ANALYSIS OF THE SAFETY EFFECTS OF CROSSWALKS WITH IN-PAVEMENT WARNING LIGHTS

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***Abstract**:* Pedestrian safety is among one of the largest concerns in the transportation profession. Many treatments have been developed and implemented to improve pedestrian safety. This current research focuses on the efficiency of in-pavement warning lights systems and involves multiple objectives. The primary objective is to evaluate the yielding rates and crosswalk usage of existing and proposed in-pavement lights systems with comparisons including before and after data through a case study approach. A secondary objective is to evaluate where drivers are looking when they approach in-pavement lights systems and develop a model to evaluate their behavior.The research described herein formulated these objectives into two research hypotheses and used statistical evaluation methodologies to provide quantitative and/or qualitative responses to the developed hypotheses. Data on pedestrian and driver behavior in the field, and the interaction between, them was collected using video camera technology in the Amherst, Massachusetts area. Data regarding drivers scan patterns during the approach to a crosswalk with in-pavement warning light system was collected using a driving simulator and an eye tracker. In total, 1,949 non-staged pedestrians and 606 staged pedestrians were observed crossing at the seven crosswalk locations in the field experiment and a total of 32 drivers participated in 576 crosswalk scenarios in the driving simulator evaluation. The field evaluation resulted in increased yielding rates and crosswalk usage after installation of in-pavement warning lights, while driving simulator evaluation resulted in drivers not becoming accustomed to scanning for lights instead of a pedestrian. Recommendations include installation of in-pavement warning lights at traditional, midblock crosswalks and continued exploration of all crosswalks in the driving simulator evaluation.

*1.*Introduction

General: Despite the increased emphasis on promoting the accommodation of pedestrians within the transportation system, pedestrians have the highest risk of injury among users of the road system. Specifically, there is a high risk of death or injury due to the interaction of pedestrians and drivers, particularly with the prevalence today of higher speeds: only 15 percent of pedestrians hit at 40 miles per hour survive, while at 20 miles per hour or less, 95 percent survive (4). Given the prevalence of walking as a critical mode of transportation, and the particular vulnerability of pedestrians, pedestrian safety is among one of the most important concerns in the transportation industry. Crashes involving pedestrians are a frequent occurrence and make up two percent of all people injured in traffic crashes and 11 percent of all traffic related fatalities. In the U.S. in 2003, 4,749 pedestrians were killed and 70,000 injured from motor vehicle crashes, which translates to an average of one pedestrian killed every 111 minutes and an average of one pedestrian injured every eight minutes (1). Extensive research and innovative strategies have been employed in an effort to counter the failures to keep the roadways safe for pedestrians in just the past few years with varying results. One of the more promising pedestrian treatments that has recently been added to the Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices (MUTCD), which the governs the use of traffic control devices and presents recommendations for regulatory, warning and guide signs, pavement markings, and traffic control and pedestrian signals, is the Crosswalk In-Roadway Warning Light System (1). Alternatively, this system has been referred to as in- pavement roadway lights. It has been the focus of myriad studies focusing on vehicle compliance and pedestrian use.

Crosswalks

The crosswalk is the most commonly used pedestrian treatment and has been standardized by the MUTCD. A crosswalk is defined by the MUTCD 2003 Edition as consisting of crosswalk markings (1). Specifically, the MUTCD states: Crosswalk markings provide guidance for pedestrians who are crossing roadways by defining and delineating paths on approaches to and within signalized intersections, and on approaches to other intersections where traffic stops. Crosswalk markings also serve to alert road users of a pedestrian crossing point across roadways not controlled by highway traffic signals or STOP signs. At nonintersecting locations, crosswalk markings legally establish the crosswalk. Crosswalks are used to mark intersections where there are substantial conflicts between pedestrian and vehicular movements, but are used at unsignalized midblock pedestrian crossings as well. A midblock crossing is a location between intersections where a crosswalk has been placed and is used when there is heavy pedestrian traffic and there are no nearby existing crosswalks to provide more frequent crossing opportunities.

2.OBJECTIVE:

A pair of objectives has been established to directly address the research needs identified in the previous section. The two objectives for the proposed experiment are as follows:

1. Evaluate the safety of alternative in-pavement lights systems with different attributes including advanced dynamic signs and raised crosswalks using a case study approach; and,
2. Evaluate the driver's scan patterns as they approach midblock crosswalks.

3.SCOPE:

The scope of this research is limited to an examination of the safety effects of crosswalks with in-pavement warning lights systems. Beyond the scope of this research is the added discussion of the myriad established and/or experimental crosswalk treatments beyond those including in-pavement warning lights. The intent of this paper is to evaluate the safety effects of in-pavement warning lights.

4.LITERATURE:

Pedestrian safety has been the focus of many research projects in just the past few years with the increased implementation of many new pedestrian treatments (5, 6, 8). To develop a framework from which to consider in-pavement lights systems and identification of potential candidate locations for such systems it is important to consider the following topical areas: increased safety of in-pavement lights systems over traditional, unsignalized midblock crosswalks and drivers' behavior at in-pavement crosswalks, specifically where are they looking and drivers' reaction to different colored warning lights. The following sections provide a review of the literature associated with in-pavement treatments and traffic signals and the safety research that has resulted from implementation. Additional discussion involves driver scan patterns when faced with different events on the roadway. Lastly, research covering the human factors, specifically reaction (i.e., braking and scanning), of different color lights is discussed.

4.1 In-Roadway Treatments

Midblock crosswalks are not as safe as crosswalks located at intersections but roads without any crosswalks are not necessarily any safer. Fisher et al. reported that Shankar found 78 percent of pedestrian crashes occurred at non-intersection crossings (6) and over 40 percent occurred on roadways without crosswalks in the U.S. (7). As sited in Fisher et al. and Ivan et al. found urban areas accounted for 69 percent of pedestrian fatalities, while over half of those occurred on marked crosswalks with signal control or at locations without marked crosswalks. Although most crashes and fatalities occur in urban areas, death is more likely from a crash in rural areas.

Malek completed a before and after study in San Jose on an in-pavement warning lights system installed in April 2000 in one location (13). The research revealed that more drivers yielded after installation, especially at night. Driver yielding rates during the day increased from 10 percent to 44 percent in the northbound direction and from 12 percent to 54 percent in the southbound direction. The rates at night on the same road increased from five percent to 80 percent northbound and 5 percent to 72 percent southbound. Pedestrian and driver surveys were only conducted after installation and the results show drivers notice the crosswalk 71 percent, a pedestrian 89 percent, and flashing lights 42 percent of the time during the day but at night a pedestrian was noticed 100 percent and flashing lights 91 percent of the time.

In 2001, an in-pavement warning lights system began operation in Cedar Rapids, IA. **Kannel and Jansen** collected spot speed and yielding to pedestrian data as well as pedestrian and driver surveys (14). The results included a slight increase in approach speed and an increase in percentage of drivers yielding. By six months, 100 percent of vehicles arriving second stopped for pedestrians (14). Another study performed with in-pavement warning lights system was in September 2000 in Denville, NJ (12).

<u>Driver Scan Patterns</u>

Substantial research has used driver scan patterns as a method of evaluation to determine how drivers react when faced with different situations while on the roadway. Knodler tracked driver eye movements at permissive left turns using a driving simulator equipped with head and eye tracking equipment (19). The results showed where drivers were looking and if they fixated on an object or just glanced at it. Furthermore, Knodler concluded that the application of the simulator and head and eye tracking equipment were appropriate for this type of analysis (19). An additional study using driver scan patterns involved airport terminal signs. Kichhanagari et al. evaluated how drivers scan for their airline to determine in which terminal it is located (20). A standard condition was compared with an alphabetical condition. The standard condition consisted of four terminal signs with airlines listed in three columns but not in alphabetical order while the alphabetical condition differed by only alphabetical listings of airlines.

4.2 Summary

The preceding sections describe current topics in the transportation industry related to pedestrian safety improvements and scan pattern evaluation. First, many different pedestrian treatments at crosswalks both with the pavement markings, in pavement lighting systems, and alternative signals have been evaluated by researchers in recent years. Researchers have found that some treatments are more successful than others at increasing safety for pedestrians; however, research is needed to evaluate the effects on safety of in-pavement warning lights systems versus traditional, unsignalized midblock crosswalks. Second, driver eye scan patterns have been successful in evaluating permissive left-turns, airport terminal signs and comparing novice and experienced drivers when looking for hazardous events. Third, in-pavement warning lights are typically amber, but there is a lack of research about using other colors or color combinations.

5. EXPERIMENTAL DESIGN AND RESEARCH METHODOLOGY

A series of tasks were developed to successfully complete the research objectives and test the established hypotheses presented previously. The sections below describe in detail the four research tasks completed.

Task 1: Literature Review

The initial task was a review of previous literature associated with pedestrian safety. The literature review remained ongoing throughout the entire research process. Several aspects of pedestrian safety were considered in order to identify significant accomplishments to date. First, different types of treatments were reviewed including both in-roadway lights and signals, specifically their effectiveness and how drivers and pedestrians interact with them. Second, research involving driver scan patterns when faced with different situations on the roadway is discussed. Third, research on driver reaction to different colors and color combinations of lights was conducted. The results of the literature review task were described previously in Chapter II.

Task 2: In-Pavement Crosswalk Field Evaluation

This task was a case study which evaluated the existing and proposed in- pavement lights and compared them to each other as well as before and a month after installation at the proposed site. Video camera data was collected at seven total locations, with the following breakdown:

Four existing in-pavement lights; and,

Three proposed in-pavement lights both before and after installation.

The hours of collection ranged from 8:00 am to 8:00 pm at the four locations of crosswalks with in-pavement warning lights and 8:00 am to 6:00 pm at the other three locations. The different collection times are a result of daylight conditions and it staying light out longer when data was collected at the crosswalks with existing in-pavement lights. The video cameras were used to analyze pedestrian and vehicular behavior and interaction. Table 1 lists the seven locations where video data was collected.

Table 1 Crosswalk Location for Video Data

Town	Crosswalk Treatments	In-Pavement Roadway System Type	Primary Rd.	Secondary Rd.
Amherst	Existing[a]	Complete[c]	Route 9	Boltwood Ave.
Amherst	Existing	Complete	Route 9	Grosvenor Dr.
Amherst	Existing	Complete	Route 9	Seelye St., Both sides
Amherst	Existing	Complete	Route 9	Dickinson St.
Amherst	Proposed[b]	Partial[d]	Route 116	Hitchcock Rd.
Amherst	Proposed	Partial	Route 116	Walnut Rd.
Amherst	Proposed	Partial	Route 116	Amherst College Service Rd. B

[a] Existing in-pavement roadway system
[b] Proposed in-pavement roadway system
[c] Complete system includes raised crosswalk
[d] Partial system includes at-grade crosswalk

A map of crosswalk locations in Amherst, MA is presented in Figure 9, and the attributes for the different crosswalks are listed in Table 2 Crosswalk Attributes

Crosswalk Type	Raised Crosswalk	Pavement Light Direction	Pedestrian Crossing Markings	Refuge Island	LED Pedestrian Sign
Complete In-Pavement Lights System	Yes	Out[a]	Yes	No	Yes
Partial In-Pavement Lights System	No	Both[b]	Yes	Yes	No
Crosswalk Type	**Advanced Yield Markings**	**Retroflective Pedestrian Crossing Signs**	**Centerline Pedestrian Crossing Signs**	**Speed (MPH)**	
Complete In-Pavement Lights System	No	Yes	No	25	
Partial In-Pavement Lights System	Yes	Yes	Yes	40	

[a] Lights are directed towards vehicles only

[b] Lights are directed out towards vehicles and in towards crosswalk	

Table 3 Crosswalk Comparisons

Crosswalk Type and Scenario Variables for Comparison	Partial IPLS After Installation with Flashing	Partial IPLS After Installation with No Flashing	Complete IPLS with No Flashing
Partial IPLS[a] Before Installation	X	X	
Partial IPLS After Installation with Flashing[b]		X	
Complete IPLS with Flashing	X		X
Complete IPLS with No Flashing		X	
[a] In-Pavement Lights System [b] Activated Lights			

Comparisons were made between, but not limited to, the following:
Partial in-pavement lights systems
Before installation and after installation with flashing
Before installation and after installation with no flashing
After installation with flashing and after installation with no flashing
Complete in-pavement lights systems
With flashing and with no flashing
Complete in-pavement lights system with flashing and partial in-pavement lights system with flashing
Complete in-pavement lights system with no flashing and partial in-pavement lights system with no flashing
The measures used to analyze these data are:
Percentage of drivers who yield to pedestrians crossing at the crosswalk; and,
Percentage of pedestrians who cross within the crosswalk;

Task 3: Driving Simulator Evaluation

The methodology of evaluation to identify driver scan patterns on the approach to a crosswalk with in-pavement warning lights was done using a fixed base, fully interactive driving simulator with an eye and head tracker in the Human Performance Laboratory (HPL) at UMass. The driving simulator consists of a 1995 four door Saturn sedan. Drivers are able to control the steering, braking, and acceleration just as they would if they were driving the vehicle on the road as the roadway adjusts accordingly to the driver's actions (23). The virtual scenes are displayed on three screens, one in front and two on the side, to create a field of view that subtends 150 degrees (24). Additional features of the simulator include three speakers, one on the left, one on the right, and a subwoofer in front of the vehicle (24), resolution up to 1024 x 768 dots per inch and a refresh rate of 60Hz (23). The driving simulator can also provide realistic noises including wind, road, and other vehicles with appropriate direction, intensity, and Doppler shift (24).

Task 4: Documentation of Findings

The results of this research were documented in the form of a Master's Thesis inaccordance with the University of Massachusetts Amherst policies and guidelines.

6. ANALYSIS OF EXISTING AND PROPOSED IN-PAVEMENT LIGHTS

The primary objective of this analysis was to evaluate the safety of alternative in- pavement lights systems by comparing data collected in the field of different types of crosswalks and different scenario variables, i.e., flashing, no flashing, before installation, and/or after installation. The two measures used in this analysis were percentage of drivers who yield to pedestrians crossing at the crosswalk and percentage of pedestrians who cross within the crosswalk. This analysis was comprised of three primary subtasks, watching of the video recordings, compiling of recorded data, and analyzing and comparing data between the different types of crosswalks and scenario variables. The following section describes the results of field evaluation. As described in Chapter III, a complete statistical analysis was completed on all results.

Field Evaluation Results and Analysis

A total of 1,949 non-staged pedestrians and 606 staged pedestrians were observed crossing at the seven crosswalk locations. The percentage of drivers who yielded to pedestrians crossing at crosswalks with the complete in-pavement lights system when lights were activated ranged from 90.6 percent to 100.0 percent. The percentage of drivers who yielded to pedestrians crossing at crosswalks with the complete in-pavement lights system when lights were not activated ranged from 90.0 percent to 98.0 percent. At the proposed sites before partial in-pavement lights systems were installed the percentage of drivers who yielded to pedestrians crossing at the crosswalk ranged from 42.5 percent to 50.0 percent. Using the test of proportions with a 95 percent confidence interval, a p-value was calculated for all comparisons. A p-value greater than 0.05 indicates that the null hypothesis can be accepted at the 95 percent level, and a p-value less than 0.05 indicates that the null hypothesis can be rejected at the 95 percent level. For all comparisons the null hypothesis was yielding percentages were equal and the alternative hypothesis was yielding percentages were not equal. When comparing yielding percentage at crosswalks before and after partial in- pavement lights systems were installed a statistically significant difference between before and after with lights activated (p=0.016) and before and after without lights activated (p=0.000) occurred. There was no significant difference between after installation with and without lights activated (p=0.066). Drivers are much more likely to yield to pedestrians crossing crosswalks when partial in-pavement lights systems are installed than when no lights systems exist and no other differences are present. The results show that just the presence of the lights increases yielding whether or not the lights are activated. The effect of the medians was not accounted for in the before and after comparisons as an isolated variable.

Table 6 Non-Staged Crosswalk Yielding Percentages

Crosswalk	**% Yield**
Partial In-Pavement Lights Systems	
Walnut Before	**42.5%**
Amherst College Before	**50.0%**
Walnut After w/ Flash	**63.9%**
South Amherst College After w/ Flash	**100.0%**
North Amherst College After w/ Flash	**100.0%**
Walnut After w/o Flash	**81.6%**
South Amherst College After w/o Flash	**95.0%**
North Amherst College After w/o Flash	**80.9%**
Complete In-Pavement Lights Systems	
Boltwood w/ Flash	**90.6%**
Grosvenor w/ Flash	**100.0%**
Seelye w/ Flash	**94.6%**
Dickinson w/ Flash	**100.0%**
Boltwood w/o Flash	**94.5%**
Grosvenor w/o Flash	**98.0%**
Seelye w/o Flash	**94.4%**
Dickinson w/o Flash	**90.0%**

Table 7 Staged Crosswalk Yielding Percentages

Crosswalk	**% Yield**
Partial In-Pavement Lights Systems	
Hitchcock Before	**30.5%**
Walnut Before	**30.9%**
Amherst College Before	**57.8%**
Hitchcock After	**68.1%**
Walnut After	**79.6%**
South Amherst College After	**71.6%**
North Amherst College After	**76.9%**
Complete In-Pavement Lights Systems	
Seelye	**95.5%**
Dickinson	**93.8%**

Table 8 Crosswalk Use Percentages

Crosswalk	**% Yield**
Partial In-Pavement Lights Systems	
Walnut Before	**63.2%**
Amherst College Before	**44.6%**

Hitchcock After	**93.8%**
Walnut After	**93.8%**
South Amherst College After	**100.0%**
North Amherst College After	**94.8%**
Complete In-Pavement Lights Systems	
Boltwood	**90.3%**
Grosvenor	**90.1%**
Seelye	**94.4%**
Dickinson	**77.2%**

Only one crosswalk with complete in-pavement lights systems had a statistically significant difference between lights activated and lights not activated (p=.0080). The p- values for two of the other three crosswalks with complete in-pavement lights systems are 0.305 and .9140. Not enough observations were made for the fourth crosswalk. The comparisons between complete and partial in-pavement lights systems were broken down into light activation and no light activation. Each individual crosswalk when lights were activated did not produce enough observations for individual comparisons so the observations were combined for all complete systems and for all partial systems. There was a statistically significant difference between complete systems with lights activation and partial systems with lights systems (p=0.000). Due to the large amount of data collected when lights were not activated each crosswalk with complete in-pavement lights systems was compared with each crosswalk with partial in- pavement lights systems. A total of 16 comparisons were made between complete and partial systems and nine produced statistically significant differences. The comparisons and respective p-values are presented in Table 9. The results show that complete in- pavement lights systems are safer than partial in-pavement lights systems due to the larger percentage of drivers yielding to pedestrians crossing the crosswalks. These results can be attributed to the main differences between the complete and partial systems including raised crosswalks for the complete systems.

7.ANALYSIS OF DRIVER'S SCAN PATTERNS

The objective of this analysis was to determine if a consistent scan pattern develops where drivers become accustomed to looking at the in-pavement lights instead of at the curb for a pedestrian. The driver scan evaluation was just the preliminary research to look at scan patterns at crosswalk 18 and then determine if further research should be conducted to delve into the other 17 crosswalks. Furthermore, comparisons were made between yielding percentages and how drivers responded at crosswalks with in-pavement lights and without in-pavement lights. To complete the analysis, drivers were first given a practice course to get accustomed to driving the simulator. Next the drivers were asked to maneuver through a virtual network of crosswalks with and without flashing lights which were created for use in the driving simulator with the eye tracking equipment described in Chapter III. The first section of this chapter provides a demographic description of the drivers that participated in the analysis. The following sections describe the results of the driver comprehension analysis including the yielding percentage and driving responses, follow- up evaluation responses, and the results of the eye tracking data for each of the 32 drivers at each crosswalk scenario. The eye tracker outputs were used to make precise inferences about where drivers were looking while approaching each crosswalk.

<u>Demographics</u>

A total of 32 drivers participated in the driving simulator experiment and follow- up evaluation. In total 576 crosswalk scenarios were evaluated in the driving simulator. Table 12 provides a breakdown of the driver demographics from the experimental and control courses. The sample size in the simulator did not allow for the disaggregating of demographic variables while still allowing for appropriate statistical comparisons.

Scanning Behavior from Crosswalk 18

This paper focuses on the scanning behavior at crosswalk number 18. Comparisons of the scanning behavior at crosswalk 18 were made between the experimental and control groups to determine if drivers were becoming accustomed to looking for the lights instead of a pedestrian on the curb. As described earlier, crosswalk 18 in both the experimental group and the control group did not contain flashing lights, but a pedestrian was standing on either the left or right curb. Scanning data was obtained from the eye tracker to determine if the driver did or did not scan left, right or in both directions for a pedestrian. This data was compared to determine if a pattern of scanning for lights occurred at crosswalks with in-pavement lights. It is important to note the limitation of the experimental approach when comparing crosswalk 18 is drivers are being conditioned the way the researchers would like. A summary of the subject's driver scan behavior is shown in table 17.

Table Summary of Subject Scanning Behavior

Group	Number of Drivers Who Scanned in Each Direction		
	Scanned Left Only	**Scanned Right Only**	**Scanned Right & Left**
Exp.	0	3	9
Control	1	2	8

The driving simulator evaluation resulted in the following:
When the driver looked only in one direction, that direction was more likely to be to the right,
When a driver looked right, it did not matter if the pedestrian was approaching from the right or left side,
Drivers scanned in both directions equally between the experimental and control group, and,
When drivers scanned in both directions, they typically scanned in both directions several times
Drivers were more likely to scan only to the right no matter which direction the pedestrian was approaching from possibly because a pedestrian approaching from the right side will appear in the driver's path of motion faster than a pedestrian approaching from the left. The difference between the control group and the experimental group was that there were no flashing lights in the control group. Both the control group and experimental group had no flashing lights and a pedestrian standing on the right or left curb at crosswalk 18. This allowed for accurate comparisons to determine if drivers would become accustomed to looking at the lights instead of scanning for a pedestrian. This was not the case because it would be expected that drivers in the experimental group would be less likely to scan for pedestrians as compared to the control group where they are not being conditioned with lights and pedestrian simultaneously. Since the number of drivers who scanned in both directions did not differ between the experimental and control group, the in-pavement lights are not leading drivers to look for just the lights. Further research into the other 17 crosswalks will delve into determining more specific scan pattern differences between the control and experimental groups.

Summary

The findings of the driving simulator experiment include:
Drivers were significantly more likely to yield to pedestrians approaching from either the left or right side of the street when in-pavement warning lights were flashing than when no in-pavement lights existed.
Drivers and pedestrians both feel safer at crosswalks with in-pavement lights and drivers are more aware of possible pedestrians at crosswalks with in-pavement warning lights.
Drivers are more likely to scan only to the right over scanning only to the left, no matter if the pedestrian is approaching from the right or left and drivers scanned to the left and right equally between the experimental and control group.

8. CONCLUSIONS AND RECOMMENDATIONS

Conclusions

Previous research has shown that the in-pavement warning lights system increases percentage of drivers who yield to pedestrians at crosswalks, reduces the rates of pedestrian-vehicle conflicts, reduces the number of pedestrians who cross outside of a crosswalk, and increased noticeability of crosswalks. As a result of these findings, in- pavement warning lights systems have become more popular to install at traditional, midblock crosswalks. After a wide array of research on the topic, a series of questions related to the safety of in-pavement warning lights systems remain and must be evaluated before in-pavement warning lights become more widespread. This research formulates several questions regarding the safety of in-pavement warning lights into research hypotheses with the overall objective of addressing these questions. A series of tasks were developed to successfully meet all of the research objectives and to statistically evaluate each of the developed hypotheses. Two separate experiments were evaluated to complete the analysis. A total of 1,949 non-staged pedestrians and 606 staged pedestrians were observed crossing at the seven crosswalk locations for the field evaluation and 32 drivers participated in the driving simulator experiment for a total of 576 crosswalk scenarios. The following sections provide summaries of the findings and results from each task, followed by a series of conclusions that addresses each research hypothesis.

Recommendations

The data and conclusions of this research effort have led to a series of research recommendations as follows:
The increased percentage of drivers yielding to pedestrians at crosswalks with in-pavement warning lights and increased use by pedestrians over traditional, midblock crosswalks is consistent with previous research findings. As a result, it recommends the installation at of in-pavement warning lights at traditional, midblock crosswalks.
Bollards for automatic activation of in-pavement warning lights should be installed at all crosswalks with in-pavement warning lights. This will allow for light activation whenever a pedestrian traverses the road, day or night, taking the decision away from the pedestrian of whether or not to activate the lights.
Further research into the remaining 17 crosswalks in the driving simulator evaluation to determine more in-depth scan patterns at crosswalks with in- pavement warning lights.