SEQUENTIAL WARNING LIGHT SYSTEM FOR WORK ZONE LANE CLOSURES

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ABSTRACT

Research performed to assess the effectiveness of a flashing warning light system for use at work zone lane closures is summarized in this paper. The system is composed of a series of interconnected, synchronized flashing warning lights that produce the illusion of motion. Researchers investigated motorist understanding and perceived usefulness of various designs of the warning light system, and the potential of this system to yield significant operational or safety benefits in actual work zone applications.

Results from proving ground and field studies show that the flashing warning light system used in the work zone lane closure is perceived positively and is not confusing to the motoring public. The field study results also revealed that the prototype warning light system may encourage motorists to vacate a closed travel lane farther upstream from the work zone (which is believed to offer a potential safety benefit). When the warning light system was activated at the urban freeway test site (which was a relatively new closure), there was a 23 percent and 63 percent reduction in the number of passenger vehicles and trucks, respectively, in the closed lane 305 m (1000 ft) upstream of the lane closure. However, it should be noted that the system did not significantly effect lane choice at the rural road test site where the lane closure had been installed for six months. Thus, the greatest potential safety benefit of the warning light system may be when it is used in conjunction with short duration or intermediate-term maintenance/construction projects.

Keywords: Work Zone Traffic Control, Lane Closure Traffic Control Devices, Warning Lights, Traffic Operations

INTRODUCTION

When a lane is closed for the maintenance and construction of a roadway, temporary traffic control devices must provide for the continuity of traffic flow and the safety of workers and motorists. Since lane closures require motorists to physically move out of a closed lane or lanes, it is important to positively indicate the direction the motorist should travel. This is especially true at night when visibility is reduced; therefore, some agencies choose to supplement channelizing devices with lighting devices to increase their visibility. One type of lighting device commonly used is the warning light.

Currently, the Manual of Uniform Traffic Control Devices (MUTCD) states that when warning lights are needed in a temporary traffic control zone to delineate the traveled way through and around obstructions, such as lane closures, the warning lights used must be steady-burn (*1*). Pain, McGee, and Knapp (*2*) found that steady-burn warning lights provided additional delineation of reflectorized channelization devices at night compared to reflectorized channelization devices without steady-burn warning lights. They recommended that steady-burn warning lights be used at night on tapers in the transition area (*2*).

Flashing warning lights mounted on barricades, drums, or advanced warning signs are also intended to warn motorists that they are approaching a potentially hazardous situation. Currently, the MUTCD does not allow flashing warning lights to be used in a series to delineate the traveled way through and around obstructions since it is believed that the independent flashing lights would tend to obscure the desired vehicle path (*1*). However, no mention is made in the MUTCD about lights flashed in a synchronous manner to convey the direction of a lane closure. It was hypothesized that such a system may help convey critical information that a lane is closed and draw more attention to the location of the actual lane closure. Consequently, the

Texas Department of Transportation (TxDOT) contracted with the Texas Transportation Institute (TTI) to examine the feasibility and potential of such a system. This paper provides a summary of some of the results of that research. Additional research information and results can be found in the original research report (*3*).

BACKGROUND

Apparent Motion

When discrete stationary flashing lights are arranged sequentially the illusion of motion can be created. This illusion of motion is called apparent motion and occurs at some range of flash rate values where the appearance of flashes changes from a succession of lamps lit up to a spot of light moving along the path (*4*).

In a study conducted in 1995 by the Human Factors Research Laboratory at the University of Minnesota for the Minnesota Department of Transportation, Vercuryssen, et al. (*5*) tested the hypothesis that flashing lights positioned on the side of the roadway parallel to the motorist which produce the illusion of apparent motion would cause the motorist to spontaneously and unconsciously adjust their speed to synchronize with the speed of the light flashes. The researchers determined that lights moving towards the motorist caused motorists to reduce their vehicle speed, while lights moving with the motorist caused motorists to increase their vehicle speed. They also concluded that stationary lights had little or no effect on speed (*5*).

A system of moving lights in a lane closure in front of the motorist, instead of a system on each side of the road parallel to the motorist, was examined in the research reported herein. Thus, the researchers did not believe that the results of the study by Vercuryssen, et al. (*5*) was directly applicable to this research. However, the researchers were cognizant of the potential for the system to affect speeds (and so included speed as an operational measure in the field study data collection plan).

Warning Light System

The subject of the research reported herein is a prototype warning light system that is composed of a series of interconnected, synchronized individual flashing warning lights that are attached to channelizing drums that form the lane closure taper. The interconnected, synchronized flashing warning lights produce the perception of a light that "moves" repeatedly in a sequential manner from the beginning of the taper to the end of the taper (Figure 1). Each individual flashing warning light connects to a junction box located on the ground next to the drum via a cable. The junction boxes are also connected with cables. The individual flashing warning lights are illuminated by an array of light-emitting diodes (LEDs) behind the lens. Each individual flashing warning light used by the warning light system meets type "A" specifications of the MUTCD (*1*). The recommended power source for the warning light system is an arrow panel battery.

The flash rate of each individual flashing warning light, which in turn controls the number of times the "moving" light sequences down the taper in a given period of time, is controlled by a starter box located at the beginning of the taper. A knob on the starter box allows for the flash rate to be adjusted from 17 flashes per minute (fpm) to 265 fpm. It should be noted that the speed of the "moving" light down the taper is not affected when the flash rate is changed, since the time between successive flashes is held constant as the flash rate is varied. Instead, as the flash rate is increased, the time between when the "moving" light sequence ends (at the end of the taper) to when the "moving" light sequence starts again (at the beginning of the taper) is decreased.

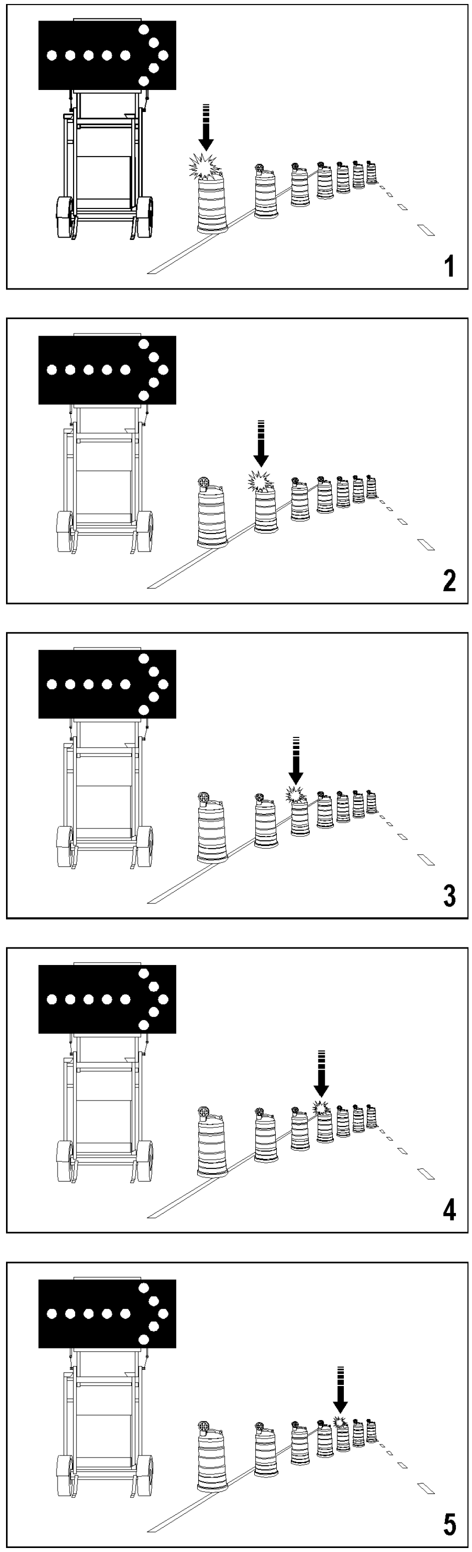

FIGURE 1 Flashing warning light system.

PROVING GROUND STUDIES

Prior to full-scale field testing on highways, proving ground studies were conducted at night to determine if the prototype warning light system performed as intended. The main objectives of the proving ground studies were to: 1) ensure that drivers in a controlled environment would not be confused by the warning light system in the transition of a work zone lane closure and 2) determine its likely effectiveness in encouraging earlier lane-changing upstream of a lane closure.

Method of Study

Study Location

The study was conducted at night at the TTI Proving Ground facility. The proving ground is a former military aircraft base comprised of four major runways and associated taxiways. For this study, one of the 2134 m (7000 ft) long concrete runways was used, which permitted simulation of freeway traffic conditions at speeds up to 105 km/h (65 mph). Striping was applied to this runway to simulate one direction of a four-lane divided roadway (two lanes in each direction).

The typical Texas lane closure on a divided highway consists of advance warning signs, a merging taper, a tangent, and a flashing arrow panel placed on the shoulder at the beginning of the lane closure. This study simulated a nighttime work zone with a left lane closure, tangent, flashing arrow panel, and prototype warning light system. The advance warning signs were not used in this study since the researchers wanted to focus strictly on the effect of the warning light flash rates and approach speeds upon motorists' reaction and preference to the warning light system.

The two lane closure taper lengths that were examined were 55 m (180 ft) and 238 m (780 ft). The following characteristics describe the two lane closure taper lengths studied:

- 48 km/h (30 mph) and 105 km/h (65 mph) speeds, respectively;
- 9 m (30 ft) and 20 m (65 ft) drum spacings, respectively;
- 7 and 13 drums, respectively;
- 3.6 m (12 ft) lane width;
- flat grades; and
- straight alignment.

The two speeds were chosen to represent typical conditions on urban and rural major arterials and freeways. A type C arrow panel was placed on the shoulder at the beginning of the lane closure. The arrow panel displayed a flashing right arrow in all of the studies. The prototype warning light system was attached to the channelizing drums that formed the lane closure taper.

In addition to the simulated lane closure, researchers positioned four flood lights in the middle of the closed lane downstream of the lane closure to simulate the illumination normally used in a work area in Texas during night work. It should be noted that no other traffic was present on the runways during the studies.

Lane Closure Treatments

Researchers surveyed motorists to determine their understanding and perceptions of two designs of the warning light system: *steady-burn light background* and *no-light background*. The steady-burn light background system continually displays steady-burn warning lights with higher intensity synchronized flashes that move down the taper. (These higher intensity flashes are emitted from the steady-burn warning lights.) In contrast, the no-light background system only produces the synchronized flashes (i.e., it does not continually display steady-burn warning lights).

Two flash rates, 17 fpm and 60 fpm (which produced the perception of a “moving” light in the direction motorists were traveling), were studied with the no-light background system, while only one flash rate, 60 fpm, was studied with the steady-burn background system. The 17 fpm flash rate was not evaluated with the steady-burn light background system, since pilot study results revealed that 1) there was not a statistically significant difference between the two flash rates (17 fpm and 60 fpm with the steady-burn light background system) with respect to the distance upstream of the lane closure at which the lane-changing maneuver was initiated, and 2) the subjects ranked the two flash rates similarly.

Each system was evaluated at the two approach speeds, 48 km/h (30 mph) and 105 km/h (65 mph). The studies also simulated a left lane closure without warning lights (i.e., normal MUTCD lane closure traffic control plan) and with steady-burn warning lights (i.e., no synchronized flashes) at the two approach speeds previously mentioned.

Overall, five treatments with a flashing arrow panel were studied at two approach speeds: no lights base, steady-burn lights base, the steady-burn light background system with a flash rate of 60 fpm, and the no-light background system with flash rates of 17 fpm and 60 fpm. Table 1 contains the five treatments and the two approach speeds (lane closure taper lengths) studied.

TABLE 1 Treatments and Approach Speeds Studied

	Base Treatment of Warning Lights on Drums in the Taper		Flash Rate Treatment Used with Steady-burn Light Background System (fpm)[a]		Flash Rate Treatment Used with No-Light Background System (fpm)[a]	
Approach Speed (Taper Length)	No Lights	Steady-burn Lights	17	60	17	60
48 km/h (55 m)	T	T	--	T	T	T
105 km/h (238 m)	T	T	--	T	T	T

1 km/h = 0.62 mph; 1 m = 3.28 ft
[a] Flash rate of each individual light
T Comparisons made; -- Not tested

Study Design

The proving ground study was subdivided into two parts. In Part 1 the subjects drove a test vehicle and evaluated one treatment at one approach speed, while in Part 2 the test administrator drove the test vehicle and the subjects evaluated all of the treatments at the approach speed used in Part 1. The following subject reactions (measures of effectiveness) were recorded during Part 1 with a distance measuring instrument (DMI):

- distance upstream of the lane closure at which the lane-changing maneuver was initiated,
- the distance upstream of the lane closure at which the subject applied the brakes, and
- the change in speed caused by braking.

During Part 2, each subject viewed all of the treatments three times. This was accomplished by showing the treatments in sets. Each set contained all of the treatments with the no lights base treatment always being shown first. The other treatments were then presented in random order to counter any learning effects that may have been present. Within each set, but after each treatment, the subjects were asked 1) how the treatment effected the lane closure compared to the first treatment (no lights base) and 2) to compare the treatment with the previously viewed treatments in that set. After the subjects had viewed the three sets of treatments, the subjects were asked to rank the five treatments.

Subjects

A total of 59 motorists participated in the study. Thirty participants were between 18 and 35 years old (younger drivers), and 29 participants were 60+ years old (older drivers). Both males and females were recruited.

Results

The objective of Part 1 was to collect observations of subjects' reactions to the prototype warning light systems. The subjects' reactions were used to determine if the warning light systems encouraged subjects to leave the closed lane without causing confusion and to determine the effectiveness of the systems in encouraging earlier lane changing upstream of a lane closure.

An analysis of variance ("=0.05) was used to examine the effects of three independent variables (approach speed, treatment, and subject age) on the mean distance upstream of the lane closure at which the lane-changing maneuver was initiated. However, it was determined that there was no significant difference or interaction (at a 95 percent level of confidence) between the five treatments, two age groups, or two approach speeds. Thus, it was concluded that the warning light systems did not encourage earlier lane changing upstream of a lane closure compared to the two base treatments (no lights and steady-burn lights).

Although 28 out of the 58 subjects (approximately 50 percent) applied their brakes during Part 1 of the study, the reason why the subjects applied their brakes is unknown. Unfortunately, the researchers did not ask the subjects why they applied their brakes, and so neither the distance upstream of the lane closure that the subjects applied the brakes nor the change in speed associated with the braking could be used to determine if the warning light systems caused confusion. However, according to the test administrator, the subjects' reactions to the warning light systems showed that the systems did encourage subjects to leave the closed lane without causing confusion.

The purpose of Part 2 of the study was to collect observations of subjects' preferences of the prototype warning light systems. The observations of subjects' preferences were used to determine if the warning light systems caused confusion and to assess whether or not the systems were preferred by subjects over the two base treatments (no lights and steady-burn lights).

The effect the warning light systems had on the subjects' perception of the helpfulness of the traffic control devices in the lane closure compared to the no lights base treatment (i.e., normal MUTCD set-up) was evaluated in the form of a multiple choice question (e.g., How did the second treatment you just viewed affect the lane closure compared to the first treatment [no lights base treatment]?). Subjects could choose one of the following responses:

- caused confusion,
- did not make any difference, and
- was helpful.

The Chi-Square (P^2) test of independence was used to determine if there were any significant differences among the answers to the effect questions based on three independent variables: approach speed, treatment, and subject age. It should be noted that multiple comparisons on the same sample were performed; thus, the overall error rate ("=0.05) was controlled by using a Type I error of 0.01 for the individual tests.

Researchers determined (at a 95 percent level of confidence) that the subjects' perception of the relative helpfulness of the traffic control devices in the lane closure compared to the normal MUTCD set-up (no lights) was not dependent on the approach speed ($P^2_{computed} = 2.03 < P^2_{table} = 9.21$) or age group variables ($P^2_{computed} = 4.82 < P^2_{table} = 9.21$). However, subject perceptions of helpfulness were dependent on the treatment variable ($P^2_{computed} = 29.19 > P^2_{table} = 16.81$). Based on the percentages given in Table 2, the following findings can be summarized:

- For the steady-burn lights base treatment and the steady-burn light background system with a flash rate of 60 fpm, the majority of the subjects (68 percent and 79 percent, respectively) stated that the treatments were helpful, while only 4 percent and 10 percent of the subjects, respectively, stated the treatments confused them.

- For the no light background system with flash rates of 17 fpm and 60 fpm, 56 percent and 45 percent of the subjects, respectively, stated that the treatments were helpful, while 29 percent and 34 percent of the subjects, respectively, stated the treatments confused them.

As shown in Figure 2, a majority (a combined 62 percent) of the subjects participating in the proving ground studies preferred the warning light systems over the steady-burn lights (i.e., no synchronized flashes) and the no warning lights (i.e., normal MUTCD set-up). Also, most drivers ranked the steady-burn light background system with a flash rate of 60 fpm better than the no light background system with flash rates of 17 fpm and 60 fpm.

TABLE 2 Percentage of Subjects That Chose Each Effect Based on Treatment

	Treatment			
Answer	Steady-burn Lights Base	Steady-burn Light Background System with a Flash Rate of 60 fpm[a]	No-Light Background System with a Flash Rate of 17 fpm[a]	No Light Background System with a Flash Rate of 60 fpm[a]
Caused Confusion	4%	10%	29%	34%
Did Not Make Any Difference	28%	11%	15%	21%
Was Helpful	68%	79%	56%	45%
Sum	100%	100%	100%	100%
Sample Size	57	52	56	52
Computed P^2 Value = 29.19*				
Table P^2 Value = $P^2_{",df}$ = 16.81[b]				

[a] Flash rate of each individual warning light
[b] Type I error (") = 0.01 and degrees of freedom (df) = 6
* Significant since the computed P^2 value is greater than the table P^2 value

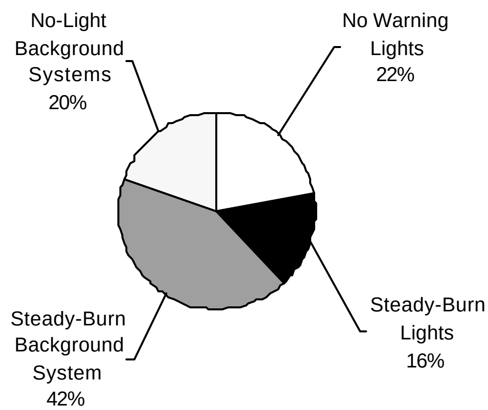

FIGURE 2 Percent of Subjects Preferring Each Treatment.

Summary of Findings

No differences were found among the three warning light systems studied and the two base treatments (no lights and steady-burn lights) in terms of subject performance. Specifically:

- All five of the treatments encouraged subjects to leave the closed lane without causing confusion.
- The warning light systems did not encourage earlier lane-changing upstream of the lane closure compared to the two base treatments (no warning lights and steady-burn lights).

Based on the subjects' preferences, the following findings are summarized:

- The majority of the subjects stated that the steady-burn lights base treatment (68 percent) and the "moving" light produced by the steady-burn light background system with a flash rate of 60 fpm (79 percent) were helpful compared to the no lights base treatment.
- For the no light background system with flash rates of 17 fpm and 60 fpm, 29 percent and 34 percent of the subjects, respectively, stated that the treatments confused them compared to the

no lights base treatment, while only 10 percent of the subjects stated that the steady-burn light background system with a flash rate of 60 fpm confused them.

- The majority of the subjects (62 percent) preferred the warning light systems over the two base treatments (no warning lights and steady-burn lights).

FIELD STUDIES

The results of the proving ground studies indicated that none of the prototype warning light systems tested caused any apparent adverse effects (i.e., confusion) to the subjects in terms of subject performance. Furthermore, motorist perceptions of the system were generally positive, leading researchers to evaluate the system in a real-world environment. However, it was not deemed necessary to evaluate all of the warning light systems in the field. Since, the steady-burn light background system with a flash rate of 60 fpm was ranked best by the subjects, this treatment was selected for examination in subsequent nighttime field studies.

It should be noted that the flash rate used with the warning light system was modified prior to the field studies due to concerns raised about the potential for the lights to trigger photosensitive epilepsy. Photosensitive epilepsy is a type of epilepsy in which seizures are caused by visual stimuli, such as flashing or flickering lights (*6*, *7*). The frequency of the flashing light that provokes seizures varies from person to person; however, it is generally between five to 30 flashes per second (300 to 1800 fpm, respectively). Some people are photosensitive at higher flash frequencies, but it is uncommon to have photosensitivity below five flashes per second (*7*).

The recommended flash rate of each individual warning light (60 fpm) does not fall into the frequency range discussed above; however, the flash rate of the whole system (720 fpm) does. Although it was not known for sure if the warning light system could cause such seizures, the system was altered such that the flash rate of the whole system was below 300 fpm. To accomplish this, the "flash" time (time that the higher intensity flash is on) of each individual warning light was hardwired to be at least 0.2 second.

TxDOT requested and received permission from the Federal Highway Administration (FHWA) to experiment with the warning light system in field applications to determine if the warning light system would yield significant operational or safety benefits in actual work zone applications. As part of the approval process, a plan to evaluate the use of the system was required. The plan approved by the FHWA is discussed in the following section.

Study Design

To determine if the prototype warning light system would yield significant operational or safety benefits in actual work zone applications, the system was compared to the normal MUTCD lane closure traffic control plan (consisting of advance warning signs, a flashing arrow panel, and channelizing drums). The main objective of this research was to identify whether the system resulted in significant differences (relative to the normal MUTCD set-up) in the following operational measures of performance:

- speed statistics at the beginning of the taper,
- lane choice statistics at the beginning of the taper and upstream of the taper, and
- erratic maneuvers/vehicle conflicts at the beginning of the taper and upstream of the taper.

As a minimum, lane choice statistics were computed at 305 m (1000 ft) upstream of the beginning of the taper, 153 m (500 ft) upstream of the beginning of the taper, and at the beginning of the lane closure (i.e., last-minute lane-changers). Erratic maneuvers were also assessed over the 305 m (1000 ft) distance upstream of the beginning of the taper. As a minimum, speeds of at least 125 free-flowing vehicles were collected for the normal MUTCD lane closure traffic control plan with and without the warning light system. To evaluate motorist lane choice, researchers obtained between 300 and 1000 vehicle samples per condition. Analysis of variance ("=0.05) was conducted to determine if the prototype system resulted in significant differences with respect to lane choice and speed.

Test Sites

Test site 1 was located on a rural Farm-to-Market (FM) road west of College Station, Texas, where a bridge construction project required that the westbound direction be reduced from two lanes to one lane. This is a low volume roadway with very little truck traffic. The posted nighttime speed limit at the site is 105 km/h (65 mph). The roadway has gentle rolling alignment, and no overhead lighting. The warning light system was installed on 12 drums in the 235 m (770 ft) section beyond the arrow panel where the left travel lane was actually being closed (i.e., in the taper). It should be noted that the lane closure at this site was installed six months prior to this study. Consequently, most motorists using the roadway were already highly accustomed to the presence of the lane closure.

The operational measures of performance were collected for both treatments (normal MUTCD traffic control plan with and without the warning light system) at night. A portable video camera trailer was used to collect lane choice and erratic maneuver traffic data upstream of the test site. The trailer was positioned upstream of the test site such that a camera view of the 305 m (1000 ft) zone upstream of the lane closure was obtained. Speed data at the beginning of the lane closure taper were collected using a laser speed gun from an unmarked research vehicle located off of the travel lanes.

Test site 2 was located on I-10 west, an urban freeway in Houston, Texas. A re-striping project that began one month prior to the research study required alternate lanes in the area to be closed at night. Specifically, the research study was conducted at a location where the re-striping project required that the westbound direction of the roadway be reduced from three lanes to one lane. The study was conducted the first night these closures where set up at this location.

The posted nighttime speed limit at the site is 105 km/h (65 mph) for passenger vehicles and 89 km/h (55 mph) for trucks. The roadway has a gentle rolling alignment, and overhead lighting in the median between the eastbound main lanes and the eastbound frontage road. The warning light system was installed on 11 drums in the 184 m (605 ft) section beyond the second arrow panel, where the middle travel lane was actually being closed.

The operational measures of performance were again collected for the normal MUTCD traffic control plan with and without the warning light system at night. Lane choice traffic data were collected 1000 ft upstream, 500 ft upstream, and at the beginning of the taper in unmarked research vehicles located in a high occupancy lane (HOV) lane. Speed data at the beginning of the lane closure taper were collected using a laser speed gun from an unmarked research vehicle in a HOV lane. The lane choice and speed data were recorded for passenger vehicles and trucks, separately. The data for trucks were recorded separately because the eye level of a truck driver is higher than that of a passenger vehicle driver. Researchers recognized that truck drivers may see and react to the lane closure (i.e., arrow panels, warning light system, etc.) before the drivers of passenger vehicles. A closed-circuit television camera (CCTV) located upstream of the test site was used to collect erratic maneuver traffic data. The camera’s view captured the 305 m (1000 ft) zone upstream of the lane closure.

Results

In the nighttime field studies, the prototype warning light system did not significantly affect the speed of vehicles at either test site (at a 95 percent level of confidence). Researchers also did not observe any erratic maneuvers at either test site that were attributable to the warning light system. With respect to driver lane choice, the system did not significantly affect driver behavior at the low-volume FM road test site (at a 95 percent level of confidence). However, this was expected by the researchers since the lane closure had been installed at that location for six months prior to the study. Researchers hypothesized that motorists in the area were probably already familiar with the lane closure, and so made speed and lane choice decisions more out of habit than in response to the traffic control devices present.

In contrast, the warning light system did affect the lane choice of both passenger vehicles and trucks at the I-10 site (which was a new closure). Table 3 contains the percent of passenger vehicles and trucks in each lane upstream of the lane closure (i.e., 305 m [1000 ft] and 153 m [500 ft]) and at the beginning of the taper (i.e., last-minute lane changing) for both treatments. In general, the percentages of passenger vehicles and trucks in the closed lane were lower when the warning light system was activated. However, it was determined (at a 95 percent level of confidence) that the only significant difference between the two treatments was with respect to lane choice 305 m (1000 ft) upstream of the closure.

As shown in Figure 3, without the warning light system 30 percent of the passenger vehicles were in the closed lane 305 m (1000 ft) upstream of the lane closure. In contrast, when the warning light system was activated, 23 percent of the passenger vehicles were in the closed lane. This represents a one-fourth reduction in the number of passenger vehicles in the closed lane.

TABLE 3 Lane Choice Statistics Upstream of the Lane Closure at I-10 Test Site

Normal MUTCD Lane Closure Traffic Control Plan	Distance Upstream of the Lane Closure (m)		
	305	153	0[a]
	Percent of Passenger Vehicles in Closed Lane		
With Warning Light System	23%* (N=428)	15% (N=451)	9% (N=442)
Without Warning Light System	30% (N=735)	19% (N=754)	12% (N=764)
	Percent of Trucks in Closed Lane		
With Warning Light System	7%* (N=75)	5% (N=74)	5% (N=75)
Without Warning Light System	19% (N=85)	10% (N=90)	3% (N=91)

1 m = 3.3 ft
[a] At the beginning of the lane closure taper (i.e., last-minute lane changing)
* Significantly different from the normal MUTCD set up without system at a 95 percent level of confidence

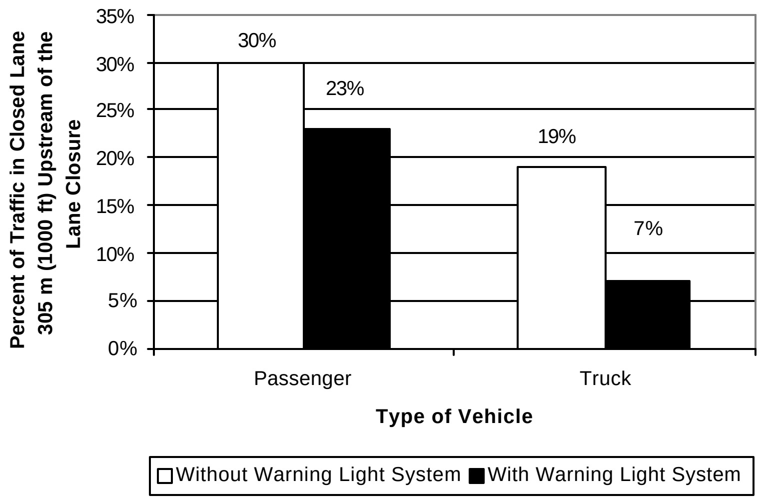

FIGURE 3 Lane choice 305 m (1000 ft) upstream of the lane closure at I-10 test site.

As the figure further shows, the effect was more pronounced for trucks. The percent of trucks in the closed lane at the same location decreased from 19 percent without the system to 7 percent with the system. This represents a two-thirds reduction in the number of trucks in the closed lane. It should be noted that the truck volume at this site was approximately 100 vph, with the majority of the trucks originally traveling in the outside lane (open lane). Even though, the volume of trucks in the closed lane 305 m (1000 ft) upstream of the lane closure decreased from 21 vph without the system to 7 vph with the system. This 14 vph reduction (more than half of the trucks) in the closed lane was considered to be a substantial benefit for work zone safety by the researchers.

DESIGN CONSTRAINTS

As discussed previously, the prototype warning light system examined in this research consists of several components: warning lights, junction boxes, cables, and a starter box. In addition to these components, if the lane closure taper requires that more than 153 m (500 ft) of cable be used, then a cable booster box must be placed between the first junction box and the starter box to amplify the signal sent down the taper.

During the proving ground and field studies several design constraints were identified by the researchers. For example, the set-up of the system was found to be cumbersome and time consuming to implement because of the large number of components involved (particularly the use of cables and external junction boxes to interconnect the lights). Also, the reliance on cables meant that the warning light system could not be used on lane closures that required more than 274 m (900 ft) of cable to connect the system. Another major problem encountered was the inability to keep the system working properly, because the connections between the junction boxes and the cables tended to lose contact, interrupting the communication signal between lights. Another problem noted by the researchers was that the warning lights used provided a rather limited cone of vision (primarily because of the LED technology used). Thus, if the drums they were attached to became slightly misaligned, the lights would not be directly facing the oncoming traffic, which in turn would disrupt the perception of a “moving” light produced by the warning light system. It should be noted that since the conclusion of this project, a prototype wireless system has been developed by the vendor.

CONCLUSIONS

Overall, the proving ground and field studies show that the flashing warning light system used in the work zone lane closure is perceived positively and is not confusing to the motoring public. The field studies also revealed that the prototype warning light system may encourage motorists to vacate a closed travel lane farther upstream of the lane closure (which is believed to offer a potential safety benefit). When the warning light system was activated at the urban freeway test site (which was a new closure), there was a one-fourth reduction in the number of passenger vehicles and a two-thirds reduction in the number of trucks in the closed lane 305 m (1000 ft) upstream of the lane closure. However, it should be noted that the system did not significantly effect lane choice at the rural test site where the lane closure had been installed for six months. Thus, the greatest potential safety benefit of the warning light system may be when it is used in conjunction with short duration or intermediate-term maintenance/construction projects or with projects where there is likely to be a low number of repeat (familiar) drivers.

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