**Traffic Control Devices Pooled Fund Study**

# Pavement Markings for Speed Reduction

## Final Report

## December 2004

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This research project was sponsored by the Traffic Control Devices Pooled Fund Study, TPF-5(065). Members of the Pooled Fund Study Panel are as follows:

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The objective of the Traffic Control Devices Pooled Fund Study (TCD PFS) is to assemble a group composed of State and local agencies, appropriate organizations and the FHWA to 1) establish a systematic procedure to select, test, and evaluate approaches to novel TCD concepts as well as incorporation of results into the MUTCD; 2) select novel TCD approaches to test and evaluate; 3) determine methods of evaluation for novel TCD approaches; 4) initiate and monitor projects intended to address evaluation of the novel TCDs; 5) disseminate results; and 6) assist MUTCD incorporation and implementation of results.

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## EXECUTIVE SUMMARY

In the United States, speeding is considered to be a contributing factor in about 30 percent of fatal crashes according to the USDOT Speed Management Team Work Plan, written in 2000. Because higher vehicle speeds result in more severe crashes, if vehicle speeds can be reduced in dangerous road sections, then presumably safety can be improved. One speed reduction method that has shown promise in past research is to use pavement marking patterns to give drivers the perception that they are traveling faster than they really are. This illusion is created by making the travel lanes appear narrow or adding optical patterns to the roadway surface.

The present research project examined whether perceptual countermeasures such as pavement marking patterns have the potential to reduce vehicle speeds. Sites were chosen in New York, Mississippi, and Texas. Speed measures were taken to evaluate the effectiveness of the markings during three phases: 1) before installation; 2) shortly after the installation; and 3) six months after the installation to examine long-term effects at each site.

The markings resulted in a decrease in overall vehicle speeds with total vehicles as well as specific classifications of vehicles. There were also reductions in speed with vehicles traveling with headways greater than four seconds. Speed reductions were found to be higher at the New York site and Mississippi site, which were interstate and arterial roadways whereas in Texas where the markings were placed on a local road, the effects were not as large. The results of the analysis will be used to make recommendations to the Federal Highway Administration (FHWA) Manual on Uniform Traffic Control Devices (MUTCD) team with input from the Traffic Control Devices Pooled Fund Study members.

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# ACKNOWLEDGEMENTS

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# INTRODUCTION

## Statement of Problem

In the United States, speeding is considered to be a contributing factor in about 30 percent of fatal crashes (US DOT, 2000). In an attempt to reduce speeds on roadway segments where speed is considered to be a safety concern, various pavement marking patterns that create the appearance of narrowing and/or increasing speed have been considered as a relatively low-cost countermeasure. Perceptual countermeasures are one potential method of influencing motorists to slow down, and ultimately, to save lives. These perceptual techniques might be useful at lowering speeds in a variety of driving situations such as work zones, curves, roundabouts, and toll plazas. Other similar treatments include the use of other text and symbol pavement markings that get the attention of motorists. Although the perceptual countermeasures are not widely used in the United States, some treatment alternatives have undergone experimentation with varying results. There are several pavement marking patterns that have been tried in the field as well as in simulator studies. Further evaluation of marking pattern alternatives is needed to determine which patterns are best at encouraging drivers to maintain safe and appropriate speeds. This paper describes how motorists perceive speed, several pavement marking treatments with a high probability of success based on previous research, and three field locations in New York, Mississippi, and Texas where the markings were evaluated.

## Research Goals

There are several pavement marking patterns that have been field tested as well as tested in simulator studies. One of these markings was examined in this study. The goals of this study are to:

- Determine a low-cost pavement marking treatment with a high probability of success based on previous research
- Determine the effectiveness of the marking through a field evaluation at three different locations
- Provide recommendations for pavement marking use as a speed reduction device for possible inclusion in the Manual on Uniform Traffic Control Devices (MUTCD).

# LITERATURE REVIEW

## How Motorists Perceive Speed

### *Road Factors*

In a report entitled *Down With Speed*, the New Zealand Accident Compensation Corporation and Land Transport Safety Authority discussed many roadway factors and their impacts on speed (2000). The report points out that psychological factors play a major role on the speed motorists select and that decisions depend on both perceptual and cognitive factors. That is, motorists rely on the roadway environment in order to select an appropriate speed. The speed decision made is most likely related to the level of safety that a motorist feels while driving a particular roadway segment. A driver's perception of his or her environment will influence the speed that he or she will travel. The New Zealand report describes four factors that affect speed selection decision, including roadside development, physical attributes of the road, traffic-related characteristics, and operating conditions (e.g., time of day and weather).

The first road factor that the report discusses is roadside development. If there is more development on the roadside, then motorists are more apt to reduce their speeds. For example, drivers traveling on rural roads are much more likely to drive faster than on urban roads with a lot of roadside development. In urban areas, roadside development usually consists of houses and buildings whereas in rural areas, roadside development typically consists of trees and other forms of vegetation.

The second road factor deals with the physical attributes of the road. Various attributes such as the number of lanes, lane width, pavement markings, geometry, and smoothness have generally been shown to play a role in a motorist's speed choice. Generally, motorists will travel at a much faster speed on four-lane divided highways as opposed to two-lane highways. Decreasing the lane width at a similar facility compared to one with a wider lane width will generally lower the average speeds. Pavement markings of varying widths have been used on curves to exaggerate the appearance of curve sharpness to get motorists to slow down. Another major physical attribute is roadway geometry. Motorists tend to drive slower on roads with horizontal and vertical curvature as opposed to a straight road on level terrain. Additionally, motorists will generally drive faster on a smooth roadway as opposed to a rough roadway surface.

The third road factor discussed in *Down with Speed* concerns traffic related characteristics. As traffic volume and density of a roadway increase, vehicle speed will decrease. Additionally, as motorists approach an intersection, there is generally a change in speed. The sight distance at the intersection is considered to be a major factor in determining the speed a motorist will choose to proceed through an intersection.

The final road factor discussed concerns the time of day and weather. In Sweden, for example, speeds tended to be higher at night than during the day, perhaps because of a decrease in congestion at night. Additionally, when roadway surfaces are wet or covered in snow, studies have shown that motorists are more apt to decrease their speed.

### *Perceptual Cues*

In a presentation entitled *Driver Speed Estimation: What Road Designers Should Know,* Alison Smiley presented the concept of perceptual cues for speed estimation (Smiley 1999). She states that motorists primarily use peripheral vision for determining speed. If only the central field of view is used to determine speed, the ability to estimate speed is poor; alternatively, if only the peripheral view is used, then motorists better estimate their speed. Another major perceptual cue is eye height. When a motorist is closer to the road, angular velocities appear higher and so sensations of faster speeds are stronger. Smiley cites the example that a sports car feels faster at a given speed than a truck at the same speed simply because it is closer to the roadway. Noise level also is an important perceptual cue to speed, but technology may be reducing its influence. For example, by making cars quieter and building roads with smoother pavements, a motorist's sensitivity to his or her speed will probably decrease.

### *Environmentally Adapted and Self-Explaining Roads*

The concept of achieving a reduction in speed due to the roadway environment is known as an environmentally adapted road. In a report entitled *Recommendations for Speed Management Strategies and Policies*, Kallberg et al. describe an environmentally adapted road as "reshaping the environment in a way that the visual impression, together with the changed design of the road, makes the driver lower his speed." Examples would include village gateways, rumble strips, and changes to the road surface. The effectiveness of these treatments on reducing speed has been significant; however, generally there are high installation costs involved with changing the environment surrounding a road.

Self-explaining roads are defined by Kallberg et al. (1998) as "roads with a design that evokes correct expectations from road users, which in turn leads to correct choices of speed." Generally, there is less speed variation when self-explaining roads are developed. Safety is also improved because motorists know what to expect from the particular class of highway judging from the experience of similar roads.

## **Conventional Techniques For Speed Reduction**

Before discussing types of perceptual countermeasures to speeding, it is important to understand what conventional countermeasures have been used. A report written by Eric Meyer (2000) describes several conventional countermeasures, with particular attention to those used in work zone applications (see Figure 1). The most obvious of these are posted speeds. Posted speeds can be either regulatory signs or warning signs. Other conventional countermeasures are flagging and police traffic control. The use of flagging and police traffic control can be effective; however, both are very expensive and it is relatively impossible to have a large enough work force to cover every possible high-risk location. Regulatory signs, warning signs, and flagging control are all countermeasures to speeding that can be found in the Manual on Uniform Traffic Control Devices (MUTCD, 2001); however, it is difficult without enforcement to expect a large amount of compliance.

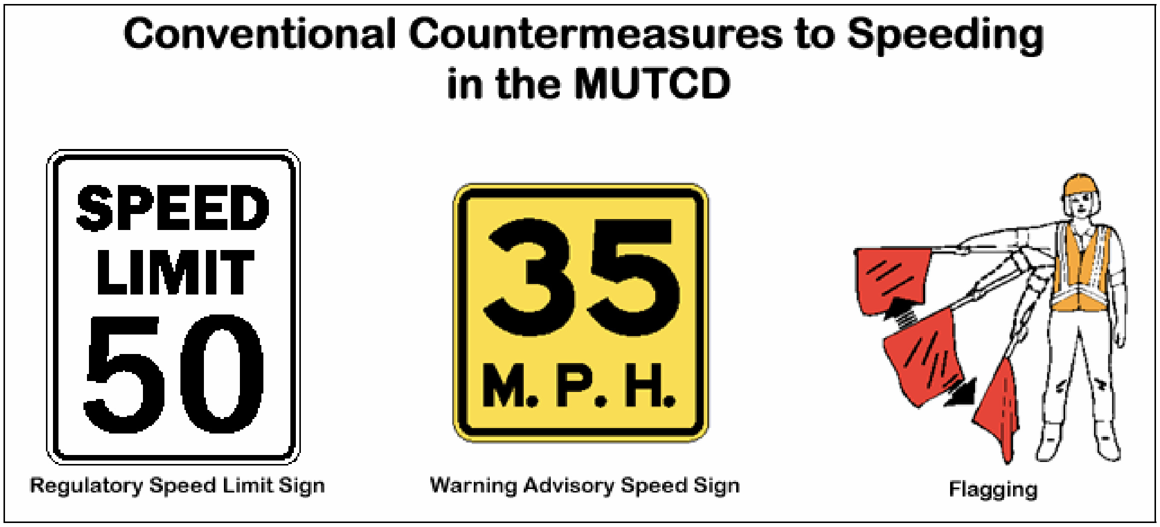


**Figure 1: Conventional countermeasures to speeding (source: MUTCD)**

Law enforcement (e.g. speed traps) is another countermeasure to speeding; however, similar to the use of flagging and police traffic control, it is very expensive. Changeable message signs can be used as well to reduce speeds, particularly in work zones; however, over the long term, the signs may cease to be effective. The last countermeasure that Meyer discusses is the use of lane width restrictions. They have proven effective at reducing speed; however, there are several safety issues involved. When lane reductions are used, studies have shown that there tends to be an increase in speed variance as well as an increase in erratic maneuvers. Although law enforcement and some conventional countermeasures proven somewhat successful in reducing speed, most of the countermeasures are very expensive and thus are not feasible for widespread use.

## Perceptual Countermeasures for Speed Reduction

Both longitudinal as well as transverse pavement markings have been used to influence drivers' perceptions of their roadway environment. Longitudinal markings consist of either centerlines or edge lines and can be used to reduce lane widths. Some studies (Yagar and Van Aerde, 1984) have found a reduction in speed as lane width decreases. However, several studies (Lum, 1984; Richards et al., 1985) did not show any decrease in speeds when lane widths were decreased using pavement markings. Both studies only investigated the effects of using pavement markings alone to reduce speed without any forms of hatching or other markings on the shoulder. Another study (Retting et al., 2000) looked into the effects of speeds on markings used to narrow freeway exit ramps to reduce speeds. In their study, results indicated that the added markings were effective in reducing speeds by approximately 1 mph on average, but the study used diagonal lines next to the edge lines rather than simply edge lines alone.

Transverse pavement markings, a series of lines or bars (typically white) which are perpendicular to the path of travel and are placed across the road like rumble strips, are the most commonly used form of pavement markings in speed reduction. Transverse pavement markings typically take the form of either transverse bars or transverse chevrons and are placed closer to each other to give the perception that the driver is speeding up as a driver drives down the roadway. In a Kansas study (Meyer, 2000), transverse bars were placed in a work zone in which three patterns were used. The first pattern was a "leading pattern" with constant widths and constant spacing to warn drivers of the upcoming work zone. The second pattern or "primary pattern" consisted of bars with varying widths and varying distances which led up to the work zone. The actual "work zone pattern" consisted of four sets of six bars spaced every 500 feet. The results showed a decrease in speeds at a 95% confidence level; however, the magnitudes of the speed reductions were fairly small. An earlier study (Agent, 1980) was performed on a sharp curve with a high accident rate in Kentucky. In six years, there were 48 accidents at the location and speed was considered as a contributing factor in 36 of the 48. There was a reduction in speeds six months after the installation compared to before the installation; however, the long-term effects during nighttime were much smaller than the long-term effects during daylight hours.

A recent study by Drakopoulas and Vergou (2003) evaluated converging chevron pavement marking patterns in Wisconsin. These markings were placed on Interstate 94 on a freeway exit ramp at the Mitchell Interchange in Milwaukee, Wisconsin as shown in Figure 2. The mean speed of the exit ramp was determined to be 70 mph (113 km/h) before the installation and 53 mph (85 km/h) twenty months after the installation for an overall reduction of 17 mph (27 km/h).

**Figure 2: Converging Chevron Pavement Marking in Wisconsin**
**Source:** ***Pavement Markings Shed Light on Speed Reduction, 2004***

Another study by Godley, Triggs, and Fildes (2000) evaluated transverse lines as well as peripheral transverse lines versus a control section of roadway in a driving simulator. Transverse lines are stripes that are placed across the entire travel lane whereas the peripheral transverse lines are placed only on the edges of the travel lane. The study showed that driving speeds were only slower for the transverse lines (as compared to the peripheral transverse lines) for the initial section of the treatment. The overall results indicated that the peripheral lines performed the same and sometimes better than the regular transverse lines.

# METHOD

## Pavement Marking Selection

After analyzing the perceptual countermeasure field and simulator literature, it was determined that peripheral transverse lines have potential to encourage slower driving speeds. New York, Mississippi, and Texas Departments of Transportation also agreed that these markings would be the best alternative for their sites because: 1) Peripheral transverse lines are very easy to install and maintain; 2) They are not located in the wheel path of a vehicle and thus do not provide a slick surface under wet conditions on a road segment that already has safety concerns; and 3) Since only a small amount of pavement marking material is needed, the treatment is very cost effective.

## Research Approach

The underlying approach to this study was to determine possible pavement marking alternatives that seem to have promise in reducing vehicle speeds and implementing one of those alternatives in the field. Three field locations were chosen in which before and after speed data were collected. To avoid the need for a multi-year accident analysis study for determining safety effects, this method assumes that speed is a surrogate safety measure and it will be assumed that a higher safety rating is achieved if vehicle speeds are reduced. Data were collected at a common site upstream during all data collection periods to check for environmental or seasonal differences. Additionally, data were collected just prior to entering the curve to determine the reduction in speeds. There were three data collection periods. The first was prior to the installation of the markings. The second was directly after the installation of the markings where it was expected there might have been some novelty effects. The third and final data collection period took place approximately four months after the installation.

## Data Collection

Traffic data collection devices are used in this study to collect characteristics such as time, speed, volume, vehicle headway, and vehicle classification. Additionally, weather data as well as pavement condition (e.g., wet, dry) were noted and data were only used for periods with dry roadway conditions. Data were collected at a point just upstream of the treatment area (shown in Figures 2, 4, and 6) as well as at the point of curvature of the curve. The traffic data collection devices were verified with radar or laser speed gun periodically for accuracy. A laptop computer was used to verify the data periodically as well to download the data.

In summary, the following equipment was used in the course of data collection:

- Traffic Speed Measuring Devices (Jamar Traffic Counters)
- Laser Speed Gun
- Laptop Computer (for downloading data)

## Data Analysis

The data collected from the traffic data collection devices were examined by individual vehicle speeds to determine characteristics of each vehicle traveling through the site.

Several data analyses were performed to determine the effectiveness of the pavement markings. For each speed analysis, the mean, median, variance, and 85th percentile speeds were observed. The following analyses were performed:

- Effects of the pavement markings on speed for all vehicles
- Effects of the pavement markings on speed of vehicles by vehicle classification
- Effect of the pavement markings on speed by vehicles with varying headways.

## Site Selection and Pavement Marking Installation

Three sites, where speeding has been cited as a safety problem, were chosen for the installation of the experimental markings. The markings were designed individually for each site such that a comfortable deceleration could be made to go from the initial speed to the final speed at the curve. Thus the overall design was slightly different for each site. The first site was Interstate 690 in Syracuse, New York at the exit ramp for the New York State Thruway (see Figure 3). The portion of Interstate 90 marked on the figure represents the access ramp and toll plaza for the exit to and from Interstate 690. The speed limit on the freeway is 65 mph (105 km/h) and the posted advisory speed on the ramp is 30 mph (48 km/h). There are two thru lanes at the location with one exit only lane where the ramp is located. There is also a bridge abutment very close to the ramp and the abutment causes a very limited sight distance of the sharp curve on the ramp; it is hard to see how severe the curve actually is until the driver is too close. Therefore, drivers travel too fast approaching the ramp and decelerate at a very rapid rate when approaching the gore area. The treatment as installed used 12 inch (30.5 cm) wide pavement markings extending 18 inches (45.7 cm) into the roadway spaced increasingly closer together and placed perpendicular to the travel lane on both the left and right edges of the travel lane (see Figure 4).

The second site was on a two lane rural roadway in Flowood, Mississippi near Jackson, Mississippi (see Figure 5). The speed limit on the tangent section is 45 mph (72 km/h) and the advisory speed for the curve is 40 mph (64 km/h). Figure 6 shows the marking treatment with 12 inch wide (30.5 cm), 18 inch long (45.7 cm) pavement markings spaced increasingly closer together and placed perpendicular to the travel lane on both the left and right edges of the travel lane.

The third installation was on a two lane rural highway in Waller, Texas near Houston, Texas (see Figure 7). The speed limit on the tangent section is 65 mph (105 km/h) and the advisory speed for the curve is 40 mph (64 km/h). A similar treatment was placed in Houston as was placed in Jackson; however, the need to reduce travel speeds from 65 to 40 miles per hour as opposed to from 45 to 40 miles per hour meant that more markings needed to be placed at the Houston site. Figure 8 shows the marking treatment as installed. The spacing design used for all three locations is included in Appendix A of this report. Additionally, the Requests for Experimentation from FHWA are included in Appendix B.

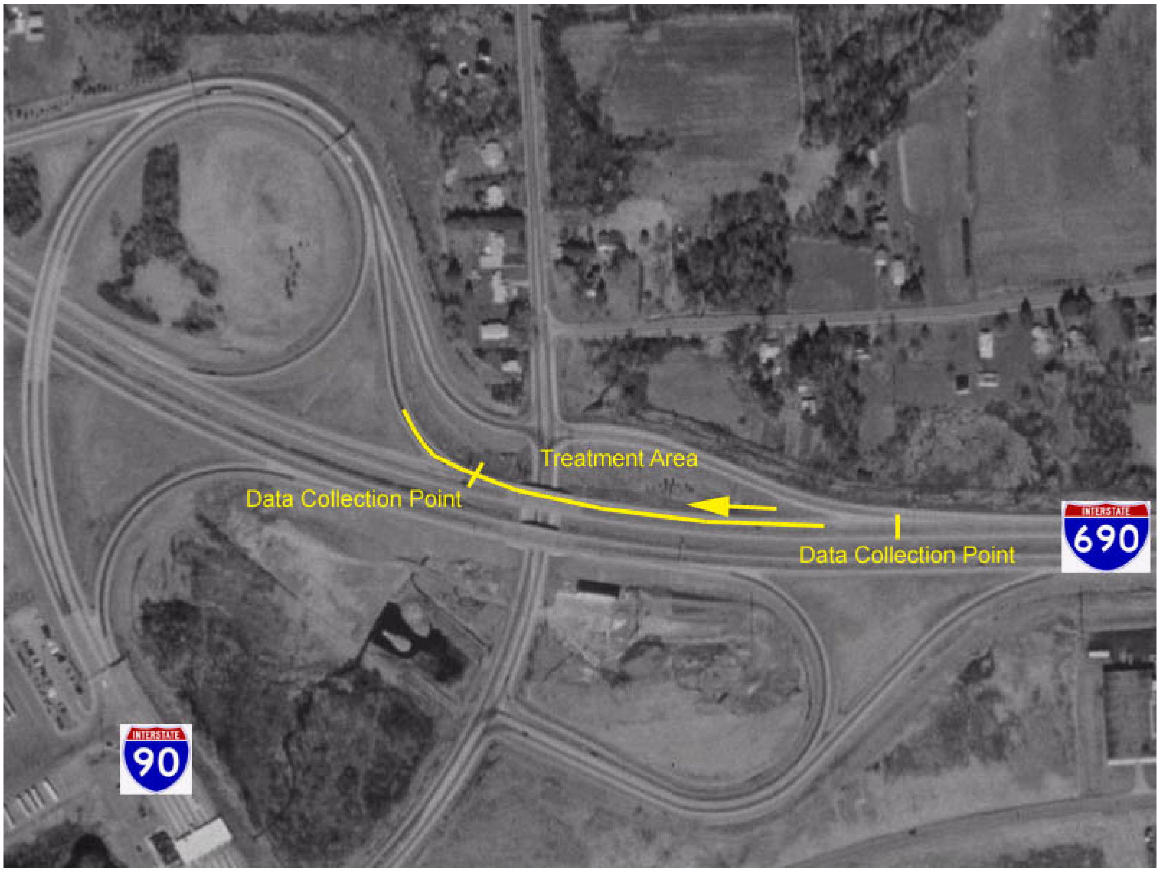


**Figure 3: Syracuse, New York Data Collection Site**

Figure 4: Peripheral Transverse Lines Treatment on I-690 in Syracuse, New York

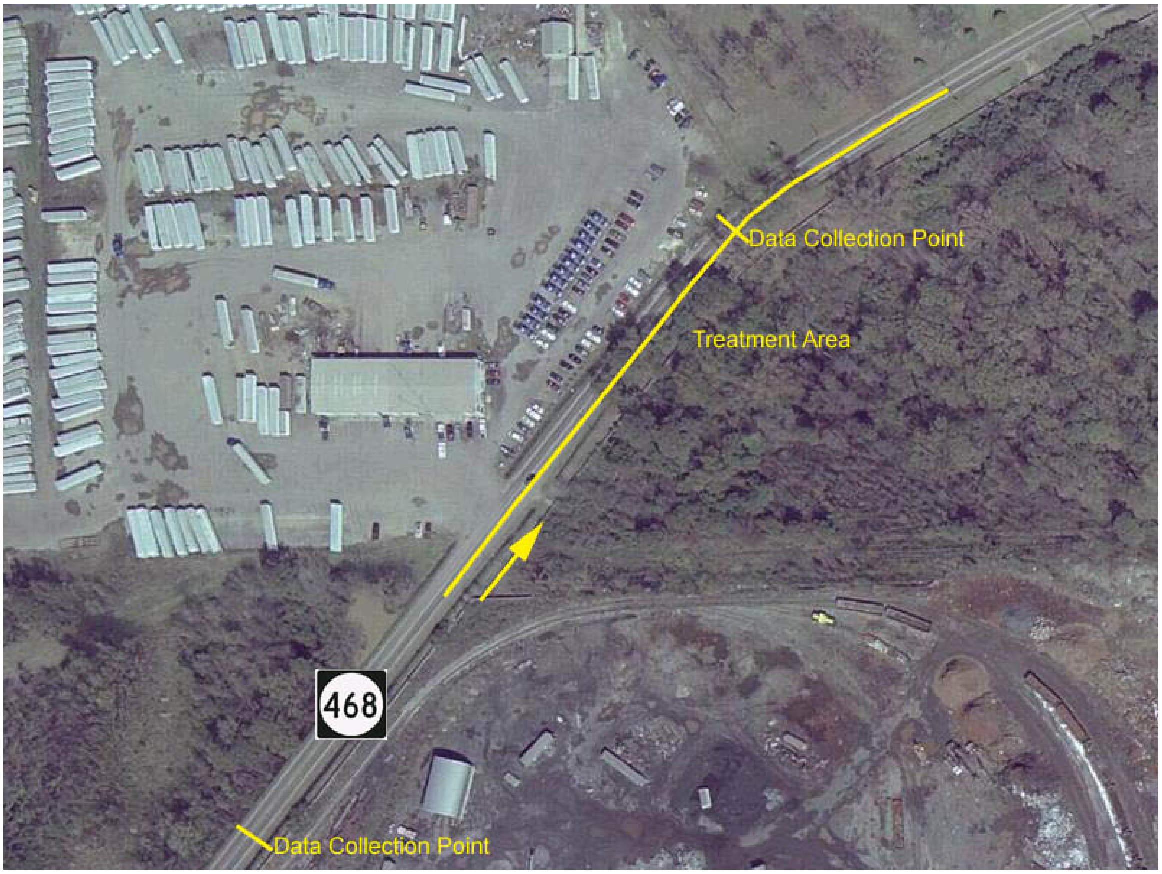


Figure 5: Flowood, Mississippi Data Collection Site

**Figure 6: Peripheral Transverse Lines Treatment on MS 468 in Flowood, Mississippi**

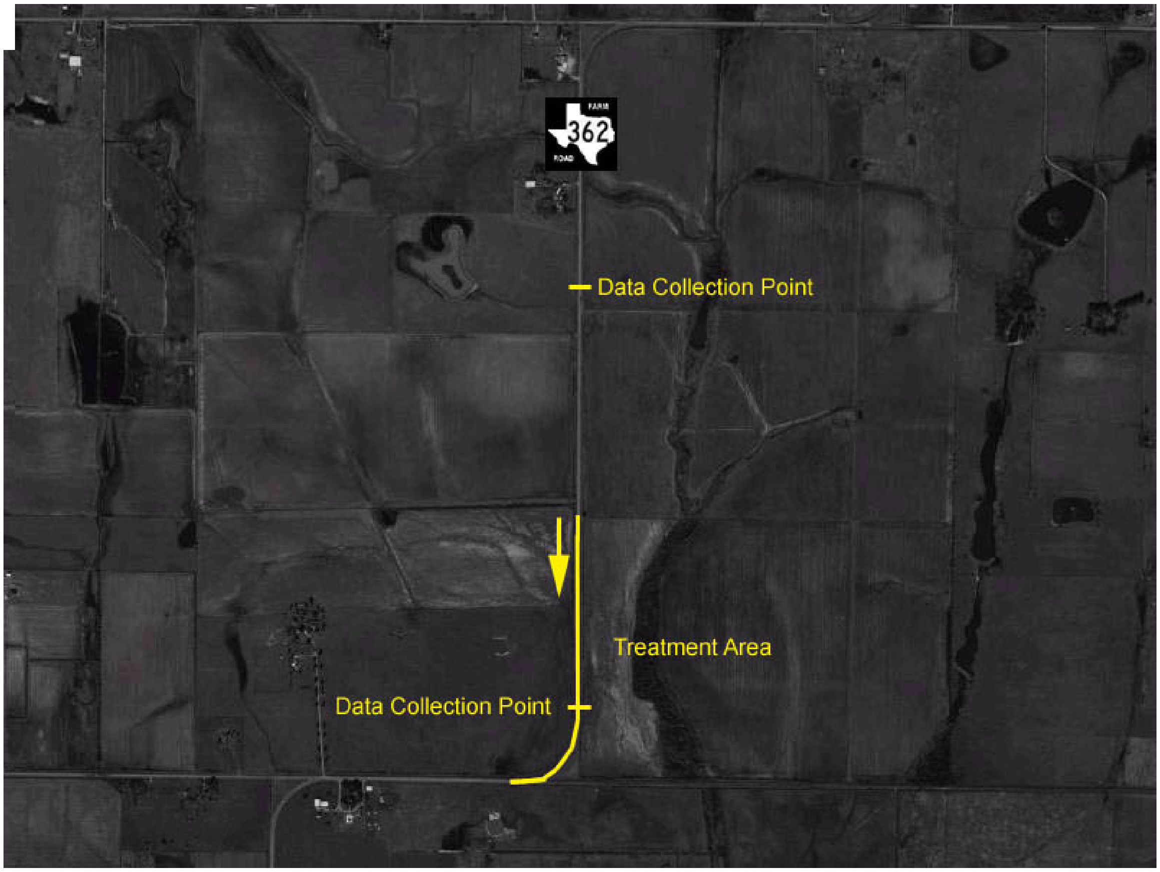


**Figure 7: Waller, Texas Data Collection Site**

**Figure 8: Peripheral Transverse Lines Treatment on FM 362 in Waller, Texas**

# RESULTS

## Effects of Pavement Markings on Speed of All Vehicles

For the Syracuse, New York site, the pavement markings appeared to have an effect on the speed of all types of vehicles when observing the before, after, and extended after data as shown in Table 1. Data collection occurred upstream of the treatment as well as downstream at the end of the treatment area, just prior to entering the curve (see Figure 2). In both the after data and the extended after data, there was approximately a 4 mph reduction (6 km/h) in the average speeds, a 4 mph reduction (6 km/h) in the median speed, and a 5 mph reduction (8 km/h) in the 85th percentile speeds. The effects of the immediately after data are even stronger when noting that there was actually a 5.6 mph (9.0 km/h) increase in the upstream counter. When correcting for possible environmental conditions such as weather or time of year trends that may have led to the increase, there was an actual adjusted decrease of 9.5 mph (15.3 km/h). The net decrease; however, was 4 mph (6 km/h) in the extended after data. When testing for statistical significance between the before and after speeds downstream of the curve, the mean difference was significant at the .05 level using Analysis of Variance (ANOVA).

**Table 1: Effects of Pavement Markings on Speed for All Vehicles (in mph) - Syracuse, New York**

|  |  | Upstream | Downstream |
|---|---|---|---|
| **Before** |  | **6526** | **6532** |
|  | Average | 55.275 | 37.995 |
|  | Std Dev | 7.785 | 6.119 |
|  | Median | 56 | 38 |
|  | 85th Percentile | 63 | 44 |
| **After** |  | **4590** | **4573** |
|  | Average | 60.860 | 34.129 |
|  | Std Dev | 9.088 | 5.089 |
|  | Median | 61 | 34 |
|  | 85th Percentile | 70 | 39 |
|  | Average Reduction |  | 3.87 |
|  | Std Dev Reduction |  | 1.03 |
|  | Median Reduction |  | 4.00 |
|  | 85th Perc Reduction |  | 5.00 |
| **Extended After** |  | **6835** | **6663** |
|  | Average | 55.481 | 34.118 |
|  | Std Dev | 7.212 | 4.929 |
|  | Median | 56 | 34 |
|  | 85th Percentile | 63 | 39 |
|  | Average Reduction |  | 3.88 |
|  | Std Dev Reduction |  | 1.19 |
|  | Median Reduction |  | 4.00 |
|  | 85th Perc Reduction |  | 5.00 |

For the Flowood, Mississippi test location, the pavement markings also had an effect on total vehicle speeds (shown in Table 2), but not as large as the effect in Syracuse. At this location, it turned out that the effects of the pavement markings on speed were slightly greater in the extended after period as opposed to the directly after period. After adjusting for environmental conditions (i.e. accounting for the changes at the upstream control location), the adjusted decrease would be 4.6 mph (7.4 km/h). The total net decrease is 1.84 mph (2.96 km/h). When testing for statistical significance between the before and after speeds downstream of the curve, the mean difference was significant at the .05 level using ANOVA.

**Table 2: Effects of Pavement Markings on Speed for All Vehicles (in mph) - Flowood, Mississippi**

| | Upstream | Downstream |
|---|---|---|
| **Before** | **7348** | **7358** |
| Average | 41.202 | 43.563 |
| Std Dev | 7.133 | 6.025 |
| Median | 42 | 44 |
| 85th Percentile | 47 | 49 |
| **After** | **8129** | **8064** |
| Average | 40.732 | 43.016 |
| Std Dev | 7.471 | 6.293 |
| Median | 42 | 43 |
| 85th Percentile | 47 | 49 |
| Average Reduction | | 0.55 |
| Std Dev Reduction | | -0.27 |
| Median Reduction | | 1.00 |
| 85th Perc Reduction | | 0.00 |
| **Extended After** | **10415** | **10129** |
| Average | 43.952 | 41.718 |
| Std Dev | 8.095 | 7.598 |
| Median | 45 | 43 |
| 85th Percentile | 51 | 48 |
| Average Reduction | | 1.84 |
| Std Dev Reduction | | -1.57 |
| Median Reduction | | 1.00 |
| 85th Perc Reduction | | 1.00 |

Waller, Texas provided some very interesting observations. Although drivers at the upstream location would not be able to view the markings, the data showed a decrease in speed in the after and extended after periods for the upstream location. However, the speeds for vehicles downstream of the markings (at the curve) were all reasonably similar through all three periods. There was a slight reduction in average speed over the before period at the downstream data collection point but the magnitude is not as large as the reduction in average speed over the before period at the upstream data collection point. It is interesting to note that there was no statistical difference in the average speed at the .05 level downstream of the curve in the extended after period compared to the before period; however, when testing for statistical significance between the before and after speeds upstream of the curve, the mean difference was significant at the .05 level using ANOVA. This might indicate that drivers familiar with the road decided to slow down in advance because of the markings.

**Table 3: Effects of Pavement Markings on Speed for All Vehicles (in mph) - Waller, Texas**

| | Upstream | Downstream |
|---|---|---|
| **Before** | **970** | **903** |
| Average | 65.553 | 53.116 |
| Std Dev | 7.681 | 5.691 |
| Median | 65 | 53 |
| 85th Percentile | 72 | 55 |
| **After** | **2477** | **2506** |
| Average | 54.704 | 55.835 |
| Std Dev | 5.330 | 7.017 |
| Median | 55 | 56 |
| 85th Percentile | 60 | 63 |
| Average Reduction | | -2.72 |
| Std Dev Reduction | | -1.33 |
| Median Reduction | | -3.00 |
| 85th Perc Reduction | | -8.00 |
| **Extended After** | **1022** | **718** |
| Average | 59.717 | 52.776 |
| Std Dev | 5.710 | 5.640 |
| Median | 60 | 53 |
| 85th Percentile | 65 | 58 |
| Average Reduction | | 0.34 |
| Std Dev Reduction | | 0.05 |
| Median Reduction | | 0.00 |
| 85th Perc Reduction | | -3.00 |

## Effects of Pavement Markings on Speed of Vehicles by Vehicle Classification

The data for the effects of pavement markings on speed of vehicles by vehicle classification are shown in Table 4, Table 5, and Table 6 for New York, Mississippi, and Texas, respectively. As expected because of the need to navigate curves at a slower speed for safety reasons, vehicles with more than two axles tend to drive slower than vehicles with only two axles. However, the general trends of the reductions are consistent with what was seen in the analysis of all vehicles. The overall results show that the greatest effects were found in New York with a mild reduction in Mississippi and a reduction in speed upstream of the markings in Texas for both two axle vehicles and vehicles with more than two axles.

## Table 4: Effects on Speed by Number of Axles (in mph) - Syracuse, New York

| **Two Axle Vehicles** | | | **Vehicles with >2 Axles** | | |
|---|---|---|---|---|---|
| | **Upstream** | **Downstream** | | **Upstream** | **Downstream** |
| **Before** | **5051** | **4977** | **Before** | **1475** | **1555** |
| Average | 57.240 | 39.630 | Average | 48.560 | 32.760 |
| Std Dev | 7.030 | 5.519 | Std Dev | 6.366 | 4.874 |
| Median | 57 | 40 | Median | 49 | 33 |
| 85th Percentile | 64 | 45 | 85th Percentile | 55 | 38 |
| **After** | **3583** | **3537** | **After** | **1007** | **1036** |
| Average | 63.190 | 35.520 | Average | 52.560 | 29.380 |
| Std Dev | 8.100 | 4.560 | Std Dev | 7.409 | 3.774 |
| Median | 63 | 36 | Median | 52 | 29 |
| 85th Percentile | 71 | 40 | 85th Percentile | 60 | 33 |
| Average Reduction | | 4.11 | Average Reduction | | 3.38 |
| Std Dev Reduction | | 0.96 | Std Dev Reduction | | 1.10 |
| Median Reduction | | 4.00 | Median Reduction | | 4.00 |
| 85th Perc Reduction | | 5.00 | 85th Perc Reduction | | 5.00 |
| **Extended After** | **5490** | **5281** | **Extended After** | **1345** | **1382** |
| Average | 56.970 | 35.200 | Average | 49.390 | 29.970 |
| Std Dev | 6.724 | 4.587 | Std Dev | 5.798 | 3.877 |
| Median | 57 | 35 | Median | 49 | 30 |
| 85th Percentile | 63 | 40 | 85th Percentile | 55 | 34 |
| Average Reduction | | 4.43 | Average Reduction | | 2.79 |
| Std Dev Reduction | | 0.93 | Std Dev Reduction | | 1.00 |
| Median Reduction | | 5.00 | Median Reduction | | 3.00 |
| 85th Perc Reduction | | 5.00 | 85th Perc Reduction | | 4.00 |

## Table 5: Effects on Speed by Number of Axles (in mph) – Flowood, Mississippi

| **Two Axle Vehicles** | | | **Vehicles with >2 Axles** | | |
|---|---|---|---|---|---|
| | **Upstream** | **Downstream** | | **Upstream** | **Downstream** |
| **Before** | **6728** | **6744** | **Before** | **620** | **614** |
| Average | 41.460 | 43.810 | Average | 38.360 | 40.890 |
| Std Dev | 7.114 | 5.990 | Std Dev | 6.710 | 5.754 |
| Median | 42 | 44 | Median | 39 | 41 |
| 85th Percentile | 48 | 50 | 85th Percentile | 45 | 47 |
| **After** | **7429** | **7392** | **After** | **700** | **672** |
| Average | 41.040 | 43.300 | Average | 37.500 | 39.880 |
| Std Dev | 7.446 | 6.237 | Std Dev | 6.954 | 6.051 |
| Median | 42 | 44 | Median | 38.5 | 40 |
| 85th Percentile | 47 | 49 | 85th Percentile | 44 | 46 |
| Average Reduction | | 0.51 | Average Reduction | | 1.01 |
| Std Dev Reduction | | -0.25 | Std Dev Reduction | | -0.30 |
| Median Reduction | | 0.00 | Median Reduction | | 1.00 |
| 85th Perc Reduction | | 1.00 | 85th Perc Reduction | | 1.00 |
| **Extended After** | **9423** | **9127** | **Extended After** | **992** | **1002** |
| Average | 44.350 | 42.120 | Average | 40.190 | 38.090 |
| Std Dev | 7.954 | 7.398 | Std Dev | 8.455 | 8.396 |
| Median | 45 | 43 | Median | 41 | 40 |
| 85th Percentile | 52 | 48 | 85th Percentile | 48 | 45 |
| Average Reduction | | 1.69 | Average Reduction | | 2.80 |
| Std Dev Reduction | | -1.41 | Std Dev Reduction | | -2.64 |
| Median Reduction | | 1.00 | Median Reduction | | 1.00 |
| 85th Perc Reduction | | 2.00 | 85th Perc Reduction | | 2.00 |

**Table 6: Effects on Speed by Number of Axles (in mph) - Waller, Texas**

| **Two Axle Vehicles** | | | **Vehicles with >2 Axles** | | |
|---|---|---|---|---|---|
| | **Upstream** | **Downstream** | | **Upstream** | **Downstream** |
| **Before** | **829** | **763** | **Before** | **141** | **140** |
| Average | 65.830 | 53.660 | Average | 63.900 | 50.140 |
| Std Dev | 7.910 | 5.574 | Std Dev | 5.929 | 5.413 |
| Median | 66 | 54 | Median | 64 | 51 |
| 85th Percentile | 73 | 59 | 85th Percentile | 69 | 56 |
| **After** | **2035** | **2058** | **After** | **442** | **448** |
| Average | 55.150 | 56.570 | Average | 52.630 | 52.440 |
| Std Dev | 5.380 | 6.907 | Std Dev | 4.552 | 6.509 |
| Median | 55 | 57 | Median | 53 | 53 |
| 85th Percentile | 60 | 63 | 85th Percentile | 57 | 59 |
| Average Reduction | | -2.91 | Average Reduction | | -2.30 |
| Std Dev Reduction | | -1.33 | Std Dev Reduction | | -1.10 |
| Median Reduction | | -3.00 | Median Reduction | | -2.00 |
| 85th Perc Reduction | | -4.00 | 85th Perc Reduction | | -3.00 |
| **Extended After** | **845** | **599** | **Extended After** | **177** | **119** |
| Average | 60.190 | 53.340 | Average | 57.470 | 49.930 |
| Std Dev | 5.696 | 5.451 | Std Dev | 5.242 | 5.741 |
| Median | 60 | 54 | Median | 58 | 50 |
| 85th Percentile | 66 | 59 | 85th Percentile | 62 | 56 |
| Average Reduction | | 0.32 | Average Reduction | | 0.21 |
| Std Dev Reduction | | 0.12 | Std Dev Reduction | | -0.33 |
| Median Reduction | | 0.00 | Median Reduction | | 1.00 |
| 85th Perc Reduction | | 0.00 | 85th Perc Reduction | | 0.00 |

## Effect of the Pavement Markings on Speed by Vehicles with Varying Headways

To determine whether or not the effects of other vehicles had an influence on driver speed choice, it is important to look at various gap sizes and their effects on speed. Speed comparisons were made using both 4 seconds and 10 seconds as cut points. For example, vehicles with headways of 4 seconds or less were compared to vehicles with headways longer than 4 seconds using t-tests. The results of the analysis are shown below in Table 7, Table 8, and Table 9 for New York, Mississippi, and Texas, respectively. Bold values indicate statistical significance of the means between the gap being “less than” or “greater than or equal to” each of the tested gap sizes indicating that vehicles with increased headway tend to have faster speeds. The analysis showed that for the most part, the mean speeds were significant at a cutoff with a gap size of four seconds. Therefore, a four second gap was used to perform an analysis similar to that performed in the first analysis in this section to determine the effect of the pavement markings on driver speed choice when negating the effects of platoons.

**Table 7: Effects of Gap Size on Mean Speed (Syracuse, New York)**

| | **Upstream** | **Downstream** |
|---|---|---|
| **Before** | | |
| Mean (Gap <4) | **53.98** | **37.00** |
| Mean (Gap >=4) | **55.71** | **38.35** |
| Mean (Gap <10) | 55.25 | 37.92 |
| Mean (Gap >=10) | 55.30 | 38.07 |
| **After** | | |
| Mean (Gap <4) | **59.57** | **33.34** |
| Mean (Gap >=4) | **61.32** | **34.40** |
| Mean (Gap <10) | 60.80 | 34.02 |
| Mean (Gap >=10) | 60.92 | 34.24 |
| **Extended After** | | |
| Mean (Gap <4) | **54.30** | **33.22** |
| Mean (Gap >=4) | **55.93** | **34.45** |
| Mean (Gap <10) | **55.25** | **33.99** |
| Mean (Gap >=10) | **55.73** | **34.26** |

***Note: Bold Values Indicate Significance at the .05 level***

**Table 8: Effects of Gap Size on Mean Speed (Flowood, Mississippi)**

| | **Upstream** | **Downstream** |
|---|---|---|
| **Before** | | |
| Mean (Gap <4) | **39.73** | **42.16** |
| Mean (Gap >=4) | **42.60** | **45.01** |
| Mean (Gap <10) | **40.49** | **42.95** |
| Mean (Gap >=10) | **43.08** | **45.22** |
| **After** | | |
| Mean (Gap <4) | **39.33** | **41.91** |
| Mean (Gap >=4) | **42.18** | **44.22** |
| Mean (Gap <10) | **40.06** | **42.56** |
| Mean (Gap >=10) | **42.76** | **44.43** |
| **Extended After** | | |
| Mean (Gap <4) | **42.26** | **40.84** |
| Mean (Gap >=4) | **45.74** | **42.65** |
| Mean (Gap <10) | **43.15** | **41.22** |
| Mean (Gap >=10) | **46.52** | **43.23** |

***Note: Bold Values Indicate Significance at the .05 level***

**Table 9: Effects of Gap Size on Mean Speed (Waller, Texas)**

| | Upstream | Downstream |
|---|---|---|
| **Before** | | |
| Mean (Gap <4) | **63.17** | **51.44** |
| Mean (Gap >=4) | **65.90** | **53.38** |
| Mean (Gap <10) | **64.13** | 52.49 |
| Mean (Gap >=10) | **65.93** | 53.30 |
| **After** | | |
| Mean (Gap <4) | **53.50** | **52.71** |
| Mean (Gap >=4) | **54.89** | **56.37** |
| Mean (Gap <10) | **54.00** | **54.64** |
| Mean (Gap >=10) | **54.91** | **56.22** |
| **Extended After** | | |
| Mean (Gap <4) | **58.57** | 52.29 |
| Mean (Gap >=4) | **59.87** | 52.85 |
| Mean (Gap <10) | 59.23 | 52.81 |
| Mean (Gap >=10) | 59.85 | 52.77 |

***Note: Bold Values Indicate Significance at the .05 level***

Upon performing an analysis including only vehicles with gap sizes of greater than four seconds, the results from the first analysis look somewhat different. Similar to the first analysis including all vehicles, there was a significant difference at the .05 level between the Before speeds at the curve and the After and Extended After speeds at the curve for the Syracuse, New York site and the Flowood, Mississippi site. There was also a significant difference in speeds upstream at the Waller, Texas site between the Before data collection period and the After and Extended After periods. There was a reduction in speed as well at the Waller, Texas site; however, the reduction was not statistically significant; however, there was a slight decrease in the average and 85th percentile speeds, so there was a slight effect at the Texas site as well. Therefore, it is apparent that the gap size has an effect on vehicle speeds in the treatment area and when following vehicles are removed from the analysis, the pavement markings still show to be very effective in reducing vehicle speeds.

**Table 10: Effects on Speed for Vehicles with Gap >= 4 seconds (in mph) - Syracuse, New York**

| | | Upstream | Downstream |
|---|---|---|---|
| **Before** | | **4879** | **4812** |
| | Average | 55.710 | 38.350 |
| | Std Dev | 7.778 | 6.114 |
| | Median | 56 | 39 |
| | 85th Percentile | 63 | 45 |
| **After** | | **3388** | **3394** |
| | Average | 61.320 | 34.400 |
| | Std Dev | 9.303 | 5.186 |
| | Median | 62 | 35 |
| | 85th Percentile | 71 | 40 |
| | Average Reduction | | 3.95 |
| | Std Dev Reduction | | 0.93 |
| | Median Reduction | | 4.00 |
| | 85th Perc Reduction | | 5.00 |
| **Extended After** | | **4954** | **4876** |
| | Average | 55.930 | 34.450 |
| | Std Dev | 7.207 | 4.908 |
| | Median | 56 | 35 |
| | 85th Percentile | 63 | 39 |
| | Average Reduction | | 3.90 |
| | Std Dev Reduction | | 1.21 |
| | Median Reduction | | 4.00 |
| | 85th Perc Reduction | | 6.00 |

**Table 11: Effects on Speed for Vehicles with Gap >= 4 seconds (in mph) - Flowood, Mississippi**

| | | Upstream | Downstream |
|---|---|---|---|
| **Before** | | **3774** | **3621** |
| | Average | 42.600 | 45.010 |
| | Std Dev | 6.893 | 5.930 |
| | Median | 43 | 45 |
| | 85th Percentile | 48 | 51 |
| **After** | | **3991** | **3864** |
| | Average | 42.180 | 44.220 |
| | Std Dev | 7.237 | 6.421 |
| | Median | 43 | 45 |
| | 85th Percentile | 48 | 50 |
| | Average Reduction | | 0.79 |
| | Std Dev Reduction | | -0.49 |
| | Median Reduction | | 0.00 |
| | 85th Perc Reduction | | 1.00 |
| **Extended After** | | **5060** | **4920** |
| | Average | 45.740 | 42.650 |
| | Std Dev | 7.992 | 8.216 |
| | Median | 47 | 44 |
| | 85th Percentile | 53 | 49 |
| | Average Reduction | | 2.36 |
| | Std Dev Reduction | | -2.29 |
| | Median Reduction | | 1.00 |
| | 85th Perc Reduction | | 2.00 |

**Table 12: Effects on Speed for Vehicles with Gap >= 4 seconds (in mph) - Waller, Texas**

| | | Upstream | Downstream |
|---|---|---|---|
| **Before** | | **848** | **903** |
| | Average | 65.900 | 53.380 |
| | Std Dev | 7.711 | 5.527 |
| | Median | 66 | 53 |
| | 85th Percentile | 73 | 59 |
| **After** | | **2140** | **2138** |
| | Average | 54.890 | 56.370 |
| | Std Dev | 5.305 | 6.609 |
| | Median | 55 | 56 |
| | 85th Percentile | 60 | 63 |
| | Average Reduction | | -2.99 |
| | Std Dev Reduction | | -1.08 |
| | Median Reduction | | -3.00 |
| | 85th Perc Reduction | | -4.00 |
| **Extended After** | | **903** | **619** |
| | Average | 59.870 | 52.850 |
| | Std Dev | 5.810 | 5.639 |
| | Median | 60 | 53 |
| | 85th Percentile | 66 | 58 |
| | Average Reduction | | 0.53 |
| | Std Dev Reduction | | -0.11 |
| | Median Reduction | | 0.00 |
| | 85th Perc Reduction | | 1.00 |

# CONCLUSIONS

Overall, the pavement markings seemed to have an effect on overall vehicle speeds when comparing total vehicles, two axle vehicles, vehicles with more than two axles, and particularly with vehicles following further than four seconds behind the previous vehicle. There are several factors that impact the magnitude of the effect, particularly driver familiarity with the road. For example, at the New York site where the traffic is interstate traffic on a freeway the markings had more of an effect than at Texas where most of the traffic is most likely local and at Mississippi which is somewhere in between with traffic primarily traveling on a rural arterial between Jackson, Mississippi and its suburbs. Another major factor is the degree of curvature in the road. The Syracuse, New York site requires the most rapid deceleration for the curve in the exit ramp and thus drivers are forced to slow down much faster than at the other two sites. The Jackson, Mississippi site does not require as much of a reduction in speed to safely navigate the curve. Another factor is the visibility of the pavement markings. The New York and Mississippi sites were very visible with a dark asphalt pavement with white markings whereas the Texas site had a lighter colored pavement and the markings were more difficult to see because of the color contrast.

The Waller, Texas site presented the most interesting case where although there was only a slight decrease in speed at the curve over the long term, the upstream data showed a significant decrease in speed for the after and extended after data. One possible reason is that since traffic is mostly local where drivers are familiar with the road, the travelers are aware that the markings are coming up and thus they are slowing down more gradually through the section prior to entering the curve. This may indicate that the transverse bars provided a warning for drivers familiar with the road.

## RECOMMENDATIONS

Based on the results of this study and the given that other studies have shown to have seen an effect on pavement markings as a speed reduction technique, focus needs to be given to determine alternative pavement marking patterns to see if some have more of an effect than others. Overall, it appears that particularly for locations with unfamiliar drivers (such as at the Syracuse, New York site), the pavement markings have a larger effect on vehicle speeds. Therefore, this application may be applied to other similar sites or perhaps other settings that drivers encounter where vehicle speeds need to be reduced such as work zones. It is not recommended that this treatment be used to reduce speeds on long stretches of roadway because the anticipated effect would not last for a long period of time.

It is also recommended that the FHWA MUTCD Team review the findings of this study and consider the addition of pavement markings as a speed reduction technique with this particular application used as an option. Other types of patterns that have been experimented with and determined successful may be considered as other options.

# REFERENCES

Agent, K. *Transverse Pavement Markings for Speed Control and Accident Reduction*. Transportation Research Record 773, 1980.

*Down with Speed: A Review of the Literature, and the Impact of Speed on New Zealanders.* Accident Compensation Corporation and Land Transport Safety Authority, New Zealand, 2000.

Drakopoulos, A. and G. Vergou. *Evaluation of the Converging Chevron Pavement Marking Pattern at one Wisconsin Location*. AAA Foundation for Traffic Safety, Washington, DC, 2003.

Godley, S.T., T.J. Triggs, and B.N. Fildes. *Speed Reduction Mechanisms of Transverse Lines*. Transportation Human Factors, vol. 2, no.4, pp. 297-312. Lawrence Erlbaum Associates, Mahwah, New Jersey, 2000.

Kallberg, V-P., Allsop, R.E., Ward, H., van der Horst, R., and Varhelyi, A.. *Recommendations for Speed Management Strategies and Policies*. VTT Communities and Infrastructure, Finland, 1998.

Lum, H. *The Use of Road Markings to Narrow Lanes for Controlling Speed in Residential Areas*. Institute of Transportation Engineers (ITE) Journal, June 1984.

*Manual on Uniform Traffic Control Devices, Millenium Edition*. U.S. Department of Transportation, Washington, DC, 2001.

Meyer, E. *A Literature Review of Perceptual Countermeasures to Speeding*. University of Kansas, Lawrence, KS, 2000.

*Pavement Markings Shed Light on Speed Reduction.* Research and Technology Transporter. US Department of Transportation. February 2004. http://www.tfhrc.gov/trnsptr/feb04/.

Retting, R.A., McGee, H., and Farmer, C. *Influence of Experimental Pavement Markings on Urban Freeway Exit-Ramp Speeds*. Transportation Research Record, No. 1705, 2000.

Richards, S.H., Wunderlich, R.E., Dudek, C.L., and Brackett, R.Q. *Improvements and New Concepts for Traffic Control in Work Zones*. FHWA-RD-85-037. US Department of Transportation, Federal Highway Administration, 1985.

Smiley, A. *Driver Speed Estimation: What Road Designers Should Know*. Presented at TRB Meeting, January 1999.

*Speed Management Team Work Plan*. U.S. Department of Transportation, Washington, DC, 2000.

Yagar, S., and Van Aerde, M. *Geometric and Environmental Effects on Speeds on 2-lane Rural Roads*. Transportation Research Record, Vol. 17A, 4, 1984.

# APPENDIX A: PAVEMENT MARKING SPACING

**New York Site Peripheral Transverse Stripe Spacing**

| | | |
|---|---|---|
| Initial Speed | 65 | miles per hour |
| Desired Speed | 30 | miles per hour |
| Distance | 527 | feet |
| Required Decel | -6.8 | ft/s$^2$ |
| Bar Frequency | 4 | bars per second |

| Marking Number | Distance (Rounded For Design) | Distance Traveled | Desired Speed (mph) | Desired Speed (ft/s) |
|---|---|---|---|---|
| 1 | 0 | 0.00 | 65 | 95.55 |
| 2 | 24 | 23.89 | 64 | 93.83 |
| 3 | 47 | 47.35 | 63 | 92.12 |
| 4 | 70 | 70.38 | 61 | 90.40 |
| 5 | 93 | 92.98 | 60 | 88.69 |
| 6 | 115 | 115.15 | 59 | 86.97 |
| 7 | 137 | 136.89 | 58 | 85.25 |
| 8 | 158 | 158.20 | 57 | 83.54 |
| 9 | 179 | 179.09 | 56 | 81.82 |
| 10 | 200 | 199.54 | 54 | 80.10 |
| 11 | 220 | 219.57 | 53 | 78.38 |
| 12 | 239 | 239.16 | 52 | 76.66 |
| 13 | 258 | 258.33 | 51 | 74.94 |
| 14 | 277 | 277.06 | 50 | 73.22 |
| 15 | 295 | 295.37 | 49 | 71.50 |
| 16 | 313 | 313.25 | 47 | 69.78 |
| 17 | 331 | 330.69 | 46 | 68.06 |
| 18 | 348 | 347.71 | 45 | 66.34 |
| 19 | 364 | 364.29 | 44 | 64.62 |
| 20 | 380 | 380.45 | 43 | 62.89 |
| 21 | 396 | 396.17 | 42 | 61.17 |
| 22 | 411 | 411.46 | 40 | 59.45 |
| 23 | 426 | 426.32 | 39 | 57.72 |
| 24 | 441 | 440.76 | 38 | 56.00 |
| 25 | 455 | 454.75 | 37 | 54.27 |
| 26 | 468 | 468.32 | 36 | 52.54 |
| 27 | 481 | 481.46 | 35 | 50.81 |
| 28 | 494 | 494.16 | 33 | 49.08 |
| 29 | 506 | 506.43 | 32 | 47.35 |
| 30 | 518 | 518.27 | 31 | 45.62 |
| 31 | 530 | 529.68 | 30 | 43.89 |

**Mississippi Site Peripheral Transverse Stripe Spacing**

| | | |
|---|---|---|
| Initial Speed | 55 | miles per hour |
| Desired Speed | 40 | miles per hour |
| Distance | 550 | feet |
| Required Decel | -2.80 | ft/s$^2$ |
| Bar Frequency | 4 | bars per second |

| Marking Number | Distance (Rounded For Design) | Distance Traveled | Desired Speed (mph) | Desired Speed (ft/s) |
|---|---|---|---|---|
| 1 | 0 | 0.00 | 55 | 80.85 |
| 2 | 20 | 20.21 | 55 | 80.15 |
| 3 | 40 | 40.25 | 54 | 79.44 |
| 4 | 60 | 60.11 | 54 | 78.74 |
| 5 | 80 | 79.80 | 53 | 78.04 |
| 6 | 99 | 99.31 | 53 | 77.34 |
| 7 | 119 | 118.64 | 52 | 76.63 |
| 8 | 138 | 137.80 | 52 | 75.93 |
| 9 | 157 | 156.78 | 51 | 75.23 |
| 10 | 176 | 175.59 | 51 | 74.52 |
| 11 | 194 | 194.22 | 50 | 73.82 |
| 12 | 213 | 212.67 | 50 | 73.12 |
| 13 | 231 | 230.95 | 49 | 72.41 |
| 14 | 249 | 249.05 | 49 | 71.71 |
| 15 | 267 | 266.98 | 48 | 71.01 |
| 16 | 285 | 284.73 | 48 | 70.30 |
| 17 | 302 | 302.31 | 47 | 69.60 |
| 18 | 320 | 319.71 | 47 | 68.90 |
| 19 | 337 | 336.93 | 46 | 68.19 |
| 20 | 354 | 353.98 | 46 | 67.49 |
| 21 | 371 | 370.85 | 45 | 66.79 |
| 22 | 388 | 387.55 | 45 | 66.08 |
| 23 | 404 | 404.07 | 44 | 65.38 |
| 24 | 420 | 420.42 | 44 | 64.68 |
| 25 | 437 | 436.59 | 44 | 63.97 |
| 26 | 453 | 452.58 | 43 | 63.27 |
| 27 | 468 | 468.40 | 43 | 62.56 |
| 28 | 484 | 484.04 | 42 | 61.86 |
| 29 | 500 | 499.50 | 42 | 61.16 |
| 30 | 515 | 514.79 | 41 | 60.45 |
| 31 | 530 | 529.90 | 41 | 59.75 |
| 32 | 545 | 544.84 | 40 | 59.05 |
| 33 | 560 | 559.60 | 40 | 58.34 |
| 34 | 574 | 574.19 | 39 | 57.64 |
| 35 | 589 | 588.60 | 39 | 56.93 |
| 36 | 603 | 602.83 | 38 | 56.23 |
| 37 | 617 | 616.89 | 38 | 55.52 |
| 38 | 631 | 630.77 | 37 | 54.82 |
| 39 | 644 | 644.47 | 37 | 54.12 |
| 40 | 658 | 658.00 | 36 | 53.41 |
| 41 | 671 | 671.36 | 36 | 52.71 |
| 42 | 685 | 684.53 | 35 | 52.00 |

**Mississippi Site Peripheral Transverse Stripe Spacing (cont'd)**

| Marking Number | Distance (Rounded For Design) | Distance Traveled | Desired Speed (mph) | Desired Speed (ft/s) |
|---|---|---|---|---|
| 43 | 698 | 697.53 | 35 | 51.30 |
| 44 | 710 | 710.36 | 34 | 50.59 |
| 45 | 723 | 723.01 | 34 | 49.89 |
| 46 | 735 | 735.48 | 33 | 49.18 |
| 47 | 748 | 747.77 | 33 | 48.48 |
| 48 | 760 | 759.89 | 32 | 47.77 |
| 49 | 772 | 771.84 | 32 | 47.07 |
| 50 | 784 | 783.60 | 32 | 46.36 |
| 51 | 795 | 795.19 | 31 | 45.66 |
| 52 | 807 | 806.61 | 31 | 44.95 |
| 53 | 818 | 817.85 | 30 | 44.25 |
| 54 | 829 | 828.91 | 30 | 43.54 |
| 55 | 840 | 839.79 | 29 | 42.84 |
| 56 | 851 | 850.50 | 29 | 42.13 |
| 57 | 861 | 861.04 | 28 | 41.43 |
| 58 | 871 | 871.39 | 28 | 40.72 |
| 59 | 882 | 881.57 | 27 | 40.01 |
| 60 | 892 | 891.58 | 27 | 39.31 |
| 61 | 901 | 901.40 | 26 | 38.60 |
| 62 | 911 | 911.05 | 26 | 37.89 |
| 63 | 921 | 920.53 | 25 | 37.19 |
| 64 | 930 | 929.82 | 25 | 36.48 |
| 65 | 939 | 938.94 | 24 | 35.78 |
| 66 | 948 | 947.89 | 24 | 35.07 |
| 67 | 957 | 956.65 | 23 | 34.36 |
| 68 | 965 | 965.25 | 23 | 33.65 |
| 69 | 974 | 973.66 | 22 | 32.95 |
| 70 | 982 | 981.90 | 22 | 32.24 |
| 71 | 990 | 989.96 | 21 | 31.53 |
| 72 | 998 | 997.84 | 21 | 30.82 |
| 73 | 1006 | 1005.54 | 20 | 30.12 |
| 74 | 1013 | 1013.07 | 20 | 29.41 |
| 75 | 1020 | 1020.43 | 20 | 28.70 |

**Texas Site Peripheral Transverse Stripe Spacing**

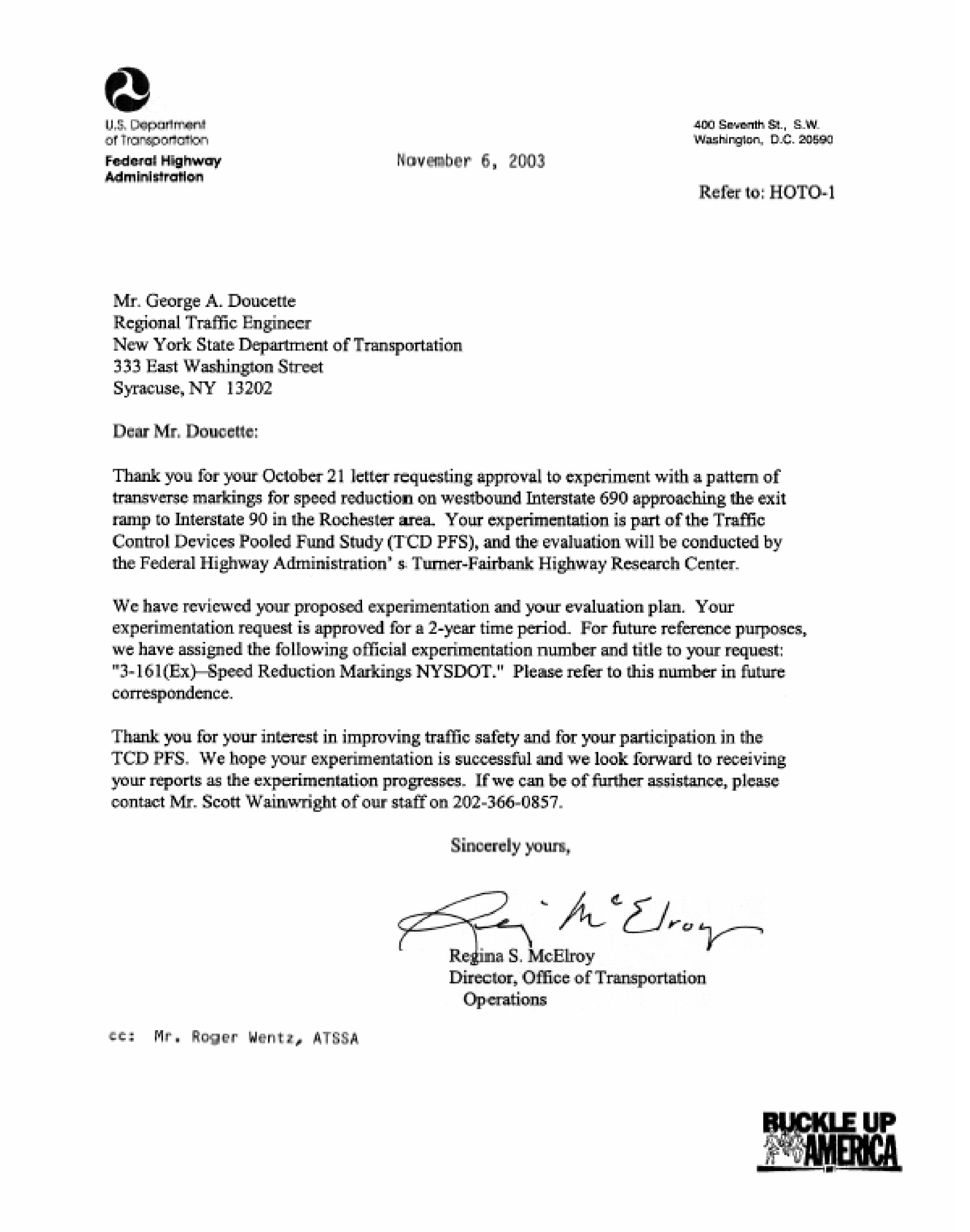
| | | |
|---|---|---|
| Initial Speed | 72 | miles per hour |
| Desired Speed | 40 | miles per hour |
| Distance | 1000 | feet |
| Required Decel | -3.87 | $ft/s^2$ |
| Bar Frequency | 4 | bars per second |

| Marking Number | Distance (Rounded For Design) | Distance Traveled | Desired Speed (mph) | Desired Speed (ft/s) |
|---|---|---|---|---|
| 1 | 0 | 0.00 | 72 | 105.84 |
| 2 | 26 | 26.46 | 71 | 104.87 |
| 3 | 53 | 52.68 | 71 | 103.89 |
| 4 | 79 | 78.65 | 70 | 102.92 |
| 5 | 104 | 104.38 | 69 | 101.95 |
| 6 | 130 | 129.87 | 69 | 100.98 |
| 7 | 155 | 155.11 | 68 | 100.00 |
| 8 | 180 | 180.11 | 67 | 99.03 |
| 9 | 205 | 204.87 | 67 | 98.06 |
| 10 | 229 | 229.39 | 66 | 97.09 |
| 11 | 254 | 253.66 | 65 | 96.11 |
| 12 | 278 | 277.69 | 65 | 95.14 |
| 13 | 301 | 301.47 | 64 | 94.17 |
| 14 | 325 | 325.01 | 63 | 93.19 |
| 15 | 348 | 348.31 | 63 | 92.22 |
| 16 | 371 | 371.37 | 62 | 91.25 |
| 17 | 394 | 394.18 | 61 | 90.27 |
| 18 | 417 | 416.75 | 61 | 89.30 |
| 19 | 439 | 439.07 | 60 | 88.33 |
| 20 | 461 | 461.15 | 59 | 87.35 |
| 21 | 483 | 482.99 | 59 | 86.38 |
| 22 | 505 | 504.59 | 58 | 85.41 |
| 23 | 526 | 525.94 | 57 | 84.43 |
| 24 | 547 | 547.05 | 57 | 83.46 |
| 25 | 568 | 567.91 | 56 | 82.49 |
| 26 | 589 | 588.53 | 55 | 81.51 |
| 27 | 609 | 608.91 | 55 | 80.54 |
| 28 | 629 | 629.04 | 54 | 79.56 |
| 29 | 649 | 648.93 | 53 | 78.59 |
| 30 | 669 | 668.58 | 53 | 77.62 |
| 31 | 688 | 687.99 | 52 | 76.64 |
| 32 | 707 | 707.15 | 51 | 75.67 |
| 33 | 726 | 726.06 | 51 | 74.69 |
| 34 | 745 | 744.74 | 50 | 73.72 |
| 35 | 763 | 763.17 | 49 | 72.74 |
| 36 | 781 | 781.35 | 49 | 71.77 |
| 37 | 799 | 799.29 | 48 | 70.79 |
| 38 | 817 | 816.99 | 47 | 69.82 |
| 39 | 834 | 834.45 | 47 | 68.84 |
| 40 | 852 | 851.66 | 46 | 67.87 |
| 41 | 869 | 868.63 | 46 | 66.89 |
| 42 | 885 | 885.35 | 45 | 65.92 |

**Texas Site Peripheral Transverse Stripe Spacing (cont'd)**

| Marking Number | Distance (Rounded For Design) | Distance Traveled | Desired Speed (mph) | Desired Speed (ft/s) |
|---|---|---|---|---|
| 43 | 902 | 901.83 | 44 | 64.94 |
| 44 | 918 | 918.07 | 44 | 63.97 |
| 45 | 934 | 934.06 | 43 | 62.99 |
| 46 | 950 | 949.81 | 42 | 62.02 |
| 47 | 965 | 965.31 | 42 | 61.04 |
| 48 | 981 | 980.57 | 41 | 60.07 |
| 49 | 996 | 995.59 | 40 | 59.09 |
| 50 | 1010 | 1010.36 | 40 | 58.11 |

# APPENDIX B: REQUESTS FOR EXPERIMENTATION



U.S. Department
of Transportation

**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

November 6, 2003

Refer to: HOTO-1

Mr. George A. Doucette
Regional Traffic Engineer
New York State Department of Transportation
333 East Washington Street
Syracuse, NY 13202

Dear Mr. Doucette:

Thank you for your October 21 letter requesting approval to experiment with a pattern of transverse markings for speed reduction on westbound Interstate 690 approaching the exit ramp to Interstate 90 in the Rochester area. Your experimentation is part of the Traffic Control Devices Pooled Fund Study (TCD PFS), and the evaluation will be conducted by the Federal Highway Administration' s Turner-Fairbank Highway Research Center.

We have reviewed your proposed experimentation and your evaluation plan. Your experimentation request is approved for a 2-year time period. For future reference purposes, we have assigned the following official experimentation number and title to your request: "3-161(Ex)—Speed Reduction Markings NYSDOT." Please refer to this number in future correspondence.

Thank you for your interest in improving traffic safety and for your participation in the TCD PFS. We hope your experimentation is successful and we look forward to receiving your reports as the experimentation progresses. If we can be of further assistance, please contact Mr. Scott Wainwright of our staff on 202-366-0857.

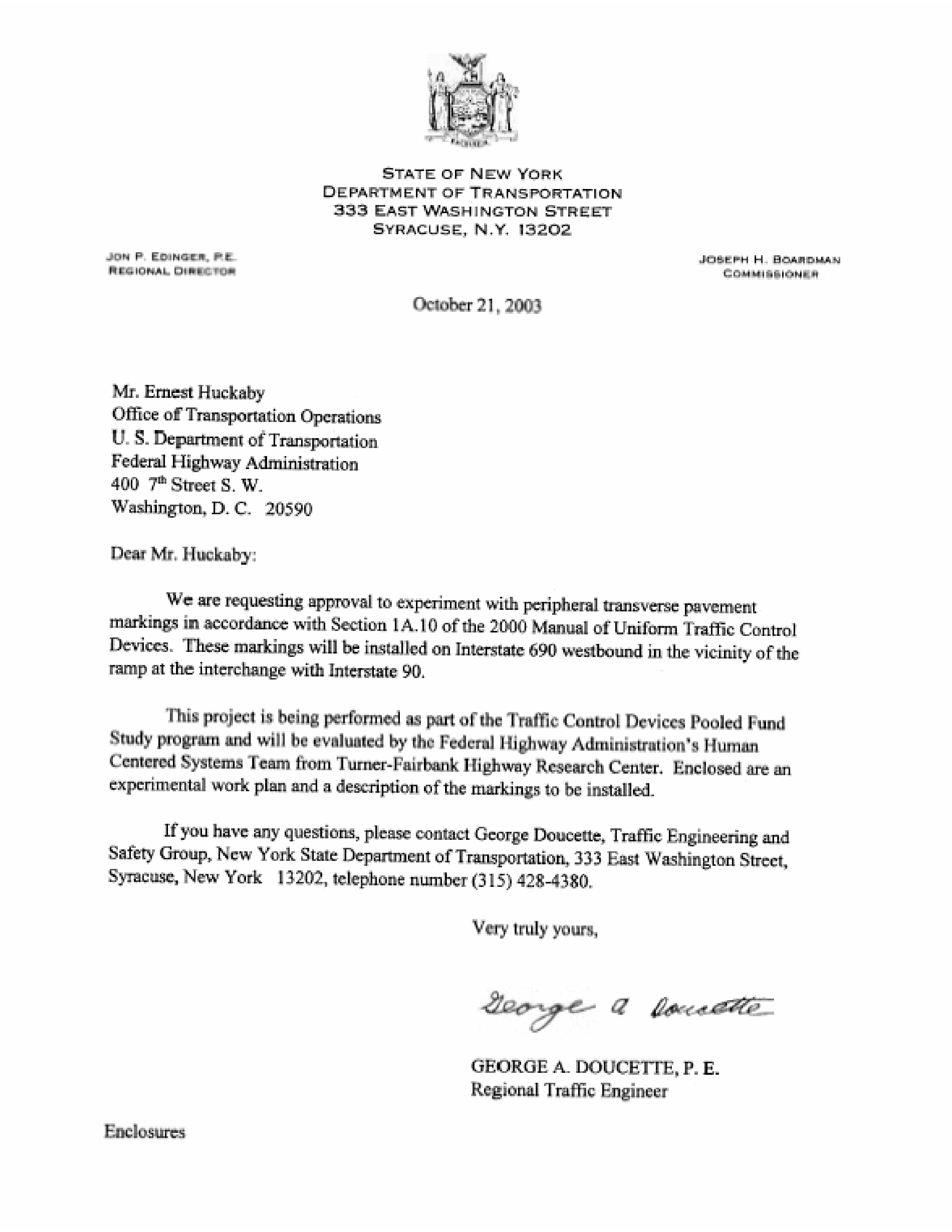
Sincerely yours,

McElroy

Regina S. McElroy
Director, Office of Transportation
Operations

cc: Mr. Roger Wentz, ATSSA

BUCKLE UP AMERICA



STATE OF NEW YORK
DEPARTMENT OF TRANSPORTATION
333 EAST WASHINGTON STREET
SYRACUSE, N.Y. 13202

JON P. EDINGER, P.E.
REGIONAL DIRECTOR

JOSEPH H. BOARDMAN
COMMISSIONER

October 21, 2003

Mr. Ernest Huckaby
Office of Transportation Operations
U. S. Department of Transportation
Federal Highway Administration
400 7th Street S. W.
Washington, D. C. 20590

Dear Mr. Huckaby:

We are requesting approval to experiment with peripheral transverse pavement markings in accordance with Section 1A.10 of the 2000 Manual of Uniform Traffic Control Devices. These markings will be installed on Interstate 690 westbound in the vicinity of the ramp at the interchange with Interstate 90.

This project is being performed as part of the Traffic Control Devices Pooled Fund Study program and will be evaluated by the Federal Highway Administration's Human Centered Systems Team from Turner-Fairbank Highway Research Center. Enclosed are an experimental work plan and a description of the markings to be installed.

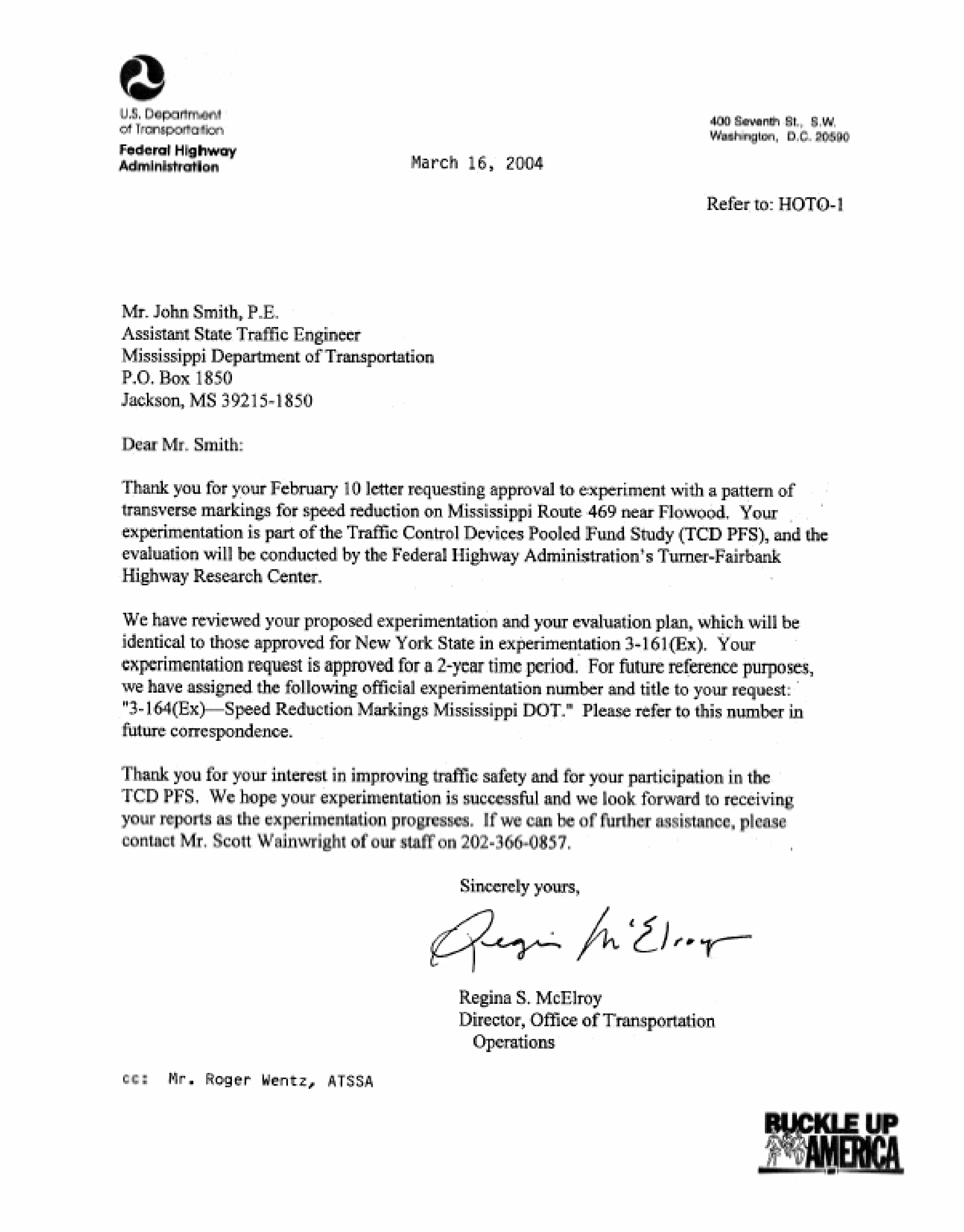
If you have any questions, please contact George Doucette, Traffic Engineering and Safety Group, New York State Department of Transportation, 333 East Washington Street, Syracuse, New York 13202, telephone number (315) 428-4380.

Very truly yours,

George a Doucette

GEORGE A. DOUCETTE, P. E.
Regional Traffic Engineer

Enclosures



U.S. Department
of Transportation
**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

March 16, 2004

Refer to: HOTO-1

Mr. John Smith, P.E.
Assistant State Traffic Engineer
Mississippi Department of Transportation
P.O. Box 1850
Jackson, MS 39215-1850

Dear Mr. Smith:

Thank you for your February 10 letter requesting approval to experiment with a pattern of transverse markings for speed reduction on Mississippi Route 469 near Flowood. Your experimentation is part of the Traffic Control Devices Pooled Fund Study (TCD PFS), and the evaluation will be conducted by the Federal Highway Administration's Turner-Fairbank Highway Research Center.

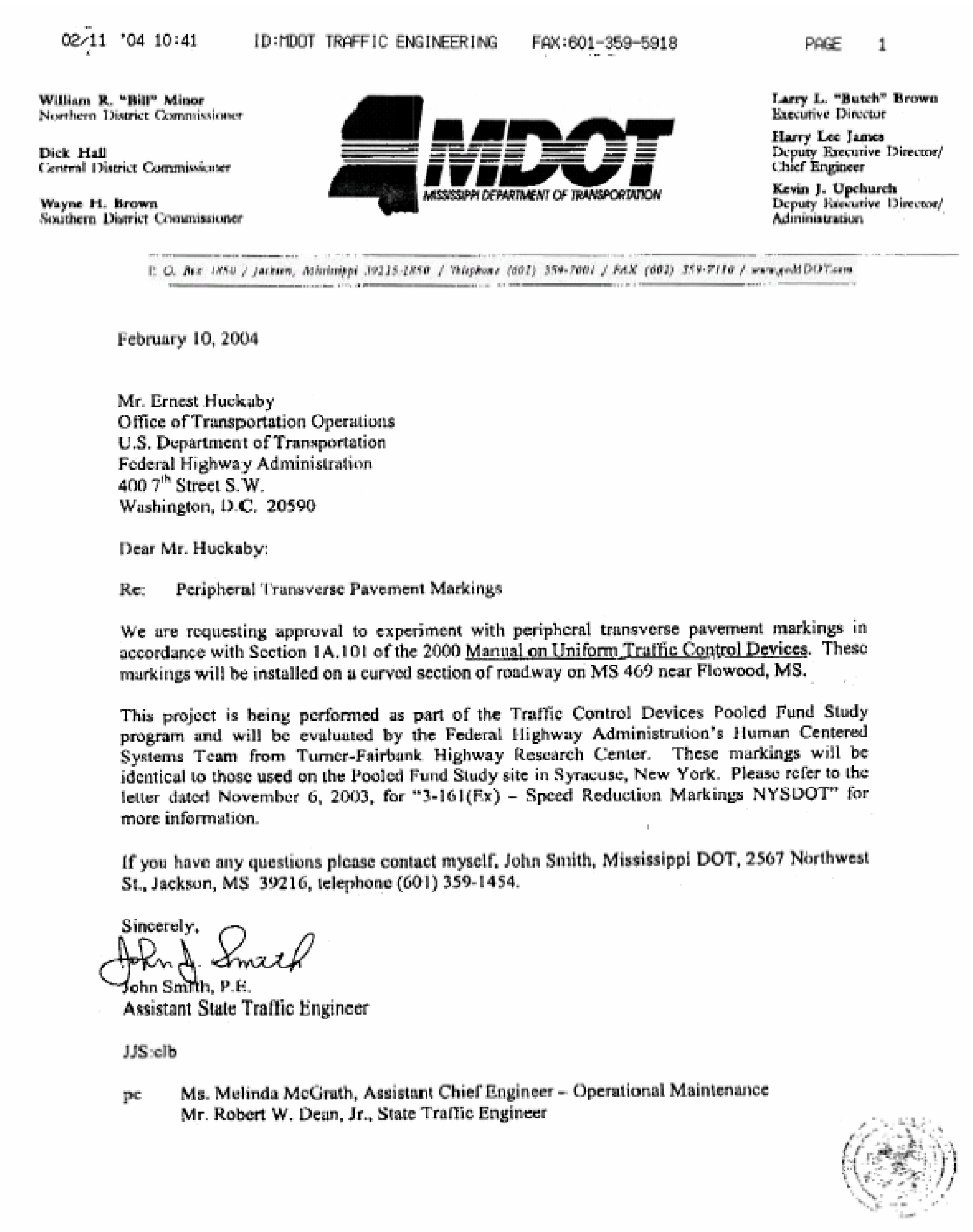
We have reviewed your proposed experimentation and your evaluation plan, which will be identical to those approved for New York State in experimentation 3-161(Ex). Your experimentation request is approved for a 2-year time period. For future reference purposes, we have assigned the following official experimentation number and title to your request: "3-164(Ex)—Speed Reduction Markings Mississippi DOT." Please refer to this number in future correspondence.

Thank you for your interest in improving traffic safety and for your participation in the TCD PFS. We hope your experimentation is successful and we look forward to receiving your reports as the experimentation progresses. If we can be of further assistance, please contact Mr. Scott Wainwright of our staff on 202-366-0857.

Sincerely yours,

Regina S. McElroy
Director, Office of Transportation
Operations

cc: Mr. Roger Wentz, ATSSA



02/11 '04 10:41 ID:MDOT TRAFFIC ENGINEERING FAX:601-359-5918 PAGE 1

**William R. "Bill" Minor**
Northern District Commissioner

**Dick Hall**
Central District Commissioner

**Wayne H. Brown**
Southern District Commissioner

MDOT
MISSISSIPPI DEPARTMENT OF TRANSPORTATION

**Larry L. "Butch" Brown**
Executive Director

**Harry Lee James**
Deputy Executive Director/
Chief Engineer

**Kevin J. Upchurch**
Deputy Executive Director/
Administration

P. O. Box 1850 / Jackson, Mississippi 39215-1850 / Telephone (601) 359-7001 / FAX (601) 359-7110 / www.goMDOT.com

February 10, 2004

Mr. Ernest Huckaby
Office of Transportation Operations
U.S. Department of Transportation
Federal Highway Administration
400 7th Street S.W.
Washington, D.C. 20590

Dear Mr. Huckaby:

Re: Peripheral Transverse Pavement Markings

We are requesting approval to experiment with peripheral transverse pavement markings in accordance with Section 1A.101 of the 2000 Manual on Uniform Traffic Control Devices. These markings will be installed on a curved section of roadway on MS 469 near Flowood, MS.

This project is being performed as part of the Traffic Control Devices Pooled Fund Study program and will be evaluated by the Federal Highway Administration's Human Centered Systems Team from Turner-Fairbank Highway Research Center. These markings will be identical to those used on the Pooled Fund Study site in Syracuse, New York. Please refer to the letter dated November 6, 2003, for "3-161(Ex) – Speed Reduction Markings NYSDOT" for more information.

If you have any questions please contact myself, John Smith, Mississippi DOT, 2567 Northwest St., Jackson, MS 39216, telephone (601) 359-1454.

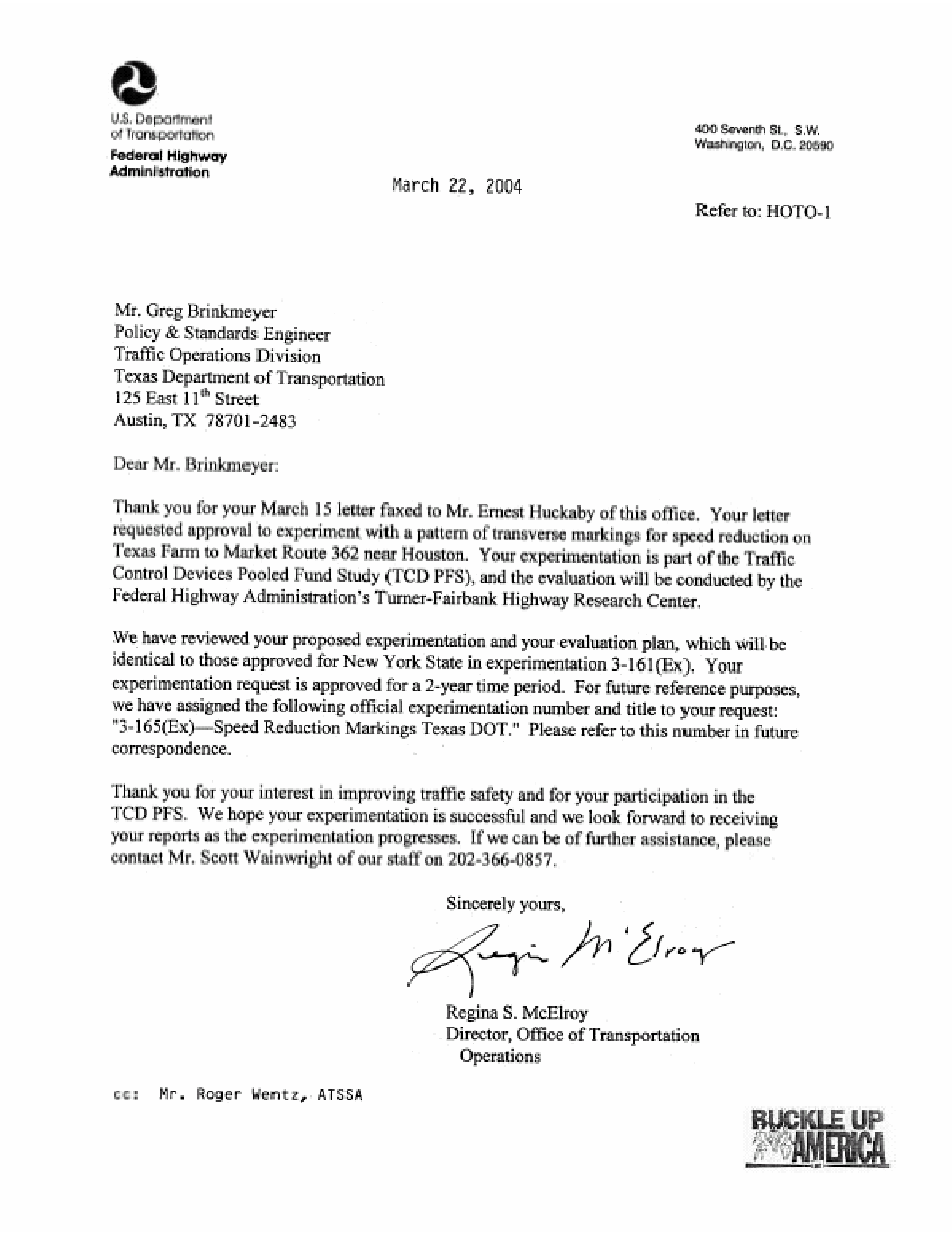
Sincerely,

John J. Smith

John Smith, P.E.
Assistant State Traffic Engineer

JJS:clb

pc Ms. Melinda McGrath, Assistant Chief Engineer – Operational Maintenance
Mr. Robert W. Dean, Jr., State Traffic Engineer



U.S. Department
of Transportation
**Federal Highway
Administration**

400 Seventh St., S.W.
Washington, D.C. 20590

March 22, 2004

Refer to: HOTO-1

Mr. Greg Brinkmeyer
Policy & Standards Engineer
Traffic Operations Division
Texas Department of Transportation
125 East 11th Street
Austin, TX 78701-2483

Dear Mr. Brinkmeyer:

Thank you for your March 15 letter faxed to Mr. Ernest Huckaby of this office. Your letter requested approval to experiment with a pattern of transverse markings for speed reduction on Texas Farm to Market Route 362 near Houston. Your experimentation is part of the Traffic Control Devices Pooled Fund Study (TCD PFS), and the evaluation will be conducted by the Federal Highway Administration's Turner-Fairbank Highway Research Center.

We have reviewed your proposed experimentation and your evaluation plan, which will be identical to those approved for New York State in experimentation 3-161(Ex). Your experimentation request is approved for a 2-year time period. For future reference purposes, we have assigned the following official experimentation number and title to your request: "3-165(Ex)—Speed Reduction Markings Texas DOT." Please refer to this number in future correspondence.

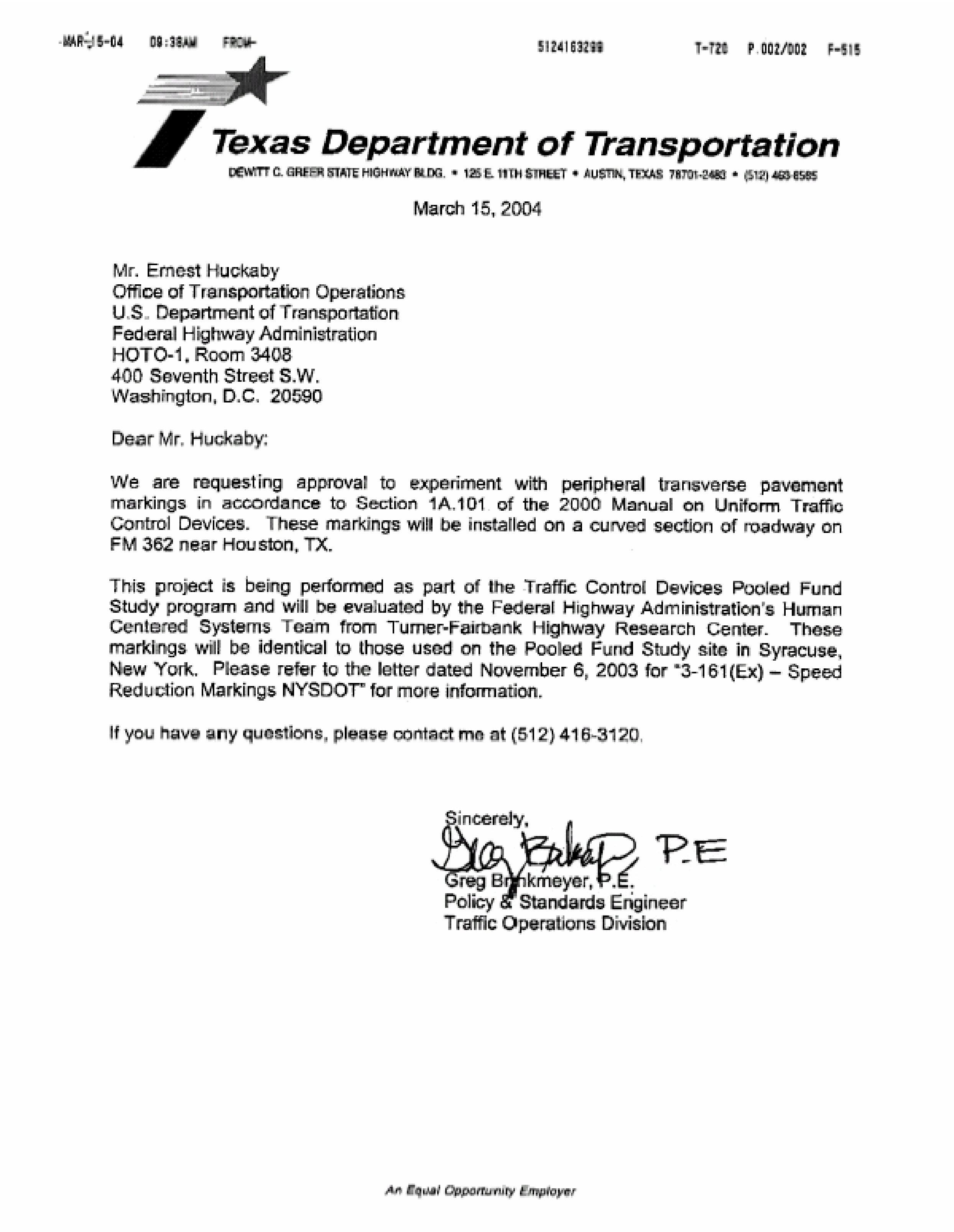
Thank you for your interest in improving traffic safety and for your participation in the TCD PFS. We hope your experimentation is successful and we look forward to receiving your reports as the experimentation progresses. If we can be of further assistance, please contact Mr. Scott Wainwright of our staff on 202-366-0857.

Sincerely yours,

Regina S. McElroy
Director, Office of Transportation
Operations

cc: Mr. Roger Wentz, ATSSA

BUCKLE UP AMERICA



MAR-15-04 09:38AM FROM- 5124163299 T-720 P.002/002 F-515

**Texas Department of Transportation**
DEWITT C. GREER STATE HIGHWAY BLDG. • 125 E. 11TH STREET • AUSTIN, TEXAS 78701-2483 • (512) 463-8585

March 15, 2004

Mr. Ernest Huckaby
Office of Transportation Operations
U.S. Department of Transportation
Federal Highway Administration
HOTO-1, Room 3408
400 Seventh Street S.W.
Washington, D.C. 20590

Dear Mr. Huckaby:

We are requesting approval to experiment with peripheral transverse pavement markings in accordance to Section 1A.101 of the 2000 Manual on Uniform Traffic Control Devices. These markings will be installed on a curved section of roadway on FM 362 near Houston, TX.

This project is being performed as part of the Traffic Control Devices Pooled Fund Study program and will be evaluated by the Federal Highway Administration's Human Centered Systems Team from Turner-Fairbank Highway Research Center. These markings will be identical to those used on the Pooled Fund Study site in Syracuse, New York. Please refer to the letter dated November 6, 2003 for "3-161(Ex) – Speed Reduction Markings NYSDOT" for more information.

If you have any questions, please contact me at (512) 416-3120.

Sincerely,

P.E

Greg Brinkmeyer, P.E.
Policy & Standards Engineer
Traffic Operations Division

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