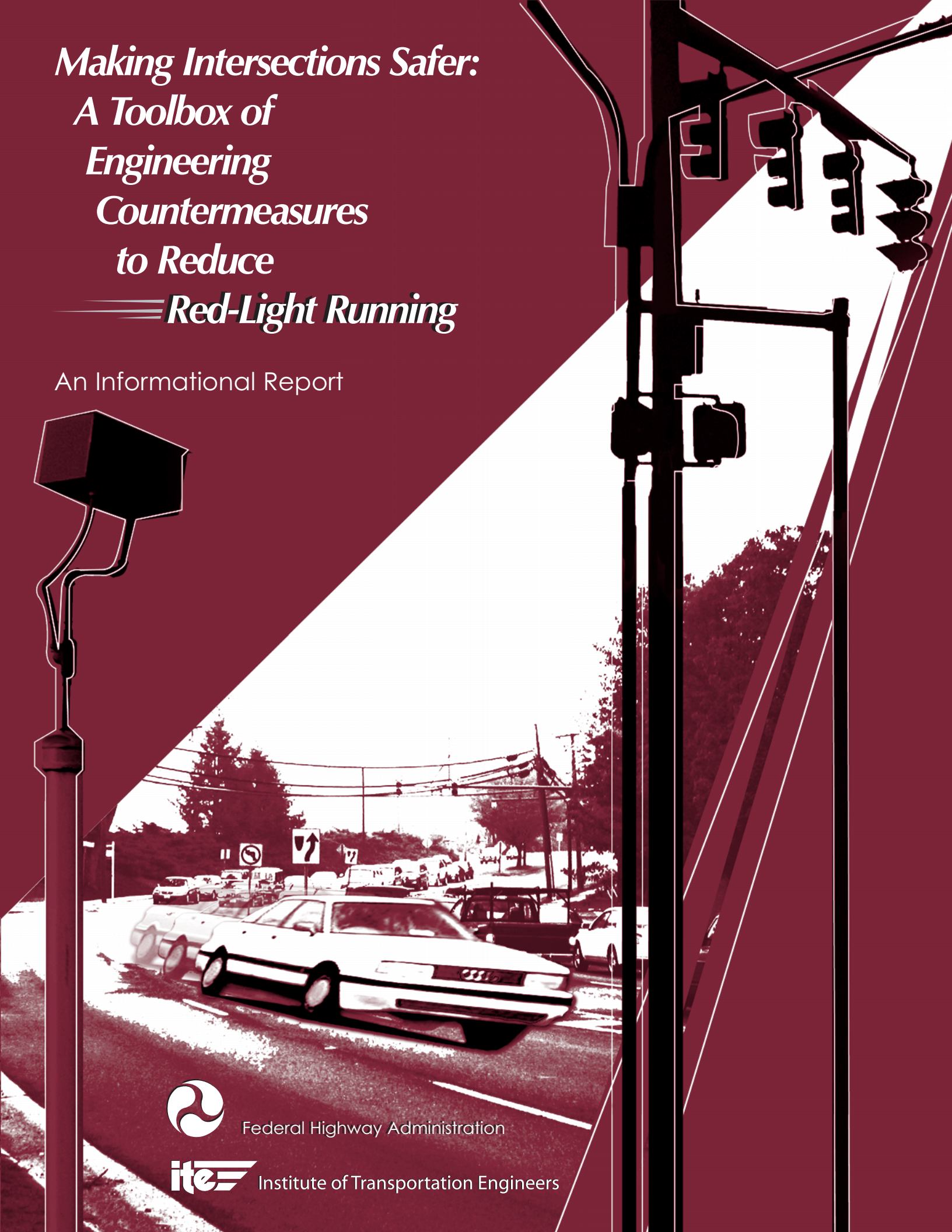
Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce Red-Light Running

An Informational Report



Federal Highway Administration

Institute of Transportation Engineers

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The Institute of Transportation Engineers (ITE) is an international educational and scientific association of transportation and traffic engineers and other professionals who are responsible for meeting mobility and safety needs. ITE facilitates the application of technology and scientific principles to research, planning, functional design, implementation, operation, policy development and management for any mode of transportation by promoting professional development of members, supporting and encouraging education, stimulating research, developing public awareness, and exchanging professional information; and by maintaining a central point of reference and action.

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table of contents

LIST OF FIGURES AND TABLES v

EXECUTIVE SUMMARY vii

ACKNOWLEDGEMENTS 1

CHAPTER 1
Introduction

The Problem 3
Alternative Solutions 3
Objective of Report 4
Report Organization 4

CHAPTER 2
Understanding Red-Light Running

Red-Light Running Defined 5
Red-Light Running Violation Frequency 6
Safety Impacts of Red-Light Running 6
Crash Types Related to Red-Light Running 9
Driver Characteristics 10
Intersection Characteristics 12
Drivers' Stop-Go Decision 14
Causal Factors and Potential Countermeasures 15
Summary 16

CHAPTER 3
Engineering Countermeasures

Introduction 17
Improve Signal Visibility 17
Improve Signal Conspicuity 24
Increase Likelihood of Stopping 28
Address Intentional Violations 31
Eliminate Need to Stop 36
Summary 39

CHAPTER 4
Red-Light Running Problem Identification and Resolution Process

Introduction 41
The Process 42
Summary 49

CHAPTER 5
Future Needs

Research and Development 51
Improved Crash Data for Red-Light Running 53
Improved Guidelines and/or Standards 53
Improved Procedures and Programs 53

REFERENCES 55

list of figures and tables

CHAPTER 2

Table 2–1
Summary of Violation Data for Iowa Cities 6
Figure 2–1
Red-Light Running Crashes Injury Distribution 8
Table 2–2
Summary of Costs Resulting from Ran Traffic-Signal Crashes in Iowa (1996–1998) 8
Figure 2–2
Common Crash Types Associated with Red-Light Running 9
Table 2–3
Summary of Intersection Characteristics on Likelihood of Red-Light Running Crash 14
Table 2–4
Factors Affecting the Stop-Go Decision 14
Table 2–5
Driver Population Types 15
Table 2–6
Possible Causes and Appropriate Countermeasures for Red-Light Running 16

CHAPTER 3

Figure 3–1
Intersection with One Signal Head 18
Table 3–1
Minimum Sight Distance 18
Figure 3–2
Post-Mounted Signal Blocked by Vehicle 19
Figure 3–3
Post-Mounted Signal no Longer Blocked by Vehicle 19
Figure 3–4
Intersection Approach with Two Signal Heads 20
Figure 3–5
Approach Updated with One Overhead Signal for Each Through Lane 20
Figure 3–6
Intersection with One Lane Approach with Two Overhead Signals 20
Figure 3–7
More Than One Primary Overhead Signal Per Lane, Plus Pole-Mounted Secondary and Tertiary Signal Heads 21
Figure 3–8
Two Overhead Signals for a One Lane Approach and Supplemental Pole-Mounted Signal 21
Figure 3–9
Approach View of Supplemental Signal on Near Side at Intersection 21
Figure 3–10
Supplemental Signal for an Intersection in the Middle of a Reverse Curve 22
Figure 3–11
Comparison of Signal Heads Using 8-in. and 12-in. Lenses 22
Figure 3–12
Louvers Used on Traffic Signals on Two Closely Spaced Approaches 24
Figure 3–13
Alternative Arrangements of Two Red-Signal Sections 25
Figure 3–14
Field Use of Two Red-Signal Sections 25
Figure 3–15
Traffic Signals with Backplates 26

Figure 3–16
Signal with High Intensity Yellow Retroreflective Tape on the Backplate 27
Figure 3–17
SIGNAL AHEAD Sign 28
Figure 3–18
Example of AWF and Sign Treatment 29
Figure 3–19
Example of AWF and Sign Treatment 29
Figure 3–20
Rumble Strips and Pavement Markings Used to Alert Drivers of Signal Ahead 30
Figure 3–21
LEFT-TURN SIGNAL Signs at an Intersection 30
Figure 3–22
Factors to Consider in Signal Removal 37
Figure 3–23
Roundabout 38
Figure 3–24
Summary of Engineering Countermeasures by Category 40

CHAPTER 4

Figure 4–1
Red-Light Running Problem Identification 42
Figure 4–2
Traffic Signal Field Review Checklist 44
Figure 4–3
Example of Signal View Restricted Utility Wires 45
Figure 4–4
Placement of Rat Box at an Intersection 48
Figure 4–5
Enforcement Light Installation 48

CHAPTER 5

Figure 5–1
Infrastructure-Based ITS System that Warns Potential Red-Light Violators Approaching Intersection 52

executive summary

FHWA AND ITE BRIDGE THE GAP

In 2000, the Federal Highway Administration (FHWA) and the Institute of Transportation Engineers (ITE) initiated preparation of an Informational Report entitled, *Engineering Intersections to Reduce Red-Light Running*. The principal focus of the effort was to examine the engineering features of an intersection that could reduce red-light running. The intended purpose of the report was to provide information that could be used to proactively ensure that intersections were engineered to discourage red-light running. The report was to serve as an educational tool for law enforcement agencies and others who may design red-light camera systems.

In order to develop the toolbox, ITE formed a panel of experts from federal, state and local governments, as well as academia and the private sector, to share knowledge and experiences in addressing red-light running using engineering countermeasures. In addition, a process was established to collect information and survey practicing engineers to collect the broadest information possible on the topic. The end result was a toolbox that identifies engineering features at an intersection that should be considered to discourage red-light running. *Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce Red-Light Running* addresses design and operational features that may need to be upgraded as necessary. It provides a background of the characteristics of the red-light running problem; identifies how various engineering measures can be implemented to address this problem; suggests a procedure for selecting the appropriate engineering measures and provides guidance on when enforcement, including red light cameras, may be appropriate.

THE GROUNDWORK FOR IMPLEMENTING ENGINEERING COUNTERMEASURES

Research cited in the report suggests that “intentional” red-light runners are most affected by enforcement countermeasures while “unintentional” red-light runners are most affected by engineering countermeasures. The report also establishes the essential need for sound engineering at an intersection for the successful implementation of long-term and effective enforcement activities, particularly automated enforcement. The report further concludes that education initiatives can be an effective complement for any approach or as a stand-alone program in its own right. Overall, red-light running is recognized as a complex problem requiring a reasoned and balanced application of the three “E”s.

The engineering features presented in the report are categorized according to the type of problem they address. The expected benefits of various countermeasures in terms of reduced red-light running violations or crashes are presented where data are available. Other countermeasures are presented when there is substantial confidence in their effects based on the field experience of practicing engineers.

COUNTERMEASURES WITH PROMISE

The problems contributing to red-light running that can be addressed with engineering countermeasures include signal visibility, the likelihood of stopping, eliminating the need to stop and signal conspicuity.

Improve Signal Visibility

One recent survey shows that motorists who violate the red traffic signal frequently claim, "I didn't see the signal." In fact, 40 percent of red-light runners claim they did not see the signal and another 12 percent apparently mistook the signal indication and claimed they had a green-signal indication. For whatever reason—motorist inattention, poor vision, poor signal visibility—the motorist did not see the signal, and specifically, the red signal in time to come to a stop safely. Signal heads placed in accordance with the MUTCD should ensure their visibility for all motorists. Yet, there are locations that are still not in compliance with the MUTCD. At a minimum, stricter adherence to the guidelines and standards presented in the MUTCD are needed to improve signal visibility. The countermeasures described in the report include the placement and number of signal heads, the size of the signal display and line of sight.

Improve Signal Conspicuity

In addition to improving the visibility of a traffic signal, various countermeasures can be applied to capture the motorist's attention, i.e. making the signal more conspicuous. Redundancy by providing two red-signal displays within each signal head can be effective in increasing conspicuity. LED signal lenses are beneficial in that they are brighter, which is especially helpful during poor weather or bright sunlight. Backplates improve signal visibility by providing a black background around the signals, thereby enhancing the contrast. They are particularly useful for signals oriented in an east-west direction. Finally, strobe lights are considered because they attract the attention of the motorist and provide emphasis on the signal.

Increase Likelihood of Stopping

Intersections and intersection devices should be carefully engineered so that the motorist is not enticed to intentionally enter the intersection on red. This may include providing additional information to the motorist regarding the traffic signal. With the additional information, the probability that a driver will stop for a red signal may increase. Additionally, the intersections must be designed so that a driver who tries to stop his/her vehicle can successfully do so before entering the intersection on red. An improvement in intersection pavement condition may increase the likelihood of stopping by making it easier for the driver to stop. The countermeasures detailed in the report include signal-ahead signs, advanced-warning flashers, rumble strips, left-turn signal sign and pavement surface condition.

Address Intentional Violations

The countermeasures presented in this section of the report are mainly intended for those violators who "push the limits" of the signal phasing or try to "beat" the yellow signal. Previous surveys indicate that the common reasons drivers speed up and try to beat a yellow light include being in a rush and saving time. Although these drivers may not have intended to violate the red signal, they did intentionally enter towards the end of the phase knowing that there was the potential that they would violate the signal. Often times, these drivers do miss the yellow and end up running the red. The countermeasures presented relate to signal timing. There are many different and specific signal countermeasures that can be implemented regarding signal timing. The range in countermeasures includes signal optimization, modifications to signal-cycle length, yellow-change interval, all-red clearance interval and dilemma zone protection.

Eliminate Need to Stop

Eliminating the need to stop at an intersection can obviously eliminate the potential for red-light running. This can be done by removing the signal or redesigning the traditional intersection. Other countermeasures in this category that are described in the report include unwarranted signals, roundabout intersection design and flash mode for signals.

PUTTING IT ALL TOGETHER

The solution to the red-light running problem often involves a combination of education, enforcement and

engineering countermeasures. Though the principal focus of the report is engineering countermeasures, the report also provides information on how an agency can identify the existence of a red-light running problem and then select the most appropriate countermeasure or combination of countermeasures. The report details a process for determining if a red-light running problem exists and what types of countermeasures could be implemented in a logical and systematic manner. The process respects the fact that individual agencies may already have established procedures for conducting audits and reviews of problem intersections, which may accomplish the same objective.

acknowledgements

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chapter 1

Introduction

THE PROBLEM

One of the primary causes of crashes at signalized intersections involves a vehicle entering an intersection when the red signal is displayed. This type of collision occurs frequently. According to preliminary estimates by the Federal Highway Administration (FHWA) for 2001, the most recent year for which statistics are available, there were nearly 218,000 red-light running crashes at intersections *(1)*. These crashes resulted in as many as 181,000 injuries and 880 fatalities, and an economic loss estimated at $14 billion per year. Clearly, red-light running, which is reported to be on the rise as with other aggressive driving behaviors such as speeding, tailgating and not stopping or even slowing at stop-controlled intersections, has become a national safety problem.

Red-light running is also a complex problem. There is no simple or single reason to explain why drivers run red lights. There is a tendency to cite driver error—either intentional or unintentional disregard of the traffic signal. As will be presented in the report, red-light runners are more likely to be younger than 30-years old, have a record of moving violations, are driving without a valid license and/or have consumed alcohol. There are elements of driver psychology and sociology behind the violations and any driver may be susceptible to committing a violation. There is also evidence that drivers may be induced into running red lights because of improper signal design or operation. These elements make red-light running difficult to predict and a difficult problem to solve.

ALTERNATIVE SOLUTIONS

As with many safety problems, the solution to the red-light running problem requires a combination of countermeasures involving the three "E"s stakeholders—education, enforcement and engineering. Educational solutions start with instructing newly licensed drivers on the traffic laws and the rules regarding yellow- and red-signal displays. They continue with public information campaigns, such as television and radio public service announcements, that alert the public of the red-light running problem and its crash severity consequences.

Since every crash involving a red-light runner involves a traffic violation, it is only natural that traffic law enforcement be one of the countermeasures to consider. Enforcement includes both selective police patrols, and more recently in some jurisdictions, automated-enforcement cameras. Traditionally, police enforcement involves targeted enforcement of red-light violations at intersections with a high number of violations and/or crashes. However, this type of enforcement is labor intensive and therefore costly, and it can be hazardous, providing only short-lived effectiveness.

In some jurisdictions across the country, automated-enforcement systems, which use vehicle sensors and cameras to automatically identify a red-light runner and subsequently issue a citation, are being used to reduce these violations. Based on a recent synthesis of literature related to the safety impacts of automated-enforcement programs, these systems do reduce the incidence of red-light violations and can improve

intersection safety, not only at the intersections where they are installed but at others within their influence area *(2)*. While neither thoroughly conclusive nor consistent for all intersections, these systems tend to reduce angle crashes (those that most often result from red-light running violators) to a larger extent than the increase in rear-end crashes that may be experienced. Overall intersection safety improvement is realized because angle crashes are usually more severe than rear-end crashes, resulting in injury and/or fatality. Nonetheless, these systems have come under scrutiny and criticism for a number of reasons related to privacy and fairness. With regard to the latter, they "catch" all types of red-light runners, some who violate the signal intentionally, but others who enter on red unintentionally. This may be attributed, in part, to deficiencies related to the design and/or operation of the intersection.

Numerous reports and anecdotal evidence from around the United States and the world, suggest that there are a number of engineering features of intersections that contribute to red-light running. For example, yellow-change intervals can be set so low that they trap motorists into running red lights. At intersections with limited sight distance to the signals, it can be difficult for a motorist to see the signals in enough time to avoid running the red light. Since engineering deficiencies such as these can contribute to red-light running, correcting and implementing other engineering countermeasures minimize the extent of red-light running and can sometimes obviate the use of automated-enforcement systems.

OBJECTIVE OF REPORT

Often enforcement measures, whether they be selective police or automated systems, are initiated before consideration is given to addressing the problem through engineering solutions. This "toolbox" will identify what engineering features of an intersection should be considered to discourage red-light running. It addresses design and operational features that may need to be upgraded as necessary. It is intended to provide a background of the characteristics of the red-light running problem; identify how various engineering measures can be implemented to solve this problem; suggest a procedure for selecting the appropriate engineering measures; and provide guidance on when automated-enforcement systems may be appropriate.

The report is intended for several types of readers. Engineers trained in the design and operation of signalized intersections should already be cognizant of the engineering measures discussed. Still, they can benefit from being reminded of good engineering practice with the provision of a single information source focused on this topic. Law enforcement officials should become more sensitized to the various engineering features that affect red-light running and be supportive of their implementation prior to taking aggressive enforcement measures. Other officials who feel that aggressive enforcement measures, (including automated systems) should be implemented on a large scale basis will be made aware that engineering measures have the potential to reduce red-light running, which may address the resulting safety problem more adequately and equitably.

REPORT ORGANIZATION

Beyond these introductory remarks, the reader will find in:

- Chapter 2, a discussion of the red-light running problem—what it is, who the offenders are, the characteristics of red-light running and the crash and severity consequences.
- Chapter 3, an identification and discussion of various engineering measures that can be implemented to reduce red-light running and promote a safer intersection. The measures are described, and if known, their safety effectiveness is presented, as well as other considerations for deployment.
- Chapter 4, a systematic program for identifying a red-light running problem and selecting appropriate engineering countermeasure(s) to reduce the occurrence of violations and related crashes. It also provides guidance on when and where automated systems may be beneficial.
- Chapter 5, a discussion of what future actions need to be taken to address the issue and provide the best possible guidance for minimizing red-light running.

chapter 2

Understanding Red-Light Running

This chapter is provided to better understand the problem of red-light running and its characteristics through review of past research. Investigation of the red-light running problem includes:

- Definitions;
- Understanding the frequency;
- Understanding safety implications;
- Discussing the relationship between a red-light runner or intersection characteristics and the likelihood of red-light running;
- Understanding the stop-go decision process; and
- Relating causes of red-light running to engineering, education, or enforcement countermeasures.

RED-LIGHT RUNNING DEFINED

Simply stated, red-light running is entering, and proceeding through, a signalized intersection after the signal has turned red. According to the Uniform Vehicle Code (UVC) *(3)*, a motorist "…facing a steady circular red signal shall stop at a clearly marked stop line, but if none, before entering the crosswalk on the near side of the intersection, or if none, then before entering the intersection and shall remain standing until an indication to proceed is shown …" (section §11-202). An intersection is defined in the UVC as "… the area embraced within the prolongation or connection of the lateral curb lines, or if none, then the lateral boundary lines of the roadways of two highways which join one another at, or approximately at right angles, or the area within which vehicles traveling upon different highways joining at any other angle may come in conflict" (section §1-132). From an enforcement perspective, if the motorist stops past the stop line or into the crosswalk, or even slightly into the physical intersection, a citation would likely not be given. The motorist usually has to pass through the intersection to be cited for running a red light.

The law as stated in the UVC is considered a permissive yellow law, meaning that the driver can enter the intersection during the entire yellow interval and be in the intersection during the red indication as long as he/she entered the intersection during the yellow interval. As of 1992, permissive yellow rules were followed by at least half of the states *(4)*. However, in other states there are two types of restrictive yellow laws that apply, namely:

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

In those states where the yellow phase is considered restrictive, it is possible that an officer might stop the driver to discuss the law and to take appropriate action as required. Doing such, however, includes subjectivity of the officer.

The slight differences mentioned above will surface when developing a plan to address red-light running. For instance, if an automated-enforcement plan is implemented, then the area defining the intersection will affect the placement of the detector loops and the law regarding the yellow phase may play into the decision of a grace period. If a public information and education campaign is conducted, then the public should be educated regarding the use of the yellow phase.

RED-LIGHT RUNNING VIOLATION FREQUENCY

Red-light running can be considered a "big" problem with respect to the number of violations that occur. A two-hour traditional enforcement effort at a high-volume intersection in Raleigh, NC resulted in 36 tickets, which is a rate of 18 violations per hour or an average of one violation about every 3.5 minutes (min.) *(5)*. A study conducted over several months at a busy intersection (30,000 vehicles per day) in Arlington, VA revealed violation rates of one red-light runner every 12 min. and during the morning peak hour, a higher rate of one violation every 5 min. A lower volume intersection (14,000 vehicles per day), also in Arlington, had an average of 1.3 violations per hour and 3.4 in the evening peak hour *(6)*.

The Problem

- Intersection violation rates as high as 18 violations per hour
- There was a 15 percent increase in the number of fatal red-light running crashes during the past 4 years
- For a red-light running crash there is a 47 percent injury rate, which is higher than other crash types
- Economic impact of red-light running crashes is estimated at $14 billion annually

The Center for Transportation Research and Education (CTRE) at Iowa State University completed a study in December 2000 that "examined the frequency and effects of red-light running at intersections within selected communities and estimated the overall scope of this practice in the State of Iowa" *(7)*. Table 2–1 summarizes the occurrence of violations that were presented in the final report for the study. Violations were counted by videotaping the intersection and then analyzing the tape. As seen in the table, the violation rate for the various intersections covers a wide range of values ranging from 0.45 violations per 1,000 entering vehicles to 6.08 (discounting the outlier value of 38.50 for Intersection 1 in Dubuque).

Table 2–1
Summary of Violation Data for Iowa Cities

City	Intersection Number (one approach per intersection)	Violations per Hour	Violations per 1,000 Entering Vehicles
Bettendorf	Intersection 1	1.66	2.77
	Intersection 2	0.50	1.85
Davenport	Intersection 1	2.25	2.61
	Intersection 2	0.16	0.64
Dubuque	Intersection 1	9.78	38.50
	Intersection 2	0.96	3.25
	Intersection 3	0.11	0.45
Fort Dodge	Intersection 1	0.09	0.74
Iowa City	Intersection 1	3.14	6.08
Sioux City	Intersection 1	0.15	0.79
	Intersection 2	0.20	0.69
	Intersection 3	2.24	5.23
West Des Moines	Intersection 1	0.70	1.74

Source: Reference 7

SAFETY IMPACTS OF RED-LIGHT RUNNING

Safety is the biggest concern associated with red-light running. Safety is often measured by the number and

severity of the crashes occurring. Numerous statistics have been published quantifying the problem in a specific city, state, or across the country. Some of the facts regarding the safety impacts of red-light running are presented below.

- Highway Safety Information System (HSIS) (a multi-state crash database maintained by FHWA) data from four states show that red-light running crashes account for 16 to 20 percent of the total crashes at urban signalized intersections *(8)*.
- In a study of police-reported crashes for four urban areas, "ran traffic control" was the single most common type of crash accounting for 22 percent of urban crashes and 27 percent of all injury crashes *(9)*. Of these crashes, 24 percent are the result of red-light running, meaning that about 5 percent of urban crashes are the result of red-light runners *(10)*.
- Overall, 56 percent of Americans admit to running red lights. Yet 96 percent of drivers fear a red-light runner will hit them when they enter an intersection *(11)*.
- One in three people claim they personally know someone who has been injured or killed in a red-light running crash—similar to the percentage of people who know someone who was killed or injured by a drunk driver *(11)*.
- According to a survey conducted for FHWA, approximately 21 percent of respondents said they felt that drunken driving incidents are decreasing, but only 6 percent felt that red-light running incidents were decreasing *(11)*.

These statistics show that red-light running has specifically impacted the safety of signalized intersections and is considered a very dangerous act by the motoring public.

National/Multi-State Data

Retting et al. *(9)* used two national databases to quantify the occurrence of red-light running crashes, as well as to summarize the characteristics of red-light runners. The databases include the Fatal Analysis Reporting System (FARS), which includes virtually all U.S. police-reported crashes involving a fatality, and the General Estimates System (GES), which is based on a nationally representative probability sample of crashes with a varying degree of injury and property damage. As reported between 1992 and 1996, FARS data indicated that 3,753 crashes could be attributed to red-light running, resulting in 4,238 fatalities. Also, 97 percent of the 3,753 fatal crashes from 1992 through 1996 involved two or more vehicles. The remaining 3 percent involved pedestrians or bicycles. The FARS statistics quoted in Retting's report were updated to show trends in red-light running crashes after 1996. A definition of a red-light running crash that best duplicates Retting's results isolates such crashes as those where a vehicle was proceeding straight through the intersection, a driver factor as failure to obey traffic control and at a signalized non-interchange intersection. Retting's research also used GES to look at the impact of red-light running crashes beyond fatal crashes. The results from the GES system indicate a total of 257,849 red-light running crashes during 1996, which is approximately 4 percent of the estimated total number of police-reported crashes. Additional conclusions made by Retting regarding these red-light running crashes are summarized below *(9)*:

- Red-light running crashes were more likely than other crashes to produce some degree of injury (47 percent versus 33 percent);
- Red-light running crashes were more likely to occur on urban roads than other fatal crashes; and
- Red-light running crashes were somewhat more likely to occur during the day.

For the purposes of this report, the statistics using GES were updated using the database to reproduce the injury distribution for 1999's crash data. A red-light running crash was defined as one that took place at an intersection (either at an interchange or non-interchange location) controlled by a traffic signal and involved either (1) a driver who was charged with the violation "running a traffic signal or stop sign" or (2) the accident type was either a "changing traffic-way, turn into path, turn into opposite direction crash" or an "intersecting path, straight path" crash. Using the GES weights, there were an estimated 252,506 red-light running crashes in 1999. The severity distribution for these crashes is shown in Figure 2–1.

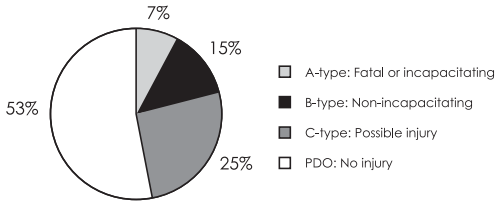

Figure 2–1. Red-Light Running Crashes Injury Distribution.

The data obtained from both the FARS and GES databases highlight the danger of red-light running. Although the number of fatal red-light running crashes seemed to peak in 1996 and has since decreased slowly, red-light running crashes still account for almost 40 percent of fatal signalized intersection crashes.

Although the magnitude of the statistics presented here is useful in portraying the size and injury severity of red-light running crashes, caution should be taken with regard to the specific numbers reported. It is difficult to create a definition for a red-light running crash, with the available database variables, that catches all true red-light running crashes and does not catch other crash types.

State/Local Data

The impacts of red-light running crashes are also reported on a state level and in smaller jurisdictions. For example, in December 2000, CTRE at Iowa State University completed a study of crashes and associated costs resulting from red-light running *(7)*. Table 2–2 shows the crash frequencies by severity type and costs for a 3-year period in seven cities in Iowa, as well as for the entire state.

In 1999, Oregon legislation approved a bill that allowed six cities to conduct a 2-year demonstration project of photo red-light enforcement. The City of Beaverton was the first Oregon city to enact the program, with cameras activated in January 2001. This action was prompted, in part, by the fact that in the 3-year period of 1997 to

Table 2–2
Summary of Costs Resulting from Ran Traffic-Signal Crashes in Iowa (1996–1998)

Jurisdiction	Fatalities	Injuries*	PDO**	Total Crashes	Total Costs
Dubuque	0	202	65	190	$ 3,115,509
Davenport	1	583	279	637	$ 11,752,603
Bettendorf	0	86	68	129	$ 1,691,487
Iowa City	0	150	125	235	$ 2,364,738
West Des Moines	0	126	70	154	$ 1,196,000
Fort Dodge	0	84	62	122	$ 1,198,732
Sioux City	1	322	146	335	$ 5,369,499
State of Iowa	**12**	**5,881**	**3,435**	**7,138**	**$ 11,428,000**

** Total injuries.*
*** Number of Property Damage Only (PDO) crashes; some jurisdictions do not report all PDO crashes.*
Source: Reference 7

1999, crashes caused by red-light running had increased by 20 percent over the prior 3-year period of 1994 to 1996, and injury crashes related to red-light running increased by 82 percent for the same periods *(12)*.

CRASH TYPES RELATED TO RED-LIGHT RUNNING

While most red-light running crashes involve at least two vehicles, crashes involving a single vehicle and an alternative transportation mode (pedestrian or bicyclist) can occur. A *single vehicle, hit fixed object* crash could occur when either the running-the-red violator or the opposing legal driver takes evasive action to avoid the other and crashes into an object, e.g. a signal pole. Also, a running-the-red violator can hit a pedestrian or bicyclist who is legally in the intersection.

The two most prominent crash types involving multiple vehicles are the angle- and turning-crash types. The *angle crash* is typically the offending motorist hitting or being hit by a vehicle legally in the intersection from the adjacent approach. A *turning crash* can occur when a left-turning vehicle collides with an on-coming vehicle from the opposite direction; either vehicle may be the red-light violator.

Past research studies that have evaluated the effect of cameras or other programs on red-light running focused on three crash types. This includes the two mentioned above (angle and turning) and also rear-end collisions. *Rear-end collisions* are not the result of red-light running but rather the result of vehicles stopping for a signal at an intersection while others behind them do not. Some studies have noted a decrease in angle and turning crashes but an increase in rear-end crashes as a result of concentrated enforcement of red-light running. Figure 2–2 displays the three crash types.

In developing a red-light camera effectiveness study, Persaud and Council *(13)* noted that the following crash types *could* be possible target crashes for a red-light study:

1. Right-angle (side impact) crashes;
2. Left turn (two vehicles turning);
3. Left turn (one vehicle oncoming);
4. Rear end (straight ahead);
5. Rear end (while turning); and
6. Other crashes, specifically identified as red-light running.

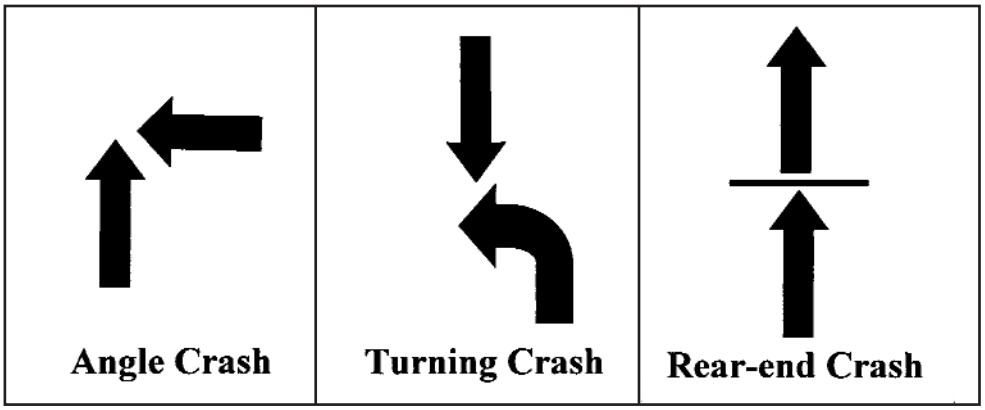

Figure 2–2. Common Crash Types Associated with Red-Light Running.

However, with these crash types, there are numerous situations where a crash could have occurred that was unrelated to red-light running.

When using an accident database to highlight red-light running crashes, defining such a crash using database variables requires particular and detailed thought. However, a jurisdiction that is looking at a specific intersection and the problem of red-light running should feel comfortable in investigating the angle, turn and rear-end crashes to monitor red-light running problems.

DRIVER CHARACTERISTICS

As mentioned in the Introduction, red-light running is a complex problem. Causal factors range from driver- to intersection-related and there is also an element of driver psychology and sociology involved in the action of violating a signal. The likelihood of committing a violation varies from day to day, intersection to intersection and from person to person. A few studies have been conducted to identify driver characteristics of red-light runners. These studies have used a variety of methods including focus groups, field data collection and observation and crash databases. These studies provide valuable information to address red-light running.

Red-Light Violators

The Department of Public Health (DPH) in San Francisco, CA has been very involved in the city's red-light running program. The agency has developed a "Stop Red-Light Running" campaign that highlights the issue of red-light running to both the public and the media through bumper stickers, billboards and press conferences. The DPH also has conducted focus groups to better understand the psychology of red-light runners and hence, target campaign messages appropriately *(14)*.

In 1998, the DPH conducted focus groups that divided red-light runners into two groups, aggressive drivers and distracted drivers. The information used in this study identified the average red-light runner in San Francisco as a male older than 40 years of age. This information was used to better focus public education efforts *(14)*.

An additional set of focus groups was held in June 2001, with plans to use the results in another media campaign. Three different groups were developed:

- Group One—*Violators* who *live outside* of San Francisco but regularly drive on San Francisco's streets and have engaged in at least four traffic infractions and have at least two tickets in the last year.
- Group Two—*Violators* who *live in* San Francisco and regularly drive on San Francisco's streets and have engaged in at least four traffic infractions and have at least two tickets in the last year.
- Group Three—*Non-violators* and *pedestrians/bicyclists* who *live in* San Francisco and have engaged in traffic infractions no more than two times and have not received any tickets in the last year.

Infractions, as defined in this study, include running a red light, speeding, running a stop sign and running through a pedestrian crosswalk without stopping when someone was present *(15)*. The findings indicate both differences and similarities among the three groups. For instance, among those participants who lived in San Francisco, there was a difference regarding driver courtesy between the violators and non-violators. Violators did not want to be "taken advantage of" while driving as opposed to the non-violators who had a more courteous attitude. On the other hand, groups felt similar regarding red-light running. Participants spoke of running red lights because they felt the person behind them was going to run it and they noted they were in a hurry and would do anything (including running red lights) to get to their destination more quickly.

Another study, involving field data collection, was conducted to profile red-light violators *(16)*. The study compared characteristics of drivers that run red lights with a group of drivers that had the opportunity to run a red light, but did not. Field observation, cameras and driver records were used to record characteristics of 462 violators and 911 compliers at one particular intersection in Arlington County, VA. Analysis of the field data and a comparison between violators and compliers indicate the following:

- Violators were less likely to drive vehicles manufactured after 1991 and drive to large cars;
- Violators were less likely than compliers to wear safety belts;
- Violators were generally younger, however, there was no difference in gender distribution between the compliers and violators; and
- Violators had significantly more tickets for moving violations and were three times more likely to have multiple speeding convictions.

During the summer of 1999, the Social Science Research Center (SSRC) of Old Dominion University conducted a telephone interview to learn more about red-light runners and driving behavior. The survey was sponsored by DaimlerChrysler Corporation, the American Trauma Society and FHWA in order to gain data for the "Stop Red-Light Running" Program. The survey focused on what drivers reported to be their red-light running *behaviors* as opposed to their beliefs. The researchers acknowledge that self-reported data is only a proxy for actual driver behaviors as respondents seek to present themselves as best possible and may stretch the truth. However, the survey results reveal interesting trends *(17)*.

Overall, 55.8 percent of the respondents reported running red lights. General characteristics of red-light runners include:

- Younger drivers;
- Persons without children;
- Driving alone (the presence of passengers significantly decreased the likelihood of running a red light, especially child passengers);
- Employed in jobs requiring less education or unemployed;
- Rushing to work or school in the morning weekday hours;
- Driving more than two miles from home; and
- More likely to have been ticketed for red-light running.

Old Dominion University Survey Results

- More than 25 percent of people surveyed would speed up to beat a red light when in a hurry
- Drivers believe red-light running is often an intentional act with few legal consequences

In the same survey, drivers were also asked of their response to the following scenario:

> *You are late for work, school, or an appointment and have been stopped by several red lights in a row. You are approaching another intersection that has had a yellow light for several seconds, but you know it is about to turn red. Which of the following would you likely do?*
>
> *A. Slow down and prepare to stop at the red light.*
> *B. Speed up to beat the red light.*

Seventy-one percent of the respondents said they would slow down and stop while 29 percent indicated they would speed up. Of those that would speed up, they were asked why. The majority of the responses (69 percent) were due to being in a rush and to save time. Only 12 percent reported being frustrated. Additionally, the main source of this frustration is discourteous drivers and not congestion. This was highlighted as a major finding to the survey "given the general assumptions among safety experts that congestion is a leading and perhaps most important factor in predicting risky driving actions such as red-light running or aggressive driving."

The final survey questions dealt with the problem and danger of red-light running. About 80 percent of respondents believe red-light running is a problem and 99 percent believe it is dangerous. When asked: "Out of every 10 red-light runners, how many do so intentionally?" the mean response was more than five. However, respondents believe that less than two out of 10 would be stopped or ticketed by police. The report summarizes that "drivers believe red-light running was often a choice with few legal consequences."

Bonneson *(39)* reports that in examining 10,018 signal cycles in 6 hours, 586 vehicles entered the intersection after the indication turned red. Of these, 84 were heavy vehicles. Overall, 0.86 percent of all heavy vehicles violated the red indication as compared to 0.38 percent of passenger vehicles running the red. Bonneson concludes that heavy vehicle drivers are twice as likely to run red lights as are passenger drivers.

Summarizing the various studies, red-light runners are more likely to:

- Be younger than 30 years old;
- Have a previous record of moving violations;
- Be driving with a revoked, suspended, or invalid driver's license; and
- Be in a hurry.

Red-Light Related Crashes

Retting et al. used crash databases to investigate the occurrence of red-light running crashes nationwide and to investigate the characteristics of red-light runners *(9)*. In order to compare driver characteristics, a subset of the red-light crashes were selected. These crashes were those involving two vehicles (as opposed to involvement of a pedestrian or bicyclist), both of which were proceeding straight through the intersection and only one was charged with red-light running. The characteristics of the violators and non-violators in the same crashes were then compared. Some results of the comparison are highlighted below.

From FARS:

- Red-light violators were more likely than non-violators to be younger than age 30 and slightly more likely to be male;
- The driver who violated the red light was more likely to be fatally injured than the non-violator (40 percent vs. 34 percent) in the same crash;
- Police were far more likely to report alcohol consumption for the red-light violators (34 percent vs. 4 percent) than the non-violators;
- In non-alcohol crashes, red-light running drivers and their passengers were more likely to be killed (58 percent vs. 40 percent). However, when the red-light runner was affected by alcohol, the *non*-red-light running driver and passengers were more likely to be fatally injured (55 percent vs. 41 percent); and
- Red-light runners were more likely to have been driving with a suspended, revoked, or invalid driver's license and were also more likely to have prior driving while intoxicated convictions and two or more moving violations than the non-violators.

From GES:

- Red-light runners were more likely to be younger than age 30 and slightly more likely to be male than non-violators; and
- Red-light drivers were slightly more likely to have been drinking alcohol than the non-violators (5 percent vs. 1 percent). The difference was more dramatic for nighttime crashes—12 percent and 1 percent for red-light runners and non-red-light runners, respectively.

INTERSECTION CHARACTERISTICS

Bonneson et al. *(18, 39)* reviewed many past studies regarding various intersection characteristics as they relate to red-light running. Three intersection characteristics were highlighted as exposure factors including flow rate, number of signal cycles and phase termination by max-out. Field studies support the logical conclusion that as more vehicles are exposed to the potential of red-light running, the violation rate increases. The findings from that report are summarized below.

- *Flow rate or volume:* Every vehicle approaching the intersection at the onset of the yellow is exposed to the potential of red-light running. A decision must be made to stop or proceed through

the intersection. As the number of approaching vehicles increases, the number of red-light runners will likely increase.

- *Number of signal cycles:* The more times the yellow phase is displayed, the more potential for red-light running. Hence, researchers should report that violation rates normalized by the number of signal cycles.
- *Phase termination by max-out:* Actuated signal systems operate using green extension time as long as the approach is occupied. However, the green may reach its maximum limit and "max-out" forcing the green phase to end regardless of whether the approach is occupied. Conversely, the signal may "gap-out" because the approach has been unoccupied for a set period of time. There is greater potential for red-light running as the frequency of max-out increases.

Bonneson cites other intersection characteristics and driver behaviors that are considered contributory factors. These include the following:

- *Actuated control and coordination:* This factor has to do with driver expectancy. In actuated control systems, vehicles often travel in platoons through several interconnected signals. Drivers expect the signal to remain green until they pass through the intersection. As a result, drivers expect the yellow to be long enough for them to make it through the intersection so they can stay with the platoon. This may result in violations.
- *Approach grade:* Drivers on downgrades are less likely to stop (at a given travel time from the stop line) than drivers on level or upgrade approaches.
- *Yellow-interval duration:* Long yellow intervals can violate driver expectancy, as drivers that stop are not "rewarded" with the red signal. In contrast, yellow intervals shorter than ITE-suggested values *(19)* have caught drivers off guard and resulted in a high number of red-light violations. (This was not discussed in the Bonneson report.)
- *Headway:* Drivers that follow closely (headway of less than 2 sec.) are more likely to run a red light. When a driver leaves a small headway, the following car is "drawn" into the intersection as more attention is given to the leading vehicle as opposed to the environment and traffic signal.

A similar study investigating intersection characteristics was conducted using accident and intersection data for California, available in HSIS *(8)*. The study investigated select intersection characteristics and the relationship to red-light running crashes by developing mathematical models. The main intersection variables of interest include the number of cross-street lanes (surrogate for intersection width), average daily traffic (ADT) and traffic-control type.

Some Intersection Characteristics that Affect Likelihood of Red-Light Running

- Traffic volume
- Actuated traffic control
- Yellow change interval
- Crossing-street width
- Approach grade

Separate models were developed for the "mainline as entering street" and the "cross-street as entering street." Therefore, a crash where the violating vehicle entered the intersection from the lower-volume road was modeled using "cross-street as entering street" and the mainline road is considered the crossing street. The analysis used a total of 4,709 two-vehicle red-light running crashes for a 4-year period. The findings are summarized in the points below and in Table 2–3.

- *Effect of cross-street lanes:* For the "cross-street as entering street" model, there is a 7 percent increase in red-light running crashes for each one-lane increase on the mainline when controlling for signal operation type, opposite street ADT and left-turn channelization. The results are different for the "mainline as entering street" where the number of cross-street lanes had no effect on the number of red-light running crashes.
- *Effect of ADT:* The number of crashes could be affected by both an increase of traffic on the entering street (more possibility of red-light

runners) and an increase of traffic on the crossing street (the greater the possibility of hitting another vehicle). For the "mainline as entering street," an increase in entering street ADT as well as an increase in crossing street ADT both resulted in an increase in red-light running crashes. For the "cross-street as entering street," there was an increase in crashes with an increase in the *entering* street volume, but there was no increase in crashes with an increase in the *crossing-street* (or mainline) volume.

- *Effect of traffic control:* For both models, fully actuated signals tend to have more crashes per approaching street than approaches with semi-actuated or pre-timed signals. The models indicate a 35 to 39 percent greater number of red-light running crashes at fully actuated signals as compared to pre-timed signals.

Table 2–3
Summary of Intersection Characteristics on Likelihood of Red-Light Running Crash

	Likelihood of Red-Light Running Crashes	
Intersection Characteristic	**Mainline as Entering Street**	**Cross-Street as Entering Street**
Increasing **Number of Crossing-Street Lanes**	No Effect	Increasing Likelihood
Increasing **ADT** on Entering Street	Increasing Likelihood	Increasing Likelihood
Increasing **ADT** on Crossing Street	Increasing Likelihood	No Effect
Traffic Control **Signal Type**	Actuated Signal Indicates the Most Crashes	Actuated Indicates the Most Crashes

Those variables shown to increase the likelihood of a red-light running crash are not negotiable design features. For example, in order to reduce the likelihood of a red-light running crash, one cannot reduce the number of lanes on the cross-street from four lanes to two lanes, if the volume requires four lanes. The study results are helpful, however, in identifying intersections that may have a high number of red-light running crashes and where careful engineering evaluations and enforcement may be necessary.

DRIVERS' STOP-GO DECISION

Bonneson also discussed the factors that affect the driver's decision to stop or proceed through the intersection upon seeing the onset of the yellow *(18)*. Based on earlier work by Van der Horst *(20)*, there are three main components of the decision process: driver behavior (expectancy and knowledge of operation of the intersection), estimated consequences of not stopping and estimated consequences of stopping. Table 2–4 summarizes these factors.

Table 2–4
Factors Affecting the Stop-Go Decision

Components of the Decision Process	Factor		
Driver Behavior	Travel time Coordination Headway	Speed Approach grade	Actuated control Yellow interval
Estimated Consequences of Not Stopping	Threat of right-angle crash Threat of citation		
Estimated Consequences of Stopping	Threat of rear-end crash Expected delay		

Source: Reference 18

What if the driver makes his decision to proceed through the intersection based on the factors above, but ends up running the red light? Bonneson divides red-light runners into two categories. The first is the *intentional* violator who, based on his/her judgment, knows they will violate the signal, yet he/she proceeds through the intersection. This type of driver is often frustrated due to long signal delays and perceives little risk by proceeding through the intersection. The second type of driver is the *unintentional* driver who is incapable of stopping or who has been inattentive while approaching the intersection. This may occur as a result of poor judgment by the driver or a deficiency in the design of the intersection. Bonneson further indicates that intentional red-light runners are most affected by enforcement countermeasures while unintentional red-light runners are most affected by engineering countermeasures.

Table 2–5
Driver Population Types

Driver Type	Characteristics
Reasonable and Prudent	- Attentive and aware - Does not intentionally act in a way to endanger himself or others along the roadway
Temporarily Inattentive	- Temporarily distracted or inattentive - Under adverse circumstances, an otherwise prudent driver may act in this manner
Reckless	- Behavior displays a willfull disregard for the safety of himself and other drivers - Aggressive driving behavior that could result in a crash
Mistaken Driver	- Attentive driver who simply makes a mistake - Unsuccessfully attempting to drive in a reasonable and prudent manner

Milazzo et al. *(10)* constructs similar distinctions in red-light running driver types. Table 2–5 describes four different driver types. As pointed out in the report, "note that any driver can assume any of these roles depending on the situation, the driver's current mindset and chance itself."

Such distinctions in driver types highlight the need for different types of countermeasures. It is difficult to determine the percentage of crashes as a result of a specific red-light running driver type since each driver is capable of acting like any of the driver types above depending on the current situation. However, engineering, enforcement and education countermeasures are plausible solutions to address the differences.

CAUSAL FACTORS AND POTENTIAL COUNTERMEASURES

As part of a FHWA study *(21)* on the feasibility of using advanced technologies to prevent crashes at intersections, the researchers reviewed the police reports of 306 crashes that occurred at 31 signalized intersections located in three states. Traffic-signal violation was established as a contributing factor and the reason for the violation was provided in 139 of the crashes. The distribution of the reported predominant causes is as follows:

- 40 percent did not see the signal or its indication;
- 25 percent tried to beat the yellow-signal indication;
- 12 percent mistook the signal indication and reported they had a green-signal indication;
- 8 percent intentionally violated the signal;
- 6 percent were unable to bring their vehicle to a stop in time due to vehicle defects or environmental conditions;
- 4 percent followed another vehicle into the intersection and did not look at the signal indication;
- 3 percent were confused by another signal at the intersection or at a closely spaced intersection; and
- 2 percent were varied in their cause.

Care should be taken in interpreting this information because it is self-reported, cannot be independently verified and is based on a small sample. If these causes are statements from the driver, it is safe to say that there will be few who will not admit that they "intentionally violated the signal." Nonetheless, from these examples, countermeasures can be identified that would address one or more of the causes.

Countermeasures can be engineering, education, or enforcement actions. Different types of measures may

be more appropriate to address the variety of causes listed above. Table 2–6 correlates the causes discussed above to the appropriate category of countermeasure. A check mark (✓) signifies that the countermeasure type is likely to address the cause, while a bullet mark (●) signifies that the countermeasure type could possibly address the cause.

Table 2–6
Possible Causes and Appropriate Countermeasures for Red-Light Running

Possible Causes of Red-Light Running	Engineering	Enforcement	Education
1. Did not see signal	✓		
2. Tried to beat yellow	●	✓	✓
3. Reported they had green	✓		
4. Intentional violation	●	✓	✓
5. Unable to stop vehicle	●		
6. Followed another vehicle	✓	✓	
7. Confused by signal	✓		

✓ – Likely countermeasure ● – Possible countermeasure

SUMMARY

Based on what we know of the extent and nature of the problem of red-light running, the three "E"s (engineering, enforcement and education) must be considered as a part of an effective solution. The three "E"s are sometimes considered separately; however, an effective program uses all types of solutions to target the problem. Each "E" addresses different deficiencies contributing to red-light running, whether that of the driver, vehicle, or intersection. However, as seen from Table 2–6, engineering countermeasures would appear to be those that would address the majority of causes of red-light running. The engineering countermeasures that aim to reduce red-light running or mitigate its consequences are the focus of this document and are discussed in detail in the next chapter.

chapter 3

Engineering Countermeasures

INTRODUCTION

As Chapter 2 described, there are a number of intentional and unintentional factors that cause drivers to run red lights. With this information, several engineering measures can now be developed that reduce the occurrence of this behavior. From an engineering perspective, red-light running may be reduced if, in general, any one of these actions is taken:

- Ensure that the traffic signal, and specifically the red display, is visible from a sufficient distance and captures the motorists' attention (i.e., it is conspicuous);
- Increase the likelihood of stopping for the red signal, once seen;
- Address intentional violations; and
- Eliminate the need to stop.

If a traffic signal is the most appropriate choice of traffic control for the intersection, it is important to ensure that the motorist can see the traffic signal far enough away from the intersection so that he/she can stop safely upon viewing the yellow and red display. Then, upon viewing the yellow, and certainly the red, ensure that signal operations and conditions do not entice the motorist to intentionally or unintentionally enter on red and ensure that a driver who tries to stop his/her vehicle can successfully do so before entering the intersection. Recognizing that there are some motorists that will intentionally violate the red signal at certain times and situations, those conditions that encourage this behavior must be minimized. Engineers should also examine whether or not the traffic signal is the most appropriate choice of control for an intersection and if it can be replaced with another form of control or design that eliminates the signal and therefore the problem.

This chapter identifies various engineering measures that can be grouped under these general solutions. For each, the measure is described, applicable design standards or guidelines in the *Manual on Uniform Traffic Control Devices* (MUTCD) *(22)* are provided, and where known, its effectiveness in reducing red-light violations and resulting crashes is presented. Other considerations in implementation and use are noted where appropriate.

IMPROVE SIGNAL VISIBILITY

Motorists who violate the red traffic signal frequently claim, "I did not see the signal." As reported in Chapter 2, 40 percent of those surveyed claim they did not see the signal and another 12 percent apparently mistook the signal indication and claimed there was a green-signal indication. While there is no doubt that many of these claims are false, there probably are situations where a more visible signal would not have been violated. For whatever reason—motorist inattention,

poor vision, poor signal visibility—the motorist did not see the signal, and specifically, the red signal in time to come to a stop safely. The countermeasure for this problem is to ensure that the signal is visible from a sufficient distance upstream.

Improve Signal Visibility

- ↳ Placement and number of signal heads
- ↳ Size of signal display
- ↳ Line of sight

Signal heads placed in accordance with the MUTCD should be visible to all motorists approaching the intersection. Although the MUTCD requires a minimum of two signal faces be provided for the major movement on an approach, locations such as that shown in Figure 3–1 are, unfortunately, not uncommon. Adherence to guidelines and standards presented in the MUTCD are needed to improve signal visibility.

Figure 3–1. Intersection with One Signal Head (Non-compliant with the MUTCD).

The MUTCD deals with signal visibility needs in a number of ways. First, it requires (standard) that at least two signals be provided for the major traffic movement Section 4D.15). Second, although it does not require a minimum visibility distance to the signal, it does require that an advance-warning sign be used if the minimum sight distance prescribed in Table 4D–1 of the MUTCD (reproduced as Table 3–1 below) is not satisfied. Third, there is a "cone of vision" requirement that states that at least one traffic signal must be not less than 40 feet (ft.) beyond the stop line and not greater than 150 ft. from the stop line and within a 40-degree cone of vision centered on the center of the approach lanes. Finally, it provides standards for when 12-inch (in.) size signal heads are to be used instead of 8-in. heads.

Table 3–1
Minimum Sight Distance

85th Percentile Speed (mph)	Minimum Sight Distance (ft.)
20	175
25	215
30	270
35	325
40	390
45	460
50	540
55	625
60	715

Source: Reference 22

Placement and Number of Signal Heads

The placement (pole-mounted versus overhead) and number of signal heads have a profound effect on traffic signal visibility. Numerous studies have been conducted regarding the benefits associated with the location of the signal head and the number of heads per approach. The following is a discussion on this issue.

Signals Placed Overhead

The MUTCD does not require that signals be placed overhead rather than mounted on poles either on the roadside or in the median. Although pole-mounted signals can serve a useful purpose (as discussed later in this chapter) there are significant benefits to providing overhead-signal head displays. Overhead-signal displays help to overcome the three most significant obstacles posed by pole-mounted signal heads, which are: (1) they generally do not provide good conspicuity, (2) mounting locations may not provide a display with clear meaning and (3) motorists' line-of-sight blockage

to the signal head due to other vehicles, particularly trucks, in the traffic stream. Figures 3–2 and 3–3 illustrate the line-of-sight blockage often associated with pole-mounted signals.

Figure 3–2. Post-Mounted Signal Blocked by Vehicle.

Figure 3–3. Posted-Mounted Signal no Longer Blocked by Vehicle.

Studies were conducted to develop guidelines for encouraging uniformity in the design of traffic-signal configurations and improving the performance of signals as critical traffic-control devices *(23)*. Key to this effort were recommendations regarding traffic-signal design configurations, which included the recognition of visibility obstacles. An important finding of this study was "that, in most cases, over-the-roadway signals would be required to ensure adequate signal visibility." Further studies have shown significant reduction in accidents attributed to replacement of pole-mounted signal heads with overhead-signal heads. For example, in Iowa, the safety impacts of replacing pedestal-mounted signals with mast-arm-mounted signals at 33 intersections, resulted in a 32 percent reduction in total crashes *(24)*. In Kansas City, MO, replacement of post-mounted signals with mast-mounted signals at six intersections contributed to a 63 percent reduction in the number of right-angle accidents and a 25 percent reduction in the total number of collisions *(25)*. Replacement of pole-mounted traffic signals with overhead signals is likely to result in a decrease in total crashes.

In some areas, there has been a conscious decision not to use any overhead signals for aesthetic reasons. Where this is the case, this recommendation could not be implemented, but the engineer should then consider the other measures discussed in this chapter.

Signal for Each Approach Lane

Even though the benefits of overhead signals are recognized, the number and placement of the signal heads are crucial to meeting the motorist's visibility needs. Currently, Section 4D.15 of the MUTCD only requires that "a minimum of two signal faces shall be provided for the major movement on the approach, even if the major movement is a turning movement." Under this standard, it would be acceptable to have only two signals on an approach with three or more through lanes. In such a scenario, the signals would not be placed over the center of each lane but at an equal distance, splitting the width of the three lanes. However, when a signal is positioned such that it is over the middle of the lane, it is in the center of the motorist's cone of vision, thereby increasing its visibility. The additional signal head further increases the likelihood that a motorist will see the signal display for the approach. Figure 3–4 shows a three-lane approach intersection with the required two-signal minimum. Figure 3–5 shows the same three-lane approach with a signal placed over each through lane. Figure 3–6 shows the use of two overhead signal displays for a one-lane approach.

Figure 3–4. Intersection Approach with Two Signal Heads (Minimum).

Figure 3–5. Approach Updated with One Overhead Signal for Each Through Lane.

Figure 3–6. Intersection with One Lane Approach with Two Overhead Signals.

In Winton-Salem, NC, an additional signal head was installed on one or more approaches at 11 different locations. At six locations, the additional signal head was mounted directly over a travel lane replacing a display where two signal heads served three lanes. At four locations, the additional head was mounted on the left side of the road in an effort to make the signal visible earlier to traffic rounding a right curve. At one intersection, the additional head was mounted high on a utility pole to make the signal visible above a vertical curve. For all intersections combined, right-angle crashes caused by motorists on the intersection approaches where the auxiliary heads were installed declined by more than 46 percent combined. Total crashes decreased significantly at five of the 11 intersections *(26)*. Care should be taken in reporting the magnitude of these findings since the study was a simple before-and-after study that did not account for other factors such as regression-to-mean that could have contributed to the crash reduction.

In British Columbia, the Insurance Corporation of British Columbia (ICBC) has adopted a specific design concept to combat the traffic signal visibility problems. The ICBC co-sponsored, with municipalities and the provincial road authority, the installation of additional primary overhead signals per lane, as well as the exploration into installing pole-mounted secondary (left side) and even tertiary (right side) signal heads at signalized intersections throughout the province (see Figure 3–7). The ICBC researched this topic thoroughly and concluded that there is a significant safety benefit to this type of signal-head installation *(27)*. This research supports similar findings of an early study *(23)*, which concluded "mixed configurations (combining overhead and post-mounted heads) are generally better than either all-post or multiple overhead configurations, except that the box span performs as well as the mixed configurations."

Based on these findings, the preferred signal configuration to improve road user visibility needs is to provide an overhead-signal display, centered over the middle of each approach lane (two overhead signals for a one-lane approach) and, if necessary for reasons cited in this report, supplemental post-mounted signals. Figure 3–8 provides a photograph of this signal configuration. For very wide approaches (perhaps four

or more lanes) it may not be practical to provide an overhead signal for each lane. Therefore, for very wide approaches, placement of overhead signals directly over each lane line of the approach may be sufficient to address the overhead visibility needs.

Figure 3–7. More Than One Primary Overhead Signal Per Lane, Plus Pole-Mounted Secondary (Left Side) and Tertiary Signal Heads (Right Side).

Figure 3–8. Two Overhead Signals for a One Lane Approach and Supplemental Pole Mounted Signal.

Supplemental Pole-Mounted Signal on Near-Side Approach

Traffic signals should be visible from a minimum distance as prescribed by Table 4D–1 of the MUTCD (previously reproduced as Table 3–1 on page 18) and be horizontally placed at the intersection a maximum of 150 ft. from the stop line (if a 12-in. signal lens is used) as shown in MUTCD Figure 4D–2.

There are situations where these design criteria cannot be met. The approach to the intersection may be on a curve, which restricts the sight distance, making it impossible to meet the visibility distance criteria without drastic changes to the roadway. Additionally, at wide intersections the signals may have to be placed beyond the 150-ft. limit. Where this is the case a supplemental signal should be provided on the near-side approach. Figure 3–9 shows how this was accomplished at an intersection in Vienna, VA. As illustrated in the figure, the intersection approach is curved. Without the supplemental signal, the drivers would not be able to see the upcoming signal due to the horizontal curvature.

Figure 3–9. Approach View of Supplemental Signal on Near Side at Intersection.

Similar to the treatment in Vienna, a supplemental-pole signal, even using a double red signal, was provided for an intersection in Naperville, IL where the signalized intersection is in the middle of a reverse curve. In addition to the supplemental signal, a BE PREPARED TO STOP WHEN FLASHING sign and flasher were used. Prior to the installation of the supplemental signal and advanced-warning devices, there was an average of three severe crashes and one fatal crash per year. After installation in 1996, there only has been one severe crash and no fatal crashes to this date *(28)*. The supplemental signal, which has a double red display, is shown in Figure 3–10.

Figure 3–10. Supplemental Signal for an Intersection in the Middle of a Reverse Curve.

Size of Signal Displays

Increasing the size of the display improves signal visibility. As specified in the MUTCD, there are two nominal diameter sizes for vehicular signal lenses, 8 in. and 12 in. Combinations of these sizes can be used in a single signal head, although an 8-in. signal lens for a circular red signal cannot be used in combination with a 12-in. signal lens for a circular green signal indication or a circular yellow signal indication. Obviously, a signal lens that is 50 percent larger than the minimum 8-in. lens will be visible from a longer distance. Figure 3–11 provides a visual comparison of these different sized traffic signals.

Figure 3–11. Comparison of Signal Heads Using 8-in. and 12-in. Lenses.

The MUTCD stipulates that 12-in. signal lens (standard) shall be used under the following conditions:

A. For signal indications for approaches where road users view both traffic control and lane-use control signal heads simultaneously;

B. If the nearest signal face is between 120 ft. and 150 ft. beyond the stop line, unless a supplemental near-side signal face is provided;

C. For signal faces located more than 150 ft. from the stop line;

D. For approaches to all signalized locations for which the minimum sight distance (specified in MUTCD) cannot be met; and

E. For arrow-signal indications.

Furthermore, it is recommended (guidance) in the MUTCD, that the 12-in. signal lens (for all signal indications) be used for the following conditions:

A. Approaches with 85th percentile approach speeds exceeding 40 mph;

B. Approaches where a traffic-control signal might be unexpected;

C. All approaches without curbs and gutters where only post-mounted signal heads are used; and

D. Locations where there is a significant percentage of elderly drivers.

Even if none of these two sets of conditions exist, using 12-in. signal lenses should be considered for all signals, and especially those displaying red indications, to increase signal visibility.

Some implementations have considered the impact of 12-in. signal lenses on crash occurrence. Under the Systematic Safety Improvement Program, the City of Winston-Salem, NC has identified, treated and evaluated countermeasures at crash locations since 1986. One such improvement was to replace existing 8-in. lenses with 12-in. lenses on at least one approach at 55 locations throughout the city. Using a simple before-and-after study, Winston-Salem reported a 47 percent decline in right-angle crashes caused by motorists on the upgraded approach at all treated locations combined *(26)*.

Winston-Salem is not the only city to use 12-in. signal lenses. In fact, the policy for the City of Troy, MI now requires a 12-in. lens for all signals (red, yellow, green) leaving no 8-in. lenses in Troy *(29)*. Similarly, Naperville, IL has a policy to use 12-in. lenses to ensure that the signal indication can be well seen. Additionally, the British Columbia Ministry of Transportation and Highways has adopted 12-in. (300-mm) signal lenses for the red, yellow and green as the new provincial standard for overhead (primary) signal heads *(30)*.

Line Of Sight

The line of sight between the signal display and the point of required visibility is critical to the motorist's ability to see the signal head. One study *(23)* researched the importance of line of sight to signal visibility. Some of the key findings were:

> "An analysis of human factors principles affecting the design of traffic-signal configurations revealed that the driver's perception-response tasks depend on his position on the approach. A conceptual model of these tasks was developed that identified and defined three distinct zones on the approach. **Important aspects of signal configurations included placing signal indications as close to the line of sight as possible and, also, placing at least one signal head in a consistent location known to and predictable by the driver.**
>
> Optical aspects of traffic-control signals were also investigated. The major variables affecting signal configuration design were found to be the distance at which the signal first becomes visible and the offset of the signal position from the line of sight. A comparison of required signal illumination at the driver's eye and luminance characteristics of commercially available traffic signals showed that, in most cases, over-the-roadway signals would be required to ensure adequate signal visibility. This comparison also led to development of specific rules for the use of oversized signal indications."

Therefore, the signal head should be installed as close as practical to the projection of the driver's line of sight. Care must be taken to eliminate obstacles, which block the motorist's line of sight, such as utility cables/wires, structures, vegetation, or large vehicles in the traffic stream. In addition, the following are other measures that can be applied to enhance the motorist's line of sight for improved signal visibility.

Programmable Lens (Visibility-Limited) Signals

The optically programmed or visibility-limited signals limit the field of view of a signal. This is similar to the purpose of louvers; however, visibility-limited signals allow greater definition and accuracy of the field of view. For example, programmable lens are used to control the motorist's lateral or longitudinal field of view. Lateral separation is useful for instances such as separating left- or right-turn lanes or locations with adjacent parallel roadways like a frontage road. An example of longitudinal separation (also known as distance separation) is for closely spaced intersections. Additionally, visibility-limited signals do not reduce the intensity of the visible light and also do not have the problem of snow and ice build-up or bird nests as sometimes incurred with louvers and visors.

The MUTCD speaks of visibility-limited signals mostly with regard to left-turning traffic at an intersection. Two examples are presented below:

- At a left turn operating under the protected mode, either a LEFT-TURN SIGNAL sign or a visibility-limited circular red signal must be used.
- With protected/permissive phasing of the left turn, if the circular green and circular yellow signal indications in the left-turn signal face are visibility-limited from the adjacent through movement, the left-turn signal face shall not be required to simultaneously display the same color of circular signal indication as the signal faces for the adjacent through movement.

Additionally, the MUTCD permits the use of visibility-limited signal faces in situations where the road user could be misdirected, particularly when the road user sees the signal indications intended for other approaches before seeing the signal indications for their own approach.

There are a few concerns and extra precautions necessary when working with visibility-limited signals. Because the field of view is restricted and requires specific alignment, these signals require rigid mounting instead of suspension on overhead wires. Additionally, there is some concern associated with glare and the limitations of seeing the signal. These signals have also been known to create driver confusion in a few specific instances. In these instances, the signal initially appears like there is no indication—a malfunction. However, as the driver gets closer to the intersection and even passes through, they notice the signal does indeed show an indication. At that point it may be too late to stop as the vehicle is already in the middle of the intersection, waiting to make a left turn. Signal-visibility alignment requires attention both in design and in field maintenance.

Visors

The addition of a visor to a traffic-signal head that is in direct sunlight can improve visibility of the signal by providing additional contrast between the lens and the signal head. There are different types of visors including complete circle (or tunnel), partial (or cut-away) and angle visors. Cut-away visors are preferred as snow and water cannot accumulate at the bottom of the signal indications. Additionally, cut-away visors reduce the problem of birds nesting in the visor.

The MUTCD requires that "in cases where irregular street design necessitates placing signal faces for different street approaches with a comparatively small angle between their respective signal lenses, each signal lens shall, to the extent practical, be shielded or directed by signal visors, signal louvers, or other means so that an approaching road user can see only the signal lens(es) controlling the movements on the road user's approach." Additionally, the inside of signal visors should have a dull black finish to minimize light reflection. The MUTCD also recommends using signal visors, which direct the light without reducing the intensity of the light, in lieu of signal louvers.

Louvers

Louvers are used to avoid confusion on intersection approaches where approaching motorists may be able to see the signal indication for another approach, typically due to a skewed approach angle at the intersection. The purpose of a louver is to block the view of the signal from another approach. They are similar to angle visors but are better in limiting signal visibility to a narrow cone to the front of the signal. The problem with louvers is that they reduce the amount of light emitted from the signal and require higher luminance to obtain the same visibility as a signal without a louver.

As stated in the discussion of visors, louvers may be used to limit the view of the signal by approaching motorists at intersections with a small angle between signal lenses. However, it is stated in the MUTCD that signal visors should be considered as an alternative to signal louvers because of the reduction in light emitted caused by the louvers. The MUTCD requires the entire surface of louvers have a dull black finish to minimize light reflection and to increase contrast between the signal indication and its background. Figure 3–12 shows louvers on traffic-signal heads at an intersection with closely spaced approaches.

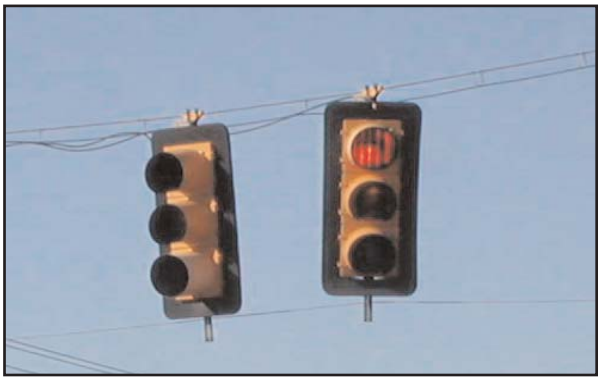

Figure 3–12. Louvers Used on Traffic Signals on Two Closely Spaced Approaches.

IMPROVE SIGNAL CONSPICUITY

In addition to improving the visibility of a traffic signal, various countermeasures can be applied to capture the motorist's attention, i.e. to make the signal more conspicuous. The following are measures, some of which are found in the MUTCD, that should be considered in improving the signal conspicuity.

Improve Signal Conspicuity

- ↳ Redundancy
- ↳ LEDs signal lenses
- ↳ Backplates
- ↳ Strobe lights

Redundancy

Providing two red-signal displays within each signal head should increase the conspicuity of the red display and further increase the likelihood that the driver will see the signal. While "doubling-up" on the red signal section is not normally needed, where there is a high incidence of red-light running, the engineer may want to consider this option. It is permitted by the MUTCD to repeat a signal indication within the same signal face (section 4D.18). The proper alternative arrangements of two red-signal sections are illustrated in Figure 3–13, excerpted from the MUTCD. A photograph of this measure is shown in Figure 3–14.

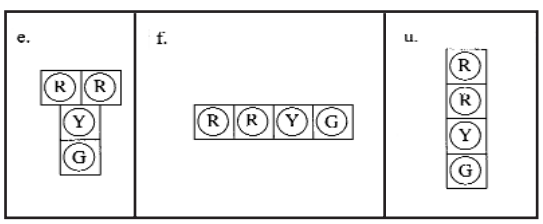

Figure 3–13. Alternative Arrangements of Two Red-Signal Sections.
Source: MUTCD Figure 4d-3.

An evaluation of this treatment applied at nine locations in Winston-Salem, NC showed a 33 percent decrease in right-angle crashes caused by motorists on the upgraded approaches following implementation *(26)*.

Figure 3–14. Field Use of Two Red-Signal Sections.

Light Emitting Diode (LED) Signal Lenses

An LED traffic signal module is made up of a lens and an array of individual LEDs that are tiny, purely electronic lights that display a single color. Each LED is about the size of a pencil eraser. LEDs can be used to replace an incandescent lamp and colored lens that make up a traditional traffic-signal optical unit.

LED units are used for three main reasons: they are very energy efficient, are brighter than incandescent bulbs and have a longer life increasing the replacement interval *(31)*. For example, in producing the same amount of light as a traffic signal with incandescent lamps, a LED traffic signal uses 90 percent less power. LEDs also emit light that is brighter because the LEDs fill the entire surface of the traffic bulb and also provide equal brightness across the entire surface. Literature providing data that would substantiate that LED signals are brighter compared to incandescent bulbs could not be found. However, it was observed by the author that at two intersections on an arterial in South Carolina, where one of the two signal displays was replaced with a red LED signal, that the LED signals were noticeably brighter and more conspicuous than the adjacent signal with the incandescent bulb. Finally, LED traffic signal modules have service lives of 6 to 10 years as compared to incandescent bulbs that have a life expectancy of only 12 to 15 months.

Section 4D.18 of the MUTCD supports the use of LED traffic-signal modules as a traffic-signal optical unit. The MUTCD states that traffic signals should conform to ITE standards *(32)* with regard to the intensity and distribution of light for a signal indication. At this time, only the red and green lamps meet specifications for traffic applications. Arrows and yellow LEDs that meet specifications are not currently available.

As stated previously, one of the major benefits of LED traffic-signal modules is that LEDs are brighter, which is especially helpful during poor weather or bright sunlight. However, there may be the potential for a glare problem at night because of the brightness.

The light output of LED traffic-signal modules is more directional than the output for traffic-signal optical units with incandescent lamps. As a result, signal indication visibility for some installations is limited to a narrow cone of vision below the horizontal axis of the signal face. If signal heads with LED traffic-signal modules are used, they should be mounted on mast arms. If they are installed on a span wire they are vulnerable to wind that can make the signal head tilt backwards and forwards, making the signal appear to be in flash mode. This is commonly referred to as "blanking." Even if they are mounted on mast arms, there is the possibility that the signal indication may not be visible due to the approach grade to the intersection. "Blanking" can be avoided by tethering the signal to a pole. If tethering is not a viable solution or if reduced visibility is caused by the approach grade, the LED application can be modified to an expanded pattern that increases the vertical visual cone of the LED by increasing the LED count and modifying the lenses *(33)*.

Laboratory research has found that with brighter lights, there are quicker reaction times and fewer missed signals among test subjects *(34)*. Although it was difficult to find a field study that confirmed the effect of LEDs on intersection safety as measured by signal violations, many cities are installing LEDs. For example, in 1998, the City of Scottsdale, AZ initiated a program to convert all of the city traffic signal's red and green indications to LEDs. The city stated four ways that LEDs improve safety at signalized intersections, including a reduction in signal indication outages, elimination of "phantom illumination" caused by colored lenses, longer re-lamping cycle (which reduces the time traffic is disrupted due to maintenance) and the ability to operate on battery backup systems during power outages *(35)*. Bonneson's research *(39)* reveals that the use of yellow LEDs may reduce red-light running by 13 percent.

Backplates

Backplates, as shown in Figure 3–15, are commonly used to improve the signal visibility by providing a black background around the signals, thereby enhancing the contrast. They are particularly useful for signals oriented in an east-west direction to counteract the glare effect of the rising and setting sun or areas of visually complex backgrounds. Guidance for their use for target value enhancement against a bright sky or bright or confusing background is provided in the MUTCD (Section 4D.17) for these very conditions. The MUTCD (Section 4D.18) requires the front surface of the backplate to have a dull black finish "to minimize light reflection and to increase contrast between the signal indication and its background." In many jurisdictions, it is general practice to use backplates for all signal heads, not just those in the east-west direction.

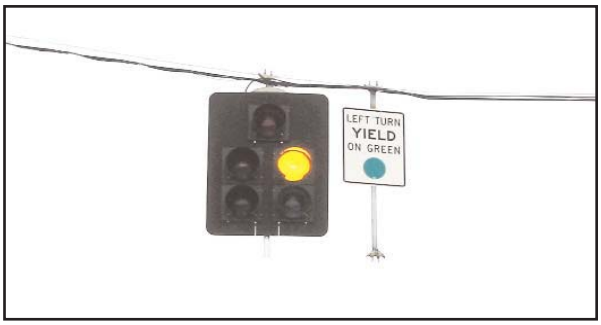

Figure 3–15. Traffic Signals with Backplates.

At six locations of varying types in Winston-Salem, NC backplates were added to signal displays on one or more approaches to call attention to the signal display. Angle crashes caused by motorists on the approach where the backplates were installed declined by more than 31 percent at all locations combined *(26)*.

In British Columbia, Canada, an evaluation was conducted of high-intensity yellow retroreflective tape on the backplates of signals at six intersections on an arterial in Saanich *(36)*. The authors hypothesized that the framed signal heads would be more visible to motorists at night and the safety of the intersection would improve. Figure 3–16 shows a daytime photograph of a signal head with the high intensity tape around the backboard.

A comparison of crash frequency for a three-year period after installation, compared to one year before, showed that the number of night crashes stayed the same the first year (14 crashes) but decreased significantly (five and three crashes) in the subsequent two years. Volume levels actually increased in each of the four years *(36)*. The use of retroreflective tape on the backplate is contrary to the MUTCD standard requiring a dull black finish. Hence, its use in the United States would require experimentation approval from FHWA.

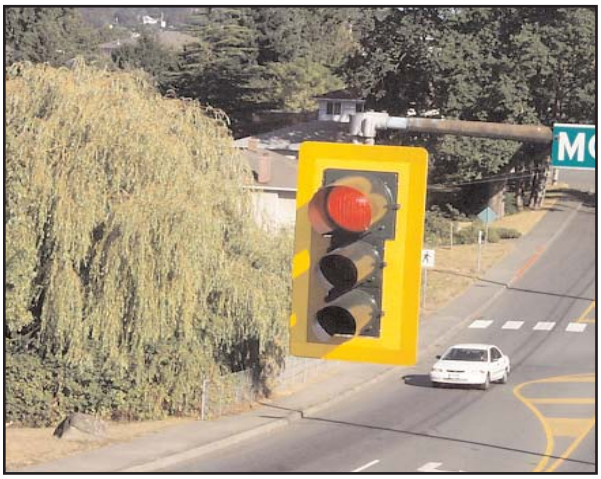

Figure 3–16. Signal with High Intensity Yellow Retroreflective Tape on the Backplate.

One precaution to note when using backplates is the additional load on the mast arm or cable caused by the backplate. This is due to the additional weight and added wind load. The additional load must be incorporated into the design of the signal-head mast arm and/or other signal parts.

Strobe Lights

Strobe lights have been used in rare occasions as a supplement to red signals to attract the attention of the motorist and provide emphasis on the signal. A strobe light, which flashes within the red signal display, can have either of two shapes—halo or horizontal—and be either of two mechanisms—xenon tube or light emitting diode (LED). Typically, a strobe light will have a flash rate of once per second. They can be used with both incandescent and LED signals.

One state's guidelines *(37)* for the use of strobe lights are as follows:

- At a location with high approach speeds (> 45 mph) and a documented accident problem;
- On an approach to the first signal in a series of traffic signals;
- On long, flat unobstructed approaches that alter perception at high speeds;
- At isolated intersections; and
- To be used only after other standard traffic control devices have failed.

There has not been a comprehensive study of this device, and the present limited evaluation has shown mixed results. A 1994 study in Virginia of six intersections with one and two strobe lights had both increases and decreases in rear-end and angle accidents—accident types that should be affected by this measure *(38)*. The overall conclusion of the researcher was that there is no clear benefit from using strobe lights and that other measures, cited in this report, should be tried.

While mentioned as a possible measure, care should be taken in using this device. Because conclusive evidence has not shown a reduction in crashes, FHWA's current position is that they will no longer be approved for experimentation. Since this device is not approved by FHWA and not included within the MUTCD, an agency using this device may be subject to liability in the event of litigation resulting from a crash.

INCREASE LIKELIHOOD OF STOPPING

Recalling the general solutions to red-light running presented in the introduction to this chapter, the second solution is to increase the likelihood of stopping for the red signal, once seen. Intersections and intersection devices should be carefully engineered so that the motorist is not enticed to intentionally enter the intersection on red. This may include providing additional information to the motorist regarding the traffic signal. With the additional information, the probability that a driver will stop for a red signal may increase. Additionally, the intersections must be designed in such a way that a driver who tries to stop his/her vehicle can successfully do so before entering the intersection on red. For example, an improvement in intersection pavement condition may increase the likelihood of stopping by making it easier for the driver to stop. These types of countermeasures deal with the following reported causes of red-light running:

- Driver reported they had green;
- Followed another vehicle into the intersection on red;
- Did not see signal; and
- Confused by signal indication.

Increase Likelihood of Stopping Through:

- Signal ahead signs;
- Advanced warning flashers;
- Rumble strips;
- Left-turn signal sign; and
- Pavement condition.

Most of the countermeasures discussed in this section are not innovative or required intersection elements, but rather are treatments used occasionally for specific reasons at targeted locations. Installation of these countermeasures requires a careful evaluation of the location and use of engineering judgment. The evaluations of specific implementations discussed below provide useful information when addressing the solution to a specific location.

Signal Ahead Sign

When the primary traffic-control device used is a traffic signal, the appropriate sign is the SIGNAL AHEAD sign (W3-3) shown in Figure 3–18.

The MUTCD requires an advance traffic control warning sign when "the primary traffic-control device is not visible from a sufficient distance to permit the road user to respond to the device." For a traffic signal, the visibility criterion is based on having a continuous view of at least two signal faces for a distance specified in Table 4D–1 of the MUTCD (See Table 3–1). The MUTCD also permits the use of this device even when the visibility distance is satisfactory. In addition, the MUTCD allows for the use of a warning beacon with the sign typically flashing yellow lights on either side or on top and bottom of the sign. The placement of this sign prior to the intersection is a function of the approach speed. Table 2C–4 in the MUTCD provides the recommended distances.

Figure 3–17. SIGNAL AHEAD Sign (W3-3).

Advance-Warning Flasher

The purpose of an advance-warning flasher (AWF) is to forewarn the driver when a traffic signal on his/her approach is about to change to the yellow and then the red phase. In North America, there are three general types of advanced warning devices and the decision of which to use is based on engineering judgment. These AWFs include:

- *Prepare to stop when flashing*—A warning sign, BE PREPARED TO STOP with two yellow flashers that begins to flash a few seconds before the onset of the yellow and continue to flash throughout the red phase. A WHEN FLASHING plaque is recommended in addition to the sign.
- *Flashing symbolic signal ahead*—Similar to previous type except the wording on the sign is replaced by a schematic of a traffic signal. The flashers operate as above.
- *Continuous flashing symbolic signal ahead*—The sign displays a schematic of a traffic-signal symbol but in this case, the flashers operate continuously (i.e. they are not connected to the signal controller).

Examples of different field implementation of the signs are shown in Figure 3–19 and Figure 3–20.

Figure 3–18. Example of AWF and Sign.

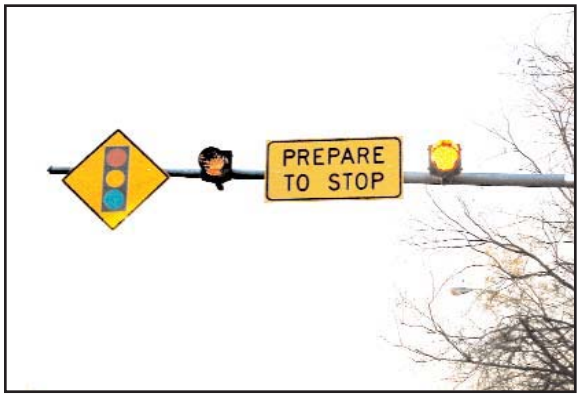

Figure 3–19. Example of AWF and Sign Treatment.

The effectiveness of AWFs is measured by vehicle speeds approaching the intersection, the number of red-light violations and its effect on accidents. A before-after study was conducted at one intersection in Bloomington, MN *(40)*. At the intersection, BE PREPARED TO STOP and WHEN FLASHING signs were pedestal mounted and accompanied by dual 8-in. yellow beacons. Data were collected immediately after installation of the AWFs and again one year after installation. During the before-period, the yellow interval was 6 sec. and the all-red interval was 2 sec. After the installation of the AWFs, the all-red was reduced to 1 sec. Data collected included the number of red-light violations and speeds, vehicle type (car versus truck), time after the onset of the red interval when the violation occurred and time of day of violation.

From these data parameters, the authors concluded the AWFs were effective in reducing the number of overall red light violators, the number of trucks violating the red light and the speed of the violating trucks. One year after installation, there was still a reduction in overall, car and truck red-light violations, as well as a slight decrease in the average speed of violating trucks. However, this was an increase from the previous years after-data indicating that the effectiveness had decreased over time. Additionally, the study did not employ a control or comparison group of intersections. Therefore, the changes observed could have been due to something other than the AWFs (for example, regression-to-mean).

Another study utilized and analyzed data from British Columbia using two different methods *(41)*. Models were used to develop expected accident rates at 106 signalized intersections for total, severe and rear-end accidents. Twenty-five of these intersections had AWFs. Although the results indicate that intersections with AWFs have a lower frequency of accidents, the difference between those with AWFs and those without is not statistically significant. An additional before-and-after study was performed for the 25 intersections equipped with AWFs to estimate the accident reduction specific to each location and its approach volumes. A correlation was found between the magnitude of the minor approach traffic volumes and the accident reduction capacity of AWFs, showing that AWF benefits exist at locations with moderate to high minor approach traffic volumes (minor street AADT of 13,000 or greater).

Rumble Strips

Another warning device that has been used to alert drivers to the presence of a signal are transverse rumble strips. Rumble strips are a series of intermittent, narrow, transverse areas of rough-textured, slightly raised, or depressed road surface *(22)*. The rumble strips provide an audible and a vibro-tactile warning to the driver. When coupled with the SIGNAL AHEAD warning sign and also the pavement marking word message—SIGNAL AHEAD—the rumble strips can be effective in alerting drivers of a signal with limited sight distance. This treatment is illustrated in Figure 3–21.

There are no known studies reporting on how this treatment can reduce red-light violations or the resulting crashes; hence their use should be restricted to special situations. If used, they should be limited to lower-speed facilities (less than 40 mph) and be reserved for locations where other treatments have not been effective.

Figure 3–20. Rumble Strips and Pavement Markings Used to Alert Drivers of Signal Ahead.

Left-turn Signal Sign

When a motorist wanting to turn left approaches a signalized intersection using left-turn protected only mode, he/she may be confused with the combination of two or more signals displaying a green ball for the through movement and a left-turn signal displaying a red ball or red arrow. To compensate for this, a sign that clearly identifies the left-turn signal is to be used. The LEFT TURN SIGNAL sign provides additional information not given in the actual signal indication to the driver by specifying the control device for different intersection movements. This is illustrated in Figure 3–22. Such information may eliminate driver confusion when approaching an intersection and prevent red-light running for left-turning traffic.

Figure 3–21. LEFT-TURN SIGNAL Signs at an Intersection.

The MUTCD provides information regarding the use of the sign for different modes controlling the left-turns (protected, permissive, protected/permissive, variable left-turn) and signal arrangements for an approach (shared versus separate). For instance, (See MUTCD Section 4D.06.C1) under protected/permissive left-turn phasing and separate signals for the left-turn and through movements that do not display the same circular signal indications, a LEFT TURN SIGNAL sign (R10-11) and a LEFT TURN YIELD ON GREEN (R10-12) sign is required. For protected left-turn phasing where the left-turn signal includes a circular red, left-turn yellow arrow and a left-turn green arrow, the circular red must not be seen by the through traffic or the signal must clearly be designated as the left-turn signal. The circular red can be limited by using hoods, shields, louvers, positioning, or design. Alternatively, a LEFT TURN SIGNAL sign can be used.

Pavement Surface Condition

According to NHTSA, 2,627 fatal crashes and 215,000 injury crashes in the year 2000 occurred during rainy weather conditions. This is approximately 7 percent of all fatal crashes and 10.4 percent of injury crashes occurring on wet pavement. Additionally, another 2.4 percent of fatal crashes and 3 percent of injury crashes occurred during snowy or sleeting weather conditions, likely on wet pavement *(42)*.

As a vehicle approaches a signalized intersection and slows to stop for a red light, it may be unable to stop due to poor pavement friction and as a result, proceed into the intersection. A vehicle will skid during braking and maneuvering when frictional demand exceeds the friction force that can be developed at the tire-road interface. The friction force is greatly reduced by a wet pavement surface. A water film thickness of 0.05 mm reduces the tire pavement friction by 20 to 30 percent of the dry surface friction. Therefore, countermeasures to improve the pavement condition should seek to increase the friction force at the tire-road interface and also reduce water on the pavement surface *(43)*.

The coefficient of friction is most influenced by speed; however, many additional factors affect skid resistance. This includes the age of the pavement, pavement condition, traffic volume, road surface type and texture, aggregates and mix characteristics, tire conditions and presence of surface water. Countermeasures to improve skid resistance include asphalt mixture (type and gradation of aggregate as well as asphalt content), pavement overlays and pavement grooving. Additionally, countermeasures such as SLIPPERY WHEN WET signs and reducing the speed limit can also be used.

The MUTCD permits a SLIPPERY WHEN WET sign to be used to warn of a possible slippery condition. The sign is to be placed an appropriate distance prior to the condition and at appropriate intervals along the affected section.

ADDRESS INTENTIONAL VIOLATIONS

The third general solution presented at the beginning of this chapter is to remove the reasons for intentional violations. The countermeasures presented in this section are mainly intended for those violators who "push the limits" of the signal phasing or try to beat the yellow signal. Previous surveys indicate that the common reasons drivers speed up and try to beat a yellow light include being in a rush and saving time. Although these drivers may not have intended to violate the red signal, they did intentionally enter towards the end of the phase knowing that there was the potential that they would violate the signal. Often times, these drivers do miss the yellow and end up running the red. The countermeasures presented in this section all relate to signal timings.

Address Intentional Violations Through:

- Signal optimization;
- Signal cycle length;
- Yellow change interval;
- All-red clearance interval; and
- Dilemma zone protection.

Installing the optimum signal timings is important to ensure respect for traffic signals. The MUTCD recommends signal timings be reviewed and updated on a regular basis (every 2 years) to ensure that it satisfies current traffic demands. There are many different and specific signal countermeasures that can be implemented regarding signal timing. The range in countermeasures includes changes to the signal system (such as progression) as well as changes to the signal-cycle length and individual signal phases (such as the yellow interval). Some of these countermeasures are discussed in the following sections beginning with system level changes and narrowing to changes in specific signal phases.

Signal Optimization

Poor signal timings are not only inefficient, but may cause a driver to become frustrated and respond inappropriately to the signal. The traffic demands at each intersection must be carefully accounted for when the phase sequence and timings are developed. Once these timings are developed, the relationship of the signal to other signals must be considered.

Interconnected signal systems provide coordination between adjacent signals and are proven to reduce stops, reduce delays, decrease accidents, increase average travel speeds and decrease emissions. An efficient signal system is also one of the most cost-effective methods for increasing the capacity of a road. With reduced stops, the opportunity to run red lights is also reduced. In addition, if drivers are given the best signal coordination practical, they may not be as compelled to beat or run a red signal.

Signal-Cycle Length

Proper timing of signal-cycle lengths can reduce driver frustration that might result from unjustified short or long cycle lengths. Timing of the various signal phases is based on the characteristics of the intersection and the individual approaches. Signal timing includes the green, yellow and red phase for each approach as well as the overall signal-cycle length.

Although there are federal and state standards that bound signal timing, there are also local or regional practices of signal timing. There are philosophies and considerations that support both shorter and longer cycle lengths for reducing signal violations. The effects of cycle length vary on traffic and driver. Drivers and traffic engineers may perceive shorter cycle lengths as more efficient as vehicles have shorter periods where they have to remain stopped. A driver that knows the wait is not excessive may be less inclined to beat the yellow or run the red. Conversely, under higher traffic volumes, the short cycle length may not be sufficient to clear all queues and drivers may find themselves waiting through two or more cycles. This may cause an increase in driver anxiety resulting in an increase in drivers attempting to beat the yellow and violate the red signal.

With longer cycle lengths, drivers strive to get through the signalized intersection or suffer the perceived long delay associated with sitting for the red signal. However, many traffic engineers use longer cycle lengths to move significant volumes on the mainline of arterial roadways. By providing a sustainable progression along a corridor, the saturated roadway can move higher volumes and reduce queue lengths. Delays associated with numerous start-up times are also diminished if progression is maintained.

When comparing cycle lengths, it should be noted that with longer cycle lengths, there are actually fewer numbers of times per hour when drivers are confronted with the yellow and red signal intervals. For example, when comparing a cycle length of 1 min. to 2 min., in an hours time in the 1-min. cycle, there will be twice as many opportunities for drivers to be confronted with the changing signal from green to red. Consequently, the longer cycle length does reduce the number of opportunities for traffic-signal violations.

After consideration of the pros and cons, one of the best tools to utilize in determining signal-cycle length is computer simulation and optimization. The computer generated optimized cycle length combined with the traffic engineers' knowledge and experience should result in the most efficient traffic-signal timing practical. As part of signal-timing strategies, the need to address specific times of day should be included. For example, typical timing plans would include multiple

plans to accommodate the morning or afternoon peak periods, midday, late night, weekends, etc.

Yellow-Change Interval

The MUTCD *(22)* requires that a yellow-signal indication be displayed immediately following every circular green or green-arrow signal indication. It is used to warn vehicle traffic that the green-signal indication is being terminated and that a red indication will be exhibited immediately thereafter.

A properly timed yellow interval is *essential* to reduce signal violations. An improperly timed yellow interval may cause vehicles to violate the signal. If the yellow interval is not long enough for the conditions at the intersection, the motorist may violate the signal. Motorists have some expectancy of what the yellow interval should be and base their decisions to proceed or stop based on their past experiences. In order to reduce signal violations, the engineer should ensure that the yellow interval is adequate for the conditions at the intersection and the expectations of the motorists.

In many jurisdictions, the yellow-change interval is followed by an all-red interval. During this all-red "clearance" interval, the red-signal indication is displayed to all traffic. The yellow interval and all-red interval are often referred to collectively as the change period or change interval. The all-red interval is addressed separately in a subsequent section.

There is currently no nationally recognized recommended practice for determining the change interval length, although numerous publications provide guidance including the MUTCD *(22)*, *Traffic Engineering Handbook (44)*, and the *Manual of Traffic Signal Design (45)*. The MUTCD provides guidance that a yellow-change interval should have a duration of approximately 3 to 6 sec., with the longer intervals reserved for use on approaches with higher speeds.

In the current edition of ITE's *Traffic Engineering Handbook (44)*, a standard kinematic equation is provided as a method to calculate the change interval length. The equation for calculating the change period, *CP*, is as follows:

$$CP = t + \frac{V}{2a + 64.4g} + \frac{W + L}{V} \qquad [1]$$

The principal factors that are taken into account in the development of the change period are:

- Perception-reaction time of the motorist, t, typically 1 sec.;
- Speed of the approaching vehicle, V, expressed in ft./sec.;
- Comfortable deceleration rate of the vehicle, a, typically 10 ft./sec.^{2};
- Width of the intersection, W;
- Length of vehicle, L, typically 20 ft.; and
- Grade of the intersection approach, g, in percent divided by 100 (downhill is negative).

The equation allows time for the motorist to see the yellow signal indication and decide whether to stop or to enter the intersection. This time is the motorist's perception-reaction time, generally 1 sec. It then provides time for motorists further away from the signal to decelerate comfortably and motorists closer to the signal to continue through to the far side of the intersection. These times are dependent on the characteristics of the traffic and the roadway environment. If there is a grade on the approach to the intersection, the equation adjusts the time needed for the vehicle to decelerate.

If available, the 85th percentile speed should be used as the approach speed in this equation. In the absence of 85th percentile speed, some jurisdictions use posted speed as the approach speed. In most cases, using the 85th percentile speed will produce intervals that are more conservative (i.e., longer). In no case should the approach speed used in the calculation be less than the posted speed limit.

The deceleration rate of 10 ft./sec.^{2} suggested by ITE is based on a comfortable deceleration rate that has been supported by research. The 2001 American Association of State Highway and Transportation Official's *A Policy on Geometric Design of Highways and Streets*, otherwise known as the "Green Book," *(46)*

recommends 11.2 ft./sec.^{2} for determining stopping-sight distance. They note that this is a comfortable deceleration for most drivers. The deceleration rate suggested by ITE is a more conservative deceleration rate for purposes of calculating the yellow interval and will result in longer intervals.

Effectiveness of Decreasing Violations

Various studies have evaluated the relationship between the length of the change interval and the occurrence of signal violations. Retting and Green *(47)* examined red-signal violations in New York where the yellow or all-red intervals were shorter than a practice proposed by ITE in 1985 *(48)* that is similar in calculation to Equation 1. They conducted a before-and-after study with a control group at 20 approaches. For the after-period, the researchers retimed the yellow interval at four sites, the all-red interval at five sites, and both the all-red and the yellow at four sites. Seven sites were used as the control group. The yellow retiming increased the yellow change interval by 0.5 to 1.6 sec., depending on the intersection. The all-red retiming increased the red-clearance interval by 0.8 to 3.6 sec. The researchers recorded the number of cycles with red-signal violations and the number of cycles with late exits at the intersections. Red-signal violation cycles were defined as cycles where at least one of the vehicles on the approach entered the intersection on red. Late-exit cycles were defined as cycles where at least one vehicle from the approach was still in the intersection at the release of conflicting traffic.

Logistic regression was used to analyze the data. The researchers concluded that increasing the length of the yellow signal towards the ITE proposed practice significantly decreased the chance of red-signal violations. They also found that late exits decreased as the all-red interval increased. It appeared that sites with shorter yellow signals had more late exits. Increasing the yellow to ITE-suggested values was as effective as increasing the all-red clearance interval at decreasing the occurrence of late exits.

Wortman et al. *(49)* conducted a similar before-and-after study at two intersections in Arizona. In the after-period, the yellow interval was extended from 3 sec. to 4 sec. The researchers observed a statistically significant reduction in the percentage of vehicles entering during the red-signal indication. These results should be viewed cautiously, however, since the treatment sites only included two intersections and since there was no indication of comparison or control sites.

R. A. van der Horst *(50)* found that increases in the yellow interval decreased the amount of red-signal violations. He conducted a behavioral before-and-after study at 23 urban and rural intersections in the Netherlands. One year after the yellow intervals were lengthened by 1 sec., the number of red-signal violations at the intersections lowered by one half. Bonneson's research indicates *(39)* that yellow increases in the range of 0.5 to 1.5 sec., that do not yield durations above 5.5 sec. can potentially reduce red-light running by about 50 percent.

Drawbacks of Lengthened Yellow Intervals

Although lengthening the yellow interval may reduce signal violations, an interval that is too long could decrease the capacity of the intersection and increase the delay to motorists and pedestrians. Present thought is that longer intervals will cause drivers to enter the intersection later and it will breed disrespect for the traffic signal. The tendency for motorists to adjust to the longer interval and enter the intersection later is referred to as *habituation*.

The before-and-after study by Retting and Greene *(47)* evaluated the presence of habituation to the longer yellow interval by using a second after-period. The same after-period measurements (cycles with signal violation and late exits) were collected in a second after-period approximately six months after the first after-period. They were compared to the first after-period. The authors concluded that habituation to the longer yellow did exist although it may have been only largely present at one site for signal violations. No significant habituation was observed for late exits. In the before-and-after study at the two intersections in Arizona, Wortman et al. *(49)* compared plots of the time of entry of vehicles into the intersection. The researchers observed an increase in the number of drivers entering towards the end of the interval, possibly due to the lengthened yellow interval.

Additional research is needed to further understand the effect of lengthening the yellow interval on driver behavior.

The goal of traffic engineers has been to find an optimum interval for the yellow change and all-red (if used) while recognizing that there are traffic and roadway variables that must be considered. The *Manual of Traffic Signal Design (45)* cautions that change intervals greater than 6 sec. 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.

All-Red Clearance Interval

An all-red interval is that portion of a traffic signal cycle where all approaches have a red-signal display. 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 during the yellow-change interval to clear the intersection before the traffic-signal display for the conflicting approaches turns to green.

In many states, it is legal to enter the intersection during any portion of the yellow interval. Hence, if a vehicle enters the intersection at the end of the yellow interval and if an all-red interval is not provided, the vehicle will be in the intersection while a conflicting approach receives the green signal. Hence, there is a potential for a crash, even when no one entered the intersection illegally.

It should be pointed out that providing an all-red interval (or the length of the all-red interval) does NOT affect the decision or the act of the motorist in running the red light. Because use of the red-clearance interval has been shown to increase the safety of an intersection, it is mentioned as a countermeasure in this toolbox because it can impact the safety of a signalized intersection.

As stipulated in the MUTCD, the all-red clearance interval is optional. The duration of the all-red interval shall be predetermined, which means the length of the interval should be calculated based on known intersection conditions and the length of time of the interval should not vary on a cycle-by-cycle basis. The MUTCD also stipulates that the duration of the all-red interval should not exceed 6 sec. There are no guidelines in the MUTCD 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. In the latest version of ITE's *Traffic Engineering Handbook (44)* it is suggested that when the calculated change interval is greater than 5 sec., an all-red interval provides the additional time beyond 5 sec. Many agencies allocate the third term of Equation [1], shown previously, as the all-red interval.

While the use of an all-red interval is optional, survey results support that most jurisdictions use it at a majority of their intersections. In response to a survey conducted by The Urban Transportation Monitor *(51)*, of the 76 city traffic engineers that responded, approximately 80 percent indicated that they use all-red at all signals and 20 percent indicated that they use it at some signals. The survey results indicate that only 35 percent apply the same standard interval length for applications. Those standard intervals ranged from 0.5 to 2 sec.

Studies have shown that providing a red interval does have a positive effect on the safety of the intersection. Four studies, summarized in Chapter 5 of the *Synthesis of Safety Research Related to Traffic Control and Roadway Elements—Volume 1 (52)*, investigated the effect of adding an all-red interval on intersection crashes. All studies were performed in the 1970s in various states and cities and all of the study results indicated more than a 40 percent reduction in right-angle accidents at the study locations. These results, however, should be viewed cautiously because the study summaries did not indicate that measures were taken to control for trends and regression to the mean bias.

A positive safety benefit was reported in a more recent study by Datta et al. *(53)*. Several improvements were made to three intersections in Detroit including the use of an all-red interval (1.5 to 2.0 seconds). Based on the

results of a statistical analysis of a multi-year before-and-after study of crashes, they concluded that there was a significant reduction in right-angle crashes and injuries after implementation of all-red intervals. This reported reduction in crashes could not be attributed solely to the all-red interval since other improvements were made. However, it does support that reductions in crashes can be realized from a combination of improvements identified in this toolbox including the use of an all-red interval.

The drawback to using an all-red is that it takes away from the green available for other movements and hence reduces the capacity of the intersection. The amount of reduction is dependent upon the number of phases and cycle length. For example, for a simple two-phase signal with a 120-sec. cycle length timing plan, the reduction in capacity is only 2.5 percent (compared to the same signal without an all-red) from the addition of a 1.5 sec. all-red after each phase. The reduction is small, however in congested corridors, its use would exacerbate delays.

Dilemma-Zone Protection

The "dilemma zone" has been defined recently 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 *(54)*. It is also referred to as the "option zone" or the "zone of indecision" *(55)*. One potential countermeasure to reduce red-light running is to reduce the likelihood that a vehicle will be in the dilemma zone at the onset of the yellow interval. This can be accomplished by placing vehicle detectors at the dilemma zone. They detect if a car is at the dilemma zone immediately before the onset of the yellow interval. If a vehicle is there, the green interval can be extended so that the vehicle can travel through the dilemma zone and prevent the onset of the yellow while in the dilemma zone. When combined with a speed detector, the countermeasure is even more beneficial. This countermeasure is referred to as dilemma-zone protection or green extension systems.

Zegeer and Deen conducted a before-and-after evaluation of green extension systems at three intersections in Kentucky to determine their effect on crashes *(56)*. The duration of the before-period was 8.5 years and the duration of the after-period was 3.7 years. There were 70 accidents in the before-period and 14 accidents in the after-period. The authors found a 54 percent reduction in accidents per year at the three sites combined. No comparison or control groups were used. McCoy and Pesti conducted an evaluation of dilemma zone protection in Nebraska *(55)* as part of an evaluation of active advance-warning signs (discussed in a previous section). Dilemma-zone protection using conventional detectors was compared to dilemma-zone protection with active advance-warning signs in a cross-sectional evaluation. Overall, the two methods performed similarly when red-signal violations were the measure of effectiveness.

ELIMINATE NEED TO STOP

The final group of solutions to red-light running as described in the introduction of this chapter involves eliminating the need to stop. This can be done by removing the signal or redesigning the traditional intersection. An intersection should be designed following standards and guidelines found in AASHTO's *A Policy on Geometric Design of Highways and Streets (46)*. Other design guidelines can be found in two ITE publications: *The Traffic Safety Toolbox: A Primer on Traffic Safety (54)* and *Traffic Engineering Handbook (44)*.

Eliminate Need to Stop Through:

- Unwarranted signal removal;
- Roundabout intersection design; and
- Flash mode.

Unwarranted Signals

If there is a high incidence of red-light running violations, this may be because the traffic signal is perceived as not being necessary and does not command the respect of the motoring public. The decision to install a traffic signal is based on the traffic volume of the intersecting streets, pedestrian traffic and

the flow of traffic through a network. Warrants are provided in the MUTCD that define the minimum conditions at which installing a traffic signal may be justified. However, sometimes signals are installed for reasons that dissipate over time. For instance, traffic volume may decrease due to changing land-use patterns or the creation of alternative routes.

There have been studies of the impact of removing traffic signals and converting the intersection to STOP sign control. Kay et al. *(57)* found that at 26 intersections converted to multi-way stop control, there was a decrease in the average annual accident frequency of more than one accident per year. Where signals were replaced by two-way stop control, they found that on average there was an increase in right-angle crashes, but it was offset in the number of collisions and injuries by a reduction in rear-end crashes.

One of the primary factors that caused an increase in overall crashes was the presence of inadequate corner-sight distance. They also found that one-way intersections with low volumes experience an overall crash reduction. This was the same finding in a study of 199 low-volume Philadelphia intersections, where it was determined that traffic-signal removal resulted in a 24 percent crash reduction *(58)*.

Kay et al. *(57)* concluded that replacing unjustified signals with two-way stop control has the following beneficial impacts:

- Total delay per vehicle is reduced by approximately 10 sec.;
- Idling delay per vehicle is reduced by approximately 5 to 6 sec.;
- Stops are reduced from approximately 50 percent of total intersection traffic to about 20 to 25 percent or even less if side road volumes are low in relation to total intersection volume; and
- Excess fuel consumption due to intersection stops and delays is reduced by approximately 0.002 gallons per vehicle.

The removal of a traffic signal should be based on an engineering study. Factors to be considered in such a study are enumerated in Figure 3–22 from ITE's *Traffic Control Devices Handbook (59)*. Specific guidance on signal removal can be found in Kay et al.'s report *(57)*. Once it is established that a signal can be removed, Section 4B.02 of the *MUTCD* suggests a five-step process for removal of the signal.

- Intersection operations that merit signal removal
- Projected traffic volumes relative to signal warrants
- Total stopped time delay with and without the signal
- Projected collision problems with and without the signal
- Treatment of any sight-distance problems
- Impact on signal system progression
- Savings in operational costs with removal such as electrical consumption, maintenance costs and repair parts
- Improvements in environmental issues such as air quality, fuel standards and noise pollution
- Analysis and recommendation of intersection traffic control to replace signal control
- Recent geometric and/or sight restriction improvements in the vicinity of the intersection

Figure 3–22. Factors to Consider in Signal Removal
Source: Traffic Control Devices Handbook (59).

Roundabout Intersection Design

A "modern" roundabout can be described as a circulatory intersection that features channelized approaches, yields control for vehicles entering the circle and geometric curvatures that promote lower speeds within the roundabout. Other features include a central island off-limits to pedestrians and raised "splitter" islands on approach legs that divide entering and exiting traffic, as well as provide a refuge for pedestrians. Figure 3–23 shows a roundabout in Colorado.

Figure 3–23. Roundabout.

With respect to the topic of this report, the roundabout replaces the traffic signal and obviously eliminates the red-light running problem. Assuming the roundabout is operationally more efficient (which may not be the case for many intersection conditions), the issue is whether or not it is a safer intersection considering all crashes.

Currently there are no recommended criteria or guidelines for when a roundabout should be considered. Roundabouts are acknowledged in the latest edition of AASHTO's *A Policy on Geometric Design of Highways and Streets (46)*, with sparse design criteria, and there is guidance for appropriate pavement marking and signage in the MUTCD (see Section 3B.24). However, the most comprehensive guidance from planning to design is found in a FHWA document called *Roundabouts: An Informational Guide (60)*.

Although use of roundabouts is limited in the United States, they are commonly used internationally. Many international studies have found that roundabouts greatly reduce the number of accidents and severity of accidents at converted intersections. Other benefits of roundabouts include: reduction in vehicle emissions, noise, fuel consumption and traffic delays, as well as eliminating the need for maintenance and electrical costs of operating a signalized intersection. The center island also provides a good location for landscaping and architectural treatments for improving the aesthetic quality of the intersection. Particular sites appropriate for roundabouts include locations with heavy delay on the minor road, an intersection with heavy left-turning traffic, an intersection with more than four legs or unusual geometry and intersections where U-turns are desirable *(61)*.

There are certain drawbacks associated with roundabouts. The biggest drawback is to pedestrians, as they are limited to cross only on the approach legs and have no exclusive right of way (i.e. no pedestrian phase). Roundabouts are not appropriate everywhere as they do require a fair amount of right-of-way (outer diameter of approximately 100 ft.) and have a limited vehicle capacity. Public support of roundabouts in the United States is also a concern.

Conversion of a signalized intersection to a roundabout eliminates red-light running because the signal has been removed. The real test of safety effectiveness is in terms of total crashes. A conversion from traffic-signal control to roundabouts reduces the total number of injury crashes by 30 to 40 percent *(62)*. Another study states that left-turn accidents are eliminated and angle accidents are reduced by 80 percent *(61)*. Such reductions can be attributed to the reduction in the number of conflict points and induced slower speeds through the intersection.

Flashing Mode

During periods of low traffic volumes no one should have to wait needlessly at a traffic signal. Today's modern traffic-signal control technologies are fully traffic actuated/adaptive systems that incorporate advanced loop or video detection methods. If working properly, even minor street traffic may not necessarily have to face a stopped condition. Yet, there are locations

that are not instrumented to take advantage of these advanced technologies. Therefore, during low volume conditions at an intersection, it may be appropriate for signalized traffic-control devices to operate on flashing mode. The *Traffic Control Devices Handbook (59)* lists the following benefits associated with flashing mode operation:

- Reduce stops and delay to major-street traffic;
- Reduce delay to cross-street traffic;
- Reduction in fuel consumption due to reduced delay; and
- Reduction in electrical consumption by the traffic control signal equipment.

By using the flashing mode, the need to stop (and/or wait) at an intersection is greatly reduced.

When in flashing mode, the MUTCD recommends a flashing yellow on the major street approaches and a flashing red on the minor street approaches. A less common arrangement (although common in California) is to use flashing red on all approaches to the intersection. The MUTCD also provides further requirements regarding the application and operation of traffic-control signals including the transition from steady to flashing mode and the need for flashing mode capability for emergency situations (see MUTCD Section 4D.11 and 4D.12).

The *Traffic Control Devices Handbook* cautions that the accident pattern at the intersection should be monitored to determine if the flashing mode has caused an increase in accidents. The indicators mentioned include the following three points:

- A short-term rate of 3.0 right-angle accidents in one year during the flashing operation;
- A long-term rate of 2.0 right-angle accidents per million vehicles entering during the flashing operation if the rate is based on three to five observed right-angle accidents; and
- A long-term rate of 1.6 right-angle accidents per million vehicles entering during the flashing operation if the rate is based on six or more right-angle accidents.

These conditions were developed as a result of a FHWA study investigating different effects of flashing signal traffic control on intersection operation and safety concluded in 1980. After studying data from across the country, the study concludes that flashing yellow/red operation significantly increases the hazard of night-time driving. The major exception is an intersection where the ratio of major street volume to minor street volume is greater than three, or where the major-street two-way volume is less than 200 vehicles per hour during flashing operation *(63)*.

The potential hazardousness of using flashing operations was recently confirmed by Polanis *(64)* in Winston-Salem, NC. At 19 intersections where low-volume flashing operations were removed (i.e., returned to normal signal control), right-angle crashes declined at every intersection (of which 16 had statistical significance), and for all the intersections combined there was a 78 percent reduction. Total accidents decreased by 33 percent, but for four locations an increase was observed. A follow-up after analysis showed that the right-angle crash reduction was sustained over a longer period. Polanis uses this finding to conclude that the use of flashing operation during low volume periods "…is a strategy to reduce delay that need not be abandoned, but its use requires careful application and additional monitoring."

SUMMARY

There are a number of factors or reasons that cause drivers to run red lights. There are also a number of countermeasures that can address these factors and discourage red-light running. The engineering countermeasures discussed in this chapter and summarized in Figure 3–24 address signal visibility/conspicuity, increasing the likelihood of stopping, removing the reasons for intentional violations and eliminating the need to stop. Most of these actions are low cost countermeasures. However, specific unit costs were not provided here since these costs can vary considerably among jurisdictions.

It is very difficult to prioritize countermeasures based on a relative estimate of cost effectiveness or crash reduction potential for a number of reasons.

Information provided from past studies that investigated the effectiveness of measures is limited. Additionally, the results of such studies are site specific. Moreover, the best countermeasure cannot be determined strictly from the effectiveness potential but must be appropriate for the specific intersection. For example, although modifying the yellow interval has been shown to reduce violations, the most appropriate countermeasure for a section with horizontal alignment problems is to provide warning of the upcoming signal.

Selecting the best countermeasure to use depends on individual site characteristics. The countermeasure most suited to the specific intersection can only be determined after conducting an engineering study that investigates the safety of the intersection as related to red-light running and also the occurrence of red-light violations. Additionally, an engineering study will investigate the existing design elements of the intersection. After such an investigation, the appropriate countermeasure for the specific site can be identified. Chapter 4 provides further information on conducting an engineering study.

Improve Signal Visibility

- Placement and number of signal heads
- Size of signal display
- Line of sight

Increase Likelihood of Stopping

- SIGNAL AHEAD signs
- Advanced-warning flashers
- Rumble strips
- Left-turn signal sign
- Pavement surface condition

Eliminate Need to Stop

- Unwarranted signals
- Roundabout intersection design
- Flash mode

Improve Signal Conspicuity

- Redundancy
- LEDs signal lenses
- Backplates
- Strobe lights

Address Intentional Violations

- Signal optimization
- Signal-cycle length
- Yellow-change interval
- All-Red clearance interval
- Dilemma-zone protection

Figure 3–24. Summary of Engineering Countermeasures by Category.

chapter 4

Red-Light Running Problem Identification and Resolution Process

INTRODUCTION

The solution to the red-light running problem involves a combination of education, enforcement and engineering measures. The focus of this report has been on engineering countermeasures, which were identified in Chapter 3. This chapter presents information on how an agency can identify the existence of a red-light running problem and then select the most appropriate countermeasure or a combination of countermeasures.

Governmental agencies may first install automated-enforcement systems at red-light running problem locations without investigating whether or not there are any engineering deficiencies and/or if certain engineering countermeasures can reduce the incidence of red-light running. Prior to the installation of red-light running cameras, an engineering study should be performed. This study should determine whether the red-light running problem is a design/operational issue (requiring engineering) or a behavioral issue (requiring enforcement and education). It is first necessary to verify that an intersection has been properly designed and constructed and that there are no engineering deficiencies that contribute to the red-light running violations.

The intent of this chapter is to provide a process to be followed to systematically address a red-light running problem at a signalized intersection. The process of investigating an intersection, looking for engineering deficiencies and implementing engineering countermeasures is known as an intersection engineering study. The goal of an engineering study is to identify *the most effective solution* to an identified problem. In this case, the problem would be red-light running. The solution could include engineering, education, or enforcement countermeasures.

A distinction should be made between a red-light running "problem" at a specific signalized intersection or a system-wide problem within a jurisdiction or area. It appears that the incidence of red-light running is increasing along with other traffic violations, collectively described as aggressive driving behaviors. If true, this increase should be experienced at a majority of signalized intersections. If that is true, then there needs to be a system-wide solution set that would consist of a combination of engineering, education and enforcement measures. The discussion that follows, however, deals with specific intersections.

THE PROCESS

The process for addressing a safety problem related to red-light running is the same as would be for any identified safety problem. From an engineering perspective, it includes the following activities:

1. Confirm that there is a safety problem;
2. Conduct an engineering analysis to identify the factors that might be causing the problem;
3. Identify alternative countermeasures;
4. Select the most appropriate single or combined set of countermeasures; and
5. Implement the countermeasures and monitor implementation of the solution to determine the extent of the continuance of the problem.

How these elements can be pursued for a red-light running safety problem is discussed below.

Red-Light Running Problem Identification

At any given signalized intersection there is likely to be some amount of red-light violations. There are also likely to be some number of crashes related to red-light running, notably angle-type crashes. Logically, the two are related with increasing violations begetting increasing crashes; however, the exact relationship has not yet been established.

The issue here is whether or not the frequency of one or both measures, violations and crashes, is high enough such that it signals a red-light running problem—that being a frequency that is higher than what would be expected. If a specific intersection has a red-light running problem, then how should the engineer, in concert with law enforcement, address the problem until it is sufficiently mitigated?

The initial identification of a red-light running problem can come from several sources, singularly or in combination as illustrated in Figure 4–1. Citizens, either as drivers, pedestrians, or bicyclists, can complain about a specific intersection having too many motorists running the red light. These complaints can be directed to either the local engineering office, the police, or to elected officials. Police can become aware of problem intersection either through citizen complaints, their own patrolling and monitoring, or from high accident location identification programs of their own or the engineering department. The engineering office may become aware of a potential problem in a similar fashion as the police. Quite often, elected officials may be most vocal about a red-light running problem that needs to be corrected.

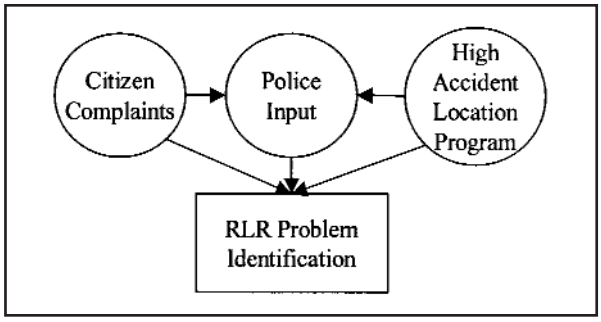

Figure 4–1. Red-Light Running Problem Identification.

However, to determine if there is indeed a red-light running problem, a traffic engineering analysis should be performed. A specific signalized intersection could be considered a red-light running problem if it is experiencing a level of violations or related crashes that is greater than some selected threshold value. Threshold value criteria, such as higher than the average or some other statistic, for violations and/or related crashes should be established and applied to quantify that there is a red-light running problem. For violations, a value could be based on local police experience. Law enforcement agencies would have data on citations issued for various traffic violations and may be able to establish if a given intersection has a higher than average violation rate. Based on the literature, violation rates can vary significantly and are likely dependent upon a number of factors. Some violation rates, in terms of violations per approach volume or per time period were presented in Chapter 2.

For crashes, the investigating agency should isolate red-light running related crashes. The ability to identify a crash that was a result of running a red light is

dependent upon the type and accuracy of the information recorded on the police report. Indicators of a red-light running related crash can be found in several sections of the report, depending upon the state, and include: contributing cause (e.g. failed to yield right of way, disregarded traffic signal), collision type (e.g. angle, left, or right turn), traffic control (i.e. presence of traffic signal), offense charged and the narrative and diagram. However, all of these data elements may not be coded or available to the analyst who is using only the coded file to identify red-light running crashes. If the analyst does not have access to the police report, angle-type crashes that are coded as occurring at an intersection, with a traffic signal and a driver action that would indicate disregard of the signal, would likely be a red-light running related crash.

To be a problem, red-light running related crashes could be either high in frequency, high in rate based on intersection entering volume, or high in comparison to other types of crashes related to the intersection. Bonneson *(39)* indicates that typical intersection approaches experience 3 to 5 red-light runners per 1,000 vehicles. Using a rate statistic for this assessment is preferred, but it requires having timely traffic volume data that may not be readily available. An alternative method would be to compare the percentage of red-light running related crashes to other crash types at the intersection. This comparison would be made against an intersection crash type distribution developed by the respective agency, where the data distribution is more representative of local intersection characteristics. If the percentage of angle crashes was much higher than the value for the distribution found for all similar intersections in the jurisdiction, than this could indicate a red-light running problem.

The data should be evaluated to determine if a red-light running problem exists. If not, then attention can be turned to other problems that might exist at the intersection and countermeasures to address those.

Site Evaluation to Identify Deficiencies and Engineering Countermeasures

If there is a confirmed problem, then the engineer should identify the factors that are contributing to the problem and then evaluate possible countermeasures in a systematic method. The initial step for this evaluation is to conduct a field review and collect the necessary data that would isolate any deficiencies. As a minimum, the data and assessments that will be needed include:

- Traffic volumes as turning movement counts (with consideration to truck volumes);
- Signal timing parameters;
- Sight distance to the signal;
- Geometric configuration;
- Traffic signs and markings and their condition;
- Pavement condition; and
- Traffic speed.

The engineer can refer to the ITE publication, *Manual of Transportation Engineering Studies (39)* regarding methods and procedures for collecting various traffic related data.

In addition, the engineer should spend some time observing the traffic flow and the occurrence of red-light running at the intersection. An hour or two of on-site observation could confirm the existence of red-light running; indicate the principal kind of red-light running event (whether or not the event appears to be intentional); and possibly how these contribute to crashes. A formal traffic conflicts study as described in the ITE *Manual of Transportation Engineering Studies* could be conducted as well. These observations will provide a sense for the traffic operational characteristics of the intersection and may offer potential clues to problem identification and solution.

One of the first considerations is to confirm that the traffic signal is still warranted. It would be unusual for a signalized intersection to have a red-light running problem where the signal is not warranted because of low traffic volumes. Still, this preliminary assessment, which can be made easily, is suggested. If there is a

possibility that the signal is not warranted, then further studies are recommended. (See reference *57* for guidance on removing unwarranted traffic signals). However, even if it is decided to investigate the possibility of signal removal, the engineer should proceed with the following field review.

A field review of the problem intersection is necessary to better understand the characteristics of the problem, to isolate deficiencies and to identify potential countermeasures. Sufficient time should be allocated to conduct a thorough review of the intersection. This means that the review may have to occur during different times of the day to observe operations and conditions under different levels of traffic flow and ambient light.

Figure 4–2 provides a listing of items that should be checked while at the intersection. They are discussed below with consideration to the alternative countermeasures discussed in Chapter 3 to resolve identified deficiencies.

Check for Signal Visibility

There are several visibility features that should be checked. The sight distance to the traffic signals should be determined and compared to the minimum sight distance requirements shown in Table 3–1. Keep in mind that this will require a knowledge or good estimate of the 85th percentile speed of approaching traffic. If the minimum sight distance is not available, there are a number of countermeasures discussed in Chapter 3 to consider:

Items to Check During Site Review

Visibility and Conspicuity Features
1. Sight distance to signals
2. Number of signals
3. Positioning of signals—overhead, post-mounted, near-side, far-side
4. Line of sight for visibility restricted signals (programmable)
5. Brightness of signals
6. Conspicuity of signals

Signal Control Parameters
1. Coordination with adjacent signals
2. Timing and cycle length
3. Yellow change interval
4. All-red clearance interval

Geometric Features
1. Grade of approach lanes
2. Pavement condition

Traffic Operations Features
1. Vehicle approach speed
2. Right-turn-on-red
3. Pedestrian usage
4. Truck usage

Figure 4–2. Traffic Signal Field Review Checklist.

- Signal Ahead Sign—the MUTCD requires that the W3-3 sign be used if minimum sight distance is not available;
- Advance warning flashers;
- Repositioning of signals; and
- Supplemental near-side signal.

While the visibility distance may be adequate, there may be obstructions to full and continuous visibility. Oftentimes, as shown in Figure 4–3, utility wires can limit the visibility to the signals. Resolution of this problem may require repositioning of the signals vertically or horizontally or, as was the case shown in Figure 3–9, installing a supplemental signal.

Figure 4–3. Example of Signal View Restricted by Utility Wires.

The next visibility feature would be the positioning of the signals to ensure they meet the cone of vision requirements and the minimum and maximum distances from the stop bar. Resolution of any deficiencies noted here would include:

- Placing signals overhead (if not already); and
- Repositioning signals.

Next, would be to check that there is an adequate number of signal heads. While a minimum of two are required for the major movement, consideration should be given to providing one for each lane where there are three or more lanes and that they are centered over the lane.

When programmable signals are used to avoid confusion, their visibility sight line should be checked. The provided sight line should be as long as possible without conflicting with other signal displays.

The brightness level of the signals should be viewed during varying ambient light conditions. Standard incandescent bulbs will deteriorate over time and need to be checked on a periodic schedule. The solution will be to replace the bulbs in a timely fashion or consider use of LED signals. While these types of signals will eventually fail, they hold their brightness level for a much longer period.

Check for Signal Conspicuity

While the signal display may meet all the visibility requirements noted above, the signals still may not be conspicuous—the ability to stand out amongst competing light sources or other information sources that compete for the motorists' visual and driving attention. Often times when the environment around the intersection is visually cluttered, the motorist can be distracted and not see the traffic signal until well into the dilemma zone. Visual competition can come in many forms. In suburban, high-density commercial corridors, there may be many other light sources from advertising signs and the like. Large overhead traffic guide signs may draw the attention of unfamiliar motorists placing more attention to navigation than intersection control. Whatever the situation, there are a number of countermeasures designed to draw the attention to the traffic signal. In addition to those noted for improving signal visibility, these would include:

- Use of double red signal displays;
- Use of backplates, and if the problem is more severe at night, the use of reflective tape; and
- Use of 12-in. signals if not already being used.

In addition to making the signals as visible and conspicuous as possible, the engineer may determine that it is necessary to get the motorists' attention as they approach the intersection. This can be accomplished a number of ways to include amber flashers on a SIGNAL AHEAD sign and advance warning flashers.

On rare occasions, some engineers have installed strobes in their red lights for the purpose of its attention-getting values. However, as noted in Chapter 3, these are not sanctioned by the MUTCD and, therefore, their use should be restricted to special circumstances. Also, rumble strips have been used in rare instances to gain the attention of approaching traffic and to reduce speed. As noted in Chapter 3, there are no known evaluations of their effectiveness and, hence, their use should be restricted to special situations. They are not suggested for high-speed (greater than 45 mph) facilities.

Check Signal Control Parameters

Having identified any visibility or conspicuity issues, the engineer should review the various traffic signal control parameters. The occurrence of red-light violations is affected, in part, by signal control parameters, specifically the change period interval and the cycle length and phasing. These are discussed below.

Change Interval Review

Probably the most significant factor that affects the incidence of red-light running is the duration of the yellow change interval. Hence, this aspect of signal operations should be reviewed for adequacy. The yellow change and all-red clearance interval was discussed in Chapter 3. Using either the agency's established procedures or procedures provided in publications such as the ITE *Traffic Engineering Handbook (44)*, the engineer should determine if the yellow change interval is appropriate for the conditions. If the yellow change interval is within the guidelines, then the engineer may want to consider further increasing the interval, but likely no more than 1 additional sec. If it is below the guidelines, then the yellow change interval should be increased to that level. Care must be exercised when using a long yellow change interval, say 5 sec. or greater. Frequent drivers may realize the signal has a long yellow display and take advantage of it by continuing through the intersection, instead of coming to a stop. As a result, it may be appropriate to shorten the yellow change interval (yet, with respect to guidelines) and add or increase an all-red clearance interval to discourage inappropriate driver behavior.

Additionally, the all-red clearance interval should be reviewed, assuming one is being used. As discussed in Chapter 3, an all-red clearance interval is that portion of a traffic signal cycle where all approaches have a red-signal display. The purpose of the all-red clearance interval is to allow time for vehicles that entered the intersection during the yellow change interval to clear the intersection before the traffic-signal display for the conflicting approaches turns to green. While the use of an all-red does not eliminate red-light running, its use can prevent a crash for the violator entering the intersection just as the signal turns red. Please refer to the ITE publication, *Traffic Engineering Handbook (44)*, concerning procedures on the application of the all-red clearance interval.

Cycle Length/Phasing Review

The traffic-signal cycle length and phasing should be reviewed. If the intersection operates within a coordinated signal system, then these two components would not likely be changed so as to disrupt progression and overall system efficiency. If the intersection is operated in isolation, then the engineer may want to consider reducing the cycle length if it is long (180 sec. or longer), or increasing the length if short (60 to 90 sec.). The possible effect of long and short cycle lengths is discussed in Chapter 3. Unexpected signal phasing sequences may contribute to red-light running and this should be examined as well.

Check Geometric Features

There are at least two geometric features that should be reviewed as they may have an effect on red-light running, namely:

- Approach grade—Grade is a factor in determining the yellow clearance and all-red intervals and is particularly important when present on high-speed facilities. The braking distance for high-speed vehicles, especially trucks, on a downgrade are significantly longer; and

- Pavement condition—The condition of the pavement on the approach should be checked at least visually. Motorists may be reluctant to come to a "quick" stop if the pavement is unusually rough or appears slippery.

Check Traffic Operational Features

As a minimum, the following traffic operational features should be examined:

- Vehicle approach speed—Visibility requirements and clearance intervals are dependent upon vehicle speed. The preferred measure is the 85th percentile speed, but this requires a speed survey for an accurate determination. When this is not practical, the engineer should observe traffic during non-peak conditions to make an approximation;
- Right turn on red (RTOR)—Red-light running crashes have been mostly associated with through traffic and left-turning traffic, however violations of RTOR can be a special form of this problem. The occurrence of conflicts or violations of a no-RTOR signing should be observed while in the field;
- Pedestrian usage—The engineer should make note of pedestrian traffic, conflicts with vehicles (especially with red-light violators) and the presence of pedestrian accommodations. Improvements to pedestrian accommodations should be considered if this appears as a problem;
- Truck usage—The assumed deceleration rate used in the formula for determining the yellow change interval may need to be decreased if there is a large percentage of trucks in the traffic stream.

Other Countermeasures To Consider

If after all the viable relatively low-cost engineering countermeasures described in the first part of this chapter and in Chapter 3 have been tried without success in eliminating the problem, then there are a variety of additional measures to consider. These include more extensive re-engineering measures, or enforcement countermeasures.

Re-Engineering of Intersection

Consideration should be given to a redesign of the intersection, if appropriate. This may involve physically improving the sight distance, if that was the problem, by a change in approach curvature and/or grade profile. This is obviously an expensive countermeasure and would require an in-depth engineering analysis to support such a decision. Also, the agency may want to consider replacing the signalized intersection with an alternative intersection design or possibly a roundabout, but again, a more comprehensive study would be needed, and quite likely there would have to be other problems beyond the red-light running issue to justify such an expensive treatment.

Enforcement

Increased enforcement should be considered if the engineering measures do not resolve the problem or until the engineering measures can be installed. Traditionally this would include selective enforcement by the police. Some cities have begun to develop specific task forces to address traffic issues and violations. Some of these special tasks often include target enforcement of red-light violations at particularly dangerous locations with a high number of violations. However, this type of measure is usually transitory in effectiveness, and can itself be hazardous because police have to follow the offender through the intersection exposing them to potential collisions.

To counter this problem, some jurisdictions use a red-light detector and enforcement light, known as a "rat box" or "red eye" unit. Figure 4–4 shows the placement of a rat box at an intersection. Figure 4–5 shows the enforcement light being used in the City of Richardson, TX. With this device, a light is attached to a pole that is activated when the red is on. This allows the police to position themselves on the far side of the intersection, which precludes the need to follow the offender through the intersection.

If the jurisdiction already has an automated-enforcement program using cameras, then they should consider adding the problem location into their

program. In so doing, the jurisdiction might want to use the following examples as a guide.

Maryland State Highway Administration Criteria for Installation of Automated Systems

The Maryland State Highway Administration (MDSHA) does not install automated systems, but does allow local jurisdictions to use them at intersections with a state road under certain requirements. MDSHA has developed a number of principles for the use of red-light camera systems, which are enumerated below:

1. Use of camera system at a specific site must serve a highway safety purpose;
2. Site must be studied to disclose engineering deficiencies and ascertain potential improvements, and deficiencies corrected and improvements made prior to the red-light camera use;
3. Traditional enforcement proven ineffective or inefficient prior to red-light camera use;
4. Red-light camera system must be proven technology, reliable, properly installed and maintained;
5. Processing of images and issuance of citation accurate, efficient and fair;
6. Effective and fair adjudication of offenders who go to court;
7. Effectiveness is continually evaluated; and
8. Public awareness maintained.

State of North Carolina Policy on the Use of Automated Systems

In developing a recommended policy for the use of automated systems for the state of North Carolina, Milazzo et al. *(10)* recommended an eight-stage process to be followed for systematically solving a red-light running problem. It is enumerated below:

1. Conduct a traffic engineering study to verify existence, extent and causes of the problem;
2. If feasible, implement traffic engineering countermeasures;
3. Consider implementation of traditional enforcement measures, perhaps with "rat boxes";
4. If engineering countermeasures and/or traditional enforcement proves to be unsuccessful or unfeasible, then select appropriate red-light camera locations;
5. Choose a financing arrangement to ensure that public safety will remain the primary goal;
6. Conduct a detailed, perpetual public information and educational effort regarding the program;
7. Implement red-light cameras at intersections with highest potential for crash reduction benefits; and
8. Monitor camera-controlled intersections, and indeed all countermeasures, for progress over time.

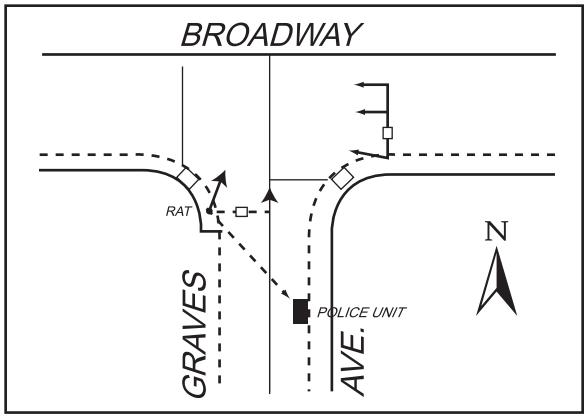

Figure 4–4. Placement of Rat Box at an Intersection.

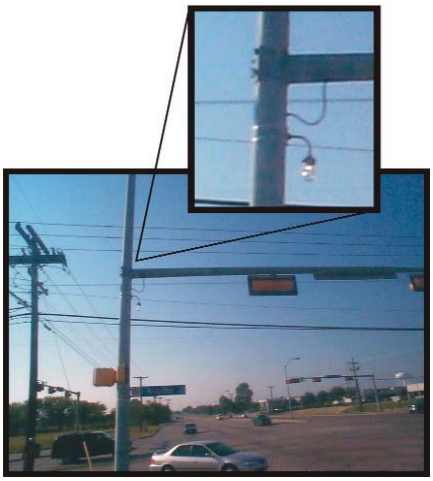

Figure 4–5. Enforcement Light Installation.

Milazzo et al. also suggest the following types of locations may be appropriate for camera installation pending the results of an engineering study:

- Through lane when opposed by a permitted or protected-permitted left turn. The reason for this is the absence of an all-red interval between these movements;
- Through lane when conflicting traffic is likely to be moving at green (either due to progression or multiple lanes on the conflicting approach);
- Through lane when conflicting traffic could attempt to anticipate the green (due to fixed signal timing or signal heads visible from conflicting approach);
- A selection from among high accident locations is permissible; and
- Other situations in which engineering deficiencies cannot be reasonably implemented, or implemented in a reasonable amount of time.

SUMMARY

What has been presented in this chapter is a process for determining if a red-light running problem exists and what types of countermeasures could be implemented in a logical and systematic manner. Individual agencies may have already established procedures for conducting audits and review of problem intersections that may accomplish the same objective. The goal of this process is to identify the most effective solution to an identified red-light running problem. The solution could include engineering, education, or enforcement countermeasures.

chapter 5

Future Needs

This report has been prepared to provide a better understanding of the red-light running problem and to provide information and case studies regarding how various engineering measures can be implemented to reduce the extent of red-light running. The solution to the red-light running problem also requires education and enforcement measures. An enforcement measure that has emerged in several jurisdictions throughout the United States is the use of automated-camera systems. These automated systems can be a viable countermeasure to red-light running violations and to resulting crashes. However, jurisdictions now using or contemplating using automated systems should ensure that candidate intersections have had engineering deficiencies corrected. In many cases, the engineering measures discussed in this report can provide a lasting and acceptable solution to a red-light running problem.

Further improvements in red-light running violations and crash reductions can be achieved through the following future activities:

- Research and development;
- Improved data related to red-light running crashes;
- Improved guidelines and standards; and
- Improved procedures and programs.

These activities are discussed below as concluding remarks to this red-light running countermeasures toolbox.

RESEARCH AND DEVELOPMENT

Research and development is suggested in the following areas:

- *Better understanding of root causes of red-light running.* With heightened awareness of the problem of red-light running, we are starting to become more knowledgeable as to why motorists intentionally or unintentionally run red lights. However, more research is needed to better understand the root causes of why motorists run red lights at traffic signals. Are the causes related to: (1) driver behavioral factors—impatience and/or disrespect for traffic laws; (2) driver capability and performance factors such as diminished vision and perception-reaction time; or (3) roadway and traffic control deficiencies such as inadequate signal visibility and/or improper signal timing? No doubt, all three factors act independently or in combination to cause a motorist to run a red light. Researchers in sociology, human factors and traffic engineering need to combine their expertise to identify the root causes of a red-light running problem. A complete understanding of this phenomenon will allow the safety community to identify appropriate countermeasures, whether they are engineering, education, or enforcement.
- *Quantification of crash reduction potential of various countermeasures.* In Chapter 3, several engineering countermeasures were presented, and where known, their effectiveness in reducing red-light running related crashes was documented. Unfortunately, only limited information is

available that would provide reliable estimates of crash reduction potential for each of the measures singularly or in combination. As jurisdictions begin to implement red-light running countermeasures, they should conduct evaluations. A clearinghouse for receiving and distributing information on evaluations would help transportation engineers to decide which countermeasures to deploy.

The safety effectiveness of automated-enforcement systems need to be fully understood and guidelines for where they should or should not be used should be developed. As noted in this toolbox, it has been shown that automated systems can reduce violations and resulting crashes. However, not enough is known about how different operating features associated with these systems, such as advance warning signs, types of intersections, level of fines, public information programs, etc., influence the level of effectiveness. Knowledge of these relationships will allow for better deployment guidelines.

➞ *Development and evaluation of Intelligent Transportation Systems (ITS) technologies.* The continuing development of a variety of ITS technologies, both for the infrastructure and the vehicle, hold promise for providing a safer road system and specifically for the red-light running problem. The Federal Highway Administration has a comprehensive research and development program for developing intersection collision avoidance systems. From the roadway side, this involves vehicle detection systems (in-pavement and overhead) and dynamic warning signs, placed roadside or adjacent to signal heads, that will determine if a motorist is likely to run a red light and give warning to the cross street motorist.

There already exists technology, known as "red-light hold" systems that will extend the cross street red signal momentarily under the same conditions; improvements can be expected soon. ITS systems are currently being developed that can predict when a vehicle will violate a signal and then provide a warning to that vehicle. An infrastructure-based warning system is illustrated in Figure 5–1.

It is anticipated that the next generation of collision avoidance systems will include in-vehicle warning systems to accompany infrastructure detection systems. The system illustrated in Figure 5–1 could be modified to a cooperative system such that the infrastructure would detect that the vehicle was in danger of violating the signal and the vehicle would provide the warning to the driver. Eventually, vehicles will have the technology to provide vehicle-to-vehicle dynamics and provide warnings of possible intersection collisions.

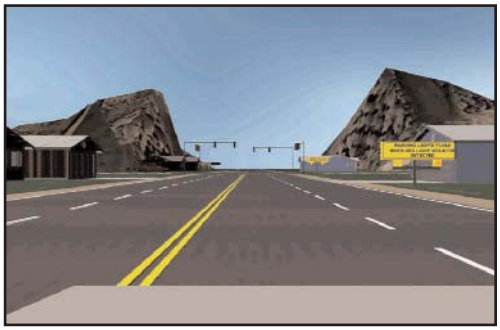

Figure 5–1. Infrastructure-Based ITS System that Warns Potential Red-Light Violators Approaching Intersection.
Source: Presentation by Robert Ferlis to the AASHTO Standing Committee on Highway Traffic Safety.

IMPROVED CRASH DATA FOR RED-LIGHT RUNNING

In Chapter 2, statistics on the frequency and characteristics of red-light running crashes were provided. However, these statistics must be viewed as estimates, albeit reasonable, because existing crash databases do not allow accurate identification of crashes attributed to red-light running. The data come from the police crash report and police are sometimes reluctant to cite the motorist for running a red light, especially if they cannot determine for certain who is the offending party. A review of the narrative or diagram requires confirmation that the crash did involve a red-light violator. While a change in the crash reporting form to deal with this issue is desirable, at least more caution in entering the data into electronic databases is needed. Also, agencies need an efficient data retrieval system that will allow the continuous monitoring suggested in Chapter 4.

IMPROVED GUIDELINES AND/OR STANDARDS

Hopefully, this informational report has given those responsible for operation of traffic signals guidance on how to identify a red-light running problem and what countermeasures, especially engineering related, could be used to mitigate the problem. As best that could be done based on available information, guidelines are provided where a specific measure is most appropriate. However, better guidance on what measure is most appropriate for a given situation is needed. This guidance can follow from the research and development program noted above and from the experiences gained by the traffic engineering community.

The *MUTCD* provides standards and guidance related to traffic-signal design and operations and the associated traffic signs and markings, which draw from research and field experience. Adherence to these standards and guidance provides for uniform and consistent application of traffic-control devices. While this is generally true, there are significant variations in practices across the country, which can lead to motorist confusion and misunderstanding that might be reflected in traffic violations. Consistency in the design—number, placement and configuration of the signals—and the operation—signal phasing, clearance intervals, etc.—would be beneficial to citizens that frequently drive in many states. While the unique requirements of a specific location will always need to be considered by the engineer, the focus of traffic-signal design and operation should be to deliver consistency (and uniformity) to the motorist in terms of head placement (signal visibility) and operation such as the length of yellow change and all-red clearance intervals.

IMPROVED PROCEDURES AND PROGRAMS

The solution to the red-light running problem requires a comprehensive and coordinated program that involves those stakeholders responsible for providing a driving environment that is as safe as possible. From the start, driver-licensing agencies should ensure that new drivers understand basic rules of the road and the meanings and operations of traffic control devices. This is normally accomplished through driver manuals and driver testing for licensing. Education officials have a role in ensuring this information is acquired through driver training. In the case of red-light running, education continues for experienced drivers through public information and awareness campaigns that highlight the problem and its consequences. Education and public information programs are especially required when automated enforcement is utilized. Automated-enforcement programs are better accepted by the community and are more effective, if the public understands why they are being used, that other measures have been used and have not solved the problem, and that the program is carried out fairly.

Enforcement officials have the responsibility of assuring that road users adhere to traffic laws and take corrective action when they do not. Coordination between the enforcement and engineering community is needed to identify where there are high incidences of violations that are resulting in crashes. Enforcement officials should have a basic understanding of traffic-control devices and recognize where there are engineering deficiencies that may contribute to the violations.

The public works and engineering professionals responsible for the streets need to be aware of accepted standards and guidance that relate to the design and operation of traffic signals. They have a responsibility for monitoring the crash experience of their street system so that they can identify when a problem is emerging.

The stakeholders representing engineering, education and enforcement need to work together, developing programs and procedures that would allow for these actions to be carried out efficiently and effectively. Sometimes, this needed alliance can be achieved through partnerships formed between public agencies and private entities. Frequently, added funding can also be obtained when private and quasi-public entities interested in safety participate. An example of this can be seen in Michigan where an alliance of several groups was forged through the efforts of AAA Michigan.

Red-light running continues to be a significant national safety problem. The occurrence of red-light running and moreover the crashes that result from red-light running can be reduced at intersections through education, enforcement and engineering. This report provides information to engineers, law enforcement officials, elected and appointed officials and the general public to help accomplish the goal to reduce red-light running crashes.

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