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A Review of ITS-Based Pedestrian Injury Countermeasures

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Abstract:
Crashes between motor vehicles and pedestrians caused at least 4,882 deaths and about 78,000 injuries in 2001 in the United States. In recognition of these troubling statistics, many public and private institutions look to Intelligent Transportation Systems (ITS) technologies. Few resources are available to provide a comprehensive summary of the effectiveness of these options. This report reviews previous scientific evaluation of red light enforcement cameras, illuminated walk signal push buttons, automated pedestrian detection systems for traffic signals, flashing crosswalk lights, countdown signals, and animated eyes. The research and policy implications of these summaries provide guidelines for future research as well as a practical outline of options for transportation planners.

A Review of ITS-Based Pedestrian Injury Countermeasures

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INTRODUCTION

A significant number of pedestrian injuries and fatalities occur each year, primarily in urban areas. In the United States, 4,882 pedestrians died and about 78,000 were injured in 2001 as a result of pedestrian motor vehicle crashes (*1*). In recognition of these troubling statistics, there have been efforts among public, private and academic organizations to reduce the number of crashes involving pedestrians.

In order to reduce the number of pedestrian-vehicle crashes, transportation planners have developed and implemented interventions utilizing Intelligent Transportation Systems (ITS). These interventions have been grouped into a broad category termed ITS pedestrian injury countermeasures. In recent years, such countermeasures have been implemented and evaluated in various settings.

The purpose of this report is to review the scientific evaluations of ITS-based pedestrian injury countermeasures within the last ten years. The descriptions and comparisons of evaluations provide a context for decision makers to consider future interventions, and also provide insight into emerging research needs with respect to pedestrian injury countermeasures.

BACKGROUND

Definition. This study reviewed ITS pedestrian injury countermeasures. The underlying concept of ITS is that the efficiency and safety of passenger and freight transport can be enhanced through the use of information technology, both at the level of the individual traveler and system-wide (*2*). It is important to note that ITS devices are not characterized solely by the technology they employ. "While the acquisition of travel-related information, its processing, and eventual utilization may involve technologies new to the transportation field, it is not the use of new or expensive technology, per se, that occasions the label 'ITS,' but rather the application of the information which that technology makes available" (*3*). Pedestrian applications of ITS technologies improve feedback to pedestrians and increase motorists' awareness of the presence of pedestrians. Generally, the common focus of pedestrian ITS applications is to create a more informative environment for users, especially through provision of information that reflects the dynamic character of transportation networks (*3*).

Literature. The degree to which different ITS-based countermeasures have been evaluated varies greatly. For example, at least forty published papers since the 1980s evaluated red light photo enforcement cameras, whereas only one published study evaluated illuminated push buttons, which are a more recent ITS injury intervention. Moreover, many studies lack statistical analysis and therefore do not draw definitive conclusions about effectiveness.

Measures of ITS Effectiveness. The studies reviewed here evaluate countermeasures based on two broad measures of effectiveness, intermediate measures of effectiveness (IMOE's) and final measures of effectiveness (FMOE's). These measures are discussed below.

Intermediate Measures of Effectiveness. Most studies analyze IMOE's, an indirect measure of effectiveness. IMOE's are measures of behaviors believed to reflect crash risk. Typical examples of IMOE's are: vehicle speeds, traffic conflicts, pedestrian/vehicle compliance with traffic regulations, driver braking distance, and various other measurable pedestrian or driver behaviors. IMOE's are often studied because of the infrequency of pedestrian injuries at any single intervention site. It often takes five or more years both before and after implementation to collect statistically significant data on actual pedestrian injuries at experimental sites. As a result, IMOE's are often used as indicators of the level of risk.

Although IMOE's are widely used in pedestrian safety research, there are few definitive studies demonstrating a correlation between pedestrian-crashes and IMOE's. Reductions in vehicle speed seem to have a strong association with the number and severity of crashes (*4*). In contrast, other IMOE's demonstrate divergent results or fail to demonstrate an association with crashes. For example, (*5*) found that traffic conflicts and crashes had divergent results. Later, (6) documented a relationship between vehicle-pedestrian conflicts that involve evasive responses and crashes. However, no studies were found that documented an association between crashes and other IMOE's (e.g., drivers yielding to pedestrians, aggressive pedestrian behavior, and pedestrian looking behavior). The lack of consistent associations between IMOE's and crashes suggest that such IMOE's may not be good surrogate measures for the safety of a countermeasure. However, IMOE's should not be completely discredited. One possible benefit of IMOE's is that they provide a measure for areas with very little pedestrian volume where few crashes with pedestrians are likely to occur. Further studies are needed to test associations between crashes and IMOE's.

Final Measures of Effectiveness. When sufficient data are available, statistical analysis of FMOE's is a superior method to identify the safety effects of a countermeasure than analysis of IMOE's. FMOE's are counts of actual pedestrian injury and fatality events. Clearly, statistically significant evaluation studies that use FMOE's are great value as they are a direct measure of safety.

Roadway User Behavior. The most accepted model for both driver and pedestrian injury avoidance is that roadway behavior can increase or decrease crash risk. In order to decrease crash risk, ITS-based pedestrian injury countermeasures focus on altering roadway behavior that increases the chance of injury.

The model prompts the use of IMOE's, as IMOE's measure roadway behavior. Many models of behavior have been developed to explain crashes. Table 1 shows the percentage of crashes involving different roadway behaviors (7). It should be noted that this is not a comprehensive list, and that a single crash might have more than one contributing factor.

Table 1: Summary Study of Contributing Factors to 830 Pedestrian-Injury Crashes across the U.S. in the 1990s. (7)

It is important that the IMOE's chosen to evaluate a countermeasure are associated with the contributing behavioral factors for the types of crashes the countermeasure is presumed to reduce. For example, when evaluating a countermeasure that is meant to make a driver more alert, a behavior that demonstrates attention to potential threats is an appropriate IMOE. In such a case, using an IMOE such as vehicle speed may not be appropriate to test the countermeasure because vehicle speed may not be directly associated with alertness of drivers to potential threats.

The majority of the countermeasures in this review concentrate on changing three driver behaviors which constitute 60% of all driver-attributed crashes: (1) failure to yield to pedestrians, (2) vehicle speed and (3) driver distraction. These countermeasures include red light photo enforcement cameras, automated pedestrian detection, and flashing crosswalk lights. The countermeasures discussed in this review that are aimed at pedestrians include illuminated push buttons, countdown signals, and animated eyes. These technologies may influence the pedestrian's chance of running into the road, jaywalking, stepping into a roadway, and failing to obey a traffic signal. These behaviors cause 56% of all pedestrian-attributed crashes.

METHODS

A comprehensive literature search was conducted for evaluations of ITS-based pedestrian injury countermeasures. The search was conducted using resources available at the Harmer E. Davis Transportation Library, which is maintained by the Institute of Transportation Studies at U.C. Berkeley. These resources included the TRIS Database, PATH Database, Melvyl Catalog, PsycINFO Database, MEDLINE Database, and various Internet sources. Studies were included in the report if (i) they included an evaluation of an ITS-based pedestrian injury countermeasure and (ii) they reported sufficient information to determine the quality and outcome of the evaluation. Table 2a and 2b summarize the evaluations reviewed for this paper. The tables contain the author(s) and year of publication, the name and type of the countermeasure that was evaluated, and the results found.

Table 2a: Summary of Reviewed Articles

Table 2b: Summary of Reviewed Articles, Continued

RESULTS

As noted above, Table 2a and 2b provide the reader with a summary of the articles relating to ITS-based pedestrian injury countermeasures that have been analyzed for this literature review. The rows of the table have been grouped by countermeasure (e.g., all of the red light camera citations are listed together). The following is a discussion of the results for each countermeasure.

Red Light Photo Enforcement Cameras (Table 2a). According to the Federal Highway Administration, drivers running red lights contributed to as many as 200,000 crashes, 150,000 injuries and 1,100 fatalities in 2001. Red-light running is the single most frequent cause of crashes at signalized intersections, and more than half of those who die in such crashes are pedestrians or vehicle occupants hit by red-light runners (*8*).

A red light camera (RLC) is a system that automatically detects whether a vehicle has run a red light, and if so, photographs the car's license plate. The RLC is connected to the traffic signal and to sensors buried in the pavement at the crosswalk or stop line. The system continuously monitors the traffic signal, and the camera is triggered by any vehicle passing over the sensors above a pre-set minimum speed and a specified time after the signal has turned red. The RLC then takes one to three photographs of the vehicle. The vehicle, and in some jurisdictions, the driver, are then identified through matching the license number on the vehicle and photograph of the driver with DMV records. Finally, the local authority sends a ticket or warning to the registered owner of the vehicle.

The RLC is presumed to cause two methods of behavioral adjustment. First, a ticket or a warning is expected to deter the violator from running red lights in the future. Second, it is expected that public knowledge of the RLC will deter motorists from running the red light. The RLC's main purpose is to reduce red-light running violations, and by extension, crashes that result from such violations.

Often RLC enforcement programs involve more than simply implementing camera systems and assessing fines. Other elements of RLC programs have included: education and publicity, varying levels of fines, adjudication, different types of signage, and varied numbers of intersections with cameras (*9*). Such factors may influence any change in crash experience. For illustration, a one-point demerit on a DMV record might cause a potential red-light runner to be more cautious, thus reducing violations, while a warning or small civil penalty may have little effect on driver behavior. Since there were slight variations in the implementation of RLCs in the evaluation studies reviewed, some variation in the reported effectiveness of automated enforcement is expected. For example, some of the implementation programs had publicity campaigns, fines for drivers, and point reductions on DMV records, while other programs did not include these features. No attempt at statistical comparison of different penalty or warning schemes has been published to date.

Although RLCs have been a popular countermeasure among both governmental officials and the public, there has been an ongoing debate whether RLCs truly reduce crashes, or, are used solely to generate revenue for municipalities and private RLC firms. The literature shows that RLCs have been profitable for the municipalities that implement them. The lack of long-term studies demonstrating crash reductions associated with RLC implementations is thus a point of contention.

Most studies of RLCs have used a pre/post study design (i.e., before-and-after) and have measured red-light running violations as the outcome (i.e., the IMOE). In the studies reviewed, installation of the RLCs was associated with reductions of 35% to 70% in red-light running violations. However, reported decreases in red-light running have not translated into a proven reduction in the FMOE, red-light running crashes. Two RLC studies have found that pedestrian-vehicle red-light running crashes did not differ significantly from the baseline period without the RLC (*10, 11*). For crashes involving two or more motor vehicles, some studies reported a change in red-light running crashes after implementation of RLCs (*12, 13*), but statistical methods and assumptions, as well as insufficient data, bring into doubt the validity of those claims. (*10*) describes these flaws in detail, and Table 2a of this paper also notes some problems of these studies.

It is unclear why implementations of RLCs have been associated with reduced violations but not reduced crashes. One possible reason is that the violations that are being reduced at RLC intersections occur within a short duration after the signal has changed to red. It may be that these "short duration" violations are not the type that leads to crashes. Vehicles that enter the intersection illegally, but only less than one or two seconds after the red, may still be able to clear the intersection without causing a crash. Further study of RLC's is needed to address this question.

Illuminated Push Buttons (Table 2a). At locations where pedestrian activity is infrequent and pedestrian signal phasing is not warranted on a full-time basis, pedestrian push buttons are often used to actuate the walk signal. An illuminated push button is a standard pedestrian push button with an LED indicator that is illuminated when pressed. Once the walk signal is activated, the illuminated button goes dark. The device is similar to an elevator push button that lights up when pressed and then goes out once the elevator has reached the floor where the button was pressed. Today, as many as half of all pedestrians do not use the push buttons at intersections where they are provided (*14*). One of the primary reasons is that pedestrians do not know whether the button has been pressed or whether it functions properly. If the "WALK" phase is not activated soon after the button has been pressed, pedestrians may believe the button does not function properly and cross against the "DON'T WALK" indication. The illuminated push button provides more information to pedestrians about the operation of the signals by giving pedestrians instantaneous feedback when the button is pushed, so that they will know the button is functioning and presumably be encouraged to wait for the "WALK" phase. It is hoped that they will consequently be more likely to use the button in the future. The goal of the illuminated push buttons is to decrease the probability that pedestrians disobey traffic signals and run into traffic, two behaviors that can lead to injury.

Only one study was identified that evaluated illuminated push buttons. Using a pre/post intervention design, (*15*) found that illuminated push buttons were ineffective in almost every area studied, with little or no effect on IMOE's. The measures of effectiveness included (i) the number of pedestrians pushing the button, (ii) the number of cycles in which the button was pushed (normalized by cycles in which pedestrians were present), (iii) changes in pedestrian compliance with "WALK"/ "DON'T WALK" signals and (iv) changes in pedestrian "abnormal behavior" (e.g., pedestrians running to avoid cars). Based on this study, illuminated push buttons do not appear to be an effective pedestrian injury countermeasure. However, further studies could be conducted to verify this result, or to test their effectiveness in limited situations or over longer time periods. Messages that give pedestrians additional information in conjunction with the illuminated push button, such as "Please wait for walk signal," should be evaluated.

Automated Pedestrian Detection (Table 2a and 2b). Pedestrian detection has traditionally relied on push buttons. Unfortunately, the lack of feedback to pedestrians and poor installation and maintenance practices often leads to nonuse (*14*). Automated, or passive, pedestrian detection technologies use microwave or infrared sensors to detect the presence of pedestrians at the curbside area of a pedestrian crossing or in the crosswalk. Automated pedestrian detection can be used to automatically call the "WALK" signal, lengthen the timing of the pedestrian interval at the intersection when necessary, and/or eliminate unnecessary calls if the pedestrian has left the crosswalk.

At uncontrolled crossings, crosswalks are fitted with detection devices that activate flashing beacons or other warnings to alert motorists when pedestrians are present. At signalized intersections, pedestrians are detected at the curbside and/or in the crosswalk, and detectors extend the pedestrian "WALK" signal where necessary. A less extensive use of the technology involves pedestrian actuation via a push button, with automated detection used to cancel the pedestrian signal phase if the pedestrian leaves the curb (i.e., decides not to cross at the location). Infrared detection devices can also be used for disabled-accessible crossing signals using emitters and receivers.

Since the device is activated passively rather than relying on the pedestrian to push a button, it is expected that fewer pedestrians will cross against the "DON'T WALK" phase because the detection system will call the signal for them. Thus, automated detection of pedestrians and extension of the amount of time available to cross the intersection is expected to lead to fewer pedestrian-vehicle crashes by reducing pedestrians' exposure to oncoming traffic.

A common flaw in automated detection is their tendency to generate both false positive and false negative indications of pedestrian presence. The rate of false negative detections is between 0-45% of all pedestrians, and the rate of false positive detection is between 0-3% of all pedestrians (*16, 17*). False positive detections usually occur because the systems detect objects such as vehicles or leaves. False negative detections usually occur when the detector is not correctly positioned or it does not sense a pedestrian because of the type of clothing worn or because the pedestrian crosses the street outside the detection area of the sensor. Detection errors can have a negative impact on both pedestrians and drivers. False negatives result in insufficient crossing time for pedestrians, and false positives force motorists to wait a longer time period at the intersection. Further testing and refinement of detection sensors is needed.

Only two published evaluations have drawn statistically rigorous conclusions about the effectiveness of the detection systems. (*18*) found an 89% reduction in traffic conflicts and an 81% reduction in pedestrians crossing illegally. (Before the intervention, the pedestrian signals required push-button activation, so automatic detection of the pedestrians drastically reduced the number who crossed illegally). Similarly, (*19*) found small reductions in pedestrian-vehicle conflicts. Reductions in IMOE's (mostly traffic conflicts) have been shown in other descriptive pedestrian detection studies (*20, 21*), but lack of statistical tests makes it difficult to determine the effectiveness of the device.

Unfortunately, there were no studies reviewed that examined the effects of automated pedestrian-detection devices on crashes. Pedestrian detectors seem to show promise in terms of IMOE's, but before they are recommended for widespread use, crash data should be evaluated with proper statistical techniques. In the absence of long term crash data, the devices could be further evaluated using IMOE's. Different combinations of sensors and newer technologies could possibly increase the value of pedestrian detection, and the safety effects of these should be measured as well. It should be noted that pedestrian detection is often used in conjunction with various other countermeasures, such as flashing crosswalk lights or flashing warning beacons. The need for further careful study described above also applies to these applications of pedestrian detection.

Flashing Crosswalk Lights (Table 2b). Pedestrian crossings at uncontrolled locations frequently are problematic for pedestrians. According to the traffic law in most jurisdictions in the U.S., on such a crossing a driver must yield to pedestrians, but in practice many drivers do not behave accordingly (*22*). Flashing crosswalk lights (also known as in-pavement flashers) and crosswalk pavement lights (illuminated crosswalks) seek to increase driver yielding at crosswalks, particularly at uncontrolled locations.

Flashing crosswalk lights were created in response to a high incidence of pedestrian crashes in Santa Rosa, CA. The inventor of the system (an airline pilot whose friend was involved in a pedestrian-vehicle crash) believed that a row of lights, similar to runway lights at an airport, would give drivers an advanced warning of pedestrians crossing a crosswalk. The invention was a series of lights to be imbedded in the pavement adjacent to the crosswalk and facing oncoming vehicles. The lights shine toward approaching traffic to warn drivers of a pedestrian's presence. The lights are activated either by an automated pedestrian detector or by a push button. Once the pedestrian enters the detection area or pushes the button, the lights stay activated for a predetermined amount of time.

Four studies to date have evaluated flashing crosswalks as a pedestrian injury countermeasure. Using a pre/post intervention design, (*23*) found that the system was effective at increasing the number of drivers who yielded to pedestrians, especially during nighttime and inclement weather conditions. This study found a 17% daytime increase and 53% nighttime increase in driver braking distance. Findings suggest that flashing crosswalk lights offer the potential of increased safety through better compliance with the pedestrian right-of-way.

One study found that flashing crosswalk lights caused more motorists to stop or slow for pedestrians and reduced pedestrian-vehicle conflicts, but did not decrease vehicle speed significantly (*24)*. The magnitude of the changes in this study was less than that reported by others (*23*). One possible explanation for this difference could be study site characteristics. For example, a crossing analyzed by (*24*). experienced unusually high volumes of pedestrians at certain times due to a theatre adjacent to the crosswalk. (*22*) found similar results to the (*24*) study with respect to vehicle yielding and pedestrian-vehicle conflicts. In addition, (*22*) found a significant 2-5 kph reduction in average vehicle speeds at sites with initial speeds greater than 30 kph.

One author reviewed all of the current implementations of flashing crosswalk lights in the U.S. (*25*). This review reported anecdotal evidence that the public generally approved of the systems and that the lights had been effective in reducing crashes, a FMOE. Additionally, the study found an 80% average reduction in crashes based on aggregated crash data from all the intersections and a hypothetical expected number of crashes based on vehicle volumes at those intersections. However, the localities that used the flashing crosswalk lights in conjunction with automated pedestrian detection consistently noted that there were problems with the detection systems making false calls. All such reports suggested that flashing crosswalk lights be implemented without the current pedestrian detection systems.

The study results reported to date suggest that flashing crosswalk lights may be an effective countermeasure, but as with the other more recently developed countermeasures, there is a need for rigorous long-term crash studies at multiple sites. Additionally, there is a need to compare sites with varying characteristics such as vehicle and pedestrian volumes, vehicle speeds, etc. to determine the characteristics of sites where this countermeasure would be most effective.

Countdown Signals (Table 2b). A countdown signal is a visible timer incorporated into a standard "WALK"/ "DON'T WALK" signal that counts down the total crossing time remaining before the red light. For example, the device counts down from sixty, when the green "WALK" symbol first appears, to zero, when the pedestrian phase has expired. The goal of the countdown signal is to indicate the time remaining to cross the street. The desired impact on pedestrian behavior is to (i) increase walking speed in order to cross before time runs out, or (ii) stop pedestrians from entering the crosswalk late in the pedestrian phase. The countdown timer may start either at the beginning of the pedestrian phase or at the onset of the pedestrian clearance interval (i.e., flashing "DON'T WALK"). One serious concern about the device is that it may increase the number and severity of crashes if motorists increase speeds in response to the countdown display.

There have been few statistically rigorous studies of the effectiveness of pedestrian countdown signals. For example, (*26*) documented pedestrian and driver behavior in response to pedestrian countdown signals using either before/after or control site comparisons, but reported no information on the statistical significance of the findings. In a study for the Florida Department of Transportation, researchers evaluated two intersections with countdown signals and three control sites that were similar but did not have countdown signals (*27*). The authors found that the countdown signals reduced the number of pedestrians who started running when the flashing "DON'T WALK" signal appeared, but that they also reduced compliance with the pedestrian signal. The countdown signals had no significant effect on the number of persons who ran out of time while crossing. The authors concluded that although compliance appears to have decreased at the countdown signal locations, the countdown signals also seem to cause pedestrians who leave during the flashing "DON'T WALK" to walk quickly to complete their crossing before the steady "DON'T WALK" is displayed, resulting in no significant change in the number of pedestrians who ran out of time. Similarly, a study in San Jose, California documented a significant increase in the proportion of pedestrians who completed their crossings before the end of the flashing "DON'T WALK" phase (*27*).

In general, the limited evaluation studies available suggest that the countermeasure causes more pedestrians to complete their crossings before the onset of the steady "DON'T WALK" phase. Further testing is necessary to determine their effect on pedestrian-vehicle crashes.

Animated Eyes (Table 2b). A pedestrian signal with an animated eyes display seeks to reduce injuries by making pedestrians and motorists more attentive to threats. The "eyes" on the display can be programmed to "look" from side to side, in an effort to prompt the pedestrian or the driver to scan the immediate area for conflicting pedestrian or vehicle traffic. Implementations of this countermeasure have been scarce as it is still early in its testing stages.

The literature for animated eyes is limited but suggests that it may be able to change pedestrian behavior and cause reductions in conflicts. For example, a Florida Department of Transportation Study found that at locations where animated eyes displays were used, the median number of total conflicts was reduced 59-94% (*29*). (*31*) noted similar findings and also evaluated animated eyes used to indicate the direction of the pedestrian threat to drivers. The study found significant changes in the behavior of motorists, especially at the mid-block crosswalk where there was a 50% increase in drivers yielding to pedestrians.

Further study of animated eyes to evaluate their ability to reduce actual pedestrian crashes is necessary. Additionally, the devices should be studied over the longer term to determine their novelty effect, since their effect on behaviors may decrease as pedestrians and drivers become sensitized to the signs.

Other Countermeasures. There are several other potentially beneficial uses for ITS technology in pedestrian injury countermeasures. Examples of such include:

- ITS road lighting technologies to increase lighting when a pedestrian crosses the street;
- Variable speed limit signs and ITS speed warning signs to change the posted speed limit on a roadway according to the level of pedestrian conditions activity near the roadway
- ITS No Turn on Red signs to prohibit turns on red when pedestrians are using the intersection;

To date no studies have tested the effect of these countermeasures on IMOE's or FMOE's. Like the other devices discussed in this paper, these countermeasures should also be evaluated for safety effectiveness.

DISCUSSION

Generally, this literature review found that there are limited rigorous evaluation studies of countermeasures designed to reduce pedestrian injuries. Nevertheless, available literature suggests that few countermeasures have demonstrated effectiveness in reducing either behaviors that lead to crashes or actual crashes. Table 3 summarizes the findings of this review.

Table 3: Summary of Results

Some countermeasures were effective, while others showed little to no effectiveness. Furthermore, some evaluations, particularly in the case of RLC's, suggest that a countermeasure's effect on an IMOE does not necessarily predict the FMOE. Conversely, just because a countermeasure is ineffective at reducing an IMOE does not mean that it is not effective in reducing a FMOE. Two possible reasons (among many) for such inconsistencies are: (1) the IMOE used is not an appropriate measure of the behavior that is being changed and (2) the pedestrian-vehicle crashes that occur at a site may not be related to the IMOE studied. In some cases, long-term crash studies are impractical due to time constraints. In these cases, IMOE's are the best available evidence of the countermeasure's ability to improve safety. Because of the above noted problems with IMOE's, this report recommends future research that includes analysis of long-term crash data.

Since the devices reviewed here appear not to change many of the behaviors that lead to crashes, it follows that they cannot totally eliminate pedestrian crashes. Most of the ITS-based countermeasures reviewed here seek to increase pedestrians' and/or motorists' awareness of threats. For some crash types, however, the most appropriate countermeasures may be design changes, education, and enforcement. Furthermore, even at good candidate locations for the ITS countermeasures described in this paper, countermeasures will have varying effectiveness. Since pedestrian volumes, motor vehicle volumes and speeds, roadway widths, adjacent land uses, and local driving culture can influence the effects of interventions on pedestrian safety, countermeasures discussed here should be tested at multiple locations.

In conclusion, careful consideration is necessary when choosing a countermeasure to improve pedestrian safety. Paucity of data, varying effectiveness by location, counter-intuitive effects of countermeasures, or improper study methods may give false indications of the effectiveness of countermeasures. Further study of all ITS-based pedestrian injury countermeasures based on injury data is needed. In addition, more conclusive studies on the relationship between IMOE and FMOE may grant communities a more definitive method of evaluating injury interventions.

TABLES AND FIGURES

TABLE 1 Summary Study of Contributing Factors to 830 Pedestrian-Injury Crashes across the U.S. in the 1990s.

TABLE 2A Summary of Reviewed Articles

TABLE 2B Summary of Reviewed Articles, Continued

TABLE 3 Summary of results

TABLE 1: Summary Study of Contributing Factors to 830 Pedestrian-Injury Crashes across the U.S. in the 1990s. (*6*)

Contributing factor	Percent of crashes
Pedestrians:	
Ran into road	15%
Failed to yield	11.8%
Alcohol impaired	10.3%
Stepped from between parked vehicles	7.1%
Walking or running in wrong direction	5.3%
Jaywalking	3.1%
Stepping into roadway	4.1%
Failing to obey a traffic signal	3%
Walking or standing in the road	3.1%
Lack of conspicuity	2.9%
Drivers:	
Failed to yield to pedestrian	15%
Exceeded speed limit or safe speed	6.2%
Improper backing	5.6%
Safe movement violation	4.8%
Inattention or distraction	4.2%
Reckless driving	3.4%
Alcohol impairment	3.1%

TABLE 2A: Summary of Reviewed Articles

Article	**Countermeasure**	**Results**
McGee and Eccles, 2003 (9)	RLC	RLCs appear to reduce crashes, but not entirely clear due to lack of proper experimental designs and difficulty in making comparisons across different jurisdictions.
Lum and Wong, 2003 *(32)*	RLC	40% average reduction in violation rate along RLC approaches (all but 1 lane statistically significant), inconclusive results for non-RLC approaches
Flannery ea, 2002 (*33)*	RLC	A 26% reduction in crashes for rear end and right angle collisions.
Harrington, 2001 *(34)*		Crashes increased 5.7%, citywide. 9.1% reduction in crashes at intersections with cameras. Number of crashes on approaches with cameras was reduced 27.1%.
Retting ea, 2001 *(13)*	2 RLC systems with different punishments	Crashes in RLC city reduced by 7%, right angle accidents reduced by 32%, injury crashes reduced by 29%, and right angle injury accidents reduced by 68%
Retting, 1999 *(35)*	RLC with $50 fine, public awareness campaign	40% (significant) reduction in violations after one year at camera and non-camera sites compared with control. No significant reduction in violations after 3 months at camera and non-camera sites compared with control.
Retting, 1999 *(36)*	2 RLC systems with different punishments.	42% (significant) reduction at camera and non-camera sites 3 to 4 months after installation.
McFadden, 1999 *(37)*	RLC in five separate implementation programs	Study shows obstacles to the implementation of an RLR program, but is weak on reliable statistical analysis (i.e. no significance testing). The crash data used is too limited to draw even preliminary conclusions.
Kruilkowski, ea 1998 *(38)*	2 RLC systems with different punishments.	40% reduction in violations overall; 1st site: 10% reduction in violations; 2nd site: 30% reduction in crashes
Lum and Wong, 1998 *(39)*	RLC, about a $215 dollar fine and 6 demerit points	Decrease in crashes after implementation, and a non-statistically significant 8.6% reduction in crashes compared with control sites.
South et al, 1988 *(11)*	RLC	No significant reduction in pedestrian-RLR crashes was identified.
Andreassen, 1995 *(10)*	RLC	At 41 sites there was a slight, but insignificant, decrease in crashes. All other crashes increased.
Winn, 1995 *(40)*	RLC, publicity campaign	69% reduction in violations, 62% reduction in injury crashes at the camera sites. Crash results not significant. Violations were reduced 39% and violations that were in the time periods most likely to cause a crash were reduced 68-69%.
Zaal, 1994 *(41)*	RLC	Claims that research in Australia has shown a 35-60% reduction in RLR crashes. Misinterpretation of the conclusions and statistics of other authors (See *10*). Conclusions about RLC not supported because of misinterpretations.
Chin, 1989 *(42)*	RLC	40% reduction in violations at RLC locations; similar reductions in violations on approaches adjacent to RLC.
Huang and Zegeer, 2001 *(15)*	Illuminated Push Buttons	No overall significant change in any of the IMOE's studied.
Hughes et al, 1999 *(18)*	Microwave pedestrian detection	89% reduction in conflicts after installation. 81% reduction in pedestrians who crossed during steady DON'T WALK.
Beckwith, 1997 *(16)*	Pedestrian Detection: Comparison of infared, utrasonic, radar.	Ultrasonic sensors (30ft detection distance; 3-45% no detection rate) did not perform well in detection tests, possibly due to angle of the detector. Passive Infrared Sensors (45ft detection distance; 0-1.5% no detection rate) were the most effective and reliable, but may require more detectors to cover a given area than other types. Radar sensors (49ft detection distance; 7% no detection rate) worked well but had false detections during rain.

TABLE 2B: Summary of Reviewed Articles Continued

Article	**Counter-measure**	**Result**
Reading et al, 1995 *(20)*	Pedestrian detection using PUFFIN system	Increased vehicle waiting times. Pedestrian delay was unaffected. Pedestrians stay in crosswalk longer, don't rush. "Some evidence" that PUFFIN system increase compliance with signals, crossing times were slightly higher, less pedestrians used the push buttons, fewer of the first arriving pedestrians used the push button.
Davies, 1992 *(21)*	Pedestrian Detection using PUFFIN system	Delay: Pedestrian delay decreased, driver delay increased at signals. Crossing Against Red: no significant difference. Looking Behavior: improved looking behavior generally, increased looking for those crossing against red. Conflicts: None observed. Crossing Time: Increased at one site, decreased at other.
Ekman and Draskocsky, 1992 *(43, study 1)*	Pedestrian Detection	"A majority" of pedestrians were detected. No significant difference in pedestrian delay or changes in pedestrian routes. If all conflicts are combined there is a significant change in conflicts from the before period.
Ekman and Draskocsky, 1992 *(43, study 2)*	Pedestrian Detection	All pedestrians in detection area were detected, with no false detections. "Large" reduction in pedestrians crossing against red. Vehicle-pedestrian conflicts reduced from 6 to 0. Reduction in waiting time for pedestrians and slight increase in vehicle waiting time.
Botha et al., 2002 *(28)*	Coundown signal	Significant increase of pedestrians entering the intersection during flashing "DON'T WALK" at 3 of 4 locations, significant decrease in proportion of pedestrians exiting the intersection during "DON'T WALK". Countdown reduced conflicts, but level of significance not reported. No significant change in other IMOE's studied.
Huang and Zegeer, 2000 *(44)*	Countdown signal	Significant decrease in pedestrian compliance, significant decrease in pedestrians who began running, no significant change in pedestrians who ran out of time.
Leonard et al., 1999 *(26)*	Countdown signal	Pedestrians are less likely to start at end of cycle. Some pedestrians will stop in the median and wait if they do not have enough time to make it across. Unlikely that drivers will use signal to beat the on coming red. Does not stop pedestrians from "jaywalking" or crossing in flashing Don't Walk.
Hakkert et al., 2002 *(22)*	Flashing Crosswalk Lights (with automated detection)	2-5 kph reduction in average vehicle speeds at sites with initial speeds greater than 30 kph; increase in the rate of yielding to pedestrians; a reduction in conflict rates; a reduction in proportion of pedestrians walking outside the crosswalk; no significant change in pedestrian compliance.
Miller, 2001 *(25)*	Flashing Crosswalk Lights	80% reduction in crashes averaged over all current implementations. Generally, public and implementing institutions are in favor of the system. Most problems are a result of faulty passive pedestrian detection systems.
Huang et al, 1999 *(24)*	Flashing Crosswalk Lights	No statistically significant change in vehicle speed. 22% more drivers slowed or stopped for pedestrians in crosswalk. Fewer conflicts in crosswalk (no significance test identified for that data).
Whitlock and Wienberger, 1998 *(23)*	Flashing Crosswalk Lights	Daytime: 15-40% increase in driver yielding. Nighttime: 30%-85% increase in driver yielding. Daytime: 0-60ft. Change in driver initial braking point. Nighttime:40-200ft. Change in driver initial braking point.
Van Houten and Malenfant, 2001 *(31)*	Animated Eyes	Garage:14% increase in drivers looking for pedestrians, 34% increase in drivers yielding to pedestrians. Midblock: 50% increase in drivers yielding to pedestrians (62% with addition of sunshade). Mean percent of pedestrians stranded at centerline decreased 11%.
Florida Dept. of Transportation, 2000 *(29)*	Animated Eyes	Median number of conflicts was reduced 59-94%. A significant increase in pedestrian looking behavior with the "eyes". Prompting pedestrians to look toward the threat was no more effective than prompting to look both ways.
Van Houten et al., 1998 *(45)*	Animated Eyes	Decrease in pedestrians not looking by 22-29%. Results similar 6 months later. Traffic conflicts reduced approximately 2.0% from 2.9%.

TABLE 3: Summary of Results

Countermeasure	Result
Red Light Camera	Reduces violations, not crashes.
Illuminated Push Button	Ineffective based on IMOE's studied
Automated Pedestrian Detection	Effective at reducing conflicts; no information on crashes
Flashing Crosswalk	Crash reduction
Countdown Signal	Effective at increasing number of pedestrians who complete crossings before red; no information on crashes
Animated Eyes	Effective at reducing conflicts; no information on crashes

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