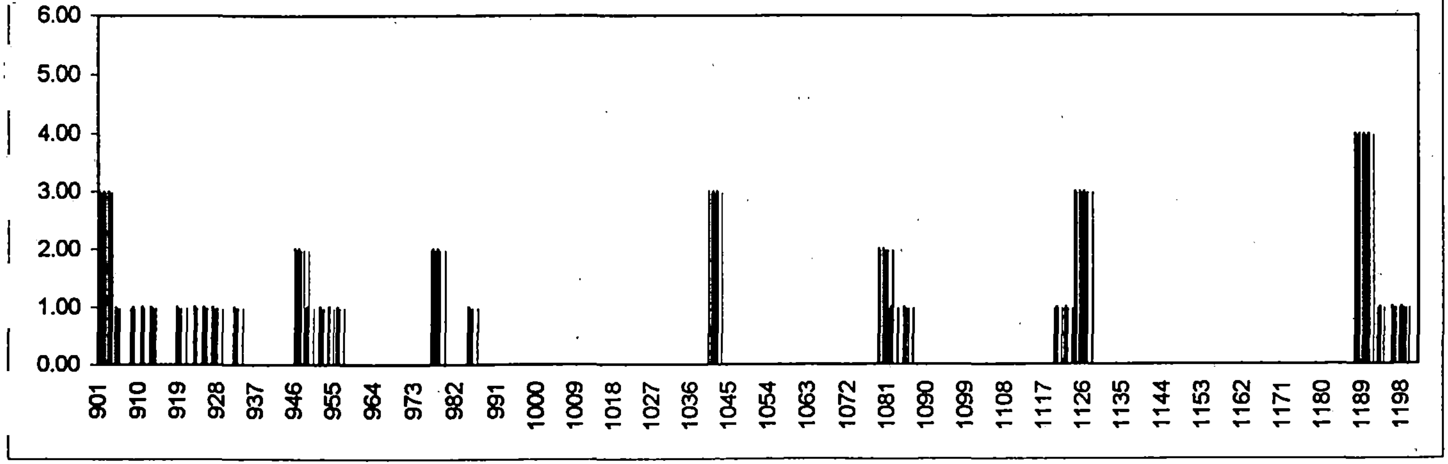
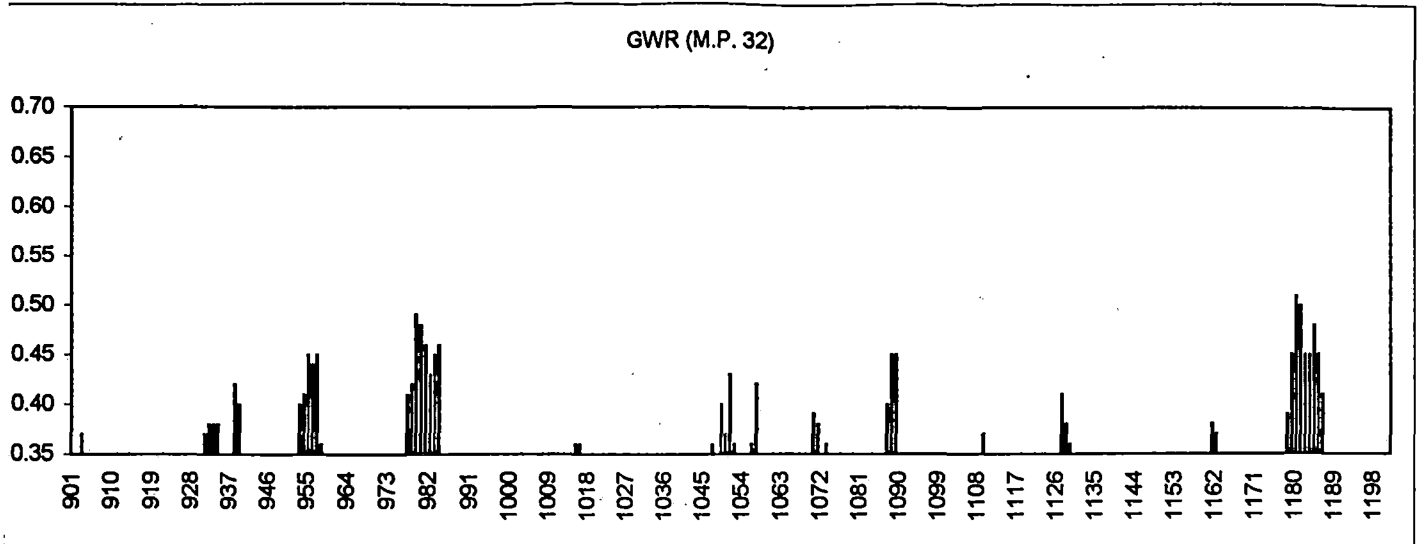
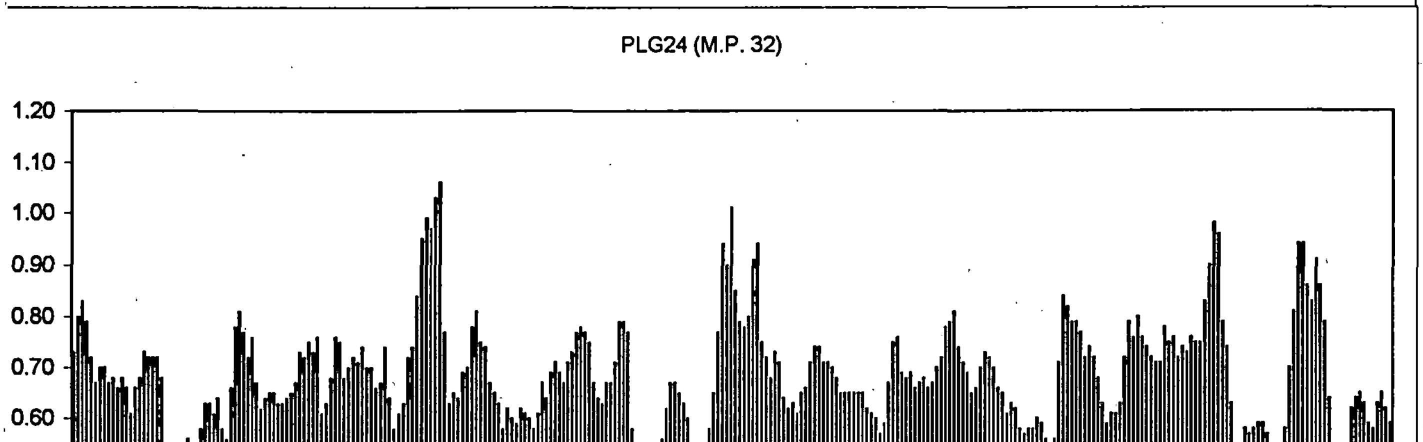
5.00
4.00
3.00
2.00
1.00
0.00
601 610 619 628 637 646 655 664 673 682 691 700 709 718 727 736 745 754 763 772 781 790 799 808 817 826 835 844 853 862 871 880 889 898



TIE CLUSTERS (M.P. 32)
Bad Ties only




GWR (M.P. 32)
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
901 910 919 928 937 946 955 964 973 982 991 1000 1009 1018 1027 1036 1045 1054 1063 1072 1081 1090 1099 1108 1117 1126 1135 1144 1153 1162 1171 1180 1189 1198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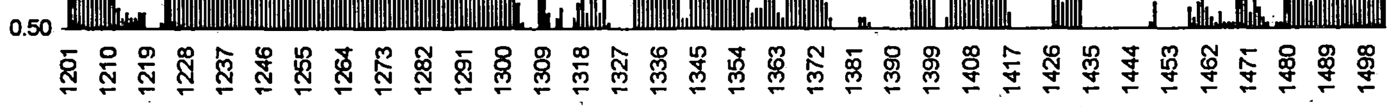
1.00
0.90
0.80
0.70
0.60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1228
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1300
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1327
1336
1345
1354
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1453
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1480
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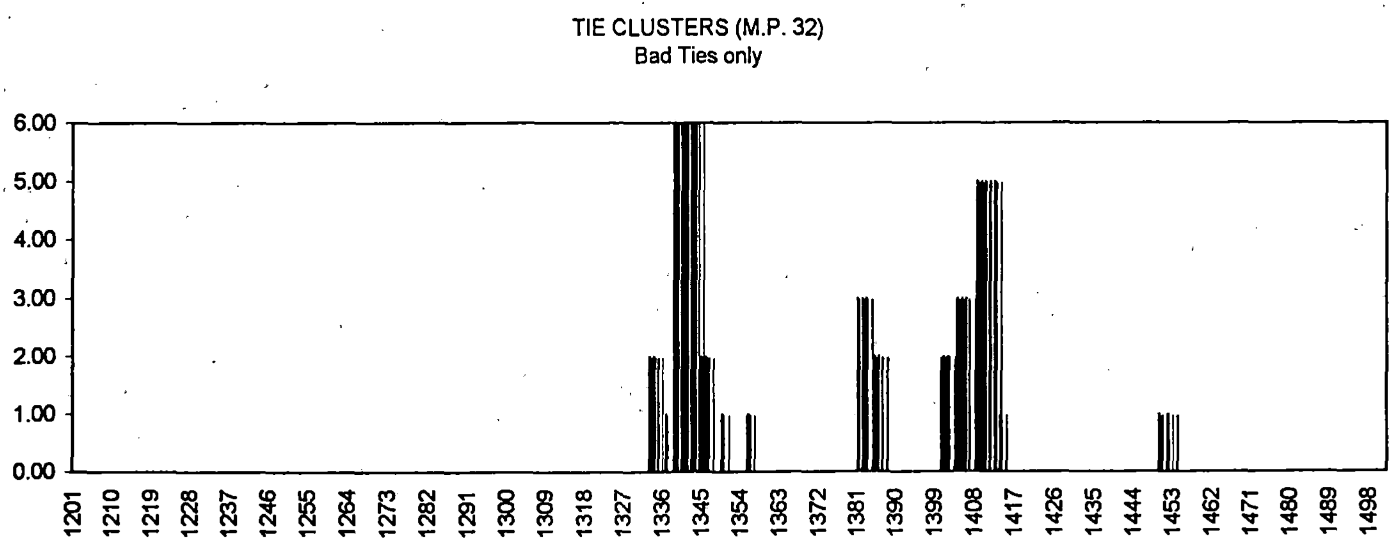
1498


TIE CLUSTERS (M.P. 32)
Bad Ties only
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4.00
3.00
2.00
1.00
0.00
1201
1210
1219
1228
1237
1246
1255
1264
1273
1282
1291
1300
1309
1318
1327
1336
1345
1354
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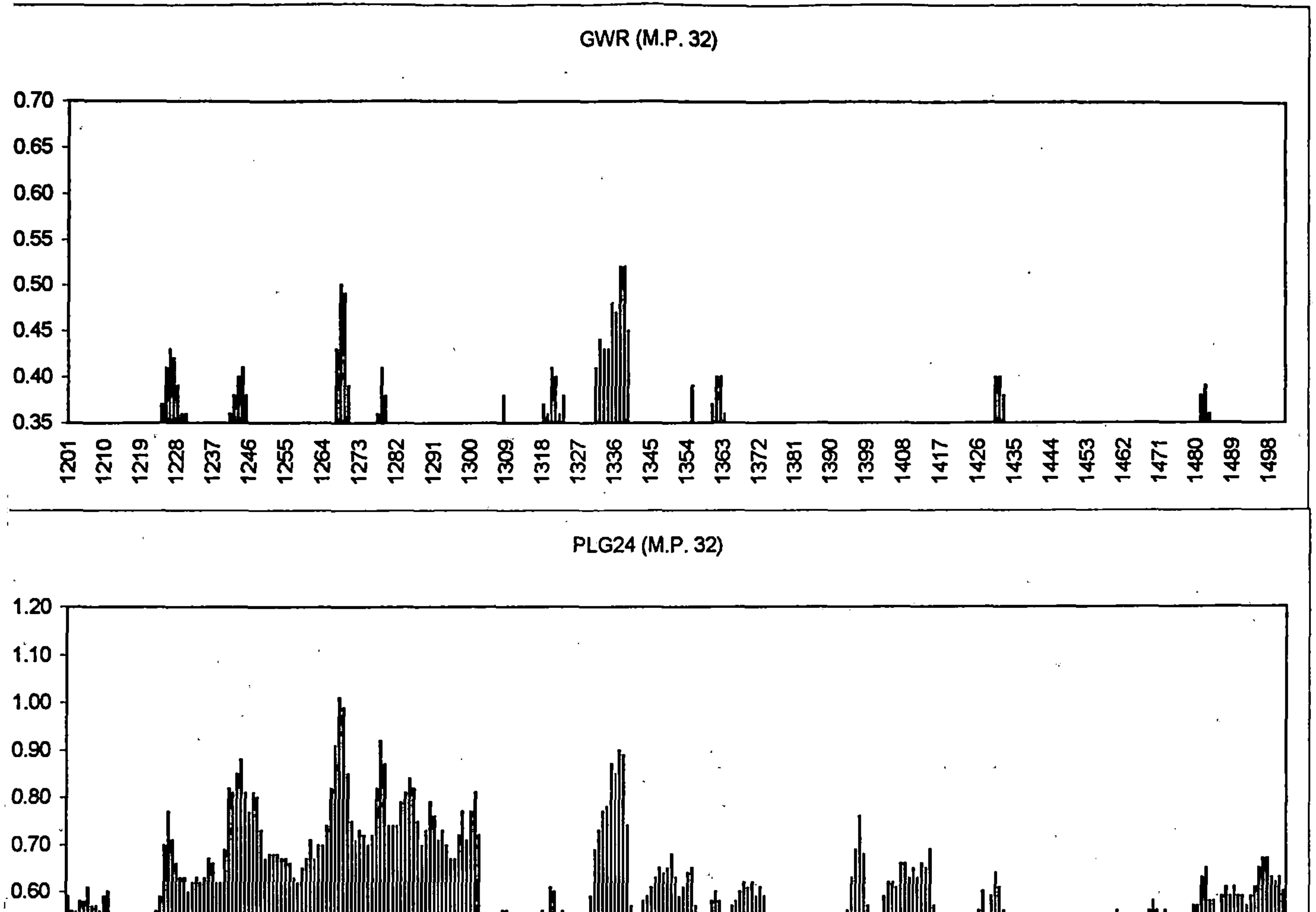
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1219
1228
1237
1246
1255
1264
1273
1282
1291
1300
1309
1318
1327
1336
1345
1354
1363
1372
1381
1390
1399
1408
1417
1426
1435
1444
1453
1462
1471
1480
1489
1498
PLG24 (M.P. 32)
1.20
1.10
1.00
0.90
0.80
0.70
0.60


0.50
1501
1510
1519
1528
1537
1546
1555
1564
1573
1582
1591
1600
1609
1618
1627
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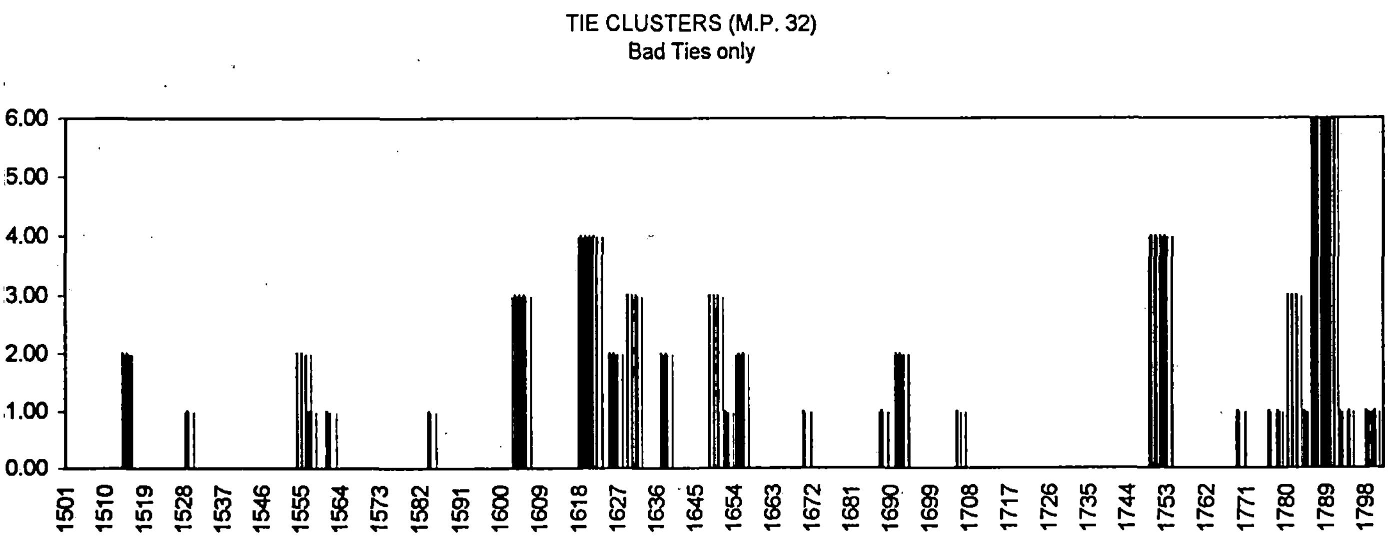
TIE CLUSTERS (M.P. 32)
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4.00
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1.00
0.00
1501
1510
1519
1528
1537
1546
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1564
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1600
1609
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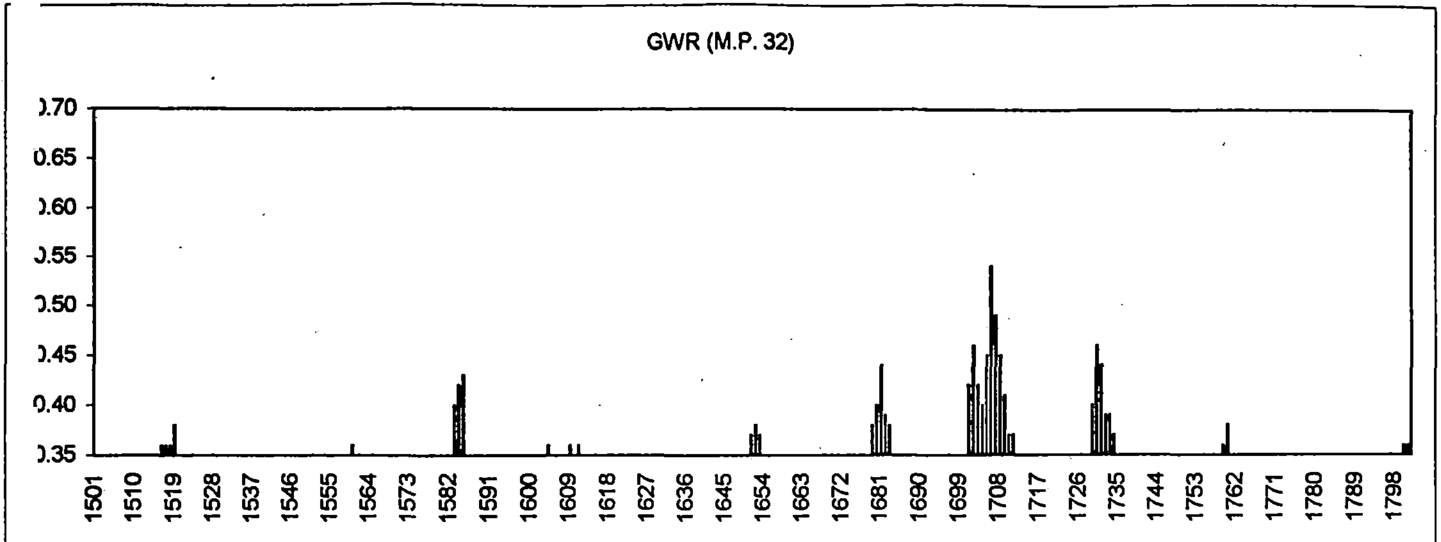
GWR (M.P. 32)
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0.65
0.60
0.55
0.50
0.45
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0.35
1501
1510
1519
1528
1537
1546
1555
1564
1573
1582
1591
1600
1609
1618
1627
1636
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1663
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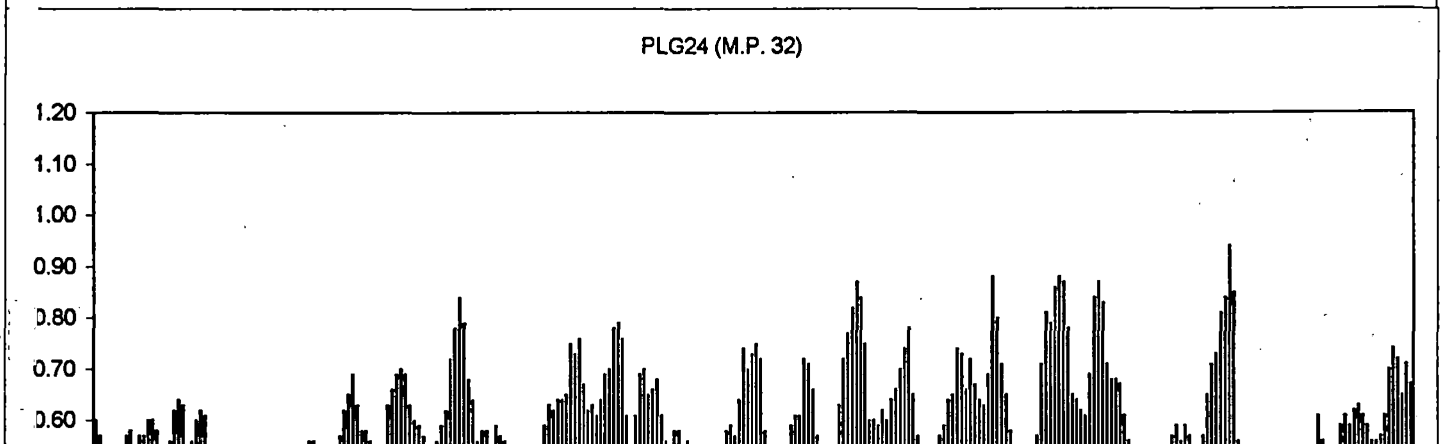
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1.00
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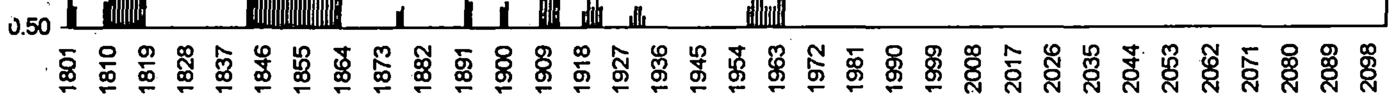

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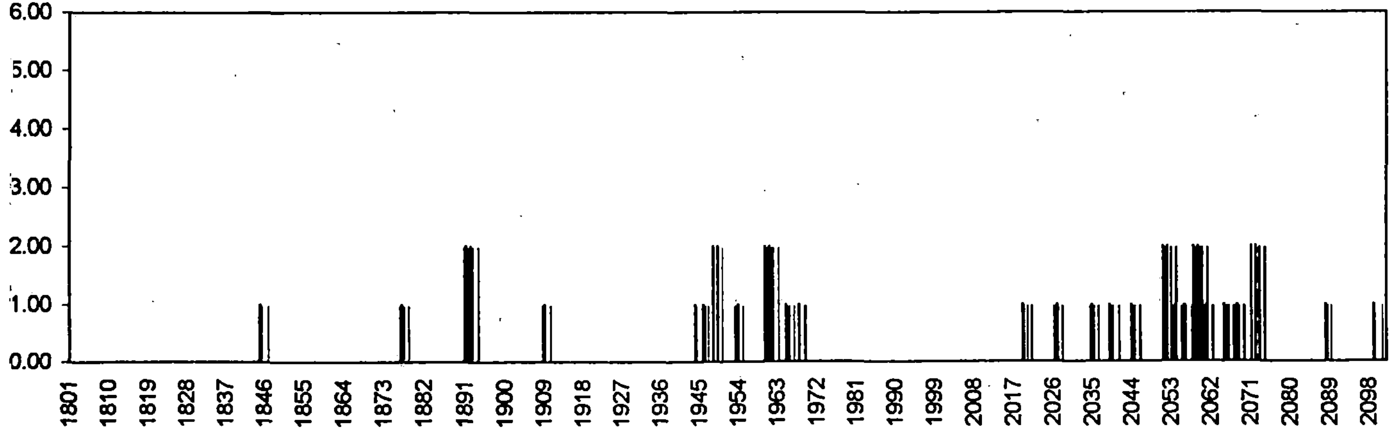
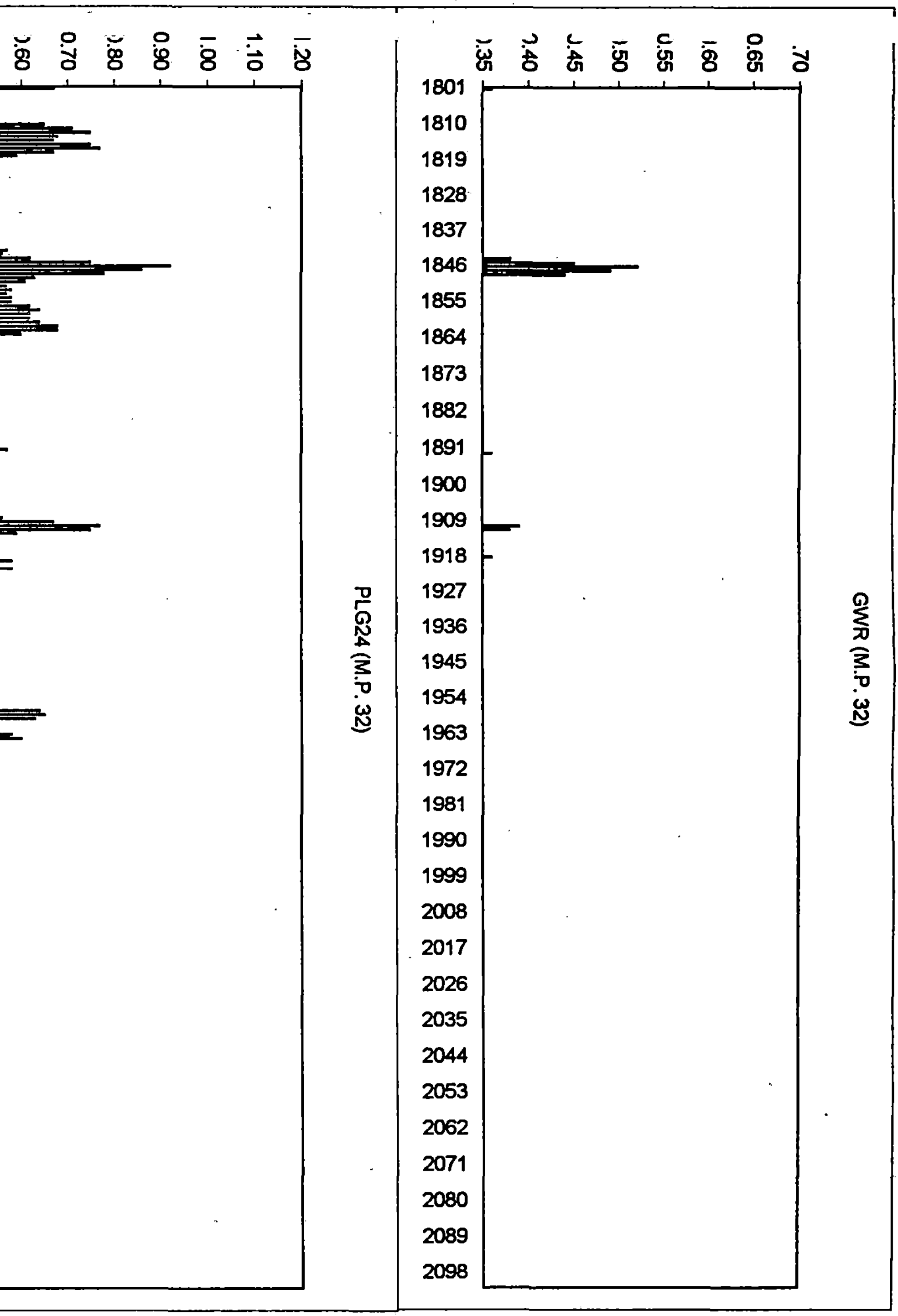
Bad Ties only





PLG24 (M.P. 32)
GWR (M.P. 32)
0.70
0.90
1.00
1.10
0.65
1801
1810
1819
1828
1837
1846
1855
1864
1873
1882
1891
1900
1909
1918
1927
1936
1945
1954
1963
1972
1981
1990
1999
2008
2017
2026
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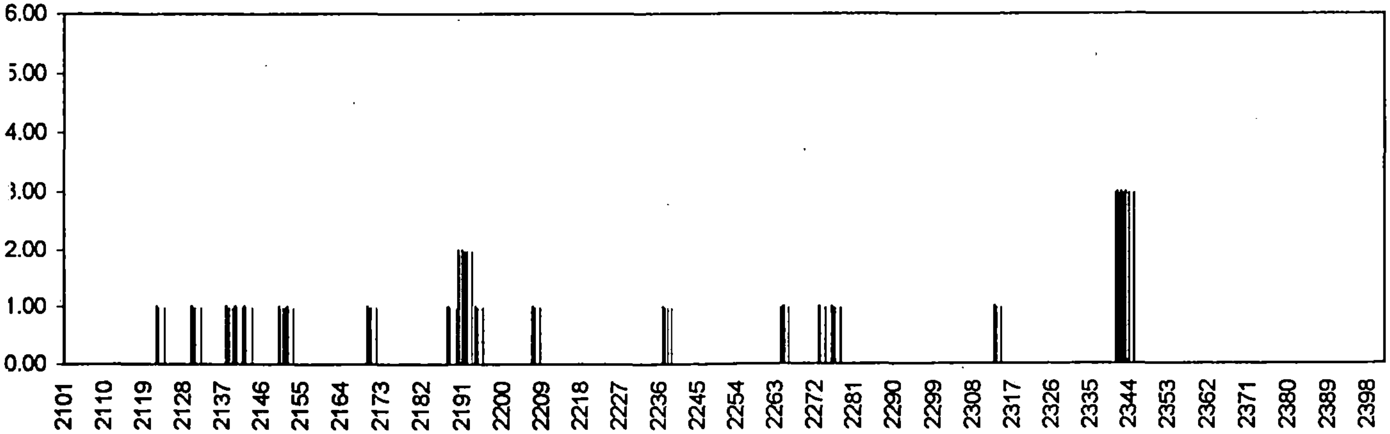
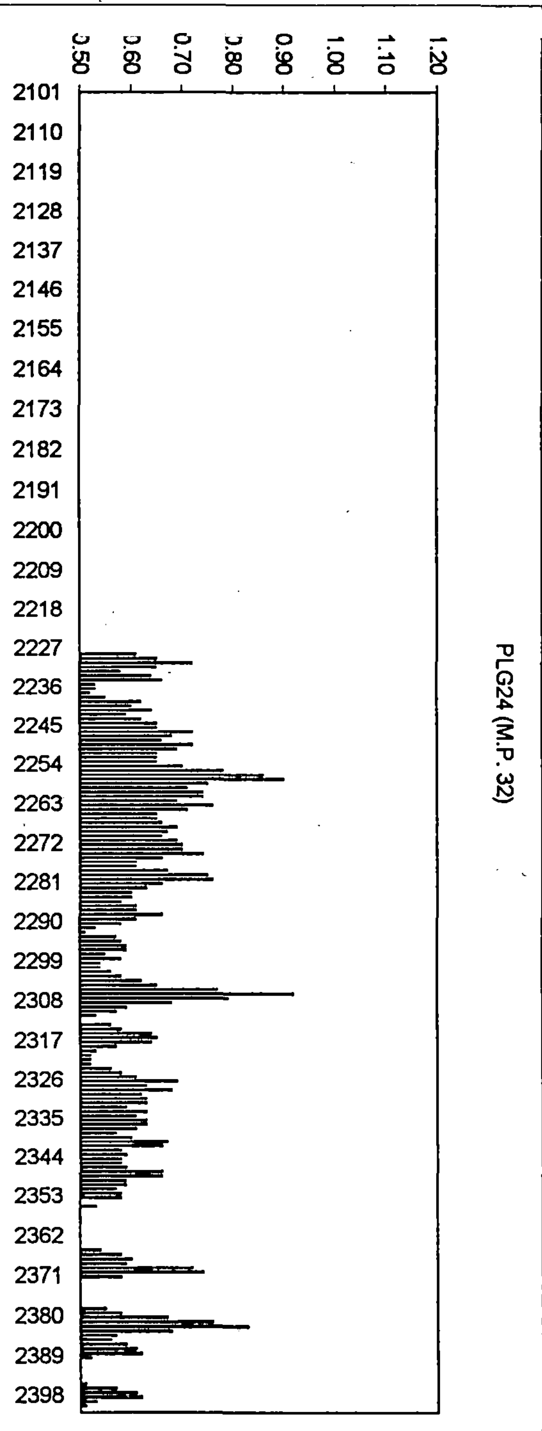
2044
2053
2062
2071
2080
2089
2098

TIE CLUSTERS (M.P. 32)
Bad Ties only

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0.70
0.80
0.90
1.00
1.10
1.20
2101
2110
2119
2128
2137
2146
2155
2164
2173
2182
2191
2200
2209
2218
2227
2236
2245
2254
2263
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2308
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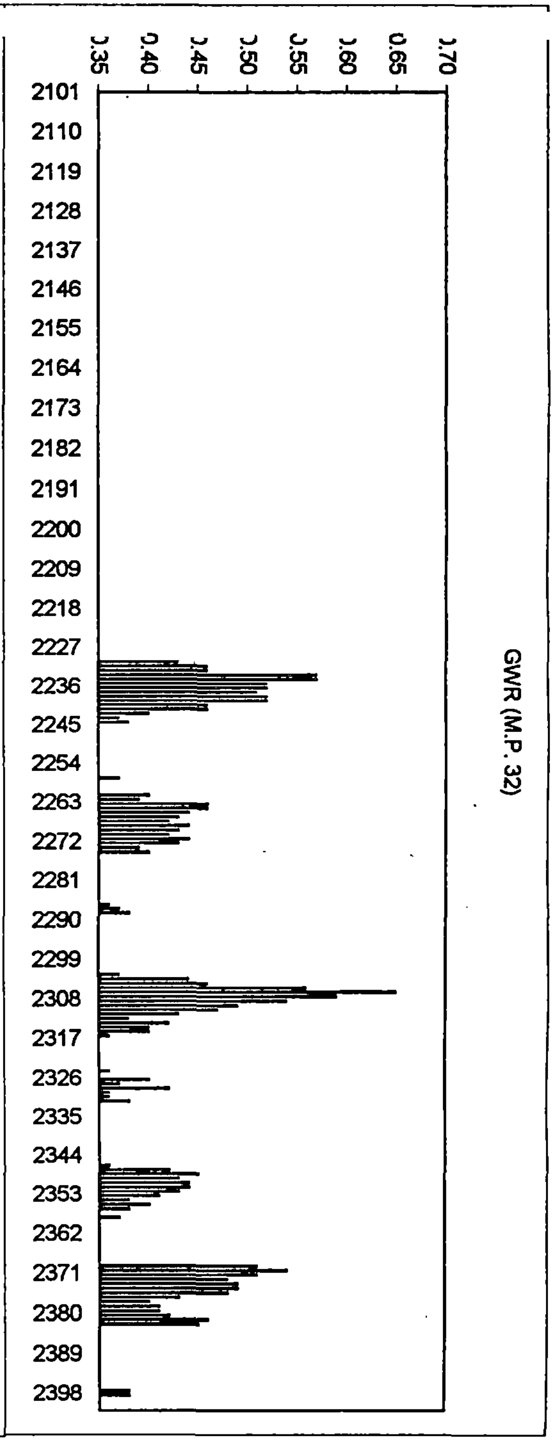
2362
2371
2380
2389
2398


GWR (M.P. 32)
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
2101
2110
2119
2128
2137
2146
2155
2164
2173
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2191
2200
2209
2218
2227
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2245
2254
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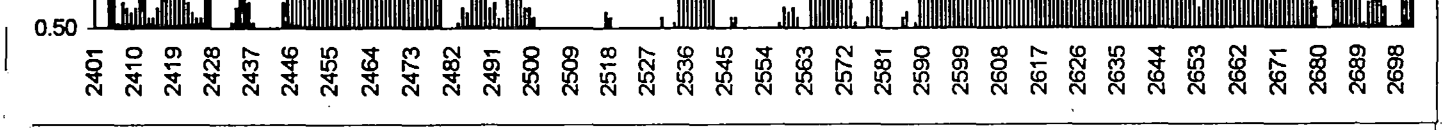

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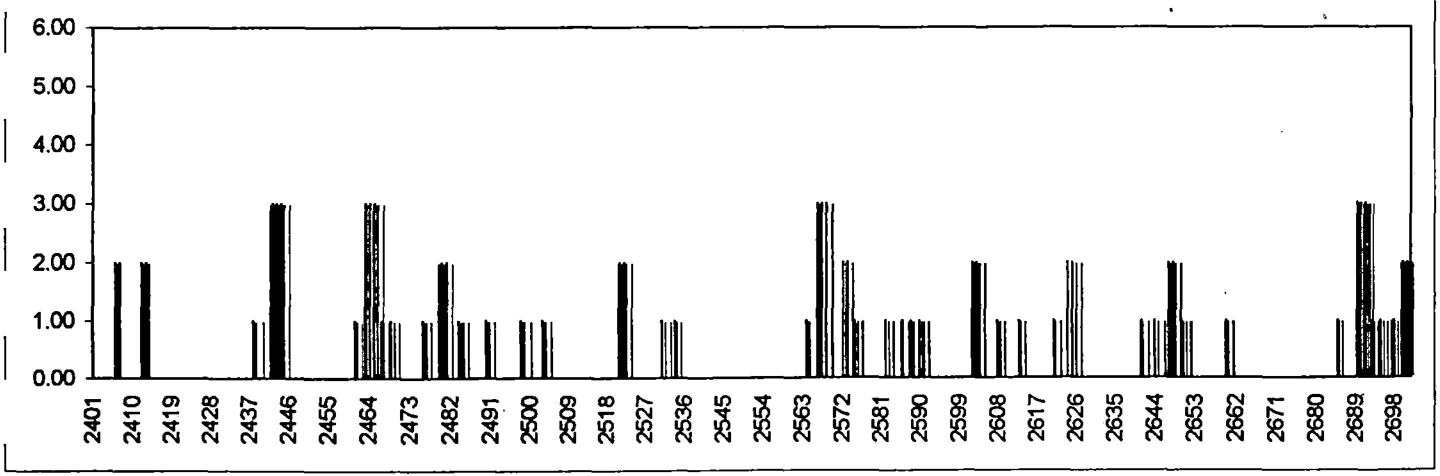
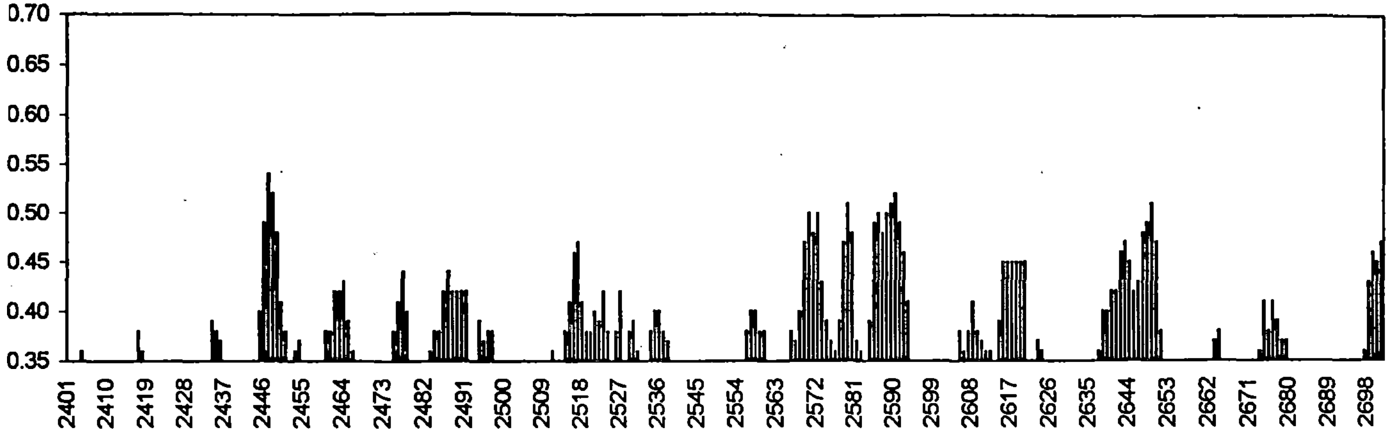
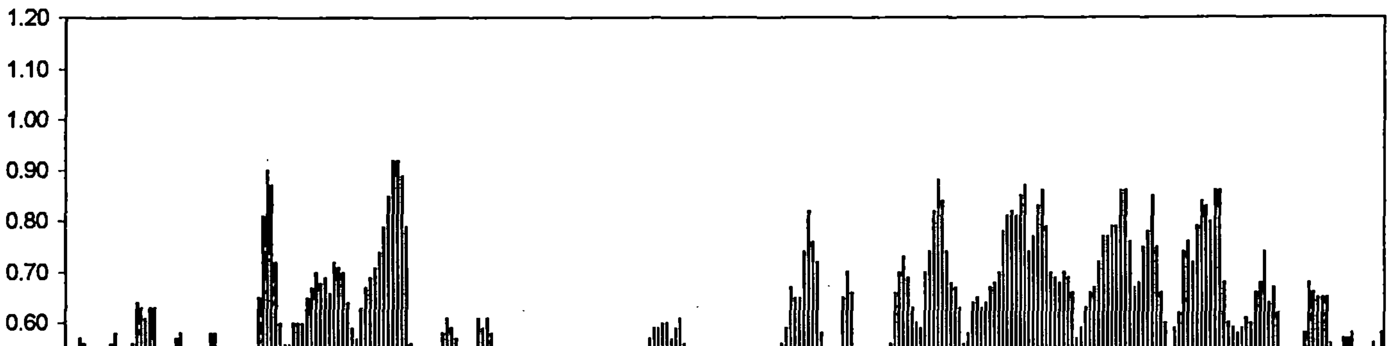
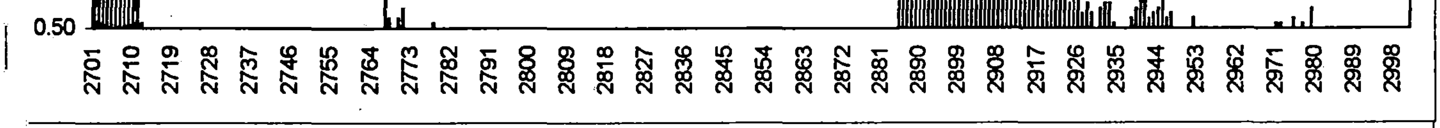


GWR (M.P. 32)



PLG24 (M.P. 32)

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2719
2728
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2746
2755
2764
2773
2782
2791
2800
2809
2818
2827
2836
2845
2854
2863
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2881
2890
2899
2908
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2926
2935
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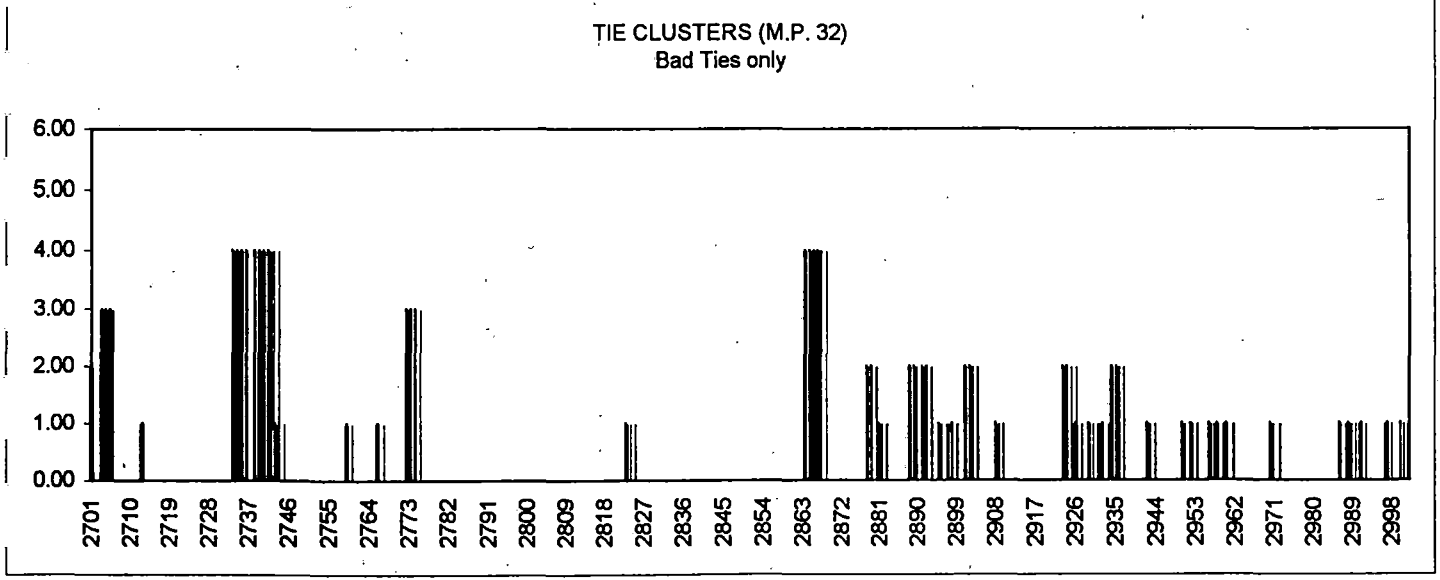
2953
2962
2971
2980
2989
2998


TIE CLUSTERS (M.P. 32)
Bad Ties only
6.00
5.00
4.00
3.00
2.00
1.00
0.00
2701
2710
2719
2728
2737
2746
2755
2764
2773
2782
2791
2800
2809
2818
2827
2836
2845
2854
2863
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2899
2908
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2926
2935
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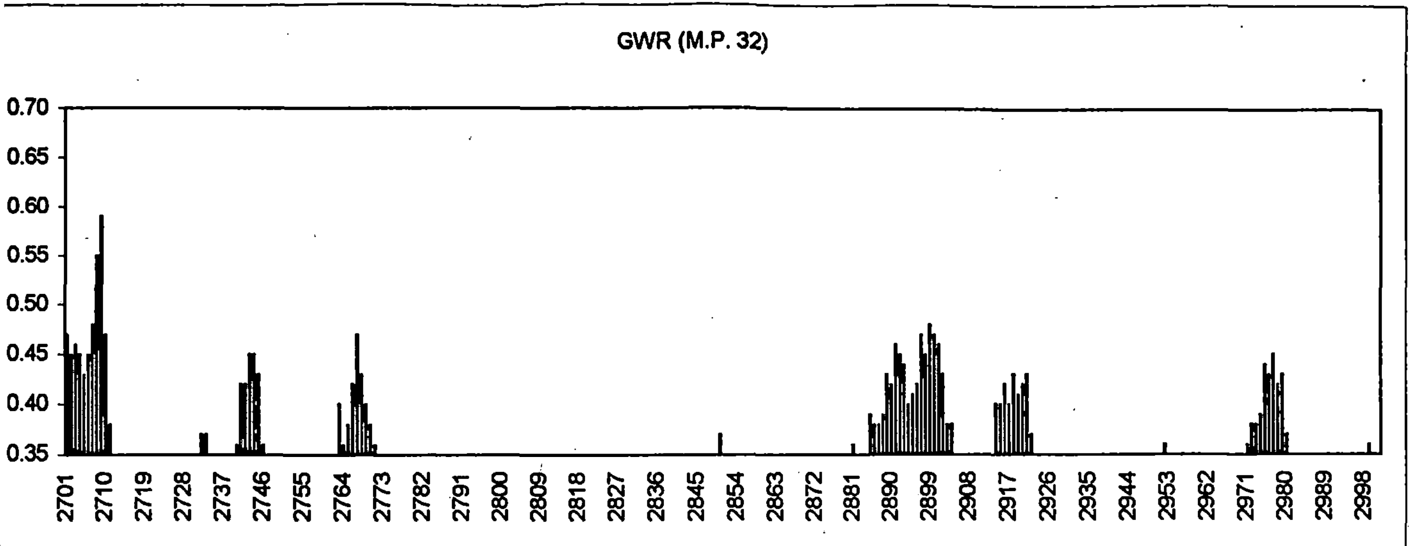
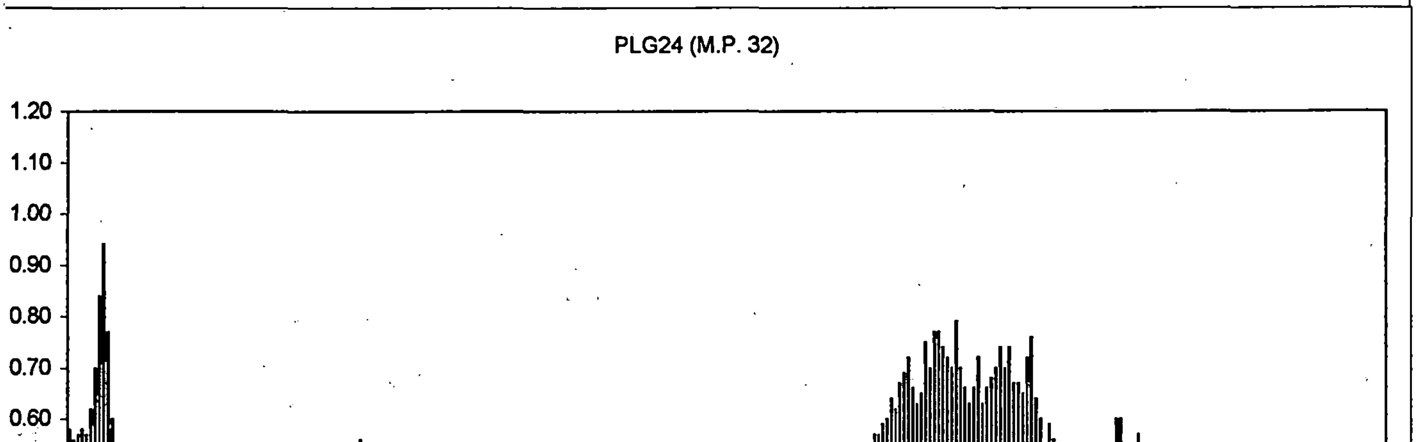
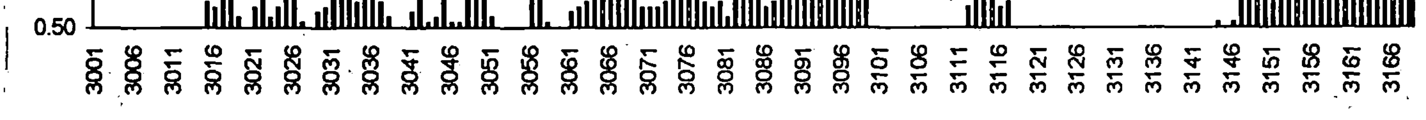
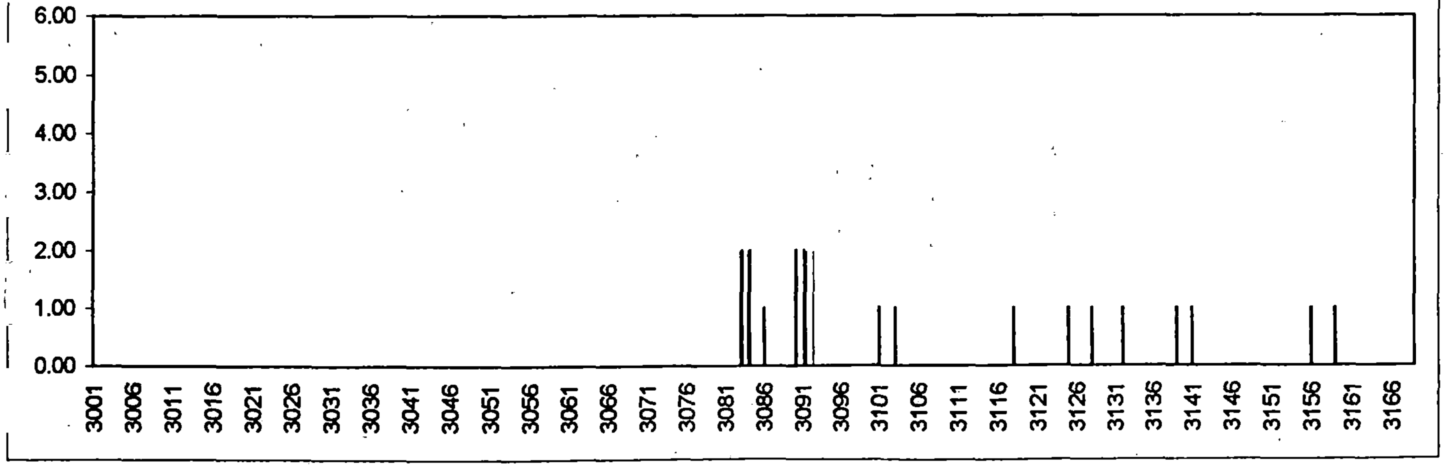
2953
2962
2971
2980
2989
2998

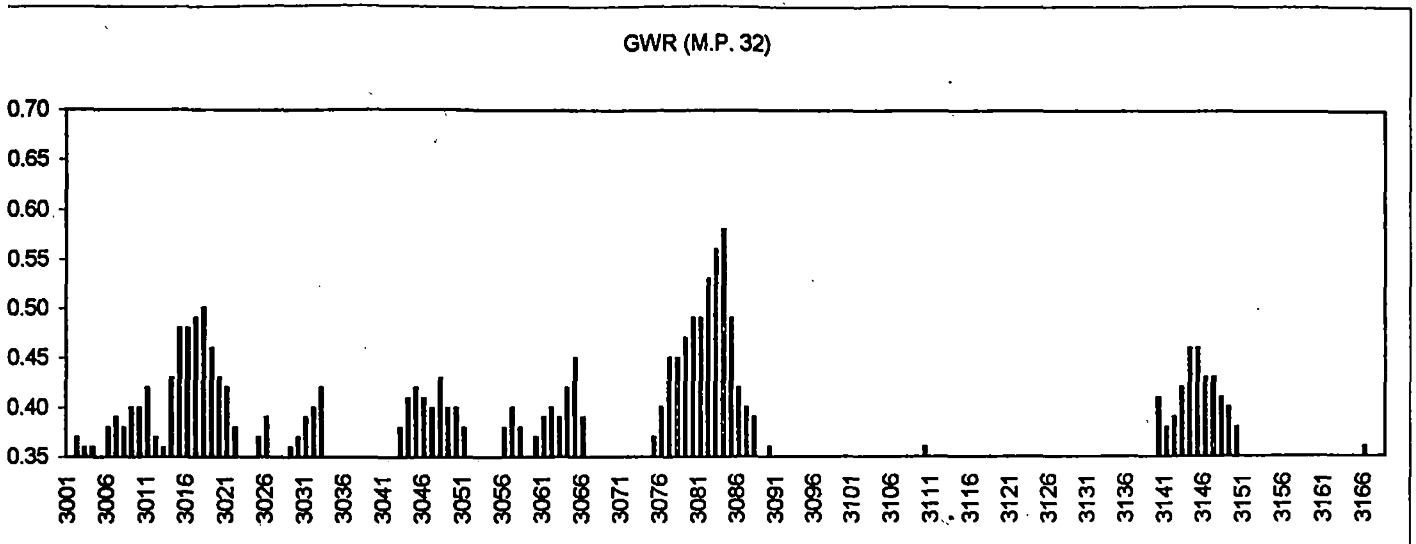

GWR (M.P. 32)
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
2701 2710 2719 2728 2737 2746 2755 2764 2773 2782 2791 2800 2809 2818 2827 2836 2845 2854 2863 2872 2881 2890 2899 2908 2917 2926 2935 2944 2953 2962 2971 2980 2989 2998


PLG24 (M.P. 32)
1.20
1.10
1.00
0.90
0.80
0.70
0.60



TIE CLUSTERS (M.P. 32)
Bad Ties only




GWR (M.P. 32)
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
3001
3006
3011
3016
3021
3026
3031
3036
3041
3046
3051
3056
3061
3066
3071
3076
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3086
3091
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3141
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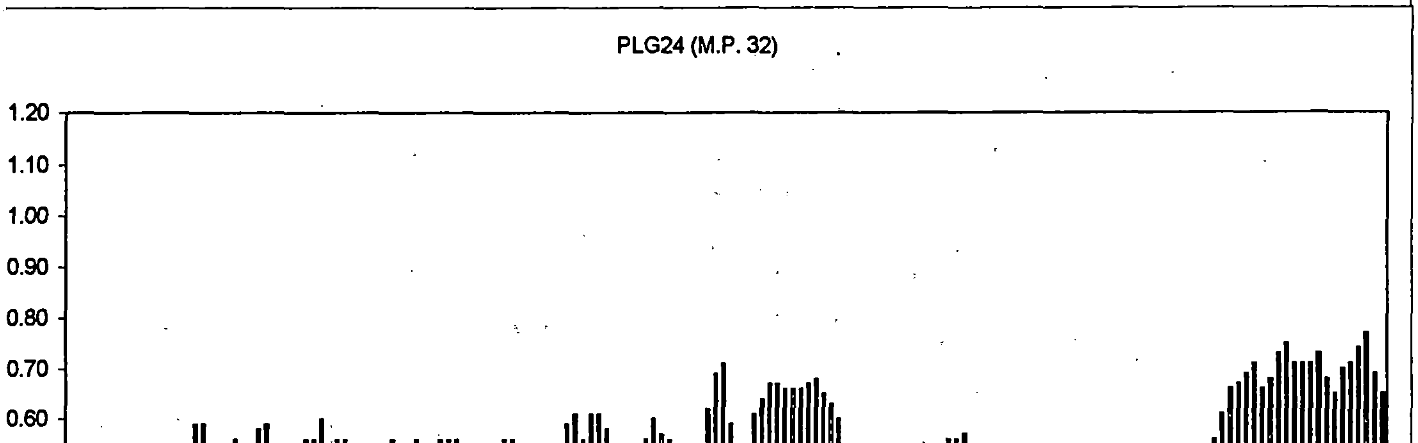
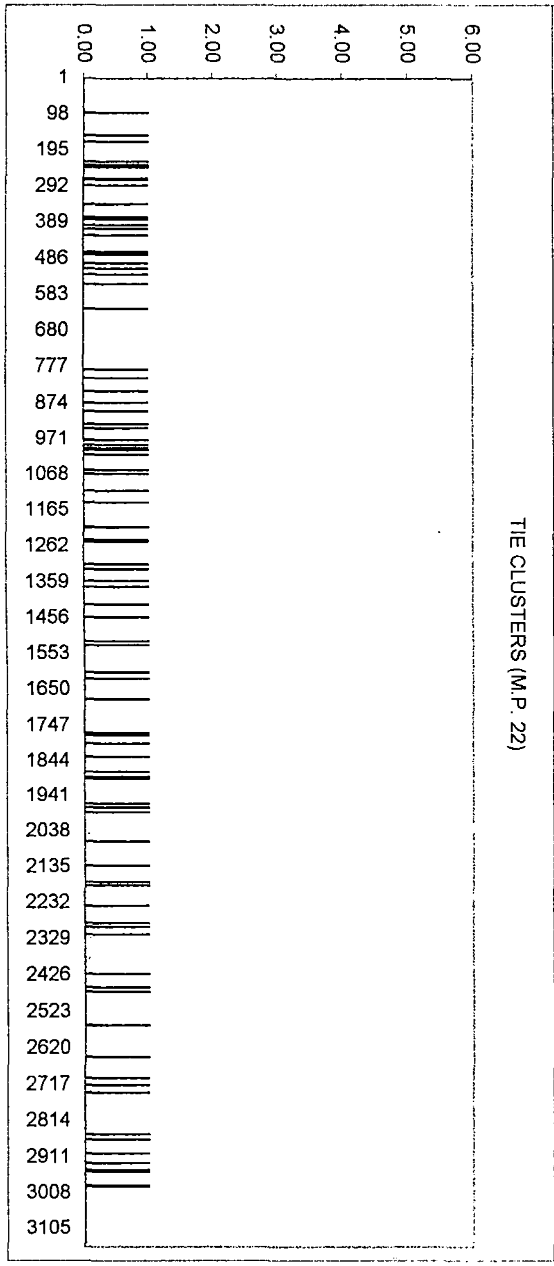
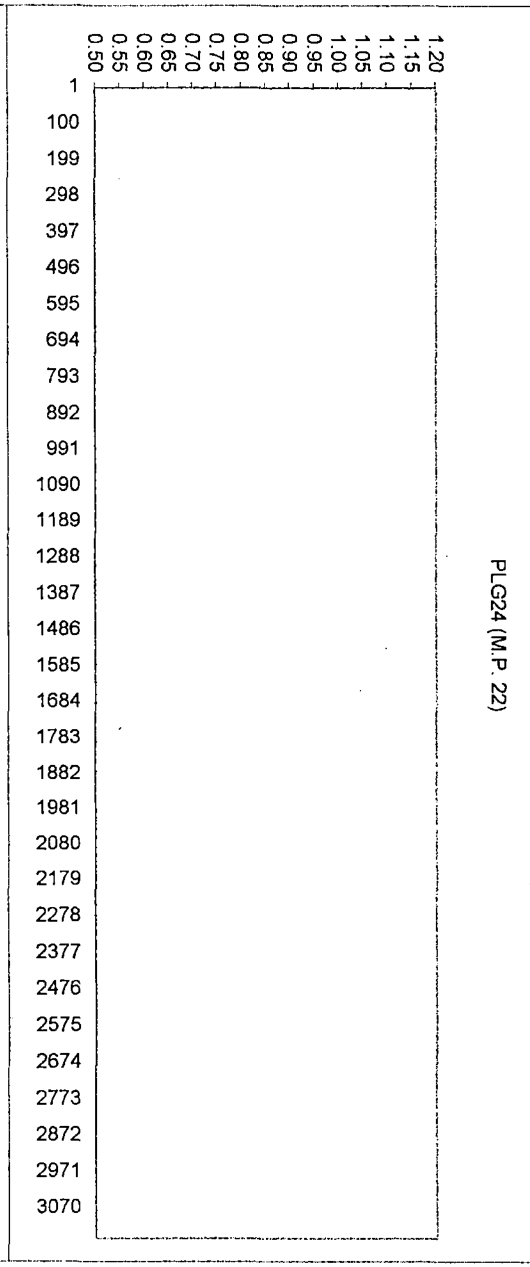
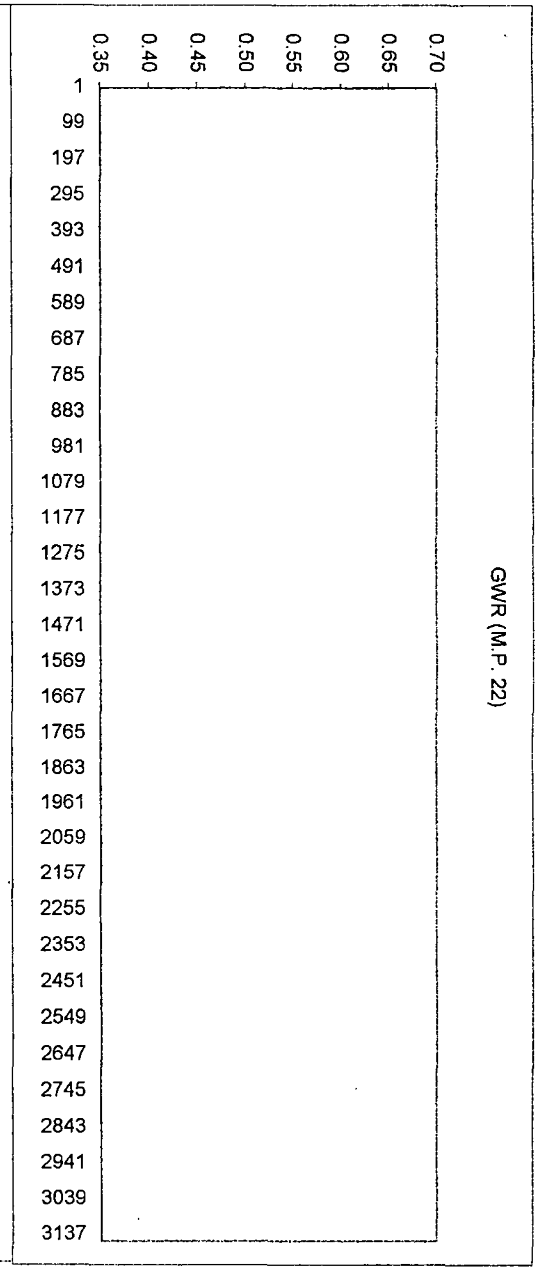
3156
3161
3166

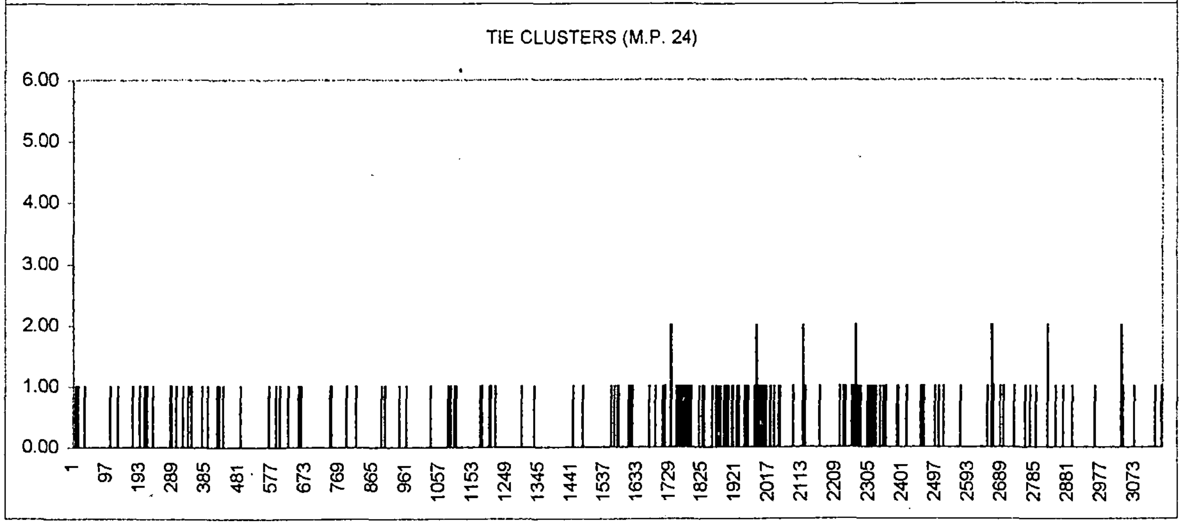

PLG24 (M.P. 32)
1.20
1.10
1.00
0.90
0.80
0.70
0.60

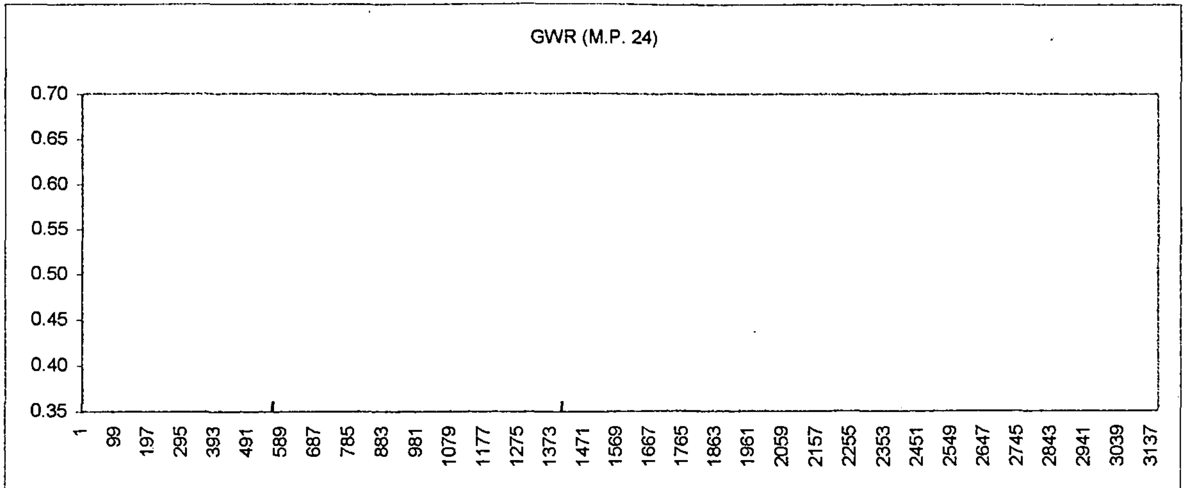
Appendix I

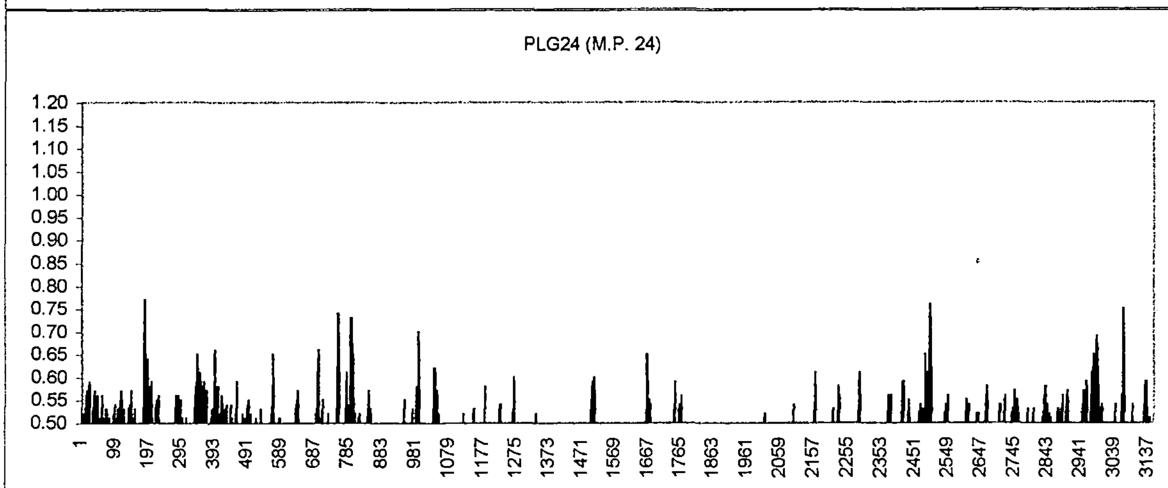

TIE CLUSTERS (M.P. 22)
0.00 1.00 2.00 3.00 4.00 5.00 6.00
1 98 195 292 389 486 583 680 777 874 971 1068 1165 1262 1359 1456 1553 1650 1747 1844 1941 2038 2135 2232 2329 2426 2523 2620 2717 2814 2911 3008 3105


PLG24 (M.P. 22)
0.50 0.55 0.60 0.65 0.70 0.75 0.80 0.85 0.90 0.95 1.00 1.05 1.10 1.15 1.20
1 100 199 298 397 496 595 694 793 892 991 1090 1189 1288 1387 1486 1585 1684 1783 1882 1981 2080 2179 2278 2377 2476 2575 2674 2773 2872 2971 3070


GWR (M.P. 22)
0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70
1 99 197 295 393 491 589 687 785 883 981 1079 1177 1275 1373 1471 1569 1667 1765 1863 1961 2059 2157 2255 2353 2451 2549 2647 2745 2843 2941 3039 3137


TIE CLUSTERS (M.P. 24)
6.00
5.00
4.00
3.00
2.00
1.00
0.00
1
97
193
289
385
481
577
673
769
865
961
1057
1153
1249
1345
1441
1537
1633
1729
1825
1921
2017
2113
2209
2305
2401
2497
2593
2689
2785
2881
2977
3073


GWR (M.P. 24)
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
1
99
197
295
393
491
589
687
785
883
981
1079
1177
1275
1373
1471
1569
1667
1765
1863
1961
2059
2157
2255
2353
2451
2549
2647
2745
2843
2941
3039
3137


PLG24 (M.P. 24)
1.20
1.15
1.10
1.05
1.00
0.95
0.90
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
1
99
197
295
393
491
589
687
785
883
981
1079
1177
1275
1373
1471
1569
1667
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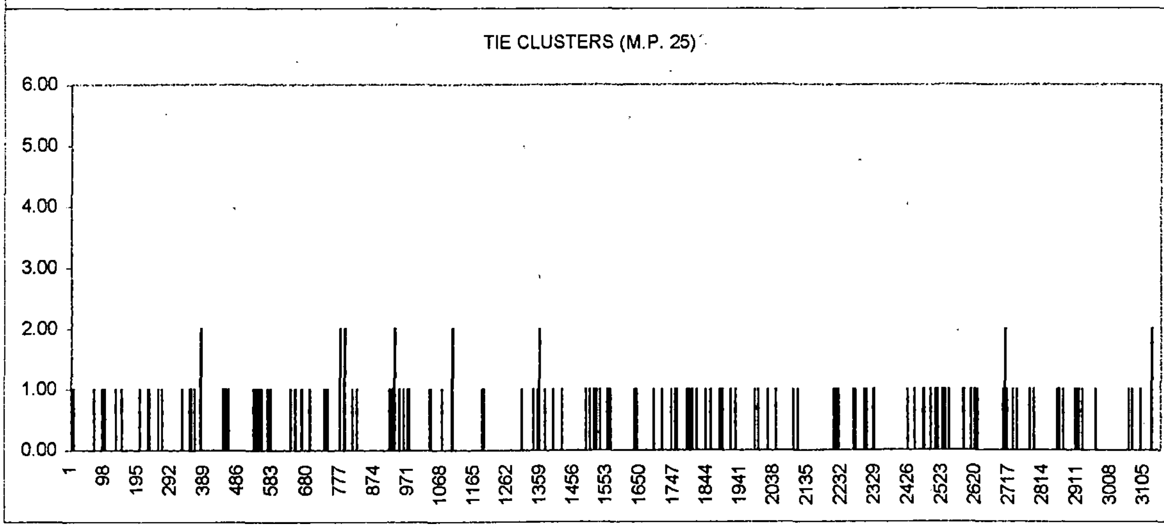
1863
1961
2059
2157
2255
2353
2451
2549
2647
2745
2843
2941
3039
3137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4.00
3.00
2.00
1.00
0.00
1
98
195
292
389
486
583
680
777
874
971
1068
1165
1262
1359
1456
1553
1650
1747
1844
1941
2038
2135
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2329
2426
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2620
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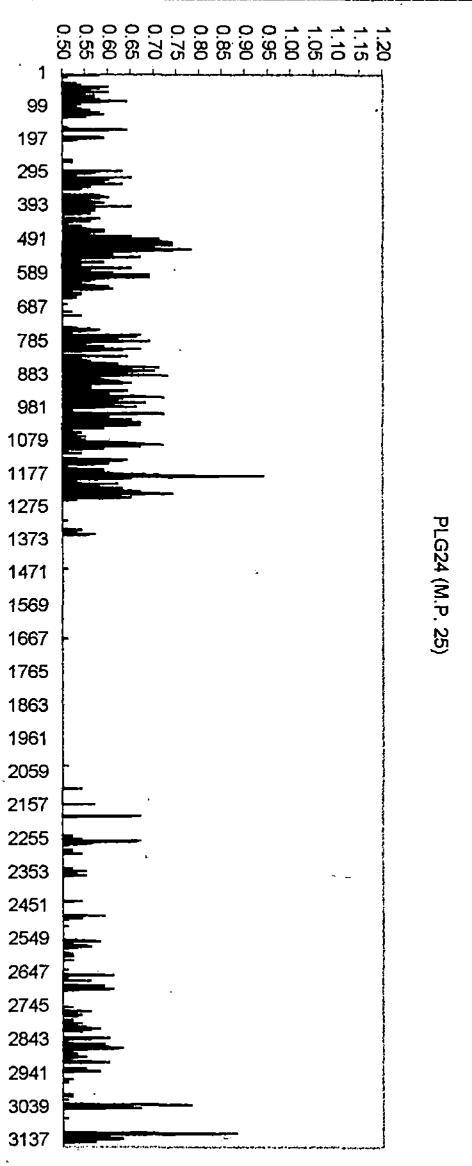
3008
3105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0.55
0.60
0.65
0.70
0.75
0.80
0.85
0.90
0.95
1.00
1.05
1.10
1.15
1.20
1
99
197
295
393
491
589
687
785
883
981
1079
1177
1275
1373
1471
1569
1667
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1863
1961
2059
2157
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2353
2451
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2647
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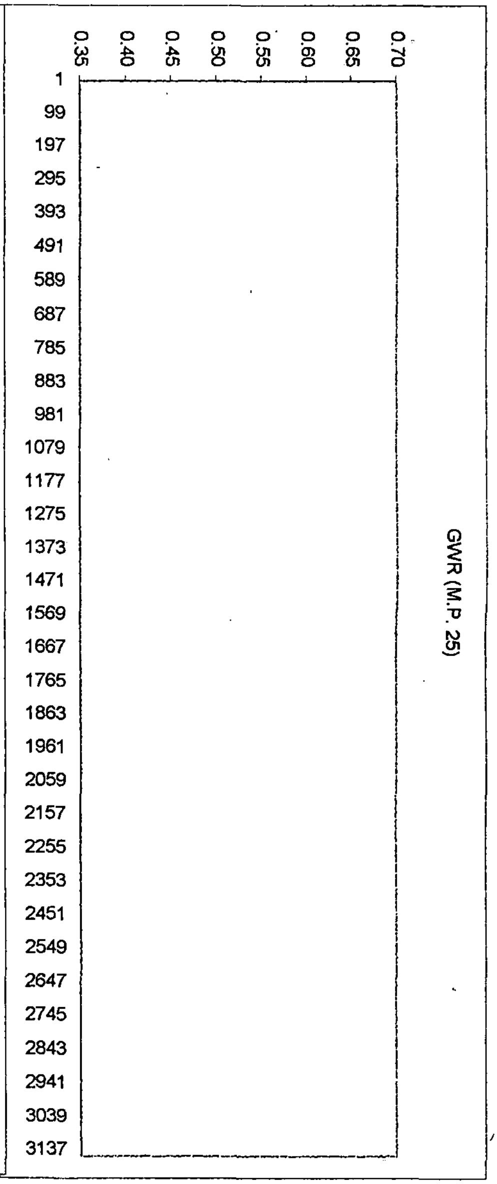
3039
3137

GWR (M.P. 25)
0.35
0.40
0.45
0.50
0.55
0.60
0.65
0.70
1
99
197
295
393
491
589
687
785
883
981
1079
1177
1275
1373
1471
1569
1667
1765
1863
1961
2059
2157
2255
2353
2451
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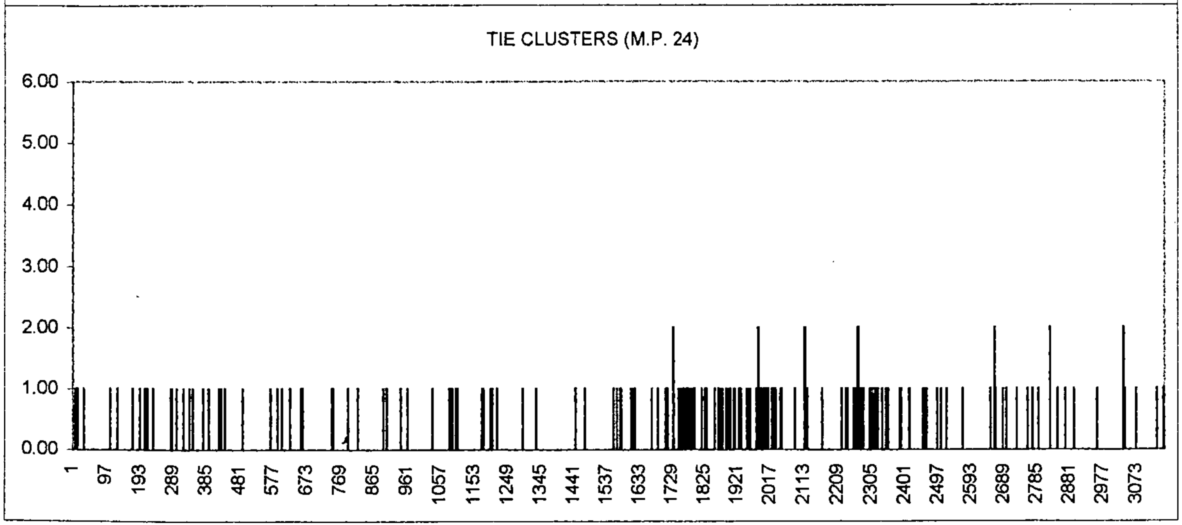
2647
2745
2843
2941
3039
3137


TIE CLUSTERS (M.P. 24)
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5.00
4.00
3.00
2.00
1.00
0.00
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193
289
385
481
577
673
769
865
961
1057
1153
1249
1345
1441
1537
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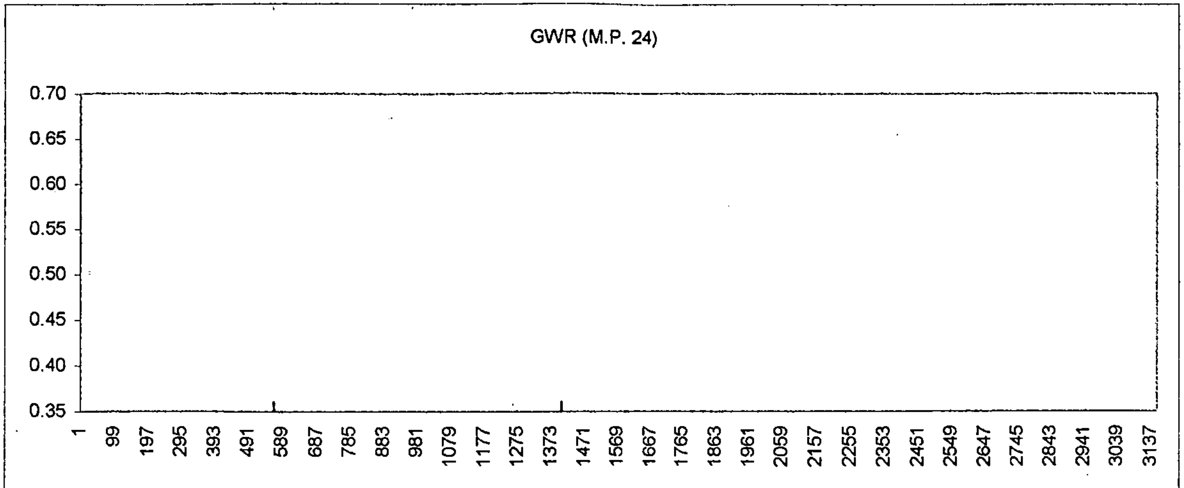
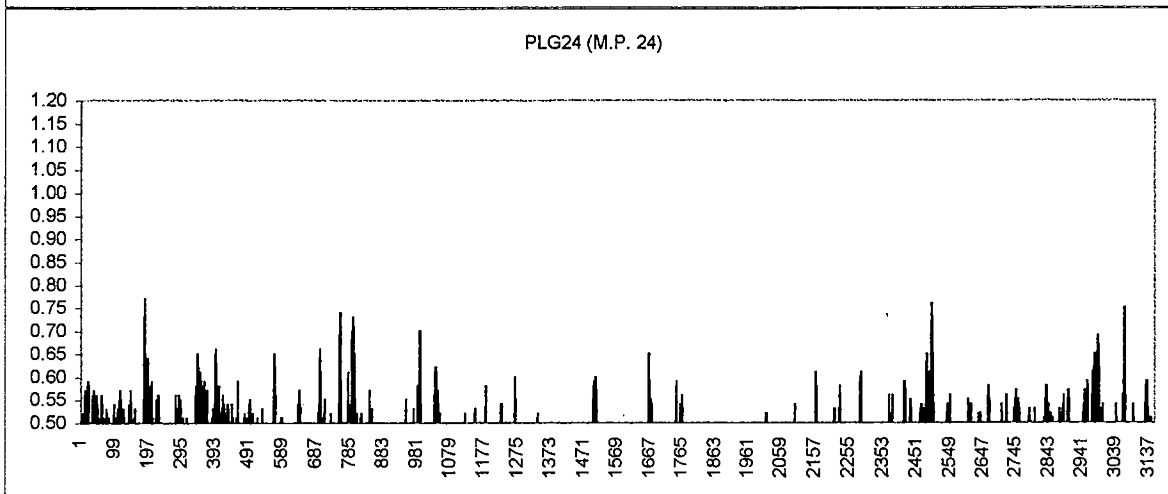

GWR (M.P. 24)


PLG24 (M.P. 24)

Demonstration of High Speed Track Maintenance Using Objective Gage Strength Data, 1999, 02-Track-Train Dynamics

ZETA-TECH

ZETA-TECH
Associates, Inc.
900 Kings Highway N.
P.O. Box 8407
Cherry Hill, NJ
08002
(609) 779-7795
FAX: (609) 779-7436

February 16, 1999

Mr. Robert J. McCown, P.E.
Director, Technology Development
High Speed Rail
Federal Railroad Administration
400 Seventh St. SW
Washington DC 20590

Dear Bob:

Attached is the revised final report for ZETA-TECH Associates, Inc.'s activity "Demonstration of High Speed Track Maintenance Using Objective Gage Strength Data".

As we discussed, I have added the supplemental analysis and have tried to gear the report more in the direction you indicated.

If you have any questions, please give me a call.

Sincerely,

Allan M. Zarembski Ph.D., P.E.
President

CC. Mr. Steven Sill (FRA)
Mr. John Choros (VNTSC)
Mr. Mike Coltman (VNTSC)

ZETA-TECH

ZETA-TECH Associates, Inc.
900 Kings Highway North
P.O. Box 8407
Cherry Hill, New Jersey 08002
(609) 779-7795
Fax: (609) 779-7436
email:zetatech@zetatech.com