METRO TRAFFIC CALMING STUDY

Phase 2

Nashville, Tennessee

PREPARED FOR:

Metropolitan Government of Nashville and Davidson County Department of Public Works

March 30, 2004

PREPARED BY:

GS&P
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Introduction

Gresham, Smith and Partners was retained by the Metro Public Works Department (MPW) to assist in an evaluation of Neighborhood Traffic Management techniques for Davidson County.

In Phase 1 of the study, "before and after" speed data was collected at 18 street locations, identified by neighborhood groups as areas of concern for speeding cut-through traffic, to see whether speed reductions could be obtained through the use of education and enforcement of neighborhood traffic management techniques. An average decrease of 2.8 mph was observed. It was concluded that installing traffic calming signs and increasing speed enforcement and educating motorists through the use of speed radar trailers is effective in reducing average speeds through neighborhood streets. Continued visible enforcement would have to be in place to maintain speed reduction and that more aggressive traffic calming measures would be required if a larger decrease in speed was desired.

In Phase 2, physical characteristics of roadways were considered, examining the relationship, if any, of vehicle speed reduction and horizontal roadway curvature. Phase 2 focused on the collection and evaluation of traffic speed data on residential streets in the metropolitan area, and how roadway design parameters affect operating speeds. This letter report summarizes the results of Phase 2 of this traffic calming study.

Methodology

Study Goal

What are the results of the study going to be used for?

The study will determine what, if any, relationship exists between vehicle speed and horizontal roadway curves and if this relationship can be used to determine the potential effectiveness of horizontal roadway design as a Neighborhood Traffic Management technique.

Required Measurements

What measurements will be required for that use?

In order to study the impact of roadway curves in reducing speed, measurements were required at various points along existing curves. The 85th percentile speed, as opposed to the average speed, was deemed the appropriate measurement required. This is because the 85th percentile speed more accurately represents the observed traffic running speeds that would be the target problem for traffic calming solutions, is closely tied to posted speed limits, and is independent of traffic volume.

Data was required both for vehicles entering a curve and vehicles exiting a curve. This would show whether vehicles leaving a curve were noticeably slower or faster than vehicles entering the curve and provide supplemental data relative to approaching and departing acceleration rates.

Data Collection Criteria

How will we get the data for that measurement? How much data do we need?

All the streets in the study were local residential streets and determined unlikely to experience major congestion during the day. Free-flow speed conditions were most likely to exist throughout the day. Therefore, 24-hour tube counts were most appropriate to gather spot speed data. The use of tube counters also had the advantage of providing a large number of data points.

In order to obtain a statistically relevant measure of the 85^{th} percentile speed at each location, a sufficient number of observations was required. The statistical goal for each location was to obtain the 85^{th} percentile speed with an 85% confidence level of getting the speed within +/- 1 mph. Based on Equation 3-2 in the *Manual of Transportation Engineering Studies* (ITE, 1994), and a projected standard deviation of 4.8 mph, 80 individual measurements would be required to obtain this statistical goal. Daily traffic along the residential streets is likely to meet this requirement; so one 24-hour period of tube counts was deemed sufficient for each location.

Curve Selection

What was the process and criteria for selecting suitable curves to measure?

The Phase 2 study focused on the speed relationships entering and exiting 90 degree curved alignments from and to unrestricted, tangent segments. MPW staff provided the GS&P study team with a list of 20 potential curved segment locations for inclusion in the study. Each curved location had two approaches (no one-way streets). This created 40 potential curves for study.

The study team visited each potential site to check their suitability for inclusion in the study. Only curves with tangent segments of at least 1000 feet in length were considered, so that nearby curves would not affect the speed at the study curves. Curve locations that had outside factors that could slow speeds, or would otherwise make the location anomalous among the data set, were deemed not suitable for study. Factors considered to affect speed were: nearby traffic control devices such as stop signs, speed zones for schools, vertical curves, or additional horizontal curves. In addition, only curves on streets with primary residential roadway traffic were desired. Any potential curve that did not meet these criteria was eliminated from consideration. The previously listed criteria was an effort to eliminate 'special causes' from the data set. This provides a truer representation of the mean of the data for comparison purposes.

Final Curve Set

What curves and locations were chosen for measurement?

Based on the field investigation and established criteria, 16 curved segment approaches on 11 different curves were identified as acceptable for measurement. Below is a list of the original 20 potential curve segments, how many approaches that could be measured at each, and, if the segment was eliminated from consideration, why it was eliminated.

1. Pierce Avenue north of Anderson Lane and east of railroad track - 1 approach

2. Freda Villa between Saunders and Due West - 1 approach

3. Jones Avenue near Capitol View - 2 approaches

4. Tanglewood Drive at Ruskin Avenue - 1 approach (low volume anticipated)

5. Delmas - Cherokee - Chickasaw Avenue between Ellington Parkway and railroad track - Industrial area near RR crossing **eliminated from consideration**

6. Fernwood Dr - Piedmont Av between McGavock Pk and Stratford Avenue - Traffic control too close to curve, **eliminated from consideration**

7. Pinehurst Drive - Willow Springs Drive between Stratford Avenue and Rosebank Avenue - 2 approaches

8. Donna Hill Drive between Kimberly Drive and Cabin Hill Road - Curve located in a school zone, **eliminated from consideration**

9. Dutchmans Drive between Mercer Drive and Albany Drive - 2 approaches (low volume anticipated)

10. Old Hydes Ferry Road at Hinkle Road - Stop controlled intersection, **eliminated from consideration**

11. Dozier Place between Trinity Lane and Gallatin Pike - 1 approach

12. Maxey Lane at Branch Street - 1 approach

13. Russell Street between 5th and 6th, and between 7th and 8th - Traffic control too close to curve, **eliminated from consideration**

14. Lake Parkway at Port Anadarko Trail - 1 approach

15. Valley Brook Road west of Cross Creek toward Woodmont - 2 approaches

16. Winthorne Drive/Finley Drive between Currey Road and Briley Parkway - existing cross streets impact the approach speeds, **eliminated from consideration**

17. Neese Drive at Glencliff Road - 2 approaches (low volume anticipated)

18. Warfield Drive and Kimbark Drive east of Hillsboro Pike - nearby curves and traffic control, **eliminated from consideration**

19. General George Patton Road off of Sawyer Brown Road - nearby curves, **eliminated from consideration**

20. Apollo Drive between Richards Road and Una-Antioch Pike - nearby curves, **eliminated from consideration**

Measurement Locations

What points of the curves were deemed suitable for measurement?

During coordination meetings with MPW, distances of 100 feet, 200 feet, 300 feet, 400 feet, and 500 feet from the point of curvature were chosen for the speed measurements. The speeds at distances less than 100 feet from the point of curvature are determined mainly by the geometrics of the curve. Speeds at distances of greater than 500 feet of from the point of curvature were considered unaffected by the presence of a curve, according to past research.

Three points along each curve approach were chosen for measurement, either at the 100, 200, 300, 400, or 500 foot mark. Thus, for 3 measurement locations on 16 curve approaches, a total of 48 measurement points were selected to record both approach and departure speeds. A mix of measurement distances at each curve was chosen so that, as much as possible, an equal number of measurements were recorded at each distance.

Data Analysis

Locations Covered

Where and when were data actually gathered?

Speed data was gathered at all measurement locations over a period of 24 hours, beginning on Wednesday, November 12 and ending on Thursday, November 13, 2003. Of the 48 selected measurement points, 45 points were successfully measured for speed data.

Spot Speed Report

What speeds were recorded?

Tables 1 and 2 present the 85^{th} percentile speed recorded at each measured location for vehicles approaching a curve and vehicles departing a curve, respectively. Graphical representations of the 85^{th} percentile speeds recorded at each curve were also developed. The approach speeds are shown in **Figure 1**, and the departure speeds are shown in **Figure 2**.

Statistical Relevancy

Did we get enough data points for our relevancy benchmarks? If not, what benchmarks were hit?

The majority of studied locations obtain a 95% confidence level with a variance of within +/- 1 mph. The minimum number of measurements to reach these goals varied according to the standard deviation of data at each location. Approximately one quarter of study locations did not have enough recorded measurements to meet the statistical goals. However, only two study locations, for approaching vehicles on the Tanglewood Drive at Ruskin Avenue curve (locations 14 and 15), did not have enough measurements to be at least within +/- 1.5 mph at an 85% confidence level. At these two locations, the speed was measured to within +/- 2 mph at a 90% confidence level.

Table 1 – 85th Percentile Speed, Approaching Curve

Location No.	Distance Measured from Curvature (Approx.)	85th Percentile Speed (mph)	Curve	Approach Leg	Radius of Curvature (Approx.)
1	100′	31	Pierce Ave north of Anderson Lane and east of RR track	Southwest leg (Pierce Ave)	80′
2	200′	34			
3	400′	41			
4	100′	34	Freda Villa between Saunders Ave and Due West Ave	North leg (Freda Villa)	300′
5	300′	36			
6	500′	38			
7	200′	34	Jones Ave at Capitol View Ave	South leg (Jones Ave)	265′
8	300′	37			
9	500′	39			
10	100′	37		West leg (Capitol View Ave)	265′
11	200′	n/a			
12	400′	34			
13	200′	26	Tanglewood Dr at Ruskin Ave	South leg (Tanglewood Dr)	55′
14	300′	29			
15	400′	33			
16	100′	28	Pinehurst Dr at Willow Springs Dr	Southwest leg (Pinehurst Dr)	55′
17	300′	36			
18	500′	37			
19	100′	29		Southeast leg (Willow Springs Dr)	55′
20	400′	37			
21	500′	37			
22	200′	27	Dutchmans Dr and Albany Dr near their intersection	West leg (Dutchmans Dr)	55′
23	300′	32			
24	400′	33			
25	200′	37		North leg (Albany Dr)	190′
26	300′	39			
27	500′	38			
28	100′	n/a	Dozier Pl between Trinity Ln and Gallatin Pk	East leg (Dozier Pl)	35′
29	400′	38			
30	500′	40			
31	100′	28	Maxey Ln at Branch St	South leg (Branch St)	50′
32	200′	37			
33	400′	39			
34	100′	29	Lake Parkway Ct at Port Anadarko Trail	West leg (Lake Parkway Ct)	42′
35	300′	33			
36	500′	35			
37	200′	37	Valley Brook Rd between Cross Creek and Woodmont	North leg (Valley Brook Dr)	300′
38	300′	37			
39	400′	38			
40	100′	37		East leg (Valley Brook Dr)	300′
41	200′	n/a			
42	500′	35			
43	300′	36	Neese Dr at Glencliff Rd	West leg (Neese Dr)	30′
44	400′	44			
45	500′	45			
46	100′	25		South leg (Glencliff Rd)	30′
47	300′	38			
48	500′	41			

Source: Gresham, Smith and Partners

Table 2 – 85th Percentile Speed, Departing Curve

Location No.	Distance Measured from Curvature (Approx.)	85th Percentile Speed (mph)	Curve	Approach Leg	Radius of Curvature (Approx.)
1	100'	28	Pierce Ave north of Anderson Lane and east of RR track	Southwest leg (Pierce Ave)	80'
2	200'	32			
3	400'	35			
4	100'	34	Freda Villa between Saunders Ave and Due West Ave	North leg (Freda Villa)	300'
5	300'	36			
6	500'	38			
7	200'	32	Jones Ave at Capitol View Ave	South leg (Jones Ave)	265'
8	300'	35			
9	500'	38			
10	100'	36		West leg (Capitol View Ave)	265'
11	200'	n/a			
12	400'	34			
13	200'	29	Tanglewood Dr at Ruskin Ave	South leg (Tanglewood Dr)	55'
14	300'	30			
15	400'	31			
16	100'	26	Pinehurst Dr at Willow Springs Dr	Southwest leg (Pinehurst Dr)	55'
17	300'	32			
18	500'	35			
19	100'	25		Southeast leg (Willow Springs Dr)	55'
20	400'	32			
21	500'	33			
22	200'	25	Dutchmans Dr and Albany Dr near their intersection	West leg (Dutchmans Dr)	55'
23	300'	30			
24	400'	31			
25	200'	29		North leg (Albany Dr)	190'
26	300'	31			
27	500'	32			
28	100'	n/a	Dozier Pl between Trinity Ln and Gallatin Pk	East leg (Dozier Pl)	35'
29	400'	36			
30	500'	39			
31	100'	26	Maxey Ln at Branch St	South leg (Branch St)	50'
32	200'	32			
33	400'	35			
34	100'	25	Lake Parkway Ct at Port Anadarko Trail	West leg (Lake Parkway Ct)	42'
35	300'	34			
36	500'	32			
37	200'	38	Valley Brook Rd between Cross Creek and Woodmont	North leg (Valley Brook Dr)	300'
38	300'	39			
39	400'	39			
40	100'	39		East leg (Valley Brook Dr)	300'
41	200'	n/a			
42	500'	33			
43	300'	33	Neese Dr at Glencliff Rd	West leg (Neese Dr)	30'
44	400'	41			
45	500'	40			
46	100'	20		South leg (Glencliff Rd)	30'
47	300'	33			
48	500'	36			

Source: Gresham, Smith and Partners

FIGURE 1 - 85th Percentile Speed Approaching Curve
By Curve Location

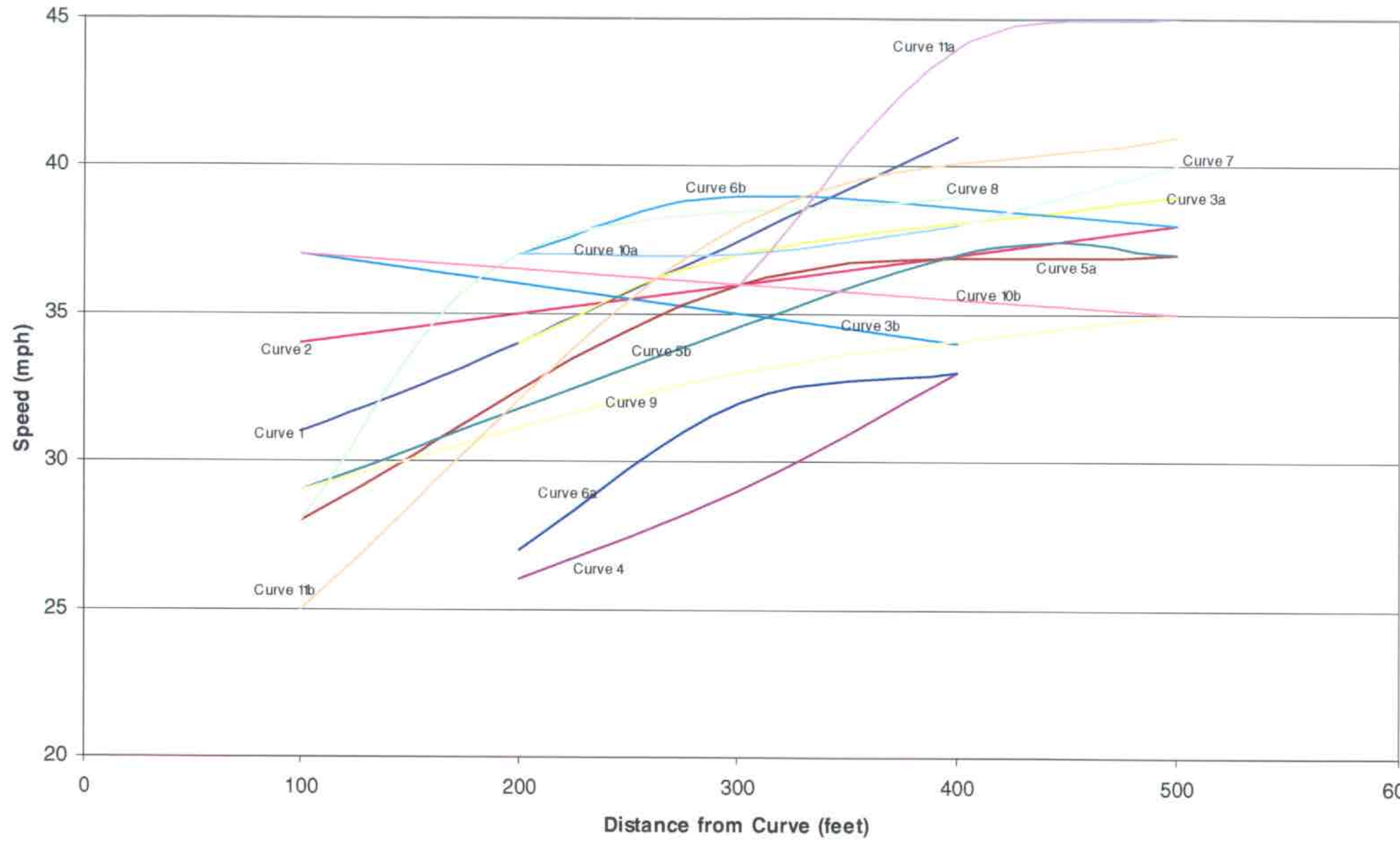
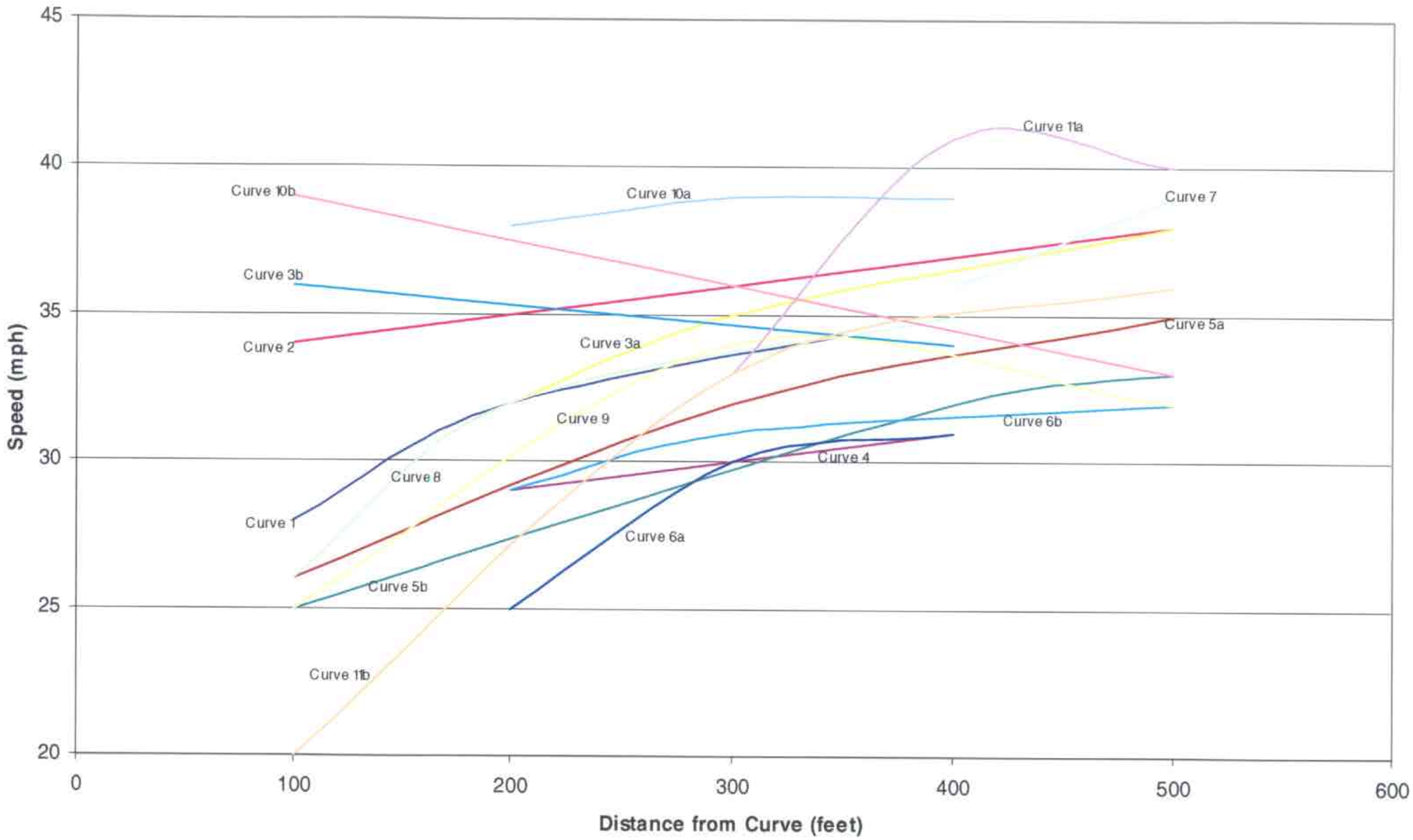


FIGURE 2 - 85th Percentile Speed Departing Curve
By Curve Location



Tables 3 and 4 show the number of measurements at each study location and the confidence level obtained if there were not enough measurements for either the 95% or 85% confidence level at +/- 1 mph.

Trend Analysis

What did the data tell us?

At almost every location, speeds departing a curve were lower than speeds approaching the same curve. Taking all the measurements together, across all distances, the average 85^{th} percentile speed approaching a curve was 35.2 mph while the average 85^{th} percentile speed departing a curve was 32.9 mph, a difference of 2.3 mph.

However, there were two locations that produced anomalous results which suggest discounting their data. At the west leg of the Jones Avenue at Capitol View Avenue curve and at the east leg of the Valley Brook Road curve, the recorded speeds were higher at closer distances to the curvature. This was true both for approaching and departing data. Further investigation at these locations revealed characteristics, outside of the curvature, that affected vehicle speeds. Specifically, the grade on these approaches allows vehicles to gain speed as they approach the curve before braking within the curve, and vehicles departing the curve slow as they climb the grade. Furthermore, when departing the Valley Brook Road curve on the east leg, trees and other horizontal curves in the road lead to decreased speed. Because speeds at these curve locations were being affected by factors other than the curve itself, data from these two locations was eliminated from consideration. When data from these two anomalous locations are not included in calculations, the average 85^{th} percentile speed approaching a curve remains 35.2 mph but the average 85^{th} percentile speed departing a curve becomes 32.6 mph, for a difference of 2.6 mph.

Trying to establish a more refined relationship between speed and proximity to a general curve was more problematic, although the trend lines show what is expected (speeds decrease with proximity to a curve). **Figures 3 and 4** show the data, trend lines, and mathematical fits, for speeds approaching and departing a curve, respectively. A linear regression line, exponential curve, and logarithmic curve are shown on the figures, though they vary little from one another. For vehicles approaching a curve, the linear regression and exponential curve r-squared values are 0.50 and the logarithmic curve r-squared value is 0.52. For vehicles departing a curve, the linear regression and exponential curve r-squared values are 0.46 and the logarithmic curve r-squared value is 0.50.

The physical characteristics of horizontal curves can have an effect on vehicle speeds. And, although all the study curves have a 90 degree alignment, the radius of curvature varies at each curve. For this reason data was considered in terms of two subsets: 1) data from tight curves; and 2) data from gentler curves.

Table 3 – Confidence Level of Approaching Curve Speed Measurements

Location No.	Curve	Measure-ments	Std Dev (mph)	Confidence Level 95%[1]	85%[1]	Other
1	Pierce Ave north of Anderson Lane and east of RR track	189	6.38		✓	
2		202	8.08			95% confidence, +/- 1.5 mph
3		232	10.38			85% confidence, +/- 1.5 mph
4	Freda Villa between Saunders Ave and Due West Ave	436	5.74	✓		
5		430	6.73	✓		
6		419	7.43	✓		
7	Jones Ave at Capitol View Ave	1436	5.19	✓		
8		1421	6.76	✓		
9		1399	5.98	✓		
10	Jones Ave at Capitol View Ave	602	5.88	✓		
11		n/a				No count available
12		631	5.00	✓		
13	Tanglewood Dr at Ruskin Ave	33	6.19			85% confidence, +/- 2 mph
14		38	7.43			90% confidence, +/- 2 mph
15		51	8.05			90% confidence, +/- 2 mph
16	Pinehurst Dr at Willow Springs Dr	191	5.01	✓		
17		200	6.98		✓	
18		249	6.38		✓	
19	Pinehurst Dr at Willow Springs Dr	208	4.98	✓		
20		170	6.78		✓	
21		165	7.19			95% confidence, +/- 1.5 mph
22	Dutchmans Dr and Albany Dr near their intersection	158	4.88	✓		
23		155	6.08		✓	
24		166	6.61		✓	
25	Dutchmans Dr and Albany Dr near their intersection	137	7.38			85% confidence, +/- 1.5 mph
26		150	8.73			85% confidence, +/- 1.5 mph
27		178	7.95			95% confidence, +/- 1.5 mph
28	Dozier Pl between Trinity Ln and Gallatin Pk	n/a				No count available
29		434	7.41	✓		
30		432	7.52	✓		
31	Maxey Ln at Branch St	176	5.21	✓		
32		179	6.92		✓	
33		190	7.71			95% confidence, +/- 1.5 mph
34	Lake Parkway Ct at Port Anadarko Trail	85	4.88		✓	
35		101	7.50			85% confidence, +/- 1.5 mph
36		99	9.00			85% confidence, +/- 2 mph
37	Valley Brook Rd between Cross Creek and Woodmont	1644	4.68	✓		
38		1641	4.49	✓		
39		1663	4.39	✓		
40	Valley Brook Rd between Cross Creek and Woodmont	1300	5.18	✓		
41		n/a				No count available
42		1309	4.23	✓		
43	Neese Dr at Glencliff Rd	1029	5.50	✓		
44		1026	6.50	✓		
45		1027	6.75	✓		
46	Neese Dr at Glencliff Rd	1397	3.40	✓		
47		1317	5.47	✓		
48		1379	5.80	✓		

Notes:
1. Confidence level to within +/- 1 mph.
Source: Gresham, Smith and Partners

Table 4 – Confidence Level of Departing Curve Speed Measurements

Location No.	Curve	Measure-ments	Std Dev (mph)	Confidence Level 95%[1]	85%[1]	Other
1	Pierce Ave north of Anderson Lane and east of RR track	189	5.32		✓	
2		202	6.75			95% confidence, +/- 1.5 mph
3		232	9.07			85% confidence, +/- 1.5 mph
4	Freda Villa between Saunders Ave and Due West Ave	436	4.24	✓		
5		430	5.51	✓		
6		419	7.06	✓		
7	Jones Ave at Capitol View Ave	1436	4.58	✓		
8		1421	5.50	✓		
9		1399	5.30	✓		
10	Jones Ave at Capitol View Ave	602	5.89	✓		
11		n/a				No count available
12		631	5.26	✓		
13	Tanglewood Dr at Ruskin Ave	33	6.65			85% confidence, +/- 2 mph
14		38	6.69			85% confidence, +/- 2 mph
15		51	6.22			85% confidence, +/- 1.5 mph
16	Pinehurst Dr at Willow Springs Dr	191	4.14	✓		
17		200	5.92	✓		
18		249	6.30	✓		
19	Pinehurst Dr at Willow Springs Dr	208	4.16	✓		
20		170	5.92		✓	
21		165	6.61			95% confidence, +/- 1.5 mph
22	Dutchmans Dr and Albany Dr near their intersection	158	4.59	✓		
23		155	5.63		✓	
24		166	6.79			95% confidence, +/- 1.5 mph
25	Dutchmans Dr and Albany Dr near their intersection	137	5.82		✓	
26		150	6.25		✓	
27		178	6.93		✓	
28	Dozier Pl between Trinity Ln and Gallatin Pk	n/a				No count available
29		434	6.05	✓		
30		432	7.03	✓		
31	Maxey Ln at Branch St	176	4.45	✓		
32		179	6.27		✓	
33		190	7.82			95% confidence, +/- 1.5 mph
34	Lake Parkway Ct at Port Anadarko Trail	85	5.24			85% confidence, +/- 1.5 mph
35		101	7.36			85% confidence, +/- 2 mph
36		99	6.83			85% confidence, +/- 1.5 mph
37	Valley Brook Rd between Cross Creek and Woodmont	1644	4.69	✓		
38		1641	5.01	✓		
39		1663	5.33	✓		
40	Valley Brook Rd between Cross Creek and Woodmont	1300	6.33	✓		
41		n/a				No count available
42		1309	4.48	✓		
43	Neese Dr at Glencliff Rd	1029	3.97	✓		
44		1026	5.87	✓		
45		1027	6.27	✓		
46	Neese Dr at Glencliff Rd	1397	2.50	✓		
47		1317	4.95	✓		
48		1379	5.50	✓		

Notes:
1. Confidence level to within +/- 1 mph.
Source: Gresham, Smith and Partners

FIGURE 3 - 85th Percentile Speed Approaching Curve
Filtered Data Locations

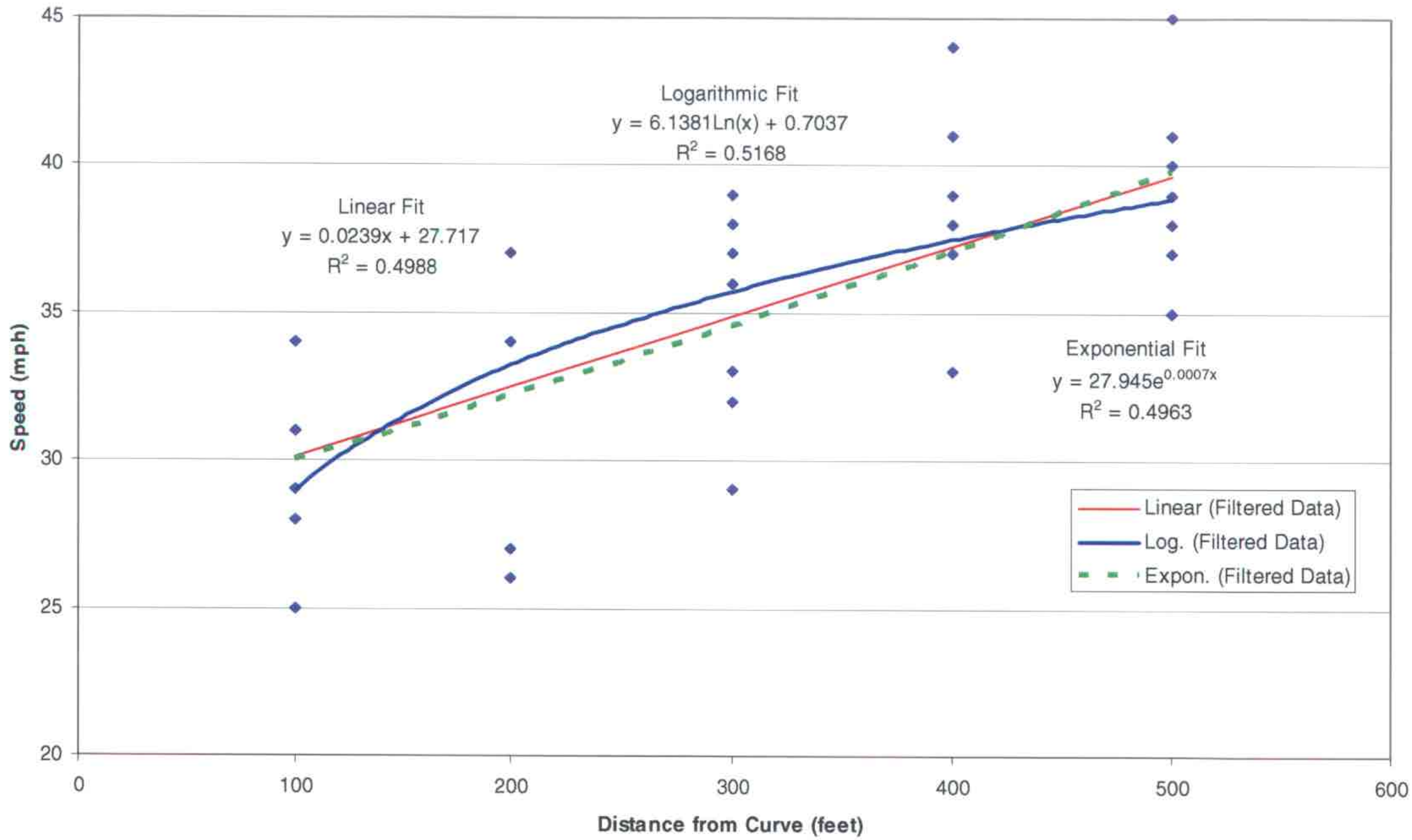
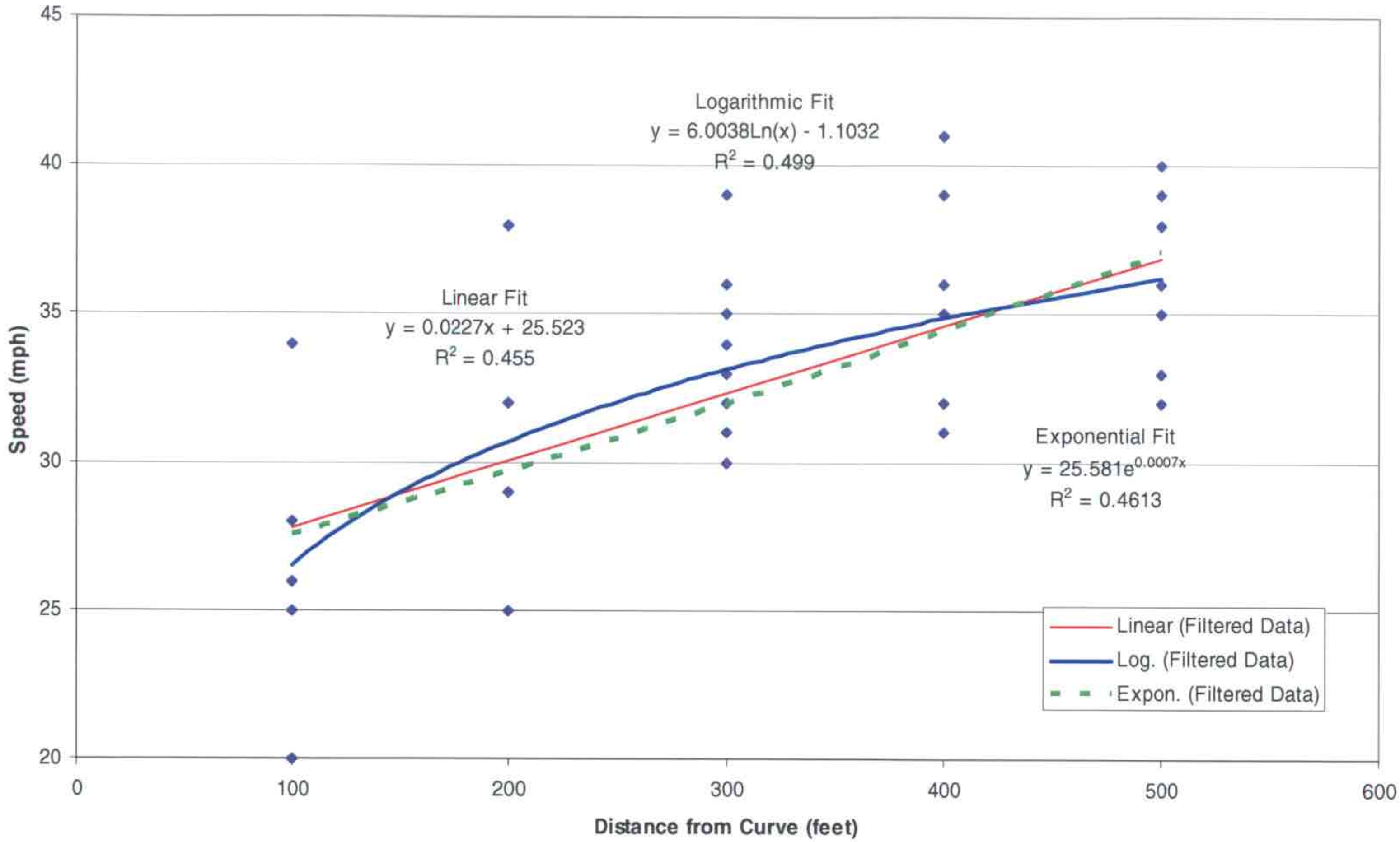


FIGURE 4 - 85th Percentile Speed Departing Curve

Filtered Data Locations



CURVE SUBSETS

The curve locations were subdivided into curve types following a natural demarcation of curvature radius. All of the study curves had either a radius of curvature of 80 feet or less or a radius of curvature of 190 feet or more. That is, no study curves had a radius of curvature between 100 feet and 190 feet.

Tight curves were defined as having a radius of curvature of 100 feet or less. Of the 14 curve approaches analyzed for this study, 10 had a radius of curvature less than 100 feet. Radii ranged from 35 feet to 80 feet.

Gentler curves were defined as having a radius of curvature of 190 feet or more. There were 4 curve approaches that qualified under this definition as gentler curves. In this subset, radii ranged from 190 feet to 300 feet.

APPROACHING CURVE

The average 85th percentile speed for vehicles approaching a tight curve was 34.4 mph. Linear regression for vehicles approaching a tight curve revealed a clear trend of decreasing speed, with an r-squared value of 0.59. The logarithmic curve and exponential curve r-squared values are 0.57 and 0.60, respectively. The trend lines for speeds approaching tight curves are shown in **Figure 5**. As seen in the figure, vehicle speeds decrease to the 30 mph level around 150 feet from the point of curvature.

The average 85th percentile speed for vehicles approaching a gentler curve was 37.0 mph. In contrast to the tight curve data set, a trend for decreased speed with proximity to the point of curvature is noticeable but not dramatic. The r-squared values for linear regression and the exponential curve are both 0.55 and the r-squared value for the logarithmic curve is 0.61. The trend lines for speeds approaching gentler curves are shown in **Figure 6**. As seen in Figure 6, vehicle speeds are not expected to decrease to the 30 mph level.

DEPARTING CURVE

The average 85th percentile speed for vehicles departing a tight curve was 31.6 mph. Linear regression for vehicles approaching a tight curve revealed a clear trend of increasing speed, with an r-squared value of 0.65. The trend lines for speeds departing tight curves can be seen in **Figure 7**. As seen in the figure, vehicle speeds reach the 30 mph level around 250 feet from the point of curvature.

The average 85th percentile speed for vehicles departing a gentler curve was 35.1 mph and a trend for increasing speed away from the curve is noticeable but, again, not dramatic. The r-squared values for the linear regression, the logarithmic curve, and the exponential curve are all 0.12. The trend lines for speeds departing tight curves can be seen in **Figure 8**. As seen in the figure, vehicle speeds are not expected to be below the 30 mph level.

FIGURE 5 - 85th Percentile Speed Approaching Curve
Tight Curves, Filtered Data Points

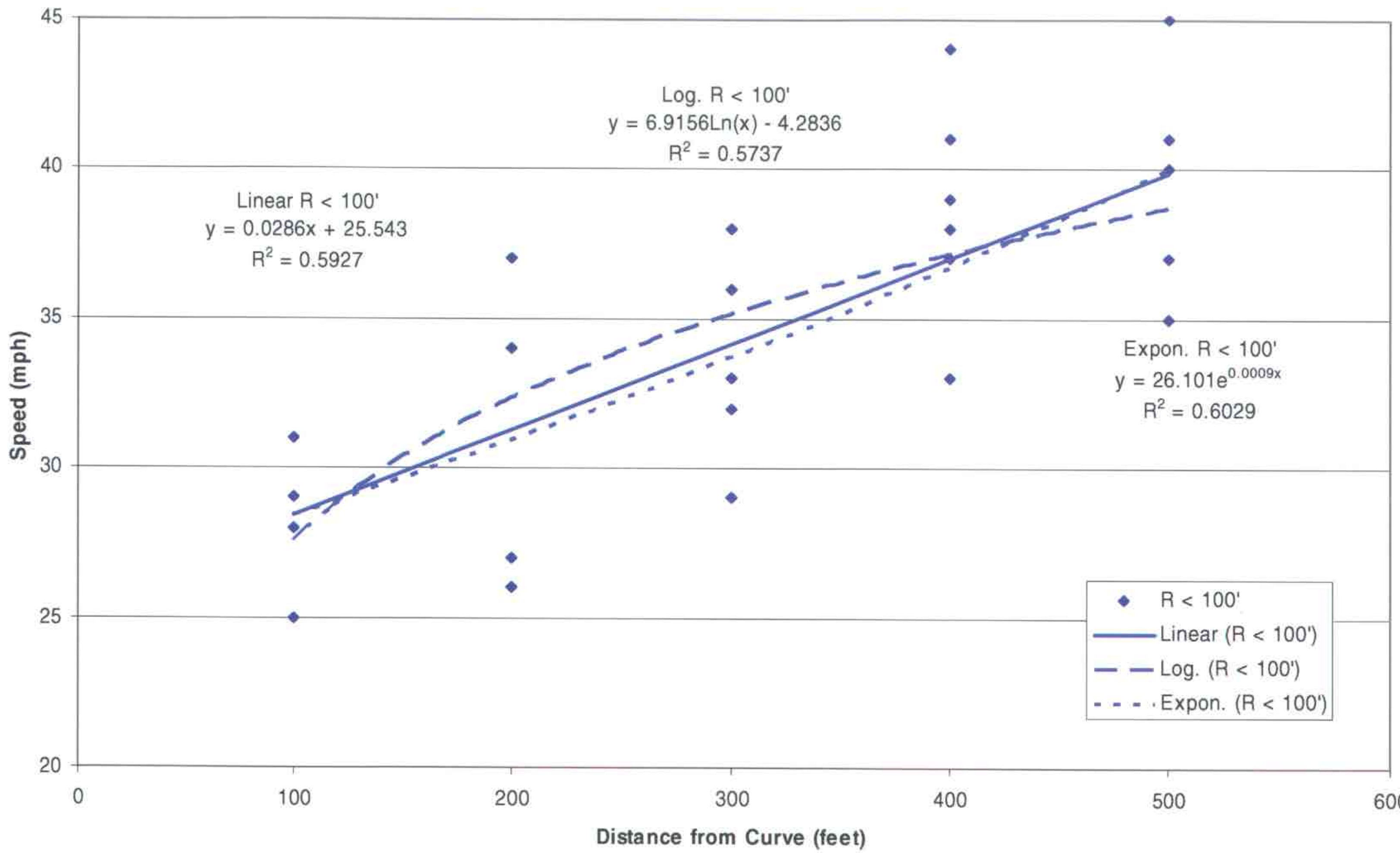


FIGURE 6 - 85th Percentile Speed Approaching Curve
Gentle Curves, Filtered Data Points

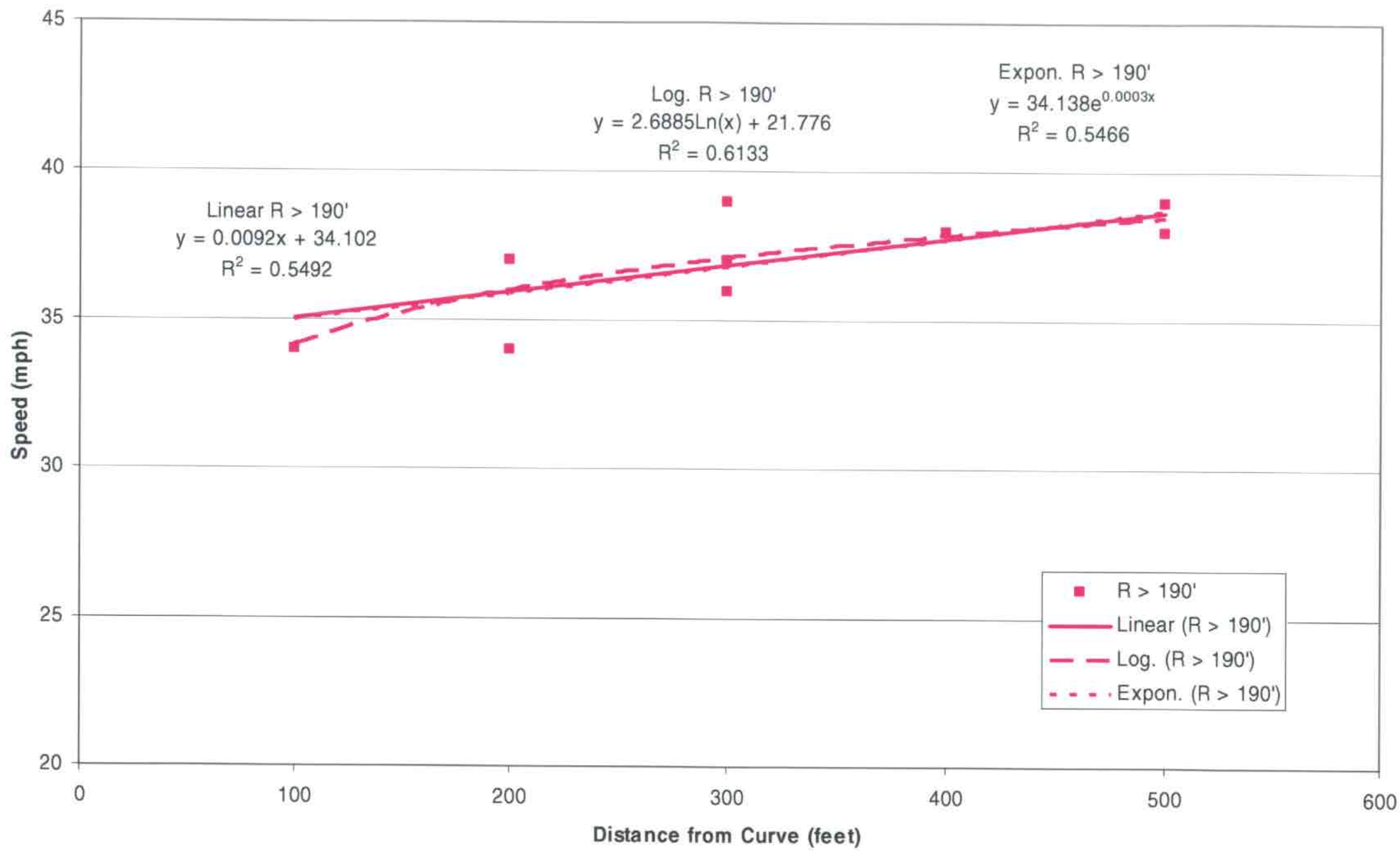


FIGURE 7 - 85th Percentile Speed Departing Curve

Tight Curves, Filtered Data Points

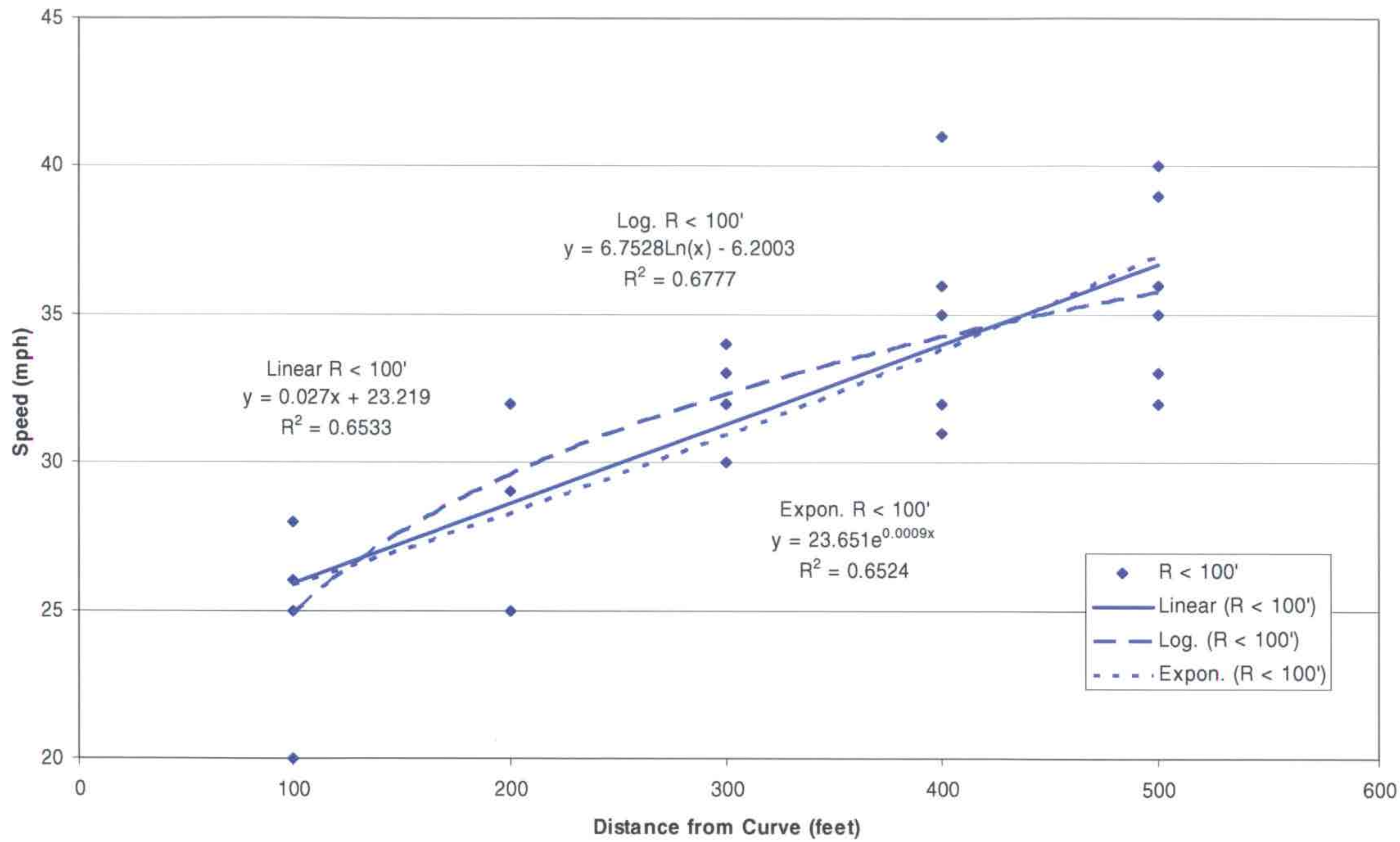
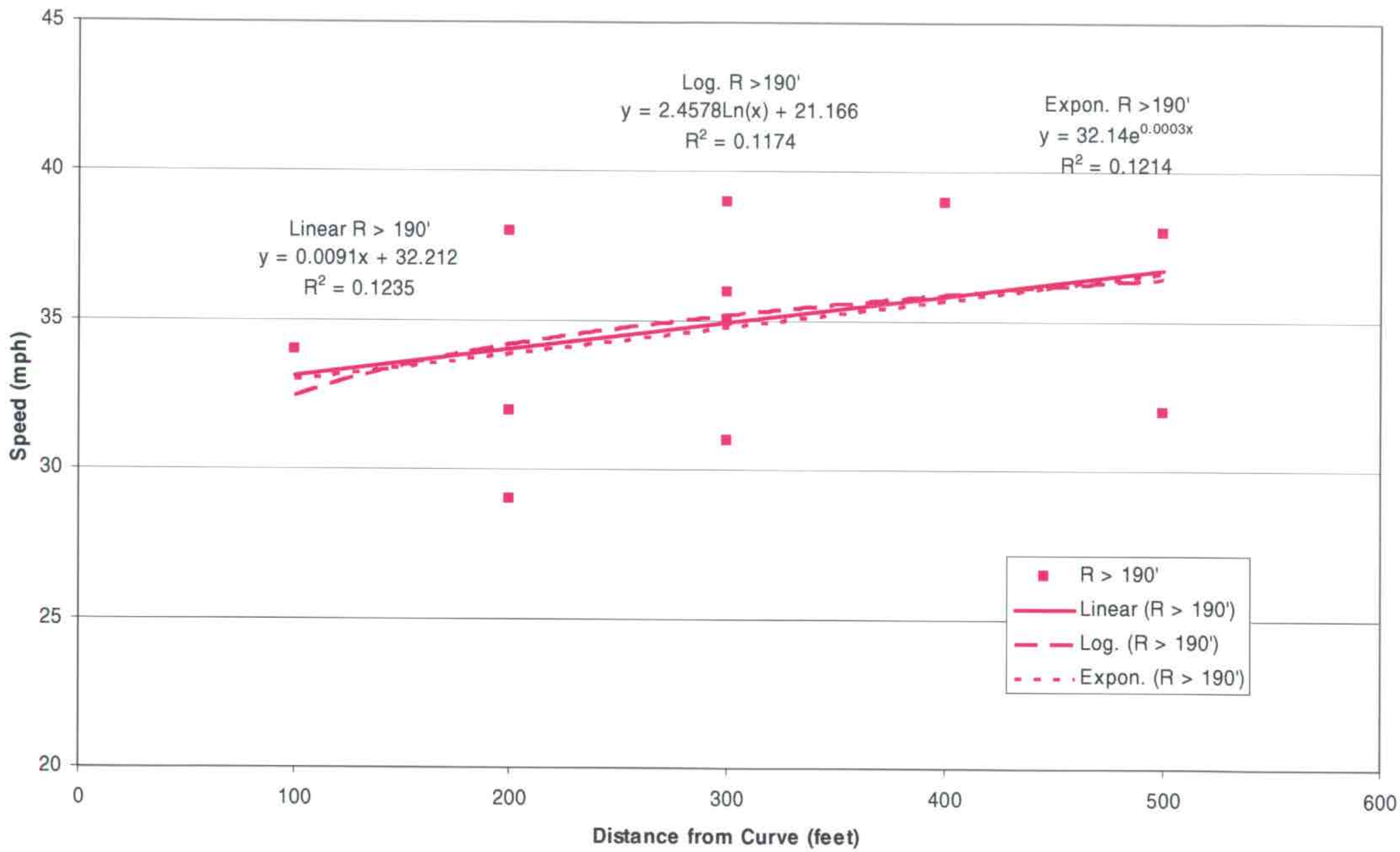


FIGURE 8 - 85th Percentile Speed Departing Curve
Gentle Curves, Filtered Data Points



Other Published Study Results

Published Literature

What other studies were examined?

"Traffic Calming Design Standards for New Residential Streets: A Proactive Approach" (Gwinnett County, Georgia)

Published Results

What did the examined studies conclude?

The Gwinnett County study examined, among other things, the effect of horizontal curve design on operating speeds. A number of curves with varying degrees of curvature and radii were studied and the 85h percentile operating speeds were recorded. The speeds were recorded by tube counters at the point of curve tangency.

No model could be found to adequately predict the relationship of design factors on operating speed (all model relationships were statistically insignificant). However, the study made a reasonable grouping of data points which showed most 85^{th} percentile operating speeds below 30 mph. (The study noted that residents express concerns about residential speeding when speeds are in excess of 30 mph.) Based on this grouping, the study then presented a table showing curve values required to maintain operating speeds in the 25-30 mph range. According to this table, a curve radius of 100 feet should be used for curve angles between 30 and 40 degrees, a radius between 120 and 130 feet should be used for angles between 41 and 50 degrees, and a curve radius between 120 and 150 feet should be used for curve angles greater than 50 degrees.

These design guidelines are cited in the study's conclusion as one of a set of measures for traffic calming on new residential streets. The study states that the preferred design, of new residential streets, to keep operating speeds under 30 mph is a curvilinear design which incorporates the above cited horizontal curve guidelines as well as the study's recommended maximum length of roadway (500 feet) between speed control points, the speed control points in this case being the horizontal curves.

Correlation of Results

Do the results from the MPW study effort correspond with other studies' results?

Phase 2 of this traffic calming study examined the relationship between vehicle operating speed and horizontal curvature, as did the Gwinnett County study. However, the nature of the curves studied and the points of measurement differed between the studies. Where the Gwinnett County study measured speeds at the point of curvature for curves of varying curve angles, this study measured speeds on the tangent before the point of curvature on curves that were all of 90 degree alignments. Also, the Gwinnett County only recorded approach speeds while the MPW study recorded approach and departure speeds. Therefore, unless otherwise stated, any comparison of MPW speeds to Gwinnett County speeds will be for approach speed only.

One would expect that the operating speeds reported in the Gwinnett County study would be somewhat lower than those for the MPW study. But, recognizing that the Gwinnett County speeds were recorded at the point of curvature, a more proper comparison would use only the speeds from this MPW study recorded closest to the point of curvature, which were the seven locations at 100 feet from the point of curvature. In the Gwinnett County study, for a 90 degree alignment, there were five locations with 85th percentile speed below 30 mph and two locations above 30 mph. The seven MPW study locations at 100 from the point of curvature also showed five locations with 85th percentile speed below 30 mph and two locations above 30 mph. This suggests a high correlation between the two studies' speed data.

Comparison Conclusions

What conclusions can be drawn from a comparison with other studies?

Based on the correlation of data between this study for metro Nashville and the Gwinnett County study, it would appear that the conclusions of the Gwinnett County study can be transferred to the metro Nashville area. Namely, that the design of horizontal curves can be harnessed as a traffic calming measure for new residential streets, and that the design guidelines can be used to maintain operating speeds below 30 mph.

Conclusions

Horizontal curves with 90 degree alignments appear effective in reducing vehicle speeds, though the radius of curvature is a key determinant to what extent speeds are reduced. This study has shown that curves with a radius of curvature less than 100 feet are more effective at reducing speeds than other, gentler curves. A relationship to predict vehicle speed at a specific distance from curvature was difficult to identify from the data (that is, the relationship would not have a high statistical relevancy). However, data from the study clearly shows that a vehicle's speed can be expected to be lower the closer the vehicle is to the curve, and that a vehicle's speed is likely to be lower departing from a 90 degree curve than approaching that curve. An average speed reduction of 2.8 mph was observed for vehicles departing a tight curve, and an average speed reduction of 1.9 mph for was observed for vehicles departing a gentler curve. Therefore, despite being able to say that a vehicle's speed will decrease as it approaches a curve, it is difficult to predict precisely what that speed will be.

When using 90 degree horizontal curves on residential streets to maintain vehicle speeds at the 30 mph level or lower, only tight curves, with a radius of curvature of 100 feet or less, should be used because more gentle, sweeping curves do not show an ability to slow vehicle speeds. Data from this study suggest that tight curves should be placed 400 feet apart (measured from the points of curvature) in order to maintain 85th percentile vehicle speeds at 30 mph or less. This conclusion has been reached by noting that vehicle speeds approaching a tight curve decrease to 30 mph around 150 feet from the point of curvature and that vehicle speeds departing a tight curve reach 30 mph around 250 feet from the point of curvature. The recommended curve spacing of 400 feet compares reasonably to the spacing recommendation of 500 feet included in the Gwinnett County study.

APPENDIX A

The analysis contained in this appendix is intended as a supplement to the Metro Traffic Calming Phase 2 report (March 3, 2004). The Phase 2 report focused on horizontal residential curve designs with 90 degree alignments and its effect on vehicle travel speeds. Speeds were evaluated on both the approach and the departure from curves in order to determine the effect, if any, that curves have on speed reduction. The study concluded that horizontal curves with 90 degree alignments appear effective in reducing vehicle speeds, though the radius of curvature is a key determinant to what extent speeds are reduced. The study showed that curves with a radius of curvature less than 100 feet are more effective at reducing speeds than other, gentler curves. The study was not able to identify a relationship to predict vehicle speed at a specific distance from curvature, however.

As a supplement to the Phase 2 work, we had determined that the physical characteristics of the roadway and surrounding environments would be examined in order to determine if any of these characteristics could be correlated with the Phase 2 findings. Specifically, it was hoped that vehicle speeds and speed reductions could be correlated with the physical characteristics of the roadway and the surrounding environment.

Because the Phase 2 report found that horizontal curves with a tight radius of curvature were more effective at reducing vehicle speeds, the supplemental examination was restricted to the ten tight curves contained in Phase 2. A number of physical factors were considered at each curve which could affect vehicle speeds:

- Roadway width
- Pavement quality
- Roadway signage
- Roadway Striping
- Grade
- Sight lines
- Side friction factors
    - On-street parking
    - Utility poles
    - Trees and shrubbery
    - Berms and ditches
- Channelization factors
    - Curb and gutter
    - Shoulders
    - Sidewalks

The pavement quality and sight lines were found to be virtually the same at each curve location, and so these two factors were eliminated as possible determinants of the different speeds at each curve. The rest of the potential factors were observed in various locations, as summarized in Table A-1.

Table A-1 – Study Curve Physical Characteristics Summary

					Side Friction Factors				Channelization Factors		
Curve Number, Street	Lane Widths	Warning Signage	Roadway Striping	Grade	Parking	Utility Poles	Trees/ Shrubs	Berms/ Ditches	Curb/ Gutter	Shoulders	Sidewalks
1. Pierce Ave	9 ft	Yes	Yes	Uphill approach	✗	✗	✓	✓	✗	✗	✗
4. Tanglewood Dr	10 ft	Yes	No	Level	✓	✗	✗	✗	✗	✗	✗
5. Pinehurst Dr	10 ft	Yes	No	Downhill approach	✗	✗	✗	✓	✗	✗	✗
5. Willow Springs Dr	10 ft	No	No	Level	✗	✗	✗	✓	✗	✗	✗
6. Dutchmans Dr	15 ft	No	No	Level	✓	✗	✗	✗	✓	✗	✗
7. Dozier Pl	10.5 ft	Yes	Yes	Hilly	✗	✗	✗	✗	✗	✗	✗
8. Branch St	10 ft	Yes	Yes	Hilly	✗	✓	✓	✓	✗	✗	✗
9. Lake Parkway Ct	12 ft	No	Yes	Uphill approach	✗	✗	✗	✗	✓	✓	✗
11. Neese Dr	10 ft	Yes	No	Hilly	✗	✗	✗	✓	✗	✗	✗
11. Glencliff Rd	10.5 ft	Yes	No	Level	✗	✗	✓	✓	✗	✗	✓

Source: Gresham, Smith and Partners

In general, no correlations were found between vehicle speeds and physical characteristics of the roadway. The physical factors listed above were compared to the approach speed at the furthest measured point from the curve, the departure speed at the furthest measured point from the curve, the decrease in speed from the approach speed to the departure speed at the furthest measured point from the curve, the average approach speed, the average departure speed, and the decrease in average speed from the approach speed to the departure speed. At all locations, the furthest measured point from the curve was either 400 or 500 feet from the point of curvature. See Tables A-2 through A-7 for a summary of Phase 2 travel speed data compared to physical roadway characteristics.

It seems reasonable to assume that roadway width would be a factor in determining travel speeds, but the data at these curves does not support that assumption. Seven of the ten locations have lane widths of either 10 or 10.5 feet. The other three locations have lane widths of 9, 12, and 15 feet. One might expect that the roads with 12 and 15 foot lanes would have higher speeds than the road with 9 foot lanes. However, the wider roads have two of the three lowest approach speeds (33 and 35 mph at furthest point, 30.7 and 32.3 mph on average), and the narrowest road has the third highest approach speed (41 mph at furthest point and 35.3 on average). A look at the departure speeds yields inconsistent results. The wider roads have two of the three lowest departure speeds measured at the furthest point from the curve (31 and 32 mph), and they have the lowest and fifth lowest departure speeds on average (28.7 and 30.3 mph). The narrow road has the fifth lowest departure speed measured at the furthest point from the curve (35 mph) but the third highest departure speed on average (31.7 mph). When looking at the decrease in travel speed between the approach speed and the departure speed, the narrow lane width appears to have more of an effect than the wider roads. The narrow road's speeds decrease the most measured at the furthest point from the curve and third most on average, while the wider roads' speeds do not decrease as much. However, as demonstrated above, the wider roads' approach speeds are among the lowest already and so a small decrease to the departure speeds was not unexpected.

Road signage to caution drivers about an approaching curve cannot be tied to lower speeds in general. Curves with warning signs have the five highest approach speeds measured at the furthest point and on average. The curve with the lowest approach speed (at the furthest point and on average) also has warning signage. It does not seem logical to conclude that the presence of curve warning signs leads to higher travel speeds. What seems more likely is that the design speed of the roadway required the warning signs. That is, the travel speeds caused the signs to be put in place, not the other way around.

Roadway striping at the observed locations has no discernable correlation with travel speeds. The curves with roadway striping seem no more likely to have low or high speeds than the curves without striping.

Table A-2 - Tight Curve Data and Characteristics, Sorted by Approach Speed Measured at the Furthest Point from the Curve

Curve No.	Street	Approach Speed, Furthest from Curve (mph)	Departure Speed, Furthest from Curve (mph)	Speed Decrease, Furthest from Curve (mph)	Average Approach Speed (mph)	Average Departure Speed (mph)	Difference of Average Speed (mph)	Lane Width (ft)	Warning Signage Present?	Roadway Striping Present?	Grade	Side Friction Factors Present	Channelizing Factors Present
4	Tanglewood Dr	33	31	2	29.3	30.0	-0.7	10	yes	no	level	parking, trees	
6	Dutchmans Dr	33	31	2	30.7	28.7	2.0	15	no	no	level	parking	curbs
9	Lake Parkway Ct	35	32	3	32.3	30.3	2.0	12	no	yes	uphill app		7' shoulders, curb
5	Pinehurst Dr	37	35	2	33.7	31.0	2.7	10	yes	no	downhill app	ditch	
5	Willow Springs Dr	37	33	4	34.3	30.0	4.3	10	no	no	level	ditch	
8	Branch St	39	35	4	34.7	31.0	3.7	10	yes	yes	hilly	ditch, mailboxes	
7	Dozier Pl	40	39	1	39.0	37.5	1.5	10.5	yes	yes	hilly	mailboxes	
1	Pierce Ave	41	35	6	35.3	31.7	3.7	9	yes	yes	uphill app	trees, berm, ditch	
11	Glencliff Rd	41	36	5	34.7	29.7	5.0	10.5	yes	no	level	ditch, trees	sidewalks
11	Neese Dr	45	40	5	41.7	38.0	3.7	10	yes	no	hilly	ditch	

Note: All speeds listed are 85th percentile speeds.
Source: Gresham, Smith and Partners

Table A-3 - Tight Curve Data and Characteristics, Sorted by Departure Speed Measured at the Furthest Point from the Curve

Curve No.	Street	Approach Speed, Furthest from Curve (mph)	Departure Speed, Furthest from Curve (mph)	Speed Decrease, Furthest from Curve (mph)	Average Approach Speed (mph)	Average Departure Speed (mph)	Difference of Average Speed (mph)	Lane Width (ft)	Warning Signage Present?	Roadway Striping Present?	Grade	Side Friction Factors Present	Channelizing Factors Present
4	Tanglewood Dr	33	31	2	29.3	30.0	-0.7	10	yes	no	level	parking, trees	
6	Dutchmans Dr	33	31	2	30.7	28.7	2.0	15	no	no	level	parking	curbs
9	Lake Parkway Ct	35	32	3	32.3	30.3	2.0	12	no	yes	uphill app		7' shoulders, curb
5	Willow Springs Dr	37	33	4	34.3	30.0	4.3	10	no	no	level	ditch	
1	Pierce Ave	41	35	6	35.3	31.7	3.7	9	yes	yes	uphill app	trees, berm, ditch	
5	Pinehurst Dr	37	35	2	33.7	31.0	2.7	10	yes	no	downhill app	ditch	
8	Branch St	39	35	4	34.7	31.0	3.7	10	yes	yes	hilly	ditch, mailboxes	
11	Glencliff Rd	41	36	5	34.7	29.7	5.0	10.5	yes	no	level	ditch, trees	sidewalks
7	Dozier Pl	40	39	1	39.0	37.5	1.5	10.5	yes	yes	hilly	mailboxes	
11	Neese Dr	45	40	5	41.7	38.0	3.7	10	yes	no	hilly	ditch	

Note: All speeds listed are 85th percentile speeds.
Source: Gresham, Smith and Partners

Table A-4 - Tight Curve Data and Characteristics, Sorted by Decrease in Speed Measured at the Furthest Point from the Curve

Curve No.	Street	Approach Speed, Furthest from Curve (mph)	Departure Speed, Furthest from Curve (mph)	Speed Decrease, Furthest from Curve (mph)	Average Approach Speed (mph)	Average Departure Speed (mph)	Difference of Average Speed (mph)	Lane Width (ft)	Warning Signage Present?	Roadway Striping Present?	Grade	Side Friction Factors Present	Channelizing Factors Present
1	Pierce Ave	41	35	6	35.3	31.7	3.7	9	yes	yes	uphill app	trees, berm, ditch	
11	Neese Dr	45	40	5	41.7	38.0	3.7	10	yes	no	hilly	ditch	
11	Glencliff Rd	41	36	5	34.7	29.7	5.0	10.5	yes	no	level	ditch, trees	sidewalks
8	Branch St	39	35	4	34.7	31.0	3.7	10	yes	yes	hilly	ditch, mailboxes	
5	Willow Springs Dr	37	33	4	34.3	30.0	4.3	10	no	no	level	ditch	
9	Lake Parkway Ct	35	32	3	32.3	30.3	2.0	12	no	yes	uphill app		7' shoulders, curb
5	Pinehurst Dr	37	35	2	33.7	31.0	2.7	10	yes	no	downhill app	ditch	
4	Tanglewood Dr	33	31	2	29.3	30.0	-0.7	10	yes	no	level	parking, trees	
6	Dutchmans Dr	33	31	2	30.7	28.7	2.0	15	no	no	level	parking	curbs
7	Dozier Pl	40	39	1	39.0	37.5	1.5	10.5	yes	yes	hilly	mailboxes	

Note: All speeds listed are 85th percentile speeds.
Source: Gresham, Smith and Partners

Table A-5 - Tight Curve Data and Characteristics, Sorted by Average Approach Speed

Curve No.	Street	Approach Speed, Furthest from Curve (mph)	Departure Speed, Furthest from Curve (mph)	Speed Decrease, Furthest from Curve (mph)	Average Approach Speed (mph)	Average Departure Speed (mph)	Difference of Average Speed (mph)	Lane Width (ft)	Warning Signage Present?	Roadway Striping Present?	Grade	Side Friction Factors Present	Channelizing Factors Present
4	Tanglewood Dr	33	31	2	29.3	30.0	-0.7	10	yes	no	level	parking, trees	
6	Dutchmans Dr	33	31	2	30.7	28.7	2.0	15	no	no	level	parking	curbs
9	Lake Parkway Ct	35	32	3	32.3	30.3	2.0	12	no	yes	uphill app		7' shoulders, curb
5	Pinehurst Dr	37	35	2	33.7	31.0	2.7	10	yes	no	downhill app	ditch	
5	Willow Springs Dr	37	33	4	34.3	30.0	4.3	10	no	no	level	ditch	
8	Branch St	39	35	4	34.7	31.0	3.7	10	yes	yes	hilly	ditch, mailboxes	
11	Glencliff Rd	41	36	5	34.7	29.7	5.0	10.5	yes	no	level	ditch, trees	sidewalks
1	Pierce Ave	41	35	6	35.3	31.7	3.7	9	yes	yes	uphill app	trees, berm, ditch	
7	Dozier Pl	40	39	1	39.0	37.5	1.5	10.5	yes	yes	hilly	mailboxes	
11	Neese Dr	45	40	5	41.7	38.0	3.7	10	yes	no	hilly	ditch	

Note: All speeds listed are 85th percentile speeds.
Source: Gresham, Smith and Partners

Table A-6 - Tight Curve Data and Characteristics, Sorted by Average Departure Speed

Curve No.	Street	Approach Speed, Furthest from Curve (mph)	Departure Speed, Furthest from Curve (mph)	Speed Decrease, Furthest from Curve (mph)	Average Approach Speed (mph)	Average Departure Speed (mph)	Difference of Average Speed (mph)	Lane Width (ft)	Warning Signage Present?	Roadway Striping Present?	Grade	Side Friction Factors Present	Channelizing Factors Present
6	Dutchmans Dr	33	31	2	30.7	28.7	2.0	15	no	no	level	parking	curbs
11	Glencliff Rd	41	36	5	34.7	29.7	5.0	10.5	yes	no	level	ditch, trees	sidewalks
4	Tanglewood Dr	33	31	2	29.3	30.0	-0.7	10	yes	no	level	parking, trees	
5	Willow Springs Dr	37	33	4	34.3	30.0	4.3	10	no	no	level	ditch	
9	Lake Parkway Ct	35	32	3	32.3	30.3	2.0	12	no	yes	uphill app		7' shoulders, curb
5	Pinehurst Dr	37	35	2	33.7	31.0	2.7	10	yes	no	downhill app	ditch	
8	Branch St	39	35	4	34.7	31.0	3.7	10	yes	yes	hilly	ditch, mailboxes	
1	Pierce Ave	41	35	6	35.3	31.7	3.7	9	yes	yes	uphill app	trees, berm, ditch	
7	Dozier Pl	40	39	1	39.0	37.5	1.5	10.5	yes	yes	hilly	mailboxes	
11	Neese Dr	45	40	5	41.7	38.0	3.7	10	yes	no	hilly	ditch	

Note: All speeds listed are 85th percentile speeds.
Source: Gresham, Smith and Partners

Table A-7 - Tight Curve Data and Characteristics, Sorted by Difference in Average Approach and Departure Speed

Curve No.	Street	Approach Speed, Furthest from Curve (mph)	Departure Speed, Furthest from Curve (mph)	Speed Decrease, Furthest from Curve (mph)	Average Approach Speed (mph)	Average Departure Speed (mph)	Difference of Average Speed (mph)	Lane Width (ft)	Warning Signage Present?	Roadway Striping Present?	Grade	Side Friction Factors Present	Channelizing Factors Present
11	Glencliff Rd	41	36	5	34.7	29.7	5.0	10.5	yes	no	level	ditch, trees	sidewalks
5	Willow Springs Dr	37	33	4	34.3	30.0	4.3	10	no	no	level	ditch	
1	Pierce Ave	41	35	6	35.3	31.7	3.7	9	yes	yes	uphill app	trees, berm, ditch	
11	Neese Dr	45	40	5	41.7	38.0	3.7	10	yes	no	hilly	ditch	
8	Branch St	39	35	4	34.7	31.0	3.7	10	yes	yes	hilly	ditch, mailboxes	
5	Pinehurst Dr	37	35	2	33.7	31.0	2.7	10	yes	no	downhill app	ditch	
9	Lake Parkway Ct	35	32	3	32.3	30.3	2.0	12	no	yes	uphill app		7' shoulders, curb
6	Dutchmans Dr	33	31	2	30.7	28.7	2.0	15	no	no	level	parking	curbs
7	Dozier Pl	40	39	1	39.0	37.5	1.5	10.5	yes	yes	hilly	mailboxes	
4	Tanglewood Dr	33	31	2	29.3	30.0	-0.7	10	yes	no	level	parking, trees	

Note: All speeds listed are 85th percentile speeds.
Source: Gresham, Smith and Partners

Only four of the tight curve locations could fairly be described as level. These locations include the two lowest approach speeds measured from the furthest point from the curve but also the fifth and ninth lowest speeds. A similar pattern is observed for departure speeds measured from the furthest point from the curve. Looking at the average approach speeds, curves on a level grade had the two lowest speeds and the fifth and seventh lowest speeds. Level curves had the four lowest average departure speeds. Looking at the decrease in speeds between the approach speed and departure speed, level curves had some of the highest and lowest speed decreases, both determined by average speeds and speeds measured from the furthest point on the curve. However, the two level roads that had the lowest speed decreases are also the two roads that have the lowest approach and departure speeds, so only a small decrease was not unexpected.

Of the curves not on a level grade, some had uphill approaches, some had hilly approaches (both uphill and downhill sections), and one had a downhill approach. It was difficult to correlate vehicle speeds to specific grade observations. For example, the curve with the downhill approach (and by definition, an uphill departure) had one of the lower approach speeds and one of the higher departure speeds, which seems counterintuitive. Also, the curves with uphill approaches (and downhill departures) showed both high and low approach and departure speeds.

Various side friction elements were present at nine of the ten tight curve locations. Side friction elements that were observed include: ditches and drop-offs, berms, trees, on-street parking, and large mailboxes that were close to the road. Most of the side friction elements could not be used to predict speeds because they were located on curves with both higher speeds and lower speeds. However, at only two curves was on-street parking observed, and these two locations had the two lowest approach speeds both on average and measured from the furthest point from the curve. These two locations also had the two lowest departure speeds measured from the furthest point from the curve, and they had the first and third lowest departure speeds on average.

According to the observations and Phase 2 data, the presence of side friction elements on a roadway is not, in itself, a strong predictor of low speeds compared to a roadway without side friction elements. The only tight curve without any substantial side friction elements also had some of the lowest travel speeds.

One might expect that channelization factors such as curbs, sidewalks, and shoulders would lead to higher travel speeds because drivers would feel safer with a clear separation from the surrounding land. However, no correlation between channelization factors and speeds was possible at the observed locations. Of the three curve locations with channelization factors present, two have two of the lowest speeds and only one has high speeds.

In conclusion, because no correlation could be found between vehicle speeds and physical roadway characteristics, it is impossible to make any specific recommendations about the design or placement of physical characteristics to achieve a specific lower speed. At most it appears that roadways with on-street parking may encourage lower approach and departure speeds, and that level roadways may encourage lower departure speeds. However, it is not possible to say definitively that these characteristics would be enough to strongly predict lower speeds.