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Effectiveness of An Experimental Stop/Slow Signal Flag In Work Zones

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EFFECTIVENESS OF AN EXPERIMENTAL STOP/SLOW SIGNAL FLAG IN WORK ZONES

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ABSTRACT

FHWA has established the STOP/SLOW paddle as the primary hand-signaling device in work zones. Although their clear messages provide motorists with positive guidance, they are cumbersome to use. Flags are much easier to handle, but are generally used only in spot locations because they do not provide such guidance. Highway Maintenance employees in NYSDOT's Region 9 have developed a hand-held flag displaying STOP and SLOW legends, combining the maneuverability of flags with the positive guidance of paddles. NYSDOT received FHWA permission to evaluate the flag's effectiveness, and comparative field tests indicated that drivers reduce speed earlier as they approach the new flag -- for example, at about 120 m motorists averaged 4.9 km/h slower in approaching the new flag than the paddle. There were also fewer erratic driver movements or violations of instructions when using the new flag. Based on this evidence of improved compliance and legibility, this new hand-signaling device warrants consideration as an alternative to the STOP/SLOW paddle.

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Figure 1. Legends displayed by the prototype device.

I. INTRODUCTION

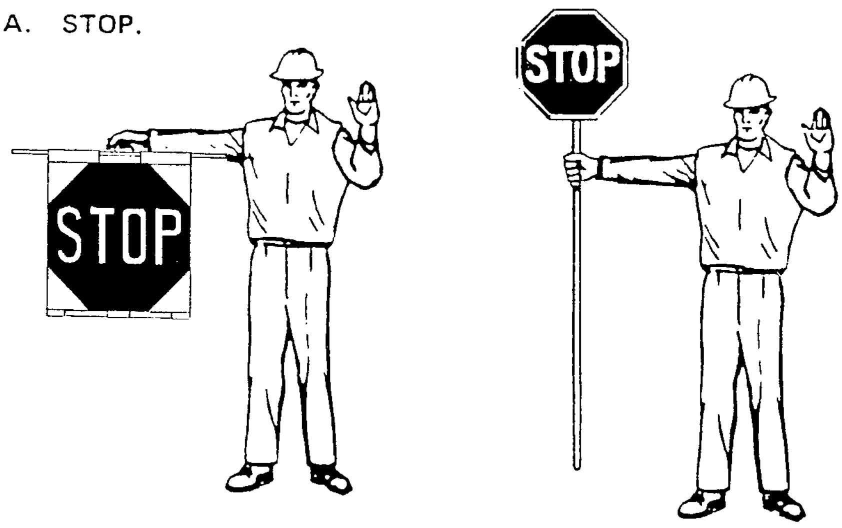
As stated in Federal Highway Administration's Manual on Uniform Traffic Devices, "Flaggers are provided at work sites to stop traffic intermittently as necessitated by work progress or to maintain continuous traffic past a work site at reduced speeds to help protect the work crew" (1). Various hand-signaling devices -- STOP/SLOW paddles, lights, and red flags -- help control traffic through work zones. The sign paddle bearing the clear messages STOP or SLOW provides motorists with more positive guidance than flags, and is recommended by FHWA as the primary hand-signaling device. Use of flags is limited to emergency situations in spot locations that can best be controlled by a single flagger (1).

Analysis of accident and operational data from Strategic Highway Research Program (SHRP) Project H108 ("Maintenance Work Zone Safety") indicated several problems with currently approved hand-signaling devices. Drivers often do not see flaggers and fail to stop when so directed. Although STOP/SLOW paddles provide more positive guidance than flags, they are cumbersome to use in the field. They are heavy -- without the support pole a 457 by 457 mm paddle weighs over 1.25 kg -- but nevertheless they are generally used with such poles, which range from at least 1.5 m to the more common 2.13 m length. Normal windload forces on the flat paddle surface are magnified by strong gusts created by passing trucks and passenger vehicles. Moment developed by weight of the paddle on a 2.13 m pole is significant enough to make adequate control of the device extremely difficult, especially for long periods. In addition, flaggers using radios to control alternating directions of traffic in a one-lane work zone are not allowed to motion to traffic with the hand holding the radio. Flaggers thus have no hand free to motion to traffic, unless they control the paddle on the pole and the radio simultaneously with the other hand. This is not a problem when using the flag, since it may easily be tucked under the arm when not in use. The pole also complicates evading errant vehicles, paddles with poles are more difficult to store, and they often must be transported outside a vehicle.

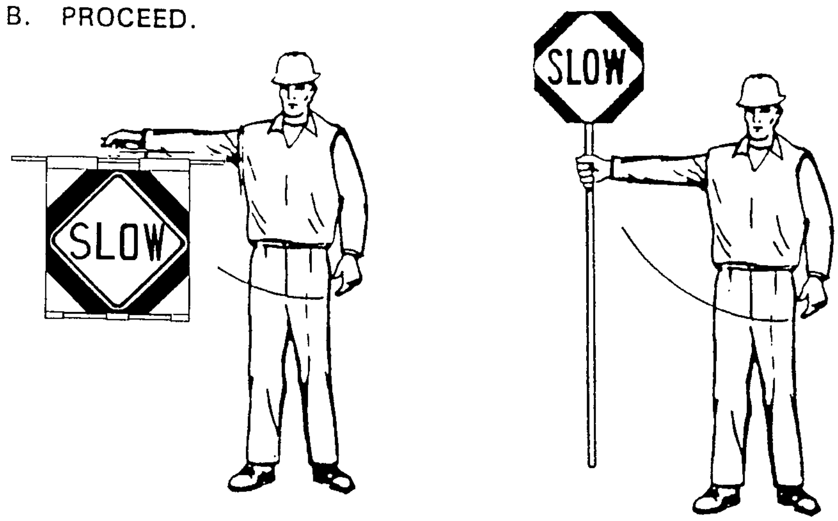
Flaggers are aware of the limited maneuverability of the signal paddle. They also know that motorists too often fail to recognize traffic control instructions even when using the more convenient and maneuverable signal flag. Through the Department's "INNOVATIONS" program, which actively seeks ideas from employees to improve work activities, NYSDOT Chenango County Residency highway maintenance staffers in Region 9 (Binghamton) developed a prototype hand-signaling device combining the advantages of the STOP/SLOW paddle's positive-guidance message with the flag's easier handling, maneuverability, and storage. As shown in Figure 1, it provides a flag displaying a 610 mm octagonal STOP in 203 mm Series C letters on one side, and a 457 mm diamond SLOW in 152 mm Series B letters on the other. It is supported at the top from a 912 mm long, 19 mm diam dowel weighted on the bottom by another 608 mm dowel.

Figure 2. Hand signaling procedure.

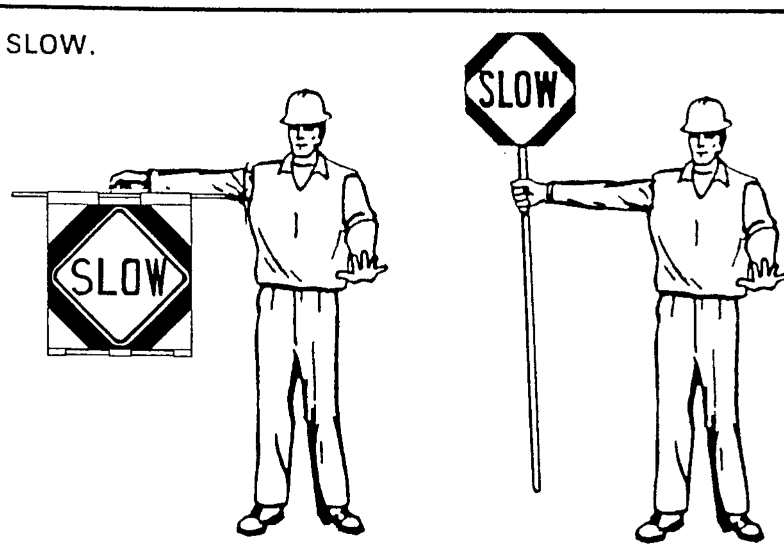
A. STOP.



B. PROCEED.



C. SLOW.



The major differences between the approved signal flag and the prototype device are legend and color. The approved all-red flag has no legend, but the prototype device features two (STOP, SLOW) similar to those of the approved paddle, providing positive guidance to the motorist. The prototype is red with white letters and borders when displaying the STOP legend, and orange with black letters and borders when displaying the SLOW legend -- color schemes also consistent with that of the approved paddle. The experimental device is made of "Reflexite" fabric, providing retroreflectivity to the device and legends.

The major differences between the signal paddle and prototype device are size and weight. The paddle is a rigid message board with a 457 mm octagonal STOP legend in 152 mm Series C letters (2), while prototype flag is flexible with a 610 mm octagonal STOP legend in 203 mm Series C letters. Both devices show a 457 mm diamond with 152 mm Series B letters for the SLOW legend. Prototype flag STOP and SLOW modes are shown in Figure 2. The 457 mm paddle, not including the support pole, weighs about 1.25 kg. The prototype, including top and bottom dowels, weights less than 500 g.

Flaggers who developed the prototype believe that if adopted, it will increase driver recognition and compliance with flagging instructions, without loss of handling ability. To test their theory, the Department requested and received FHWA approval to evaluate the prototype against the approved paddle.

Figure 3. Test section documentation.

LOCATION / IDENTIFICATION			PHYSICAL CHARACTERISTICS				TRAFFIC
Route Number	Region, County, and County Order	Mile Markers	Pavement Width (m)	Shoulder Width (m)	Approach Grade (%)	Sight Distance (m)	Traffic Volume AADT
12	9202	1102	7.3	3.0	Level	605	4950
41	9202	1175	6.7	2.1	+1.9%	575	2400
8	9203	1023	7.3	2.4	Level	605	3250

LEGEND (columns numbered from left)

1: Identifies state route number of the road where the test section was located (only state highways were used).

2 & 3: Section locations were identified by state mile-markers each having three numerical lines: the first gives the state route number: the second gives the NYSDOT region number (first digit), the county number within the region (second digit), and county order of the route from its beginning at its western or southern terminus (third and fourth digits); and the third line the control segment within each county, and mileage in 1/10-miles (160 m) within the control segment. A "control segment" indicates the sequential progress of the highway across city and county lines.

4 & 5: Pavement and shoulder widths for each roadway section.

6: Approach grades to the sites were estimated in the field and verified from record plans.

7: Determined using the laser unit, which also collected speed and distance data.

8: AADT was taken from NYSDOT's 1992 Highway Sufficiency Ratings.

II. FIELD EXPERIMENTS

During summer of 1993, field experiments designed to measure speed profiles and determine driver behavior and reaction when using the experimental flag, as compared to the approved STOP/SLOW paddle, were conducted at various locations in Chenango County. The tests were directed by the Region's Traffic Engineering and Safety Group and Employee Safety and Health Group, assisted by the Main Office Engineering Research and Development Bureau.

The tests were run on rural two-lane state highways, within an actual construction project and at two simulated maintenance sites. The approved paddle and experimental flag were operated by experienced flaggers to warn, guide, and control traffic through highway sections where workers and/or equipment were operating on or near the traveled way. They were trained in the hand-signaling procedures shown in Figure 2. Procedures for the new flag were developed and practiced off-site before it was used on the highway.

A. Selection of Appropriate Road Test Sections

Sites were limited to sections having the following features:

1. Distant from intersections where vehicles could enter from secondary roads.

2. No physical features adjoining or on the roadway that might create abnormal hazards (such as narrow bridges, etc.).

3. Normal painted delineation and paved shoulders.

4. No changes in pavement or shoulder widths.

5. Grades less than 2 percent.

For each site selected, documentation included location/identification information, pavement width, shoulder width, grade, sight distance, and traffic volume (Fig. 3). Warning signs were placed at each site according to FHWA criteria, including "WORK ZONE AHEAD" 1.1 km ahead of the flagger, "ONE LANE ROAD" 950 m ahead of the flagger, and "FLAGGER AHEAD" 800 m in front of the flagger.

B. Data Collection

Many factors affect a motorist's speed when driving a highway, the more obvious and important being the driver's capabilities and those of the vehicle, geometric characteristics of the roadway, traffic conditions, natural limitations (such as weather and visibility), and those introduced by law or control devices. To ensure that speeds measured in this study represented those desired by the driver under a given set of road conditions, not affected by other traffic on the road, the only speeds measured were those of isolated vehicles or those leading a line of other vehicles. All speeds were recorded under good weather conditions, to avoid effects of poor weather on the driver and roadway, during daytime hours on weekdays.

Speed and distance data were collected using an LTI 20•20 Speed Detection System loaned by the New York State Division of State Police. Manufactured by Laser Technology, Inc., of Englewood, Colorado, this system uses a series of invisible laser light pulses reflected off a target vehicle to measure its range and spot velocity. The operator sights the target vehicle through a scope located at the top of the unit, and pulls a trigger. Speed and range of the target vehicle are displayed in a LED readout visible to the operator.

Lasers have several advantages over traditional radar methods of speed collection. First, laser beam width is less than 1 m at a range of 300 m, providing positive identification of the target vehicle. Measurement readout begins within 0.3 seconds, allowing the operator to activate the unit, read speed and distance, and repeat the process several times as the target vehicle passes through the test section. The system cannot be monitored by standard radar detectors and does not require periodic calibration.

The laser unit was mounted on a standard tripod located at the pavement edge, facing oncoming traffic, about 12 m behind the flagger. This position allowed operating the unit within the 5-deg limit for the full 2000 m section length within which target-vehicle speeds and distances were monitored. This position also made it appear that the data-collection team was part of a construction or maintenance operation, and reduced the chance that targeted drivers would realize that their approach speeds were being monitored.

The purpose of the data collection was to develop speed profiles for sample vehicles traveling through the test section while the hand-signaling device was displaying the STOP message. With the device displaying SLOW and no other vehicle(s) present in the test section, a single vehicle or one leading a line of other vehicles was identified and targeted as it entered the test section. The laser unit was activated and vehicle speed and distance were recorded. The flagger was then told to display STOP on the traffic device and execute proper traffic control procedures (hand-signals and flagging technique) to bring the vehicle to a complete stop. Speed and distance measurement continued as the target vehicle traversed the test section. When it came to a complete stop, a final distance reading was taken (from the flagger to the stopping point). This procedure required a flagger and three-person team stationed at the laser unit -- one operated the unit and called out the speed and distance readings displayed, the second recorded them, and the third noted vehicle type, final stopping distance as indicated by lines marked on the pavement, and any erratic

Figure 4. Standard forms for information on date, time, and site (top) and speed and distance (bottom).

DATE: ___/___/___
START TIME: _________ AM/PM
DURATION: __________ HRS
SITE LOCATION: ____________________
SITE CONDITION: ____________________

Device: Date: Site Location:

Observation Number	Vehicle Type/ Color	Parameters	Number of Readings							
			1	2	3	4	5	6	7	STOPPED AT
1		Speed								
		Distance								
2		Speed								
		Distance								
3		Speed								
		Distance								
4		Speed								
		Distance								
5		Speed								
		Distance								
6		Speed								
		Distance								
7		Speed								
		Distance								
8		Speed								
		Distance								

driver maneuvers (such as late braking). Forms used to record these data shown in Figure 4.

C. Sample Size Determination

The data collection goal was to obtain and compare speed profiles of vehicles approaching the two hand-signaling devices in the STOP mode. Average speeds of vehicles approaching the devices were also compared at a fixed distance from the flagger. Kuemmel (3) recently reported average daytime legibility distance as about 120 m for construction-zone signs having both 152 and 203 mm Series C lettering. In an earlier NYSDOT study (4), average comprehension distance for the STOP message of the STOP/SLOW paddle was also found to be 120 m. The comparison point for the average vehicle speed thus was selected to be 120 m from the flagger.

Before actual field experiments, a small-scale pilot study was run to determine configuration and positioning for the crew, flagger, and instruments. From these preliminary data, the standard deviation of speed of vehicles approaching the flagger, at about 120 m, was estimated as 9 km/h. To determine if an average speed reduction of 4 km/h or more was achieved by using the new flag, speed data were to be collected for at least 110 vehicles for each device. This estimate was based on a confidence level and power of 0.95 (5). During the field experiments, speed and distance profiles were recorded for 284 vehicles (141 for the flag and 143 for the paddle), resulting in a data set of 2310 speed-and-distance pairs (about 8 speed observations per vehicle).

III. DATA ANALYSIS

To characterize speed profiles for vehicles approaching the flagger, data were collected for 141 vehicles approaching the flag and 143 approaching the paddle. Data for eight drivers who did not stop as instructed by the flagger were omitted from the analysis because their speed profiles were not consistent with the other 276 drivers who did stop. Of these eight, six were approaching the paddle and two the flag.

Included in the analysis were speed profiles of 22 drivers who exhibited delayed braking -- 15 approaching the paddle and 7 the new flag. Each driver was asked why the braking maneuver was delayed. Ten approaching the paddle said they saw the device but could not understand or read its instruction. All 12 other drivers said they simply were inattentive.

The final data set used in the analysis consisted of 2271 speed-and-distance pairs. Scatter plots of the speed data (Fig. 5) suggest that driver approach speeds at about 600 m from the flagger and their stopping distances were comparable for the two devices, but that those approaching the new flag tended to decelerate sooner than those approaching the paddle. Curvature in the relationship between speed and distance indicates that a linear model would not have been appropriate.

During exploratory data analysis various functional forms were used, but the relation between speed and distance was best captured using an exponential function:

$$Y = \beta_0 + \beta_1 e^{\beta_2 X} \tag{1}$$

where Y = speed, km/h, and

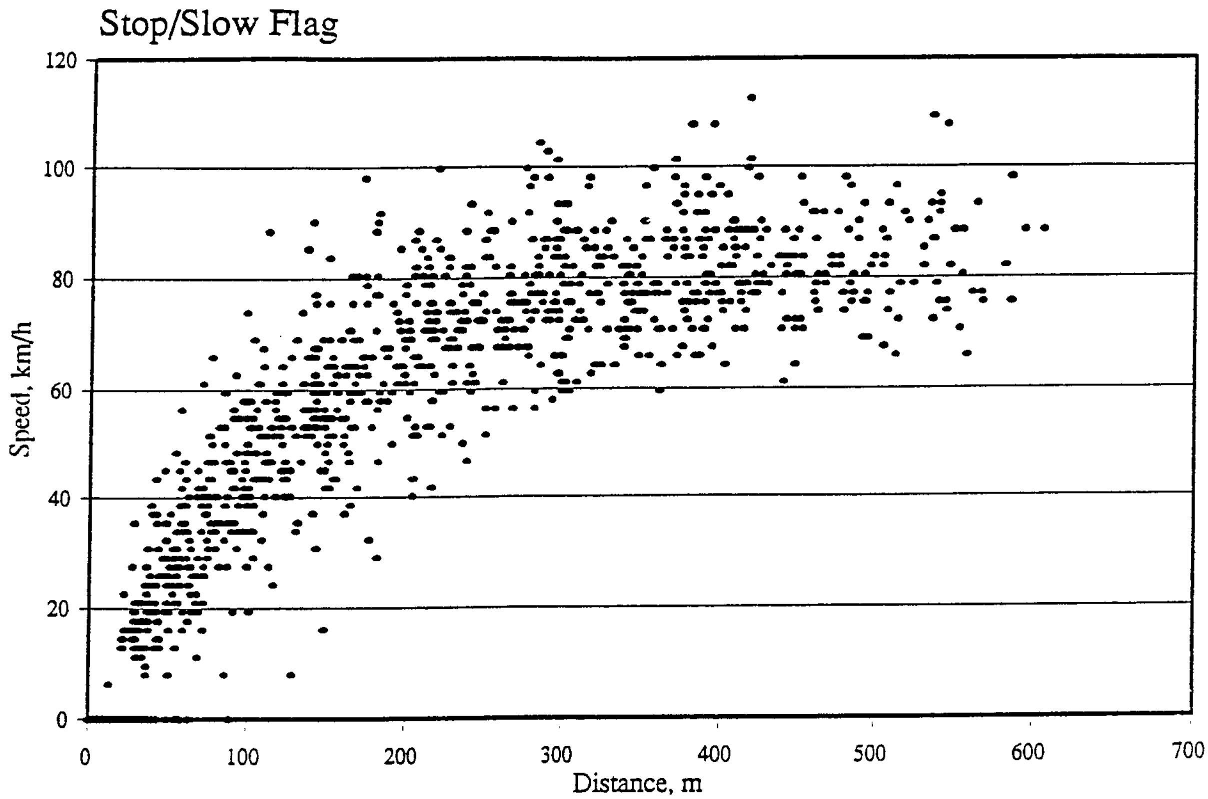
X = distance from the flagger, m.

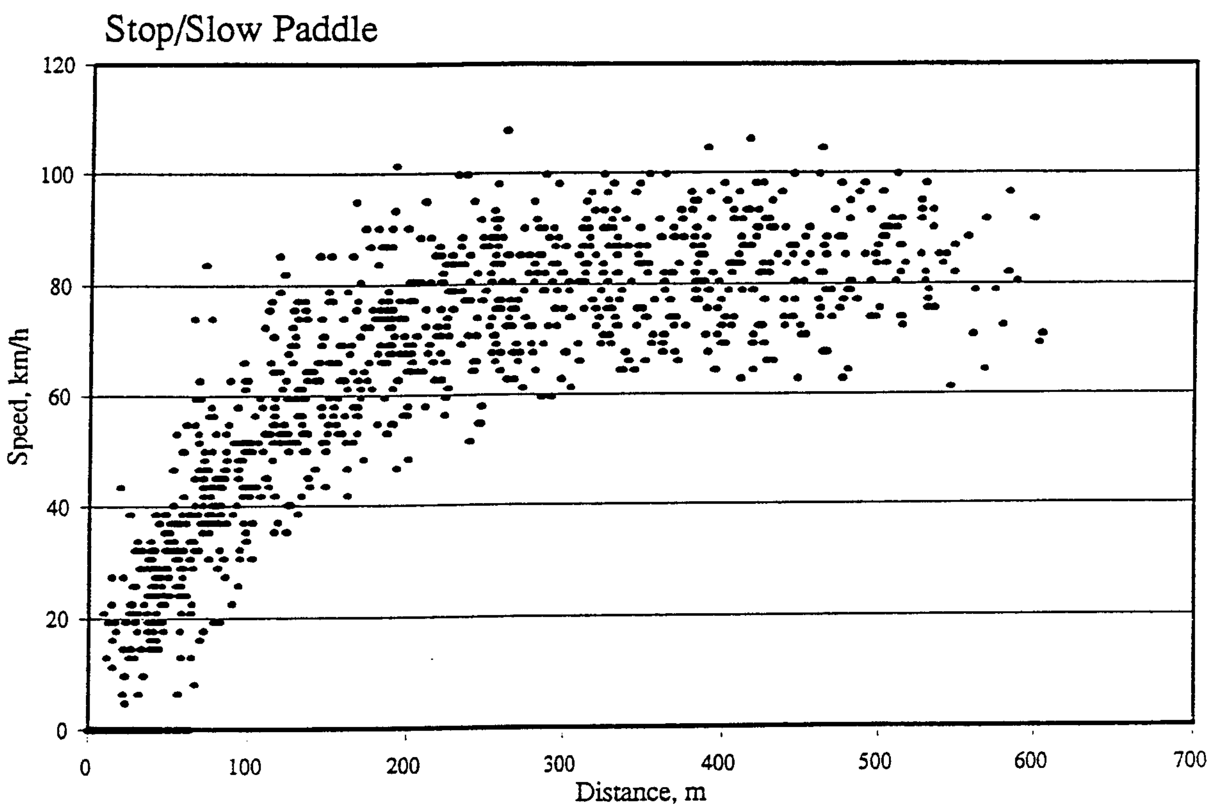
Possible effects of using different traffic control devices on the parameters β_0, β_1, and β_2 were tested by introducing a binary variable (Z = 1 for the new flag and Z = 0 for the paddle). This results in the following model:

$$Y = \beta_0 + \beta_1 e^{(\beta_2 + \beta_3 Z)X} \tag{2}$$

B_3 is statistically significant in this model and is non-zero.

Figure 5. Speed profiles.





The regression was performed on SAS Statistical Software (4) using the Gauss-Newton iterations available in the nonlinear regression procedure PROC NLIN. This method uses a Taylor series expansion to approximate the nonlinear regression model with linear terms, and then employs ordinary least-squares regression to estimate the parameters. Iterations of these steps lead to solution of the nonlinear regression problem. The Gauss-Newton method needs initial estimates of the regression parameters to begin the iterations. In this study, starting values for the parameters were estimated from exploratory data analysis and separate analyses of the data for the two traffic-control devices. In addition, several different sets of starting values were used to ensure that convergence was to the optimal values of the parameters that minimized the residual sum of squares.

The final model obtained was

$$Y_e = 84.62 - 94.73e^{(-0.0099 + 0.00132\,Z)X} \qquad (3)$$

where R^2 was 0.87 and the standard error of estimate was 10.6 km/h. In Eq. 3, Y_e is estimated speed in kilometers per hour, X is distance from the flagger in meters, and Z is 0 for the paddle and 1 for the new flag. As indicated by the R^2 value, this model explains 87 percent of the variability observed in speed. Neither the plots of residuals against the fitted values and distance nor a normal probability plot of the residuals suggested any serious departures from the modeling assumptions.

The Eq. 3 regression model results in the following two models for the two devices:

$$Y_e\ (\text{flag}) = 84.62 - 94.73e^{-0.0086X} \qquad (4)$$

and

$$Y_e\ (\text{paddle}) = 84.62 - 94.73e^{-0.0099X} \qquad (5)$$

These two functions are shown in Figure 6, which indicates that average speed of vehicles 600 m from the flagger and their stopping distances are about the same for the two devices. However, average speed is predicted to be lower with the flag, indicating earlier deceleration probably due to its earlier detection and legibility.

The estimated difference in average speed when facing the two devices, as a function of distance from the flagger, is shown in Figure 7. At 120 m from the flagger, average speed of drivers stopped by the new flag is expected to be 4.9 km/h slower than those stopped by the paddle. For a given distance and traffic control device, variance of estimated average speed may be obtained from the regression analysis (7). Variances of average speeds at 120 m were estimated as 0.24 and 0.26 km^2/h^2 for the new flag and paddle, respectively. Variance of the difference between average speeds at this distance is the sum of these two

Figure 6. Fitted regression models.

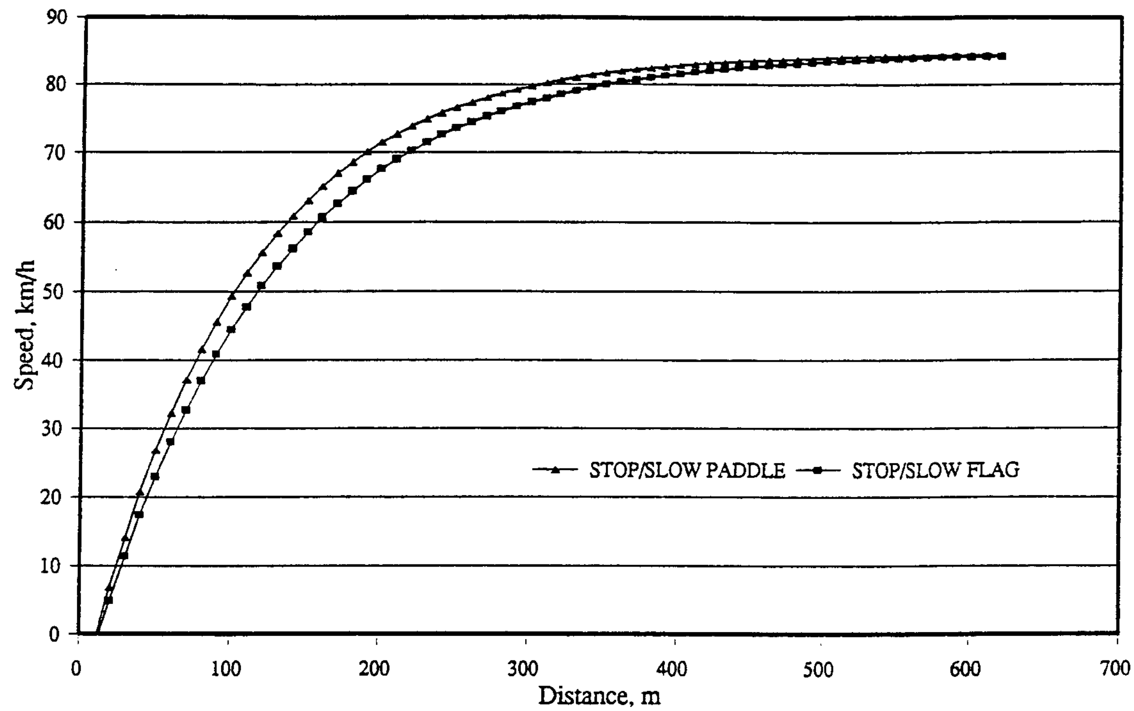
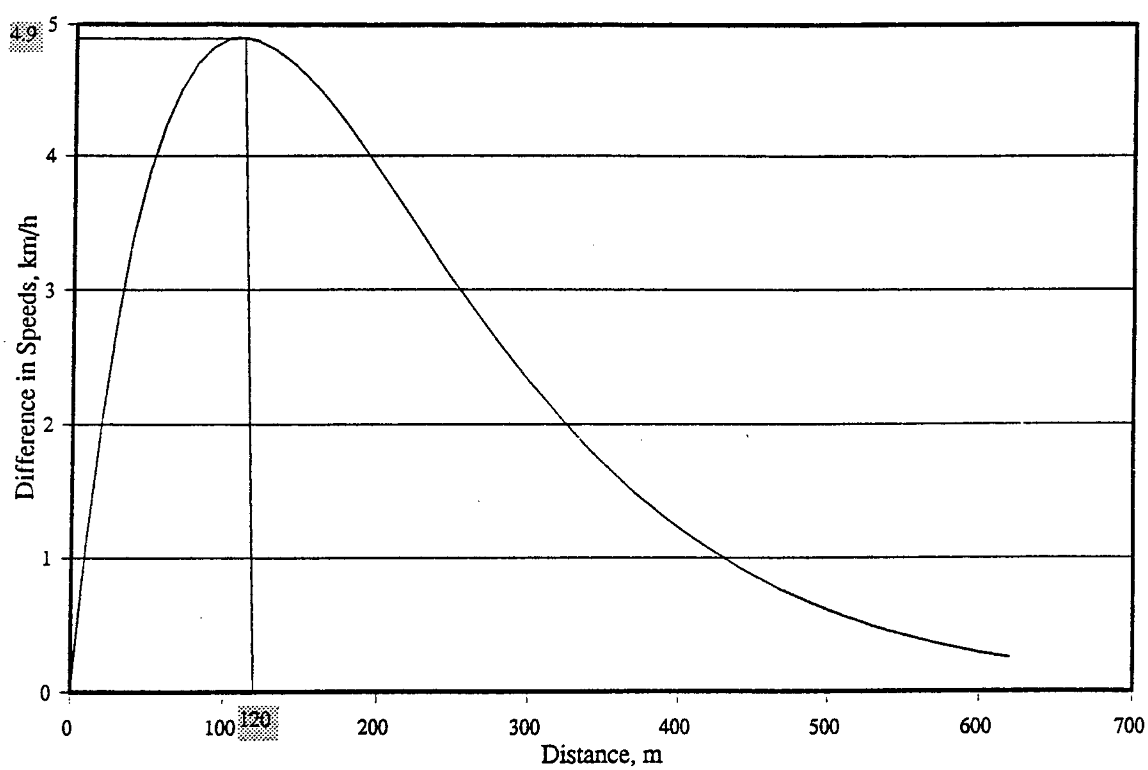


Figure 7. Difference in predicted speeds approaching the paddle and flag.



variances, yielding a standard deviation of 0.71 km/h. Thus, it may be concluded with 95-percent confidence that the average speed 120 m from the flagger is at least 3.7 km/h slower for vehicles stopped by the flag than those stopped by the paddle. (This result was obtained by constructing a one-sided lower 95-percent confidence interval for the difference in average speed.)

IV. CONCLUSIONS

The STOP/SLOW flag was developed by flaggers who noticed that motorists too often failed to follow traffic control instructions when the conventional all-red signal flag was used. They were also aware of the limited maneuverability of the approved STOP/SLOW paddle. Their experimental device was designed to combine the paddle's advantages of positive guidance and the flag's ease of handling and storage.

To evaluate the experimental flag's effectiveness, speed profiles were collected for 284 drivers instructed to STOP using the flag or paddle. The data were used to develop speed models for drivers entering work zones. Based on this analysis, improved driver recognition and compliance were apparent with the new flag. At 120 m from the flaggers, average driver speed approaching the flag was 4.9 km/h slower than that approaching the paddle. This speed reduction is attributed to larger lettering on the new flag, making it easier to read from the same distance. Percentages of motorists who did not stop and those exhibiting delayed braking were also consistently lower for the new flag, but at the 95-percent confidence level the differences cannot be considered statistically significant.

The experimental flag produced positive feedback from flaggers participating in the field tests and from other NYSDOT employees. They commented that the new flag was much easier to handle than the paddle, and also more effective because of larger lettering size.

It is recognized that the models developed here are based on limited data, and the findings thus are only preliminary in nature. Experience with sites having a variety of geometric characteristics, traffic volumes, and weather and visibility conditions, as well as input from more flaggers, are needed for complete assessment of all the potential benefits in using this new flag. However, based on the evidence of improved legibility and compliance, this new hand-signaling device warrants consideration as an alternative to the STOP/SLOW paddle.

ACKNOWLEDGMENTS

The new prototype STOP/SLOW flag was developed by Stewart T. Degroat, Highway Equipment Operator, and Darryl C. Mulwane, Laborer, in NYSDOT Region 9. The authors gratefully acknowledge the cooperation of the New York State Division of State Police, who provided a laser unit for speed and distance detection during this experiment. Its use allowed reliable and efficient data collection. Special thanks are extended to the NYSDOT Region 9 crew who assisted in the tests, and to Suman Dhar of the Engineering Research and Development Bureau for his assistance in collecting and tabulating the data.

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