A Legal Approach to Reduce Red Light Running Crashes

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Indecision at the onset of the yellow interval at signalized intersections is one of the main problems facing drivers, especially inexperienced ones. This indecision is fairly justified because the yellow interval duration varies at intersections and also because of the optional use of the all-red interval and its varied duration. This indecision has serious safety consequences for signalized intersections. This paper provides a theoretically based legal approach for reducing red light running crashes. It stresses that all-red intervals are not necessarily a cure for red light running, especially when drivers come to expect an additional safety increment and many try to misuse it. A theoretical analysis has been performed to provide information to aid drivers in deciding how far from the stop line they must stop at the onset of the yellow interval, and when and where they should proceed to cross the intersection. This information is essential in reducing red light running. Delineation of a yellow transverse line at the calculated decision line is proposed as well as instituting a traffic regulation to stop if such line is not crossed at the onset of the yellow interval. Another proposed traffic ordinance is to "yield before go" to vehicles within the intersection at the onset of green. Theoretical, legal, and logical evidence for reducing red light running accidents is provided based on the proposed traffic ordinances. However, statistical valuation is as yet impossible because such traffic ordinances have not been implemented, and there are no before and after data on which to base a statistical analysis.

Traffic laws and ordinances regulate traffic, which provides organized flow and improves safety. Traffic regulations, along with proper education and enforcement, are assumed to be the most powerful tool for traffic safety. Thus, technological advancement and theoretical analyses would be better utilized if coupled with appropriate traffic regulations.

Intersections' signals provide temporal assignment of right-of-way, thus providing a smooth traffic flow, and are intended to increase safety and efficiency. Change (yellow) intervals are the most troublesome to motorists and most challenging to traffic engineers.

The *Uniform Vehicle Code* (*1*) provides a permissive yellow law, meaning that a driver can enter the intersection during the entire yellow interval and may actually be legally within the intersection during the red indication as long as she or he entered the intersection during the yellow interval. Parsonson (*2*) noted that about half the states in the United States use the permissive yellow law, while the other states mostly use one of the two following rules:

- Vehicles can neither enter the intersection nor be in the intersection on red and
- Vehicles must stop upon receiving the yellow indication, unless it is not possible to do so safely.

The precise meaning of the yellow interval, how it is perceived by the public, and how it is enforced by the authorities are essential in determining the need, the time-setting, and the exact legal definition of the clearance (all-red) interval.

The all-red interval is not a universal rule. Some countries and localities do not use the all-red interval. Hence, the intent would be for vehicles to clear the intersection during the yellow interval. However, in such a case, a vehicle entering an intersection just before the start of the red interval is bound to be within the intersection at the onset of the green interval for the opposing traffic flow. Therefore, if an all-red interval is not provided, a vehicle could be in the intersection while a conflicting approach receives the green interval. Hence, if the permissive yellow law is used without an all-red interval there is a potential for a crash, even when no one entered the intersection illegally. This is a difficult situation to regulate or to enforce. The all-red interval allows a vehicle that entered the intersection just before the start of the red interval to traverse the intersection before the onset of the green interval for the opposing traffic flow.

The main purpose for introducing the all-red interval is to improve safety. The increase of the yellow, all-red, or even the extension of the green interval in a dilemma zone protection arrangement does not necessarily improve safety. But surely all three of the above options increase delay and reduce capacity.

The use of the all-red interval has mostly not been publicized to drivers, rightfully so, in order not to be misused, especially by providing drivers with an additional expected safety clearance margin. Furthermore, most drivers are smart enough to discover the additional clearance interval on their own; thus the undeclared safety margin becomes expected and accounted for, and in some cases misused.

This research analyzes the causes of red light running crashes, explores the theoretical bases for the capabilities of drivers and vehicles to stop or proceed safely, and recognizes various remedial solutions commonly addressed and researched. However, it particularly addresses regulations, and on the basis of theoretical analyses and logical reasoning, the author suggests new traffic regulations for signalized intersections that could reduce red light running crashes.

BACKGROUND

Legislative Issues

Drivers have the legal responsibility for their actions and omissions. Thus they must obey the traffic laws and regulations. When a police officer directly witnesses a violation and issues a citation, the liabil-

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ity of the driver is rarely questioned. In most states in the United States, moving violations, including red light running, are considered criminal offenses, while minor traffic violations such as parking are considered civil offenses (*3*). Criminal offenses are commonly more dangerous than civil offenses. Civil offenses are processed in administrative courts, which can impose fines and other penalties. The civil prosecution process is simpler and faster than the criminal prosecution process. Typically, administrative courts act on the ground the violation has occurred and the judge finds the accused guilty as charged unless the defendant can prove his innocence. In contrast, in a criminal court, the burden of persuasion lies with the prosecution. The burden of proof requires the prosecution to prove the defendant is guilty "beyond a reasonable doubt." However, when the evidence in a criminal case is so strong that the case could easily result in an indictment if presented to a grand jury, the case is termed "prima facie." Under these circumstances, the prosecution can file a complaint against the defendant, effectively placing the burden of proof on the defendant to show evidence of his or her innocence (*3*). Red light running is a serious traffic violation that can result in deaths and injuries, and despite the need to have a more efficient and cost-effective judicial process by classifying red light running a civil offense, the seriousness of such violations dictates they should be treated as a criminal offense. The automated enforcement of red light running was one of the reasons some U.S. states have changed red light running from a criminal offense to a civil offense.

Red Light Running

Intersection areas represent a very small percentage of the travel way. However, about 40% of motor vehicle crashes in the United States occur at intersections (*4*). FHWA/Institute of Transportation Engineers (ITE) (*5*) estimated for the year 2001 there were about 218,000 red light running crashes at intersections throughout the United States, resulting in 181,000 injuries, 880 fatalities, and an estimated $14 billion in economic loss. Mohamedshah et al. (*6*) used data from four states to show that red light running crashes account for 16% to 20% of the total crashes at urban signalized intersections. Thus red light running is an increasingly serious traffic problem that has been receiving significant research, regulation, and enforcement efforts but still needs more of such efforts. Furthermore, a study by Bonneson et al. (*7*) concluded that heavy vehicle drivers are twice as likely to run red lights as are passenger car drivers, which contributes to more severe accidents. Vogt (*8*) found that rural signalized intersections with 9% entering trucks had about 32% higher expected crash frequency than did similar intersections with no trucks entering. The overrepresentation of truck crashes at signalized intersections is primarily due to trucks' operating characteristics. Awadallah (*9*) noted that braking distances for heavy trucks are substantially higher than for passenger cars on dry pavement, where for passenger cars the braking mechanism is capable of providing substantial deceleration rates, in the range of 0.9 g compared to about 0.5 g for heavy trucks.

There are many reasons for red light running, which result in various types of crashes. FHWA/ITE (*5*) outline the following main factors as influential for red light running: the intersection characteristics, including cross-street width, approach grade, yellow interval, traffic control signal type, and traffic volume; drivers' education and background; and enforcement level and effectiveness. However, the reason for most reported accidents is human error. Hendricks et al. (*10*) reported that in 99% of 723 crashes investigated from four different sites in the United States in 1996 and 1997, a driver behavioral error caused or contributed to the crash. Thus, limiting drivers' behavioral errors is certainly worthy of research and exploring of various remedial solutions.

Change (Yellow) Interval

Motorists' expectancy of the duration of the change interval is based on their past experiences. The *Manual on Uniform Traffic Control Devices* (MUTCD) (*11*) provides guidance that a yellow change interval should have a duration of approximately 3–6 s, with the longer intervals reserved for use on approaches with higher speeds. Thus, the yellow signal timing should not only satisfy the basic laws of motion, but also should be consistent with motorists' expectations. Parsonson (*12*) demonstrated that the percentage of red light running increased as yellow times went from 3 s to 5 s. Thus, violation rates and safety may be an issue with long yellow intervals. However, Bonneson and Son (*13*) reported that red light running increases significantly for yellow intervals below 3.5 s and increases slightly for yellow intervals beyond 4.5 s.

FHWA/ITE (*5*) state that lengthening the yellow interval may reduce signal violations. However, long intervals increase the delay to motorists and pedestrians. A long yellow interval will eventually be realized by drivers, and they will tend to enter the intersection later within the yellow interval. This may be generalized by some drivers to other intersections with normal-length yellow intervals, which may prompt red light running. The tendency for motorists to adjust to the longer intervals and enter the intersection later is referred to as habituation. The *Manual of Traffic Signal Design* (MTSD) (*14*) cautions that yellow and all-red intervals greater than 6 s should be examined critically before being implemented. They cite loss in efficiency and capacity at the intersection and a tendency for local drivers to use more of the change interval when they know that it is longer than normal.

Clearance (All-Red) Interval

All-red simply means all signal indications for an intersection are red at the same time. This portion of a traffic signal cycle is termed an all-red interval. If used, the all-red interval follows the yellow change interval and precedes the next conflicting green interval. The purpose of the all-red interval is to allow time for vehicles that entered the intersection toward the end of the yellow interval to clear the intersection before the traffic signal display for the conflicting approaches turns green. MUTCD (*11*) stipulated that the all-red clearance interval is optional, and the duration of the all-red interval shall be predetermined, but should not exceed 6 s. This maximum value for an all-red interval (6 s) has been reported in practice in several states, especially for offset-approach diamond interchanges. There are no guidelines in the MUTCD (*11*) for when the all-red interval should or may be used. For most agencies, the decision to use an all-red interval is tied to the determination of the yellow change interval. The ITE *Traffic Engineering Handbook* (*15*) suggests that when the calculated yellow change interval is greater than 5 s, an all-red interval provides the additional time beyond 5 s.

Dilemma Zone Protection Methods

The ITE *Traffic Safety Toolbox* (*16*) defines the "dilemma zone" to be the area in which it may be difficult for a driver to decide whether to stop or proceed through an intersection at the onset of the yellow signal indication. McCoy and Pesti (*17*) also refer to it as the "option zone" or the "zone of indecision." However, McShane et al. (*18*) define the dilemma zone as a distance from the stop line where a driver is too close to stop safely before the conflicting flow is released and far enough from the stop line that the driver does not have enough time to safely cross the intersection before the conflicting flow is released.

McCoy and Pesti (*19*) noted that the two most common methods for providing dilemma zone protection on high-speed approaches to signalized intersections are advance warning flashers (AWFs) and advance detection (AD). AWFs are active warning signs, usually with yellow flashing beacons designed to operate at a predetermined time before the end of the green interval. The intention of AWFs is to reduce the indecision of drivers by providing them with information to encourage them to stop before the stop line. But no legal considerations for AWFs were introduced. Evaluations of accident experience at AWF signals by Gibby et al. (*20*), Klugman et al. (*21*), and Sayed et al. (*22*) were inconclusive in determining their effectiveness. In the case of AD, detectors are placed on the intended intersection approach to extend the green and prevent the onset of yellow while approaching vehicles are in their dilemma zone. The termination of green is based on the detectors' receiving a sufficient predetermined gap (gap-out), or the green interval reaches a maximum set time that indicates that delays for the other approaches are no longer acceptable (max-out). Gibby et al. (*20*) and Wu et al. (*23*) have indicated that AD is effective in reducing crashes on high-speed approaches to signalized intersections, while Parsonson (*2*) and Bonneson and McCoy (*24*) indicated the lost of dilemma zone protection when the "max-out" occurs.

A technique for providing separate dilemma zones for cars and trucks was investigated by Zimmerman (*25*). Testing indicated that a truck dilemma zone extending 1.5 s further upstream than the passenger car dilemma zone (i.e., to 7.0 s from the intersection) provided the most improvement in reducing the number of trucks in the dilemma zone without impacting intersection efficiency. Actually, the dilemma zone may be different for each vehicle's speed and deceleration rate, and drivers' perception–reaction time. The legal speed limit (or the 85th percentile speed), comfortable deceleration rate, and 85th percentile perception–reaction time of drivers are usually used for signal timing design; and such values, particularly the speed limit, are used in the defense of tort liability suits.

THEORETICAL ANALYSIS

Dilemma Zone

The dilemma zone definition used for this research is based on ITE's MTSD (*14*), which states that the dilemma zone is an area close to the intersection stop line where vehicles can neither physically stop nor legally proceed. The MTSD (*14*) nondilemma change period (yellow and all-red), Equation 11.3 is reproduced here in Equation 1.

$$\mathrm{CP} = t_r + \frac{V}{2a} + \frac{W+L}{V} \tag{1}$$

where

CP = combined period (yellow and all-red intervals' duration),
t_r = perception–reaction time,
V = approach speed,
a = deceleration rate,
W = width of intersection, and
L = length of design vehicle.

Compatible units may be used for the equation. Usually the first two terms of Equation 1 are set for the yellow interval and the last term for the all-red interval. The default values of a, t_r, and L are usually 3.3 m/s^2, 1.0 s, and 6.0 m, respectively. The effect of grades is substantial, but it is not included in Equation 1 to simplify the analysis; it is addressed later in this section. Figure 1 presents sketches for the dilemma zone, option zone, and no dilemma or option zone concepts. S_1 is the minimum distance to stop safely before the stop line; S_2 is the maximum distance required to proceed safely to cross the intersection before the conflicting flow is released. The equations for S_1 and S_2 are derived from the basic equations of motion and are outlined below:

$$S_1 = t_r V + \frac{V^2}{2a} \tag{2}$$

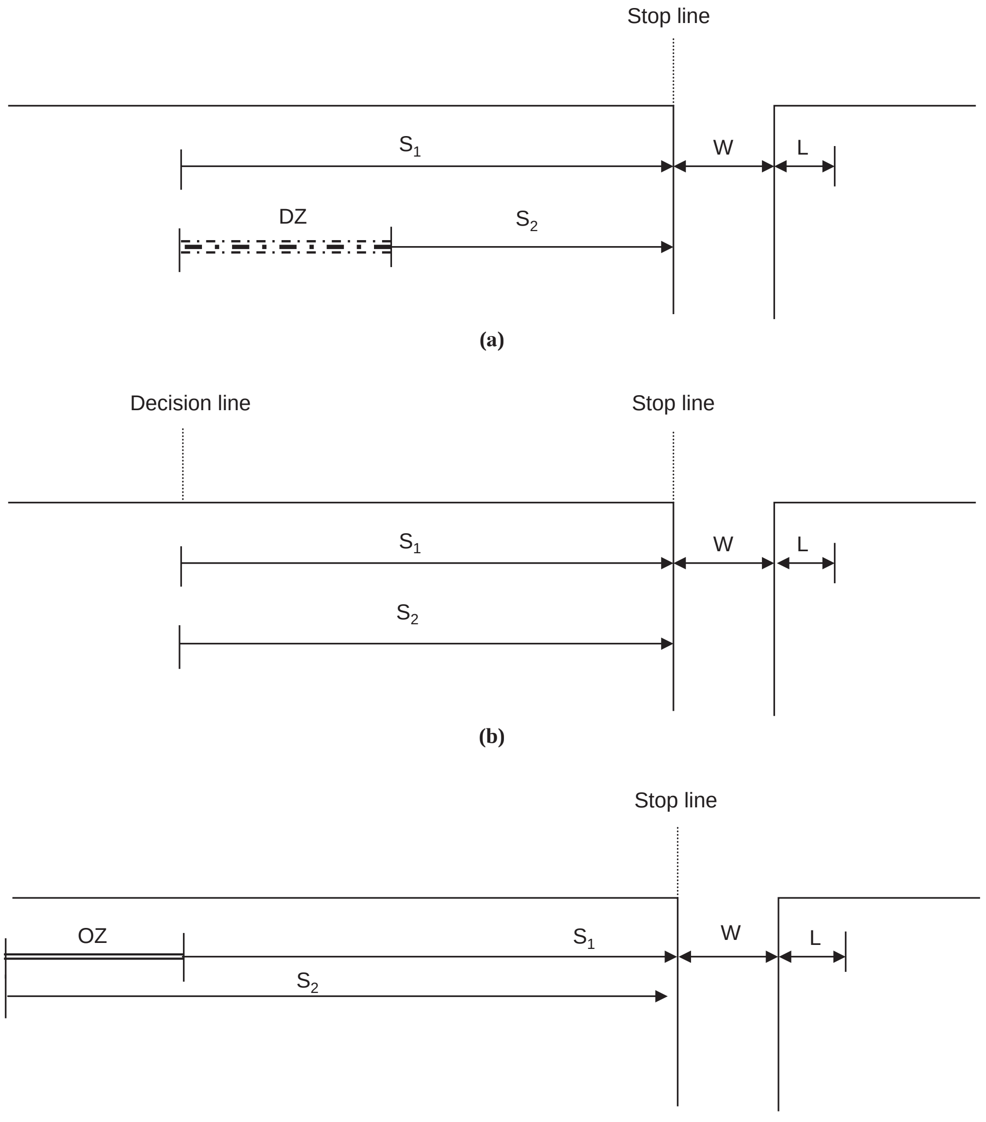
$$S_2 = t_r V + t_c V - \left(W + L\right) \tag{3}$$

All terms have been defined earlier with the exception of t_c, or time at constant speed following the perception–reaction time, which is needed for a vehicle to clear the intersection; the units are compatible. The perception–reaction distance term ($t_r V$) is the distanced traveled before applying the brakes, as in Equation 2, or before deciding to continue to travel at constant speed, as in Equation 3. There are three cases regarding S_1 and S_2. First, if $S_2 < S_1$, then there would be a dilemma zone (see Figure 1*a*) in which vehicles can neither physically stop safely nor legally proceed safely. This indeed must be avoided. In practice, no standard or procedure for change interval (yellow + all-red) permits the existence of a dilemma zone according to the definition provided. However, in some rare circumstances fine adjustment of signal timing causes such a predicament, which surely would be an engineering error.

The second case is $S_1 = S_2$. The ITE's MTSD nondilemma zone method (*14*), which is widely used in practice, specifically provides a change interval (yellow + all-red) as provided in Equation 1 based on this concept. Thus Equation 1 is derived by equating S_1 to S_2 and solving for t_c, which are the last two terms of Equation 1. Hence, by adding the perception–reaction time (t_r) to the constant speed time (t_c), the nondilemma change period (Equation 1) is formed. This method provides a decision line as shown in Figure 1*b*, at which at the onset of the yellow interval vehicles traveling at the speed limit and located before the decision line should decelerate to a stop just before the stop line, and vehicles traveling at the speed limit and located after the decision line (nearer to the intersection) should proceed at the design speed to cross the intersection.

In the third case, if $S_2 > S_1$, then there would be an option zone or a decision zone formed as shown in Figure 1*c*. Vehicles traveling at the speed limit and positioned within the option zone at the onset of the yellow interval have the option to stop safely before the stop line or proceed at the design speed to cross the intersection before the release of the conflicting movement. Furthermore, vehicles traveling at the speed limit and positioned before the option zone at the onset of the yellow interval should decelerate to stop before the stop line, while vehicles positioned after the option zone should proceed at the design speed to cross the intersection before the release of the conflicting flow.

Earlier ITE recommended practice (*26*) provided for use of the 85th percentile approach speed for the second term of Equation 1, which represents the deceleration time. The perception–reaction time and deceleration time represent the first and second terms of



(a)

(b)

(c)

FIGURE 1 Formation of dilemma zone (DZ) or option zone (OZ) when (*a*) $S_2 < S_1$, DZ is formed; (*b*) $S_2 = S_1$, no DZ or OZ is formed; and (*c*) $S_2 > S_1$, OZ is formed.

Equation 1, respectively, and together constitute the yellow interval. The ITE recommended practice (*26*) also uses the 15th percentile approach speed for the third term, which represents travel time to clear the intersection and denotes the all-red interval. This practice provides an option zone for vehicles traveling at mean speed.

Effect of Grade on the Change Interval

Intersection approach grade has a significant effect on the stopping distance of vehicles. It mainly affects the yellow interval; upgrades reduce the yellow interval and downgrades increase the braking distance, thus requiring an increase in the yellow interval. Equation 4 below shows the effect of grade:

$$\mathrm{CP}' = t_r + \frac{V}{2a + 2gG} + \frac{W + L}{V} \qquad (4)$$

where

CP′ = nondilemma zone change period (yellow + all-red intervals), including the effect of grade,
g = gravitational constant, and
G = percent grade divided by 100, with plus sign for upgrade and minus sign for downgrade.

Trucks have lower deceleration rates than passenger cars, but this is more evident when trucks travel on downgrade approaches.

TRAFFIC REGULATIONS FOR REDUCING RED LIGHT RUNNING

The great majority of red light running crashes are attributed to driver error. Drivers sometimes misjudge whether to stop or proceed during the yellow interval. Therefore endeavors to ensure the highest compliance with the basic traffic regulation to stop before the stop line and not to enter the intersection during the red interval are of paramount importance. Additional traffic regulations are proposed in this research to limit drivers' indecision and give a clear clue for drivers when to stop and when to proceed at the onset of a yellow interval, depending on their speed and location from the stop line. A comprehensible regulation, if suitably transmitted to the driving public and enforced, would not only limit red light running crashes but would also help jurisdictions in defending their cases and responsibilities for tort-liability suits.

Delineation of the Decision Line

According to the theoretical analysis section, if a vehicle just passes the decision line (Figure 1*b*) at the onset of the yellow interval, then on the basis of the default variables of a comfortable deceleration rate (usually 3.3 m/s^2) and a normal (or 85th percentile) perception–reaction time for expected stimuli (default 1.0 s), the driver could stop safely at the stop line if she or he is traveling at or below the speed limit. However, drivers who are speeding may also be able to stop safely at the stop line provided they are more vigilant than normal (perception–reaction time less than 1 s) and/or decelerate at a higher rate than the comfortable deceleration rate (more than 3.3 m/s^2). Delineating the decision line and introducing a traffic regulation that requires drivers to stop if they did not cross the delineated decision line when the signal indication turns yellow logically limits the indecision of inexperienced drivers to stop or go, and also deters drivers who intend to beat the signal and proceed before the signal turns red. Of course drivers traveling substantially beyond the speed limit may not be able to stop safely before the stop line, but the main violation of the law would be speeding and perhaps reckless driving.

The delineation of the decision line is proposed to be in its simplest form, a transverse yellow line. Thus the proposed traffic regulation is simple: basically, when drivers pass the transverse yellow line during the yellow indication they must stop at or before the stop line. Complementary regulatory signs may be posted at the edge of the pavement at the transverse yellow line location. The sign may be in a symbol form (which is possible, but several options need to be tested for most easily understood cases), or a legend sign may simply state "Stop at Yellow Indication." This implies that if a driver cannot see this sign during the yellow indication (i.e., the driver passed the decision line before the yellow is initiated), then she or he may proceed to cross the intersection (i.e., is not legally obliged to stop). Drivers may decide to stop if they cross the yellow transverse line before the onset of yellow, especially if they are traveling at a speed below the speed limit. Posting of regulatory signs at the edge of the pavement of the yellow transverse line could alert speeding drivers to slow down to the speed limit when they are approaching this line.

The more extensive and uniform a law is, the more it is understood and observed by the public. It is recommended that when a proposed new traffic regulation is approved for a given jurisdiction, proper dissemination of the new regulation is essential via driver's license instruction booklets, the local media, and other suitable forms. Enforcement after a suitable grace period is necessary to be an additional form of education and an evidence of seriousness.

Yield Before Go

The emphasis for reducing intersection crashes should not be solely directed toward red light runners; drivers at the opposing approaches, which have the onset of the green indication, should yield the right-of-way to vehicles within the intersections just before entering the intersection. MUTCD (*11*) states that "Traffic, except pedestrians, facing a circular green signal indication may proceed . . . but vehicular traffic, including vehicles turning right or left, shall yield the right-of-way to other vehicles, and to pedestrians lawfully within the intersection or an adjacent crosswalk, at the time such signal indication is exhibited." Because the word "lawfully" within the intersection could have various interpretations and could be misinterpreted, it is recommended that it be omitted. In addition, this modification of the above traffic ordinance should be lawful and binding to motorists. Furthermore, it should be communicated to drivers (especially in driver's license tests), publicized, and enforced. However, the responsibility of an accident due to a driver's entering the intersection during the red interval should not be equal to the responsibility of a driver entering the intersection at the onset of green without yielding the right-of-way to vehicles within the intersection. The author suggests the responsibility of a driver entering the intersection at the onset of green without yielding the right-of-way to vehicles within the intersection should be from 0% to 30% of that of a driver entering the intersection during the red interval. Thus a driver not yielding the right-of-way to vehicles within the intersection at the onset of green could be charged with up to 30% of the amount of the citation fee and his or her insurance company could be responsible for up to 30% of the damages for an accident caused mainly by a driver entering the intersection during the red interval.

A traffic regulation with the general concept of "yield before go" should be explained clearly to drivers. Minimum time should be devoted to this yield procedure, and the legal responsibility is only for vehicles inside the intersection when the signal turns green. It is important to emphasize these concepts in order not to cause significant delays. However, it is evident that drivers should also yield to speeding vehicles approaching the intersection that could cause an accident with them if they proceed. Even though there is no legal responsibility to do so, drivers would certainly want to avoid a crash that could cause them injury or death. Nonetheless, this would alert drivers to yield in such life-threatening cases, particularly to speeding trucks.

CONCLUSION

Numerous options to reduce red light running crashes have been researched and implemented, such as traffic-responsive signal timing, advance signal warning, and dilemma zone protection methods. However, human behavior or error is the overwhelming factor contributing to red light running crashes. Instituting new traffic ordinances to reduce red light running on the basis of theoretical and logical reasoning is argued. Traffic laws and ordinances cannot be verified without being implemented, but the justifications for the two suggested laws are evident by the number of red light running crashes that are based on drivers' error or reckless driving. This paper is intended for policy makers to evaluate the feasibility of implementation of the proposed traffic regulations, which provide a potential for saving thousands of lives and injuries with relatively low cost. It is recommended to use focus groups of traffic engineers from local, state, and federal transportation agencies; law enforcement officers; lawyers and legislators; and drivers in general. The focus groups should explore the acceptance of such proposed regulations. If generally accepted, they should provide refinements to the proposed regulations, implementation methodology alternatives, publicity concepts, and enforcement methodology options. Priority of implementation should be for high-speed approaches.

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