Low Cost Traffic Engineering Improvements: A Primer

U.S. Department of Transportation
Federal Highway Administration
Office of Transportation Management

April 2003

1. Report No. FHWA-OP-03-078	2. Government Accession No.	3. Recipient's Catalog No.

1. Title and Subtitle Low Cost Traffic Engineering Improvements: A Primer	2. Report Date April 2003 3. Performing Organization Code FHWA
4. Author(s) Fred E. Latham and Jeffrey W. Trombly	8. Performing Organization Report No.
9. Performing Organization Name and Address Science Applications International Corporation 301 Laboratory Road Oak Ridge, TN 37831	10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH61-01-C-00180
12. Sponsorship Agency Name and Address Department of Transportation FHWA Office of Transportation Management 400 Seventh Street, S.W. - Room 3404 Washington, DC 20590	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code FHWA

15. Supplementary Notes

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16. Abstract

Transportation agencies throughout the country have implemented various successful and effective low cost strategies to improve safety and reduce traffic congestion.

17. Key Words Traffic Engineering Improvements	18. Distribution Statement No restrictions. This document is available to the public from National Technical Information Service Springfield, Virginia 22161

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 15	22. Price

Form DOT F 1700.7 **(8-72)** Reproduction of completed page authorized

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Acronyms

DOT	Department of Transportation
MDSHA	Maryland State Highway Administration
NYSDOT	New York State Department of Transportation
NYSTA	New York State Thruway Authority

Introduction and Purpose

This report presents the results of an investigation into low cost traffic engineering improvements, including types of actions, costs, and benefits.

In an effort to reduce crashes and ease traffic congestion on our nation's highways, traffic engineers and planners have traditionally pursued a wide range of actions. In some cases, the most cost-effective solution requires a significant investment in public funds. In other cases, the most cost-effective solution can be achieved through implementation of lower cost solutions. The purpose of this report is to share approaches that have been implemented to provide low cost solutions for improving safety and traffic flow. The report is designed to serve as a primer, or basic introduction, to the subject of low cost traffic engineering improvements. The goal is to provide practicing traffic engineers and planners with information describing the types of low cost actions that have been implemented, along with their cost and benefits.

"Low cost" is a relative term. Agencies implementing large projects with large budgets may perceive a "low cost" project differently than an agency with a limited budget. For purposes of this discussion, "low cost" is defined as a project or strategy that generally requires an investment in the range of $10,000 to $50,000. Many of the strategies discussed range from several hundred dollars to several thousand dollars in magnitude. The research conducted for this study, however, indicates that "low cost" does not mean "low benefit."

The research results presented in this report are based on a review of the literature as well as interviews with transportation agency staff throughout the nation. The results identify a series of successful and effective low cost strategies that agencies have implemented to improve safety and reduce traffic congestion. Hopefully, many of the practices presented are transferable to other communities dealing with similar problems.

This report is divided into five parts. Following this introductory section, the second part describes several low cost traffic engineering improvements that have been implemented in a variety of locations. The third part of this report discusses why low cost traffic engineering improvements are important. Among the most significant reasons cited for pursuing low cost improvements is that limited funding is available to local jurisdictions for managing growing safety and capacity problems. The fourth part of this report examines the benefits that have been derived from the implementation of low cost improvements based on several examples that have been implemented in different parts of the nation. The fifth part of this report describes several experimental or innovative low cost approaches to increasing safety and mitigating congestion.

What Are Low Cost Traffic Engineering Improvements?

Research has confirmed that low cost, shorter-term strategies that utilize shoulders, narrow lanes, regulatory devices, and technology to manage travel and control traffic can increase capacity and improve operations and safety at a particular bottleneck along a congested metropolitan corridor.

Low cost traffic engineering improvement techniques are typically spot applications or are limited to shorter sections of roadway that do not cover an entire length of an arterial corridor. Some of these strategies include pavement markings, static and dynamic signing, roadway lighting, raised medians, curb cuts, roadway geometric changes, or lane controls. These strategies provide the guidance, warning, and control needed for drivers to ensure safe and informed operation through traffic bottlenecks or congested areas.

An understanding of the types of low cost actions that have been implemented is best gained through the examination of several successful programs, including the Automobile Club of Michigan (AAA Michigan); the Traffic Engineering Department of the City of Winston Salem, North Carolina; and the Traffic Engineering Department of the City of Knoxville, Tennessee.

AAA Michigan initiated a program to identify and treat locations in the cities of Detroit and Grand Rapids with frequent crashes. Over the past six years, AAA Michigan examined 253 intersections in Detroit and Grand Rapids and implemented low cost safety improvements at 112 sites. Actions implemented at the intersections included the following:

- implementation of all-red intervals;
- replacement of 8-inch signal heads with 12-inch signal heads;
- relocation of signal heads to improve visibility by realigning two signal heads facing each other, realigning the signal heads over each lane of travel, or mounting the signal heads using box span installations;
- installation of secondary post-mounted signal heads to improve visibility at some locations;
- installation of back plates on traffic signals to improve visibility at some locations;
- installation of left turn lanes through re-striping of approach lanes and exclusive left turn phases, where needed; and
- removal of on-street parking.

Post-implementation crash studies conducted for improvements in Detroit showed a greater than 50% reduction in total crashes and a greater than 60% reduction in total injuries at the treated intersections. A benefit-cost study conducted as part of the project found a 15:1 return for the Detroit intersection improvements and a 16:1 return for the Grand Rapid intersections.

In 1986, the Traffic Engineering Division of the City of Winston Salem, North Carolina began an annual program to locate and treat crash locations and evaluate the results of such treatments. Over time, the program has completed before-and-after studies at 364 locations, adding 40 to 50 new locations each year. As a result, the program has reduced targeted crashes by 49% and total crashes by 13%.

Low cost treatments implemented at high crash locations included the following:

- creating a left turn lane within the confines of an existing roadway,
- adding left turn phases to existing signals,
- replacing "Yield" signs with "Stop" signs at intersections,
- replacing two-way stops with multi-way stops,
- installing traffic signals,
- using bigger and/or better signs,
- installing short segments of center line and stop bars at "Stop" locations,
- installing double-indicating "Stop" signs (adding a left-side sign),
- painting the message "Stop Ahead" and "Stop" on pavement,
- removing signals from late night/early morning programmed flashing operation,
- adding back plates to existing signal installations,
- adding a signal head to an existing display,
- replacing 8-inch signal heads with 12-inch signal heads,
- adding "Signal Ahead" signs,
- installing red "T" displays (two red signal heads mounted horizontally over an amber and green),
- installing an all-red interval, and
- replacing protected/permissive left turn phases with full protected left turn phases.

The City of Knoxville, Tennessee, Traffic Engineering Department has successfully implemented a number of low cost traffic engineering improvements over the years. Examples include the following:

- installing sight distance mirrors where more expensive earthwork to remove the sight distance obstacle is not feasible,
- installing strobe lights in signals to make the public more aware of signals that are present in areas where background lighting is present,
- providing longer all-red intervals in the signal timing where such things as bridge decks interfere with signals,
- placing signal heads to provide a better view of red signals in limited sight-distance-to-signal faces,
- providing narrower lane widths to provide additional lanes,
- providing narrower lane widths to allow for a pedestrian island, and
- providing detector actuated flashers for sight distance problems that would require very expensive earthwork to correct sight distance problem.

Two state agencies in New York, New York State Department of Transportation (NYSDOT) and the New York State Thruway Authority (NYSTA), installed continuous shoulder milled rumble strips during the 1990s. NYSDOT installed approximately 8,000 shoulder-kilometers of continuous shoulder rumble strips along its existing rural interstate highways and parkways throughout the state between 1993 and 1998. During the same period, the NYSTA installed 3,131 shoulder kilometers of rumble strips on 81% of the New York Thruway (3,864 shoulder-kilometers) between 1992 and 1996.

Both agencies evaluated the effectiveness of continuous shoulder rumble strips by collecting data before and after the installation. They both concluded that the installation of the continuous shoulder rumble strips reduced the number of crashes by at least 65% to 70%. Particularly, NYSTA noted that the number of run-off-road crashes was reduced by 88% (557 cases in 1991 versus 74 cases in 1997), and fatalities declined by 95% (17 cases in 1991 versus 1 case in 1997).

With improved manufacturing efficiencies and increased numbers of installations, the cost of purchasing and installing milled rumble strips has dramatically decreased over the years. For example, NYSTA reports that the linear meter cost of a milled rumble strip was $3.63 in 1993 compared to $0.38 in 1996. These costs do not include maintenance and protection of traffic.

Table 1 contains several more examples of low cost traffic engineering improvements that have been implemented across the country. These actions include restriping pavement to provide additional travel lanes, landscaping to remove restrictions to sight distance, and installing improved signage to reduce crashes.

Table 1
Additional Examples of Low Cost Traffic Engineering Improvements

Location	Description
Barnstead, New Hampshire	Installed warning signs/beacons at intersection of Route 288 and N. Barnstead Rd.
Hampton, New Hampshire	Restriped and narrowed lanes on New Hampshire Route 111 to 11 feet to provide wider bike lanes
New Hampshire, various locations	Installed and placed driver speed feedback signs at various locations
Bow, New Hampshire	Restriping pavement to provide an auxiliary lane to convert an on- and off-ramp into a weave at interchange of I-89 and I-93
Orlando, Florida	Removed and landscaped approaches to improve sight distance at first median cut west of John Young Parkway on Town Center Boulevard due to high collision rate related to inadequate sight distance
Glenlig, Maryland	Created left turn lanes with striping and a short bulb-out section on Route 32
Stuart, Florida	Reduced number of median openings on U.S. Route 1

Why Are Low Cost Traffic Engineering Improvements Important?

Low cost traffic engineering improvements offer local traffic engineers means for improving safety in the face of increasing traffic volumes and decreasing budgets for traffic improvements.

Demand for highway travel by Americans continues to grow as population increases, particularly in metropolitan areas. Construction of new highway capacity to accommodate this growth in travel has not kept pace. Between 1980 and 1999, route miles of highways increased 1.5% while vehicle miles of travel increased 76%. The Texas Transportation Institute estimates that in 2000, the 75 largest metropolitan areas experienced 3.6 billion vehicle hours of delay, resulting in 21.6 billion liters (5.7 billion gallons) of wasted fuel and $67.5 billion in lost productivity. Traffic volumes are projected to continue to grow. Congestion is largely thought of as a big city problem, but delays are becoming increasingly common in small cities and some rural areas as well.

There is a need to provide tools and information on modest traffic improvements (roadway geometry, signage, striping, etc.) that can be implemented by state and local traffic engineers to reduce traffic congestion and improve traffic flow. Budget constraints in the face of continually increasing safety and congestion problems have meant that local traffic engineers need to apply low cost solutions wherever feasible. As the examples presented in this report show, these solutions cover a wide range of actions.

What Agencies Are Using Low Cost Improvements?

Automobile clubs, municipal agencies, and state transportation departments have all applied low cost traffic engineering solutions.

Low cost improvements are another set of tools available to traffic engineers to mitigate increasing traffic congestion and to reduce crashes. They are best viewed as one of a number of strategies that can be employed by the practicing traffic engineer to effectively and efficiently manage traffic. The research conducted for this study found a number of public and private agencies that have adopted low cost traffic engineering solutions as a continuing part of their programs.

City of Portland, Oregon

Traffic circles have been an integral part of the City of Portland's Traffic Management Program for approximately five years. Portland has utilized traffic circles to reduce vehicle speeds and eliminate very fast traffic on local residential streets. Traffic circles are frequently chosen over other devices because they do not divert truly local traffic and do not restrict access to

Traffic circles were effective in reducing speeds on residential streets in Portland.

Portland has used traffic circles like the one shown above for approximately five years, dramatically reducing multi-vehicle crashes.

adjacent streets or land uses.
Experience in Portland and other cities in the U.S. and Europe indicates that traffic circles are effective in reducing vehicle speeds and can reduce the number and severity of intersection accidents.

An evaluation by the City of Portland to determine the impact of traffic circles and their potential effect on traffic speeds and intersection safety substantiates the finding that traffic circles are successful at reducing the number of vehicles traveling at high speeds (30-35 mph) on residential streets. On many of Portland's residential streets, 15% or more of the vehicles routinely exceeded 35 mph. After traffic circles were installed, vehicles rarely exceed 35 mph. The larger circles (12-foot radius) appear to reduce vehicle speeds more than smaller traffic circle islands. Moreover, the analysis found that traffic circles have dramatically reduced, if not almost eliminated, reported accidents, especially multi-vehicle collisions. The cost to construct each circle ranges from $3,000 to $9,000.

Springfield, Missouri

The Public Works Department of the City of Springfield, Missouri routinely installed and evaluated low cost traffic engineering improvements to correct safety problems at intersections. As presented in Table 2, these treatments range in cost from $150 to $5,000.

The Department of Public Works continues to install and monitor the effectiveness of various intersection improvement strategies and report this information to city management.

Table 2
Springfield, Missouri Intersection Problem Treatments

Problem	Description	Cost
Poor signal head visibility attributed to side mounted signals	Install mast arm to mount signal heads overhead to improve visibility	$5,000
Illegal turning-left movements	Install lane use signs	$150
Poor alignment of overhead flashing signal at four-way-stop controlled intersection	Realign signal and relocate "Stop Ahead" sign to improve visibility	$300
Crashes by drivers turning left at signalized intersection	Install protected phase	$1,500

Treatments used in Springfield included installing a protected phase (left) and overhead signals (right).

AAA Michigan

AAA Michigan selected locations for improvements based on high levels of crashes. Midblock crashes along the studied corridors were insignificant when compared with the crashes at signalized intersections; therefore, midblock crash treatments were not targeted for implementation, and the focus of the effort was placed on improving signalized intersections. The improvements implemented varied by location; however, in general, they were low cost improvements on the order of approximately $30,000 per intersection (Table 3).

Table 3
Selected Intersections Treated as Part of AAA Michigan Program

Intersection	City	Description	Cost	Crash Reduction
Seven Mile Road and John R. Road	Detroit	Approach lanes re-striped to include left turn lanes at the north, south, and eastbound approaches. In addition, an exclusive left-turn phase for the east-west traffic was installed using a three-phase design. Parking was removed for 200 feet of clear sight distance. Signal heads were upgraded from 8-inch to 12-inch signal heads, and all-red intervals of sufficient length were added.	$35,200	50%
Seven Mile Road and Ryan Road	Detroit	Exclusive left turn lanes were installed along with exclusive left turn phases. No roadway widening was required because existing pavement width was available. The traffic signals were upgraded from 8-inch to 12-inch diameter signal heads, and all-red intervals of sufficient length were installed. On-street parking was removed, providing approximately 200 feet of clear sight distance.	$36,100	53%
Hubble Road and Puritan Road	Detroit	Left turn lanes were installed at all approaches. The traffic signals were upgraded from 8-inch to 12-inch diameter signal heads, and all-red intervals of sufficient length were installed.	$30,300	64%

Maryland State Highway Administration

The Maryland State Highway Administration (MDSHA) works to improve mobility through non-traditional signal timing improvements (Table 4). With considerable peak period main line traffic flowing to and from Washington D.C., engineers are challenged to maintain traffic flow while providing adequate service to local and side street traffic.

Table 4
Examples of Innovative Low Cost Implementations by Maryland State Highway Administration

Problem	Treatment	Approximate Cost
Mainline congestion resulting from inadequate storage capacity	Two exclusive left turns allowed per cycle	$5,000 per intersection
Lengthy delays for minor movements	Half-cycle variation	$5,000 per intersection
Lengthy mainline queues and congestion	Directional lead-lag	$5,000 per intersection

Signal Timing Improvements

Two turn phases per cycle – In situations where main line peak period flow requires an extended green period, left turn lanes that are not permissive can extend beyond the storage area, causing disruption to main line traffic flow. In these situations, MDSHA has begun allowing for two exclusive left turn lane periods per main line cycle. The lead- and lag-exclusive left turn is activated in the direction of peak period traffic flow. This has proven to be an effective, low cost method to improve mobility. The process requires the controller to be reprogrammed. The total cost is below $5,000, with half for reprogramming the controller and half for engineering assessment of the intersection and potential treatments.

Half-cycle variation – A variation of the "half cycle" is used to decrease delays for minor movements while maintaining traffic flow on the main line. A 3-minute cycle will consist of one long mainline movement, then a side street movement, another short mainline movement, and another side street movement. This variation is useful when developing progression on two consecutive intersections with different cycle lengths. Synchronization software is utilized to assess signal cycles prior to implementation. The innovative signal cycle improves main line traffic flow at a cost of less than $5,000.

Directional lead-lag – At intersections where only exclusive left turns are allowed, MDSHA has begun to use a signal cycle called "directional lead-lag". By utilizing signal synchronization software, the process allows one direction-exclusive left turn and mainline traffic flow during the lead phase, allowing the other direction-exclusive left turn and mainline movement during the lag phase of the green band. Field assessments have shown this to double the duration of green bands, reduce queues, and reduce unnecessary stop time. The innovative signal cycle improves main line traffic flow at a cost of less than $5,000.

Pennsylvania Department of Transportation

The Pennsylvania Department of Transportation (DOT) developed a program of low cost safety improvements as an element of its Safety Management Plan (Table 5). Improvements were targeted at high crash locations. Funds were made available to implement a variety of low cost actions, including the following:

- pedestrian channelization devices and addition of a 3-second advance for pedestrians at signalized intersections,
- centerline rumble strips where concentrations of head-on crashes occurred on two-lane highways, and
- removal or delineation of trees or utility poles where the concentration of crashes involving trees occurs in a set segment of highway.

Table 5
Sample Problems Treated by Pennsylvania DOT

Problem	Treatment	Approximate Cost
Head-on crashes	Centerline rumble strips	$5,000 per mile
Fixed objects on roadside	Tree delineation utility pole delineation Shoulder rumble strips	$90 per pole $3/linear foot
Pedestrian safety	3-second advance for pedestrians at signalized intersections	$5,000 per intersection

Centerline milled rumble strips are designed to reduce the incidence of drivers crossing into the opposing travel lane by using the sound and sensation of encroachment across the centerline to alert them. This treatment costs approximately $5,000 per mile and is effective in reducing the frequency of head-on crashes.

Pennsylvania DOT used centerline milled rumble strips (left) and pedestrian treatments (right) as elements of its Safety Management Plan.

A variety of low cost pedestrian safety treatments have been applied by the Pennsylvania DOT, including time extensions for pedestrians at signalized intersections to give pedestrians a three-second head start when crossing, installation of "Stop for Pedestrians in Crosswalk" sandwich boards, and exclusive pedestrian phases at intersections with a high level of pedestrian and vehicle crashes.

Pennsylvania DOT has also installed delineation treatments on roadside obstacles, such as utility poles. While these are very inexpensive treatments, they have proven to be effective in reducing fixed-object crashes.

Innovative Low Cost Strategies

Case study data shows the effectiveness of the low-cost approach in creating safe driving conditions for motorists.

The Pennsylvania DOT has designed and implemented several innovative strategies to treat safety problems. Many of these approaches reflect a low cost approach to traffic engineering. As presented in Table 6, these strategies are generally designed to improve safety through improved signing and pavement marking programs.

Table 6
Pennsylvania DOT Innovative Low Cost Improvements

Treatment	Description	Cost	Effectiveness
Advance curve warning	Developed to help motorists reduce speed when approaching curve. The pavement marking consists of two transverse bars, a "SLOW" legend, and an arrow indicating the direction of the upcoming curve.	Approximately $1,350 per site	Based on the evaluation of the original pilot program, there is expected to be a reduction of the 90th percentile speed. This translates into an estimated 25% reduction in curve-related deaths at each of the locations where installation is planned.
"Dot" tailgating treatment	Idea is to reduce tailgating by installing "dot" shaped pavement markings at fixed intervals such that keeping two markings apart will provide a safe following distance.	Approximately $1,800 per site	Police in South Centre Township observed a significant drop in tailgating and speeding in the area of the dots.
Intersection warning treatment	Concept is to provide advance warning to drivers proceeding through intersections under "Stop"- sign control. A series of signs and pavement markings assist drivers in judging gaps between on-coming vehicles.	Approximately $5,000 per intersection	Experimental program under evaluation.

Pennsylvania DOT's Advanced Curve Warning Treatment

The advanced curve warning treatment is a pavement marking placed on the roadway indicating that the driver should reduce speed for an upcoming curve. This treatment is being promoted in sections of roads or corridors with higher than average numbers of crashes having roadway curvature as a contributing factor. The pavement marking consists of two transverse bars, a "SLOW" legend and an arrow indicating the direction of the upcoming curve.

The advanced curve warning treatment warns drivers to reduce speeds.

The overall objective is to reduce the upper percentile speed, thus reducing the number of vehicles leaving the roadway and being involved in a crash. The total estimated cost per site, including pavement markings, installation labor, and equipment was approximately $1,350. Based on the evaluation of the original pilot program, there is expected to be a reduction of the 90th percentile speed. This translates into an estimated 25% reduction in curve-related deaths at each location where installation is planned. The larger pilot involves the treatment of nearly 200 sites with the advanced curve warning treatment.

Pennsylvania DOT's "Dot" Tailgating Treatment

The "dot" tailgating treatment marking is an effective highway safety countermeasure for assisting motorists in establishing safe following distances. This treatment is being promoted in sections of roads or corridors with higher than average numbers of crashes linked to aggressive driving or tailgating and where traffic congestion is not anticipated. Markings are spaced such that a minimum of two markings separates vehicles, which allows for a safe distance between them. Initially the Department tried painted chevrons on the pavement, with the spacing between chevrons based on the 2-second rule; however, the public had some difficulty in understanding what the chevrons meant. To address tailgating crash problems and motorists' confusion with chevrons, the Department decided to identify the area with signing and dot pavement markings, educate the motoring public with press releases and media events, and have targeted additional enforcement at particular problem areas in the corridor.

Dot treatment signage indicates safe following distances.

The total cost per installation is approximately $1,892 including signs, labor, and equipment. A test site was deployed in South Center Township since rear-end crashes represented 43% of the crashes on the US 11 corridor. South Centre Township police reported that they have observed a significant drop in tailgating and speeding in the area of the dots, and in the area north of the dots there has been a 60% drop in crashes based on a comparison of the following time periods:

- 11/1/99 to 3/1/00 = 34 crashes
- 11/1/00 to 3/1/01 = 12 crashes

The appendix to this primer contains the Guidelines for Installation of Pennsylvania "Dot" Tailgating Treatment and Design Specifications.

Pennsylvania DOT Intersection Warning Treatment

This treatment is used on a pilot basis when data show a high occurrence of crashes where vehicles on secondary roadways intersecting at grade misjudge the gap between approaching vehicles. Markings are placed to indicate safe gap length for a vehicle to accelerate from a stop into the intersection. Safe distance is defined based on posted speed for the primary roadway. The entire treatment consists of the following components: 1) placement of legend "SLOW, xxMPH" and 2) "+" symbols on the primary roadway, and 3) placement of appropriate signs on the secondary roadway.

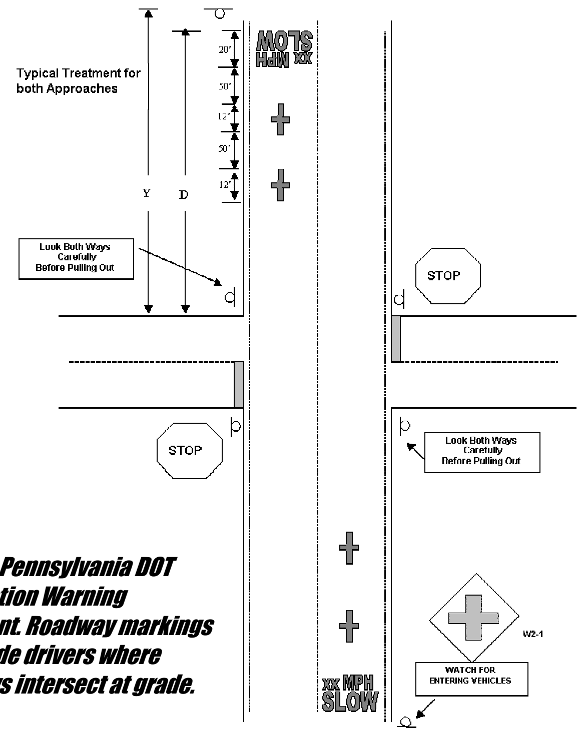

Figure 1. Pennsylvania DOT Intersection Warning Treatment. Roadway markings help guide drivers where roadways intersect at grade.

Low Cost Improvements for Rural Roads

On rural roads, low cost treatments have been used to address run-off-the-road crashes and to improve visibility.

Numerous low cost traffic-engineering improvements have been made to rural two-lane roads. Many of these treatments are designed to reduce the number of run-off-the–road crashes that account for a significant share of crashes in rural areas. Treatments installed include the following:

- bigger and brighter curve and chevron signs,
- inside- and outside-curve paved shoulder with rumble strips,
- rumble warning panels in advance of curves,
- shoulder edge drop-offs,
- installation of paved shoulders,
- brighter and more durable pavement markings, and
- flattened slopes.

It becomes more important to consider improvements to signs, signals, and markings to improve visibility as the rural population ages. Example low cost treatments that have been implemented to improve the visibility of traffic control devices include the following:

- installing larger stop signs,
- placing flags on stop ahead and stop signs,
- placing a flashing beacon on stop signs,
- installing advance stop sign rumble strips, and
- installing larger 8-inch street name signs.

Chevron signs

Night performance pavement markings

Flags on stop sign

Rumble warning panel

Before slope flattening

After slope flattening

Arlington County, Virginia Department of Public Works

The "intelligent" pedestrian crosswalk is a state-of-the-art system that provides additional pedestrian safety at high volume mid-block locations. The system uses sensor technology to trigger a set of lights, which are located along the marked crosswalk. The signals warn motorists that a pedestrian is in the crosswalk. This passive system uses an infrared eye with a one-directional setup to avoid extended activation as pedestrians clear the crosswalk. Timing is set using standard federal guidelines for crosswalk clearance times. The system in Arlington cost approximately $9,800 dollars, with an additional $10,000 in labor for installation. It has a 10-year life expectancy.

Maryland State Highway Administration

Route 4 North toward Washington, D.C. carries a significant volume of traffic to I-495, the National Capitol Beltway, and to downtown destinations during the morning peak period. The three-lane route is limited to two lanes in both directions 1.5 miles south of I-495. To eliminate the bottleneck created by the lane reduction, MDSHA needed an innovative, low cost method of maintaining adequate capacity. Using signage and pavement markings, peak period traffic is directed to use shoulders, thus relieving congestion. In the southbound direction, MDSHA has extended an on-ramp, allowing traffic to use the shoulder. Confirming signs are used to indicate the special use provision.

Shoulder use on Route 4 is permitted during peak periods (left). Signage indicates the end of the special use provision (right).

Conclusion

Low cost engineering traffic improvements have mitigated congestion and increased safety in communities across the country.

Among the solutions available to engineers and planners to ease traffic congestion and increase safety are a number of "low cost" solutions. These are projects or strategies that require investments ranging from several hundred dollars to roughly $50,000.

Treatments to achieve a more effective traffic flow include various executions of these techniques:

- innovative signal timing,
- narrower lane widths to allow for more lanes,
- shoulder usage during peak periods,
- exclusive left turn lanes and left turn phases, and
- on-street parking removals or reductions.

A number of transportation agencies have quantifiably reduced injuries and crashes by taking these actions:

- constructing pedestrian islands,
- installing pedestrian sensors in crosswalks,
- installing more visible traffic signals and signs,
- installing rumble strips,
- using traffic circles to reduce traffic speed,
- removing or delineating trees and utility poles,
- using advanced warning pavement markings, and
- using pavement markings in conjunction with a public awareness program to reduce tailgating.

While these examples, along with others presented in this primer, illustrate relatively inexpensive approaches, they have proven to be effective in mitigating congestion and increasing safety in communities across the country.

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Appendix
Guidelines for Installation of Pennsylvania "Dot" Tailgating Treatment

1. The "dot" markings are shown to be effective for assisting the motorist in establishing safe following distance. Use this treatment in areas where there is a high concentration of aggressive driving or tailgating-related crashes. Markings are spaced such that safe distance is kept between vehicles when a minimum of two markings separates them. Safe distance is defined based on a two-second following rule. Areas with significant grade differences should generally be avoided.

2. **Marking** - The marking consists of a series of ellipses (dots) marked in all lanes at equal spacing according to the posted roadway speed (see Table 1, Spacing 'S'). Marking is to be centered in the travel lane. The ratio of width to height for the elliptical mark is 1:3 based on standard oblong pavement markings referenced in the MUTCD. Markings should be applied according to Figure 1.

3. **Spacing** - The pavement markings should be placed such that the spacing is according to Table 1. Spacing is based on posted speed for any given roadway.

4. **Pattern Spacing** - The distance between successive series of dots is also based on posted speed and can be found in the Table 1. This distance should be adjusted as appropriate to meet field conditions.

5. **Signing** - There should be placed a minimum of three signs as follows:
   - "Don't Tailgate" should be placed 1,000 feet before the first pattern.
   - "Keep Min 2 Dots Apart" sign should be placed at the second marking in each set of dots.
   - "Maintain Safe Following Distance," sign should be placed 1,000 feet after the last pattern.

   For signing layout, see Figure 3. Place signs in accordance with Sign Foreman's Manual, Pub 108.

6. Refer to the attached Specification for Epoxy Pavement Marking for selection of material and construction.

7. Dot pavement markings can be installed via projects initiated exclusively for this purpose.

   Deviation from the above specifications and guidelines may be considered by Districts; however, they require approval by the Bureau of Highway Safety & Traffic Engineering prior to implementation.

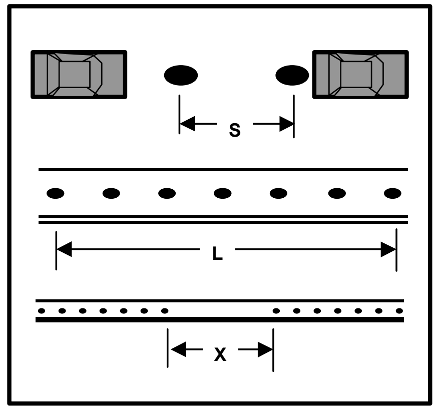
Pennsylvania "DOT" Tailgating Treatment

Experimental

Comprehension Time :	5 sec
P/R Time :	2.5 sec
Adjustment Time :	20 sec
Following Time :	2 sec
Effective Time :	60 sec
Vehicle Correction :	15 ft

Posted Speed (mph)	Posted Speed (fps)	Distance Travelled (ft)	S Marking Spacing (ft)	Minimum # Markings in Pattern	L Min Pattern Length (ft)	X Pattern Spacing (ft)
25	37	73	60	18	1020	2200
30	44	88	75	18	1275	2640
35	51	103	90	17	1440	3080
40	59	117	105	17	1680	3520
45	66	132	115	17	1840	3960
50	73	147	130	17	2080	4400
55	81	161	145	17	2320	4840
60	88	176	160	17	2560	5280
65	95	191	175	16	2625	5720

Table 1 - Spacing and Length

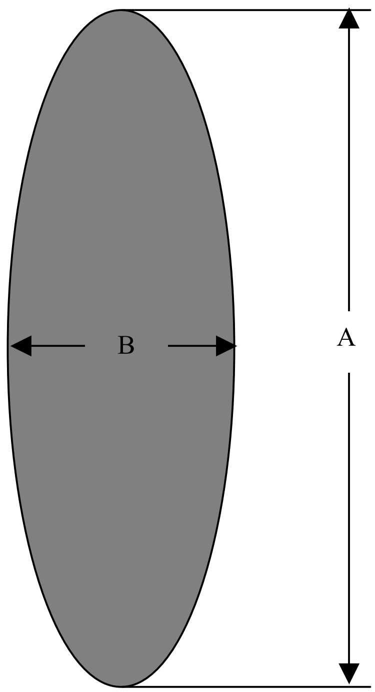


Definitions

Comprehension Time *(sec)*	Amount of Time required for driver to comprehend the meaning of the markings.
P/R Time *(sec)*	Indicates Time required for an average driver on target roadway to percieve that an action is required and to begin that action. Typical Value is 2.5 seconds.
Adjustment Time *(sec)*	Amount of Time provided for the following driver to gauge and adjust the Distance between their vehicle and the lead vehicle.
Following Time *(sec)*	The enforcable following time for target roadway. Vehicles should travel a Distance apart from each other such that this Time has passed for a following vehicle to reach the location of the lead vehicle at Time t_0.
Effective Time *(sec)*	Length of Time for which the pattern maintains an effect on the driver. Relates to how long the driver can maintain the Distance corresponding to the *Following Time* after leaving the pattern.
Posted Speed *(fps)*	Relates to the Posted Speed Limit on the target roadway.
Distance Traveled *(ft)*	At the given *Posted Speed*, this indicates the Distance the vehicle will travel in the *Following Time*. Value is *Posted Speed (fps)* times *Following Time (sec)*.
Marking Spacing, S *(ft)*	This Distance reflects the spacing between two pavement markings within the pattern such that vehicle will traverse two markings in the *Following Time*. Value is equal to *Distance Traveled (ft)* rounded to the next 5 foot length less the *Vehicle Correction*
Vehicle Correction *(ft)*	Distance vehicle must be away from the nearest DOT to allow the DOT to be visible from the drivers eye position. Value assumed to be 15 ft measured from bumper to edge of DOT marking.
# Markings in Pattern	The number of markings at the *Marking Spacing* that can be placed in the length of roadway required to travel at the Posted Speed for the total required Comprehension, P/R, and Adjustment Times. Value is that length (ft) divided by *Marking Spacing (ft)* rou
Pattern Length, L *(ft)*	Distance from the center of the first marking in the pattern to the center of the last marking in the pattern. Value is the *Number of Markings*, less one, times *Marking Spacing*.
Pattern Spacing, X *(ft)*	Distance a vehicle will travel between Marking Patterns. Relates to *Effective Time* such that the effect of the previous set of markings will just begin to fade as driver encounters the next set. Value is *Posted Speed (fps)* times *Effective Time (sec)*.

Pennsylvania “DOT” Tailgating Treatment

Experimental



Width:Length = 1:3 ratio*

Typical Marking

Alternative	**A (ft)**	**B (ft)**	**Area (sq ft)**
Two Lane Highway	7.5	2.5	14.71
Interstate	12	4	37.68

* Refer to Guidelines for more information

Figure 1 – Typical Marking

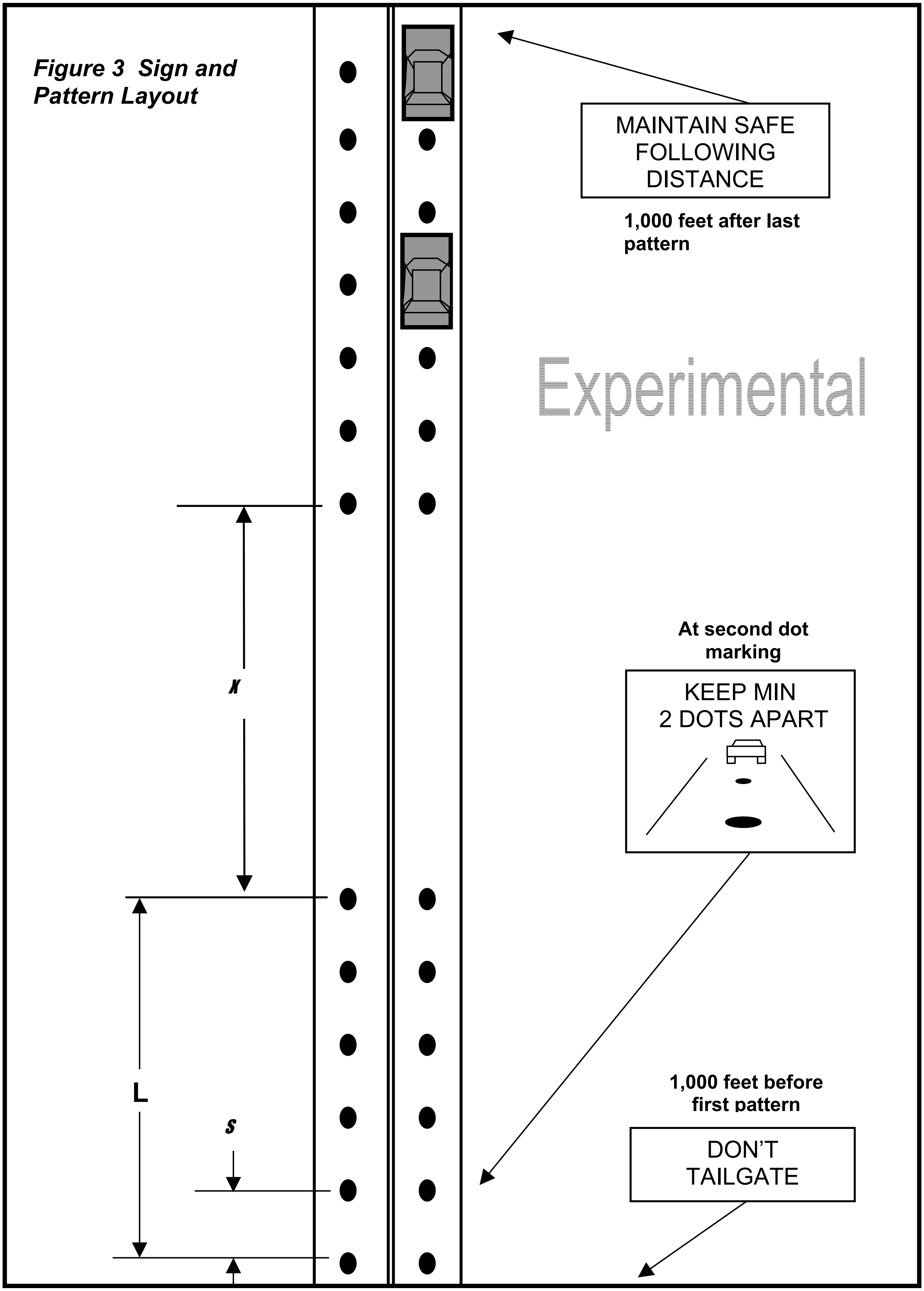


Figure 3 Sign and Pattern Layout