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16. Abstract

The problem of red-light-running is widespread and growing; its cost to society is significant. However, the literature is void of quantitative guidelines that can be used to identify and treat problem locations. Moreover, there has been concern voiced over the validity of various methods used to identify problem locations, especially when automated enforcement is being considered.

The objective of this handbook is to describe guidelines for identifying and treating locations that have an unusually large number of red-light violations or related crashes. Separate guidelines are presented for the treatment of red-light problems at individual intersections and within entire cities. The guidelines address countermeasures in both the engineering and the enforcement categories. The application of these guidelines should lead to the consistent and cost-effective treatment of red-light-related problems.

The handbook is intended for use by traffic engineers that have been charged with the evaluation of signalized intersection safety as may be influenced by red-light violations. The procedures described in the handbook are applicable to intersections on urban streets and rural highways. The intersections can be isolated or part of a coordinated signal system.

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RED-LIGHT-RUNNING HANDBOOK:
AN ENGINEER'S GUIDE TO REDUCING RED-LIGHT-RELATED CRASHES

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NOTICE

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CHAPTER 1. INTRODUCTION

OVERVIEW

The problem of red-light-running is widespread and growing; its cost to society is significant. A wide range of potential countermeasures to the red-light-running problem exist. These countermeasures are generally divided into two broad categories: engineering countermeasures and enforcement countermeasures. A study by Retting et al. (*1*) has shown that countermeasures in both categories are effective in reducing the frequency of red-light violations. To date, major impediments to the cost-effective implementation of these countermeasures have been the lack of: (1) guidance on how to identify "problem" locations, (2) guidance on how to identify the most appropriate countermeasure, and (3) accurate information on the effectiveness of various countermeasures.

The literature is currently void of quantitative guidelines that can be used to identify and treat problem locations. The few guideline documents that are available tend to speak in generalities on these topics; the premise being that their lack of specific direction provides the engineer with the flexibility to use his/her judgment in this critical task. A few of these documents indicate that the identification of problem locations should be based on a comparison of observed red-light-related violation or crash counts with threshold values determined from "representative" violation and crash rates. They leave it to the local agency to define the representative rates. The limitations of this approach are numerous and are due, in part, to its generality.

There has been concern voiced over the validity of various methods used to identify problem locations, especially when automated enforcement is being considered (*2,3*). There has also been concern expressed that engineering countermeasures are sometimes not fully considered prior to the implementation of enforcement (*2,3,4*).

The procedures described in this handbook are intended to provide a quantitative basis for the identification and treatment of problem locations. The remainder of this chapter briefly reviews the safety impact of red-light violations in the U.S., with an emphasis on Texas. Then, the objective and scope of the handbook are described. Finally, a few comments are made on the legality of using enforcement cameras in Texas.

SAFETY IMPACT OF RED-LIGHT-RUNNING

Retting et al. (*5*) found that drivers who disregard traffic signals are responsible for an estimated 260,000 red-light-related crashes each year in the U.S., of which about 750 are fatal. These crashes represent about 4 percent of all crashes and 3 percent of fatal crashes. Retting et al. also found that red-light-related crashes accounted for 5 percent of all injury crashes. This over-representation (i.e., 5 percent injury vs. 4 percent overall) led to the conclusion that red-light-related crashes are typically more severe than other crashes.

A recent review of the Fatality Analysis Reporting System (FARS) database by the Insurance Institute for Highway Safety (IIHS) indicated that an average of 95 motorists die each year on Texas streets and highways as a result of red-light violations (*6*). A ranking of red-light-related fatalities on a "per capita" basis indicates that Texas has the fourth highest rate in the nation. Only the states of Arizona, Nevada, and Michigan experienced more red-light-related fatalities per capita. Moreover, the cities of Dallas, Corpus Christi, Austin, Houston, and El Paso were specifically noted to have an above-average number of red-light-related crashes (on a "per capita" basis) relative to other U.S. cities with populations over 200,000.

A more recent analysis of Texas crash data by Bonneson et al. (*7*) indicated that the IIHS study may have underestimated the annual number of fatalities in Texas. Based on an examination of crash data for the years 1997 to 2000, they estimate that there are about 121 fatal crashes each year in Texas that are attributable to red-light violations. This number represents about 3.8 percent of the 3200 fatal crashes that occur annually on Texas streets and highways. They also found that about 37,700 red-light-related crashes occur each year in Texas. This number represents about 7.9 percent of the 478,000 crashes that occur annually on Texas streets and highways.

Finally, Bonneson et al. (*7*) reported that crashes associated with red-light violations have a societal cost to Texans of about $2.0 billion dollars each year. This cost includes the direct cost of the crash (such as property damage, medical costs, and legal fees) as well as indirect costs associated with lost earnings and a reduced quality of life. The direct economic cost to Texas motorists was estimated at $1.4 billion annually.

OBJECTIVE AND APPROACH

Objective

The objective of this handbook is to describe guidelines for identifying and treating locations that have the potential for safety improvement (i.e., "problem" locations). Separate guidelines are presented for the treatment of red-light problems at individual intersection approaches and within entire cities. The guidelines address countermeasures in both the engineering and the enforcement categories. The application of these guidelines should lead to the consistent and cost-effective treatment of red-light-related problems.

The handbook is intended for use by traffic engineers that have been charged with the evaluation of signalized intersection safety. The procedures described in the handbook are applicable to intersections on urban streets and rural highways. The intersections can be isolated or part of a coordinated signal system.

The handbook provides guidelines for red-light-related problem location identification and countermeasure selection. A detailed discussion of the development of these guidelines is provided in the research report by Bonneson et al. (*8*). The handbook does not provide an in-depth discussion of engineering countermeasures nor does it provide guidelines for using enforcement cameras. This information can be obtained from the following two reference documents:

- *Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce Red-Light Running* (i.e., *Toolbox*) (*9*), and
- *Guidance for Using Red-Light Cameras* (*10*).

Users of this handbook are encouraged to consult the first document listed if they desire more information on engineering countermeasures. They should consult the latter document if they decide to implement enforcement cameras. An electronic copy of each document can be downloaded from the Internet. An Internet address is provided with each document's reference citation in Chapter 4.

Approach

This handbook describes two procedures for addressing known (or reported) red-light-related problems. One procedure addresses problems at the local intersection level. The second procedure addresses problems at the area-wide (or jurisdiction) level. Both procedures prescribe engineering, education, and enforcement treatments at logical points in the evaluation process. The treatment approach can be described as "serial" because the engineering treatments are implemented first. Then, if the problem persists, officer enforcement can be implemented along with a public awareness campaign. Finally, if the problem still persists, camera enforcement can be implemented. At each step in this process, the effectiveness is evaluated and the findings used to justify advancement to the next step.

A Note on the Use of Enforcement Cameras in Texas

An opinion by the Office of the Attorney General - State of Texas, was offered to the City of Richardson on February 8, 2002 (Opinion No. JC-0460). In this opinion, the Attorney General stated that, in Texas, a traffic violation is a criminal charge and not a civil one. Therefore, a peace officer is needed to positively identify the suspect and issue him or her a citation. If challenged, the citation is adjudicated in a criminal court where the peace officer may be called as a witness.

In his ruling, the Attorney General writes, "While we conclude that a city ordinance creating a civil red-light violation is impermissible, we do not find any constitutional or statutory impediment to the adoption by the City of Richardson of an ordinance authorizing the use of automated enforcement equipment to identify criminal red-light violations at roadway intersections. The Transportation Code does not prescribe the method of traffic-law enforcement for local authorities, and cities may use their police powers to choose the method of enforcement."

In summary, the opinion indicates that Texas cities are free to adopt an ordinance that authorizes the use of enforcement camera systems to identify red-light violators. However, these systems must produce a photograph showing the face of the offending driver with sufficient clarity as to identify that person beyond a reasonable doubt in a court of law. This type of camera system typically requires two cameras (one in advance of the intersection and one beyond it). Two-camera systems are being used in several states, most notably California.

CHAPTER 2. RED-LIGHT VIOLATIONS, CRASHES, AND COUNTERMEASURES

OVERVIEW

This chapter briefly reviews the characteristics of red-light violations and related crashes. It also identifies the countermeasures typically considered in treating locations with a red-light-related safety problem. The objective of this chapter is to provide the reader with a basic understanding of the factors that are correlated with red-light violations and crashes. This insight will be useful during the engineering study of a problem location and will provide the necessary foundation for selecting the most helpful countermeasures.

The first section characterizes the typical red-light violator in terms of the stated cause for the violation and the factors that influence his or her response to the signal indication. In the second section, the red-light violation is defined, and typical violation rates are described. Red-light-related crash types are identified, and typical crash rates are described in the third section. The fourth section describes a wide array of countermeasures. Finally, the last section illustrates how the various characteristics can be combined to provide clues for countermeasure selection.

THE VIOLATION

Initially in this section, a definition of "red-light violation" is provided. Then, the factors that influence violation frequency are reviewed. Finally, the time of the violation, relative to the onset of the red indication, is discussed. It is offered that the distribution of violations by "time into red" provides important insight as to the likely effectiveness of some countermeasures.

Definition of Red-Light Violation

In Texas, as in most states, a driver may legally enter the intersection during the yellow signal indication and be within the intersection during a red indication. At the onset of the green indication, all drivers receiving the green are required to yield to any vehicles that are legally in the intersection. These drivers cannot legally proceed into the intersection until it is clear. It follows from these legal points that a red-light violation occurs when any vehicle enters (and proceeds through) the intersection after the signal has turned red. In this handbook, a vehicle is said to "enter" the intersection when it crosses the stop line or its equivalent location on the intersection approach. Page 5 of the *Toolbox* (*9*) cites specific passages from the Uniform Vehicle Code (*11*) as they relate to more precise definitions of the "entry reference line" and the "intersection."

Factors Correlated with Red-Light Violation Frequency

This section describes several factors that are correlated with red-light violation frequency. These factors include: traffic volume, cycle length, advance detection for green extension, speed, signal coordination, approach grade, yellow interval duration, proximity of other vehicles, presence of heavy vehicles, delay, intersection width, and signal visibility.

Volume and Cycle Length

The frequency of red-light violations is generally recognized to increase with traffic volume and the number of signal cycles per hour (*12, 13, 14*). As such, violation rates based on volume, cycles, or both are often reported in the literature. Typical volume-based violation rates are shown in Table 1. A red-light violation rate of 1.0 violations per 10,000 veh-cycles equates to 3 to 6 violations per 1000 vehicles for cycle lengths in the range of 60 to 120 s, with fewer violations associated with the longer cycle lengths.

Table 1. Typical Red-Light Violation Rates.

Location	Intersection Approaches	Red-Light-Violation Rate		Reference
		Violations/1000 veh	Violations/10,000 veh-cycles	
Iowa	13	3.0	--	*12*
United Kingdom	7	5.3	--	*13*
Texas	20	4.1	1.0	*14*

Issues with Violation Rates. The use of violation rate to evaluate risk and relative safety implies a linear relationship among the rate variables. However, this relationship may not be linear over a wide range of conditions. To illustrate this point, consider the trend lines shown in Figure 1. These lines are effectively linear for the lower range of intersection approach flow rates; however, the trend lines curve upward for higher flow rates. This curvature reflects the effect of delay on violation frequency (which is discussed in more detail in the next section). The lines shown reflect an increase in delay with increasing volume. Other trend lines could be shown that reflect other delay relationships. For example, it could be rationalized that delay is lower at higher volume approaches in reflection of their more generous signal timing and lane allocations. These trend lines would initially increase but become more horizontal at higher volumes. In short, the evaluation of approaches using violation rate can be misleading because it does not consider the effect of delay.

Use of Enforcement Cameras to Measure Violation Frequency. When comparing violation rates reported in the literature, it is important to note that differences exist in the methods used to identify red-light violations. Studies based on the direct observation of red-light violations count all entries after the onset of red as a violation. In contrast, those studies that use an enforcement camera to measure violation frequency typically define the violation as being "any entry to the intersection *after* the grace period ends." The grace period is a predetermined time period (e.g., 0.1 to 0.5 s) that must elapse after the onset of red before the camera is activated. Because many violations typically occur during this interval, violation rates based on these two types of studies are not directly comparable. The rates reported in the previous section are based on the direct observation of violations.

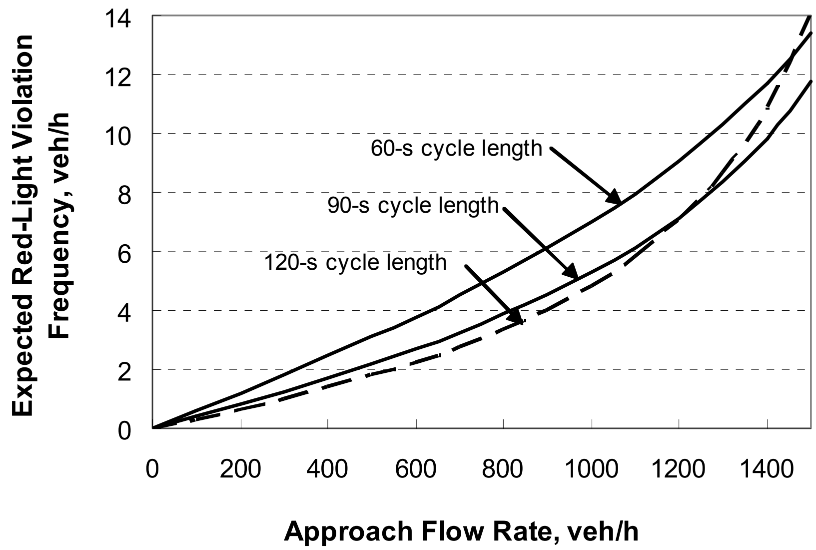


Figure 1. Relationship between Flow Rate, Cycle Length, and Red-Light Violations.

Delay

It is generally recognized that driver frustration due to excessive delay can lead to red-light violations. A survey by Porter and Berry (*15*) provided some insight into this problem. One survey question asked what the respondent would do as a driver if he or she was "late" and faced with a red signal indication. Of the respondents who indicated they would run the red indication in this situation, the reasons offered by 80 percent of them related to their desire to eliminate further delay.

Bonneson and Zimmerman (*8*) recently examined the effect of delay on red-light violation frequency at 26 intersection approaches. They found that violations increased in a predictable manner with an increase in volume-to-capacity ratio (which was used as a surrogate for delay). The effect of volume-to-capacity ratio is shown in Figure 2.

As indicated in Figure 2, red-light violations are minimal when the volume-to-capacity ratio is in the range of 0.6 to 0.7. Volume-to-capacity ratios below this range result in an increase in violations due primarily to shorter cycle lengths. Volume-to-capacity ratios above this range resulted in an increase in violations due primarily to an increase in delay. These findings imply that cycle length can be adjusted to reduce violations; however, the nature of the adjustment will depend on the volume-to-capacity ratio.

Yellow Duration

The yellow interval duration is generally recognized as a factor affecting the frequency of violations that occur just after the onset of the red indication. Researchers have shown that longer yellow interval durations are associated with fewer red-light violations, all other factors being equal (*8, 16, 17*).

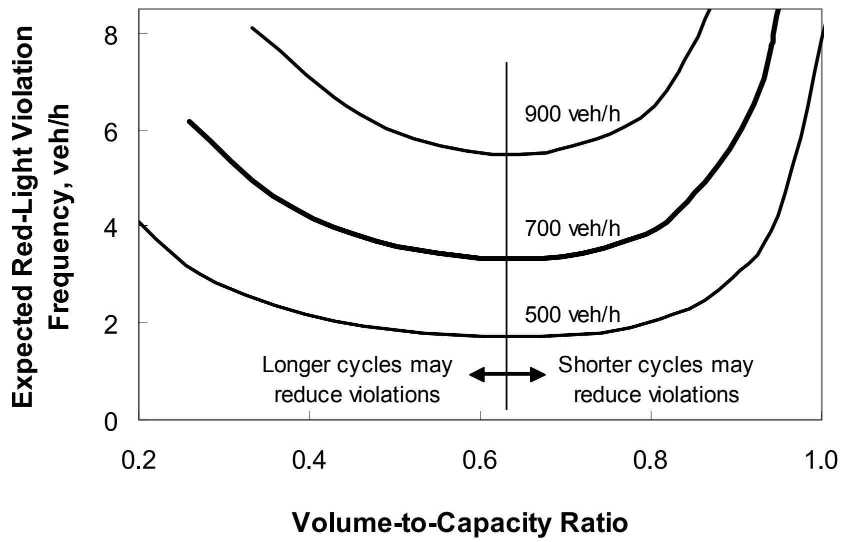


Figure 2. Effect of Volume-to-Capacity Ratio on Red-Light Violations.

One procedure for calculating the duration of the yellow interval is that proposed by Technical Committee 4A-16 working under the direction of the Institute of Transportation Engineers (ITE) (*18*). The formula recommended by this committee is:

$$Y = T_{pr} + \frac{V_a}{2\,d_r + 2\,g\,G_r} \qquad \textbf{(1)}$$

where,

Y = yellow interval duration, s;
d_r = deceleration rate, use 10 ft/s^2;
g = gravitational acceleration, use 32.2ft/s^2;
G_r = approach grade, ft/ft;
T_{pr} = driver perception-reaction time, use 1.0 s; and
V_a = 85th percentile approach speed, ft/s.

Equation 1 yields yellow durations ranging from 3.2 to 5.4 s for a level approach with speeds ranging from 30 to 60 mph, with larger values associated with higher speeds. Yellow durations based on this equation are provided in the Appendix.

The relationship between Equation 1 and red-light violation frequency was evaluated by Bonneson and Zimmerman (*8*). A "yellow interval difference" was estimated by subtracting the yellow interval computed with Equation 1 from the observed yellow interval at 26 intersection approaches. The relationship between this difference and the observed violation frequency is shown in Figure 3. The trend line in this figure indicates that there is a trend toward more red-light violations when the observed yellow duration is shorter than the computed duration.

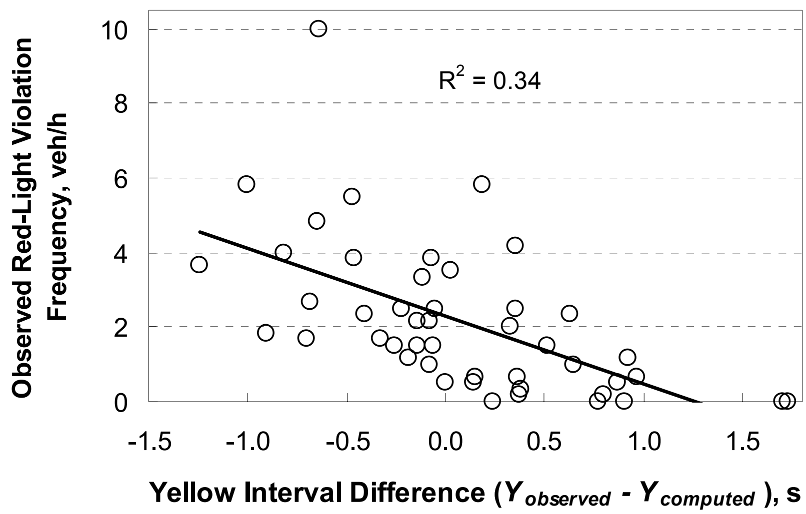


Figure 3. Effect of Yellow Interval Difference on Red-Light Violations.

Summary of Factors

In addition to volume, cycle length, delay, and yellow interval duration, several other factors have also been found to be correlated with (or influence) red-light violation frequency. These factors are listed in Table 2, as is the nature of their correlation with violation frequency. The factors that are underlined typically have an effect only on violations occurring just after the onset of red.

Time of Violation

This section examines the characteristics of red-light violations as they relate to the duration of time the signal indication was red prior to the violation. This latter characteristic is defined herein as "time-into-red." This time indirectly provides important clues to the selection of countermeasures that will be effective at reducing red-light violations and related crashes.

Several studies have investigated the amount of time after the start of red when a red-light violator enters an intersection. In one of the more recent studies, Bonneson et al. (*14*) examined 541 signal phases in which at least one through vehicle entered the intersection after the start of red. The results of this examination are shown in Figure 4. The median entry time was less than 0.5 s. About 98 percent of drivers entered the intersection within 4.0 s after the start of red (i.e., end of yellow).

Table 2. Factors Correlated with Red-Light Violation Frequency.

Category	Factor [1]	Red-Light Violations Tend to Decrease When... [2]
Traffic characteristics	Approach traffic volume	...traffic volumes decrease.
	Approach speed	...speeds decrease.
	Heavy-vehicle percentage	...fewer trucks are present.
Signal operation	Signal cycle length	...cycle length increases, provided the v/c ratio is less than 0.65. ...cycle length decreases, provided the v/c ratio is more than 0.65.
	Yellow interval duration	...yellow interval is increased (provided it does not exceed 5.5 s).
	Phase termination by max-out	...advance detection for green extension is used, provided it does not frequently extend to the maximum green limit (i.e., max-out).
Motorist information	Signal visibility	...signal visibility is improved (e.g., better signal head location, more heads, line of sight between signal and driver is improved).
	Signal conspicuity	...signal conspicuity is improved (e.g., use LED indications, 12" lenses, signal back plates, or dual red indications).
	Advance warning	...advance warning signs are added, especially if used with flashers that are active during the last few seconds of green.
Traffic operation	Approach delay	...delay decreases, especially if the v/c ratio is high.
	Signal coordination	...progression bands are adjusted so platoons do not arrive near the end of green.
Geometry	Approach grade	...grade is increased.
	Clearance path length	...distance traveled through intersection is short.
Enforcement	Threat of citation	...it is perceived that a violation is likely to result in a citation.

Notes:
1 - Underlined factors typically have an effect only on violations occurring just after the onset of red.
2 - Information in this table is derived from the following references: *8*, *9*, *14*. "v/c" = volume-to-capacity ratio.

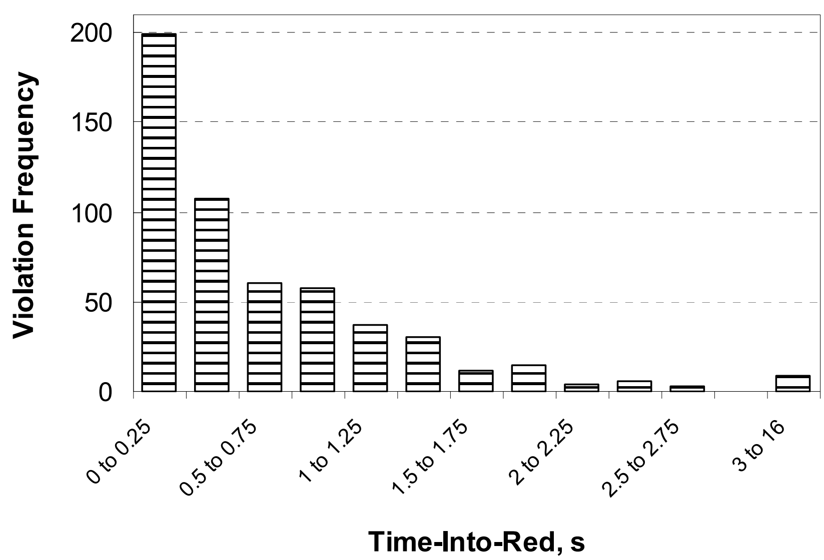


Figure 4. Relationship between Time-Into-Red and Red-Light Violations.

A recent survey of drivers indicates that most of the red-light violations that occur during the first few seconds of red are intentional (*15*). The motives of these drivers vary. Some drivers desired to avoid congestion. Other drivers indicated that they saw the light change but felt they did not have time to safely (or comfortably) stop.

There are two common types of conflict due to a red-light violation: right-angle and left-turn-opposed (the same designations are used for the resulting crash type). These two conflicts tend to occur at different times during the red indication. A right-angle conflict occurs after the driver in a conflicting traffic stream reacts to the signal's change to green and travels into the intersection. Thus, the right-angle conflict is likely to occur after the first few seconds of red have lapsed.

A left-turn-opposed conflict occurs when: (1) a left-turn movement is permitted to turn through gaps in the opposing through traffic stream, and (2) the left turn completes the permitted turn just after the light changes to red. Drivers of left-turning vehicles waiting in the intersection at the end of the phase may unintentionally turn in front of an opposing through vehicle, believing that its driver will stop for the red indication. Thus, left-turn-opposed red-light-related conflicts are likely to occur soon after the start of red (possibly prior to the end of the all-red interval).

Summary of Violation Characteristics

The points made in this section are summarized in Table 3 as they relate to a large majority of violations. The relationship between violations and crashes is discussed in a subsequent section.

Table 3. Relationship between Time of Violation and Violation Characteristics.

Time of Violation, s	Percent of Violations, %	Left-Turn Phasing	Most Likely Conflict	Cause of Violation
0.0 to 4.0	98	Protected-only	None	--
		Permitted or Prot./Perm.	Left-turn-opposed	Congestion, dense traffic, incapable of stop
4.0 to end of green	2	Any	Right-angle	Unnecessary delay, inattentive

The information in Table 3 indicates that most of the violations occur in the first 4.0 s of red. If the frequency of violations is excessive relative to other intersections, the violations are most likely caused by congestion, dense traffic streams, or conditions that make it difficult for drivers to stop. Also, it is likely that permitted left-turn movements will be most at risk to experience conflict. These findings suggest that countermeasures that address violations in the first few seconds of red are most likely to reduce left-turn-opposed crashes, should such crashes be over-represented at the treated intersection.

THE DRIVER

This section characterizes the red-light-running driver. Topics addressed include the cause of the red-light violation (from the driver's point of view) and some characterizations of these causes in terms of whether they are associated with avoidable and/or intentional violations.

Causes of Red-Light Violations

Several thousand crash reports were collected and reviewed by Bonneson et al. (7) for the purpose of identifying red-light-related crash trends and costs. A review of these reports revealed that several reasons were frequently cited by drivers involved in red-light-related crashes. The more frequently cited reasons are summarized in Table 4. They reflect some generalization by the authors and are intended to illustrate the range of causes typically cited.

Table 4. Red-Light Violation Characterizations and Possible Causes.

Cause Category	Cause of Red-Light Violation [1]	Violation Type	Driver Intent	Time of Violation
Unnecessary delay	Disregard for red (unnecessary delay)	Avoidable	Intentional	Any time during red
	Judged safe due to low conflicting volume			
Congestion, dense traffic	Congestion or excessive delay			First few seconds of red
	Judged safe as driver < 2 s ahead violated the red			
	Expectation of green when in platoon			
Incapable of stop	Downgrade steeper than expected	Unavoidable		
	Speed higher than posted limit			
	Unable to stop (yellow seemed too short)			
Inattentive	Unexpected, first signal encountered		Unintentional	Any time during red
	Distracted and did not see traffic signal			
	Not distracted, just did not see signal (e.g., drowsy)			
	Restricted view of signal due to sight obstruction			
	Confusing signal display (looked at wrong signal)			

Note:
1 - Causes listed reflect the driver's point of view.

Many of the "causes" listed in Table 4 are self-explanatory; however, a couple are worthy of added clarification. "Judged safe as driver < 2 s ahead violated the red" means that the driver has judged it safe to run the red indication because he or she is closely following (i.e., has a headway less than 2.0 s with) another red-light runner. This situation occurs most frequently when a succession of vehicles pass through the intersection after the onset of red. This sequence of red-running vehicles is quite visible to drivers in conflicting movements and rarely leads to a crash. "Expectation of green when in platoon" means that the driver was traveling along a street with a coordinated signal system. Drivers in a through movement platoon tend to develop an expectation of continued receipt of the green indication as long as they stay in the platoon. Such drivers are prone to run the red indication in order to stay within the platoon.

Characterizations of a Red-Light Violation

Shown in Table 4 are several characterizations of the red-light violation. These characterizations include "violation type" and "driver intent." Violation type describes whether the violation was perceived as "avoidable" or "unavoidable." Driver intent describes whether the violation was "intentional" or "unintentional."

Avoidable Violations

An "avoidable" violation is committed by a driver who believes that it is possible to safely stop but decides it is in his or her best interest to run the red indication. Frequent avoidable red-light violations may be an indication of congestion, dense traffic, or unnecessary delay. Avoidable violations are also characterized as "intentional."

Congestion. Violations due to congestion reflect driver frustration after experiencing lengthy delay. The violation is likely to occur in the first few seconds of red. Short of significant capacity improvements, this violation may be most effectively treated by enforcement.

Dense Traffic. Violations attributed to "dense traffic" are likely found in coordinated signal systems where the progression band is constrained at its trailing edge by the signal timing of the subject approach. In this situation, drivers in platoons have an expectation of continued receipt of green because they are in the progression band and are "surprised" at the onset of yellow. This violation is likely to occur in the first few seconds of red. Signal timing modifications may mitigate this problem. Enforcement may also be appropriate if engineering countermeasures are ineffective.

Unnecessary Delay. Violations due to "unnecessary delay" reflect a perception that there is: (1) no need to stop because the conflicting movements are vacant, or (2) previous stops led to lengthy waits at the intersection that seem unnecessary because there were numerous breaks in the crossing traffic during which the green could have been returned to the waiting driver. This perception often leads to a degradation in driver respect for traffic signals. The violation can occur any time during the red. Signal removal or timing modifications may mitigate this problem. Enforcement may also be appropriate if engineering countermeasures are ineffective.

Unavoidable Violations

An "unavoidable" violation is committed by a driver who either: (1) believes that he or she is unable to safely stop and consciously decides to run the red, or (2) is unaware of the need to stop. Frequent unavoidable violations may be caused by driver inability to stop or inattention. The former "cause" represents an intentional violation; the latter represents an unintentional violation.

Incapable of Stop. This violation occurs when a driver sees the yellow signal indication but determines that it is impossible to stop safely before reaching the intersection. This determination could be the result of a lengthy reaction time to the yellow onset, steep downgrade, high speed, or a low tolerance for high deceleration. Frequent violations may be an indication of an inconspicuous yellow indication, inadequate yellow interval duration, or excessive speed. This violation is likely to occur in the first few seconds of red. Signal timing modifications or improvements to enhance the conspicuity of the yellow indication should mitigate this problem.

Inattentive. This violation occurs when the driver is inattentive and does not see the signal (or sees it too late to respond appropriately). Frequent violations may be an indication of poor signal visibility or conspicuity. This violation can occur at any time during the red. Improvements to signal visibility or conspicuity should mitigate this problem to some degree.

THE CRASH

This section examines the red-light-related crash. The objectives of this examination are to: (1) provide guidance on how to determine the actual number of such crashes that occur, (2) provide guidance on the analysis of crash data to determine if a specific location is experiencing an excessive number of crashes, and (3) provide guidance on the selection of countermeasures based on clues in the crash distribution. Each of these objectives is addressed in sequence in the following three subsections.

Red-Light-Related Crash Characteristics

This section examines the issues associated with the identification of red-light-related crashes in public agency crash databases. These issues relate to: (1) the challenges of using the available attributes in these databases to accurately identify crashes caused by red-light violations, and (2) the extensive under-reporting of the less severe crashes allowed by most agencies. Also examined is the severity of red-light-related crashes, relative to other crashes. Finally, the societal cost implications of these crashes is examined.

Distribution of Red-Light-Related Crashes

The distribution of red-light-related crashes by "crash type" is provided in Table 5. This distribution represents 502 red-light-related crashes that occurred at 70 signalized intersections in three Texas cities (crashes on the intersection approaches were not included) (*7*). The red-light relationship of each crash was verified by manually reviewing the printed officer reports for more than 3300 crashes. The distribution of crashes by "crash type" is consistent with a generally recognized belief that the two most common crash types associated with red-light violations are the right-angle and the left-turn-opposed crash. The latter crash type occurs when a left-turning vehicle collides with an oncoming vehicle from the opposite direction.

Table 5. Red-Light-Related Crash Distributions.

Crash Type	Distribution [1], %	RLR Index [2]	First Contributing Factor	Distribution [1], %	RLR Index [2]
Right-angle	84	2.8	Not indicated (blank)	2	1.0
Head-on	0	0.0	Disregard stop and go signal	64	3.2
Left-turn-opposed	15	0.3	Disregard stop sign or light	15	3.0
Rear-end	0	0.0	Driver inattention	4	0.7
Sideswipe	0	0.0	Failed to control speed	1	0.1
Other two-vehicle	0	0.0	Failed to yield - turning left	2	0.1
Single-vehicle	1	0.2	Other	12	0.5
Total:	100	--	Total:	100	--

Notes:

1 - Data based on a review of the officer reports for 502 red-light-related crashes at 70 signalized intersections in three Texas cities (*7*).

2 - RLR (red-light-running) Index: ratio of distribution percentage shown to the percentage that the associated crash type (or first contributing factor) is represented in the total of all intersection crashes. The likelihood that a crash of a specified type (or first contributing factor) is red-light-related increases with the value of the index.

The distribution of red-light-related crashes by "first contributing factor" is also provided in Table 5. The first contributing factor is the first factor recorded on the officer report. As a matter of routine, the first factor an officer lists on the report is the one he or she believes most likely contributed to the crash. The information in Table 5 indicates that the first contributing factor listed for a majority of red-light-related crashes is "disregard of stop and go signal." Table 5 also indicates that many officers identify red-light-related crashes at signalized intersections as "disregard stop sign or light." It is not known if this is a mistake on the part of the officer completing the form; however, it is recommended that the analyst consider both "disregard" factors when attempting to identify red-light-related crashes at signalized intersections.

The "RLR Index" in columns 3 and 6 of Table 5 provide an indication of the degree to which each attribute is associated with red-light-related crashes. This index is the ratio of two percentages. The percentage in the numerator is the percentage each crash type (or first contributing factor) is of the total red-light-related crashes (i.e., the percentage listed in column 2 or 5). The percentage in the denominator is the percentage each crash type (or factor) is of the total of all crashes that occurred at the intersection (regardless of whether or not they are red-light-related). The index value of 2.8 in column 3 indicates that the chance that a crash is red-light-related increases by a factor of 2.8 if it is known that the crash is a right-angle crash.

The index values associated with the two "disregard" factors are the largest of those listed in Table 5 (columns 3 and 6 combined). This finding indicates that a search for red-light-related crashes in a large crash database would yield the most representative database if the pool of all crashes was screened to exclude all crashes except those with a first contributing factor of "disregard..."

Identifying Red-Light-Related Crashes

In preparing crash reports (or entering them into an electronic database), most cities and states do not flag crashes as being caused by a red-light violation. Hence, the most accurate method for identifying red-light-related crashes is through a manual review of the officer crash reports (with special focus on the officer narrative and diagram). Unfortunately, this method is not efficient for the review of large databases. This section describes a screening technique that can be used with large databases to obtain a reasonably accurate database of red-light-related crashes.

A variety of screening techniques are possible. All rely on the use of one or more crash attributes to identify most (if not all) red-light-related crashes, without the unknowing inclusion of "mislabeled" crashes. Mislabeled crashes are those that satisfy the screening criteria but are not red-light-related. The most often used screening attributes are "right-angle crash," "disregard stop and go signal," or both.

Based on an analysis of alternative screening attributes, Bonneson et al. (*7*) recommended that engineers use the following attributes to screen crash databases for red-light-related crashes:

- traffic control type: "stop and go signal,"
- intersection relationship: "at" the intersection (i.e., not on the intersection approach), and
- first contributing factor: "disregard stop and go signal" or "disregard stop sign or light."

The first attribute is not needed if crashes are screened for intersections known to be signalized. However, if a crash database for an entire jurisdiction (inclusive of crashes at intersections and segments) is being screened, then the first attribute is needed.

Crash Severity and Cost

Red-light-related crashes have a high cost to those involved. Such crashes tend to be more severe than the "typical" crash and, as a result, lead to significant cost to those injured in terms of medical bills, legal fees, and lost income. Table 6 tabulates the total cost of red-light-related crashes borne by motorists in Texas, as estimated by Bonneson et al. (*7*). The data in this table indicate that crashes associated with red-light-running have a societal cost to Texans of about $2.0 billion each year. The average cost of a red-light-related crash is estimated to be $52,600.

The crash database prepared by the Texas Department of Public Safety (DPS) indicates that property-damage-only (PDO) crashes represent 28 percent of all red-light-related crashes. However, an analysis by Bonneson et al. (*7*) of crash data from several Texas cities and FARS indicated that PDO crashes are under-reported in the DPS database. Their analysis indicated that PDO crashes truly account for about 50 percent of all red-light-related crashes. Thus, the number of PDO crashes obtained from the DPS database was increased such that the resulting distribution of crashes reflected 50 percent PDO crashes. This distribution is shown in Table 6.

Table 6. Cost of Red-Light-Related Crashes in Texas for 2003.

Severity [1]	Crash Cost [2]	Annual Crashes	Crash Dist., %	Annual Injuries	Annual Cost
K	3,237,000	121	0	133	$431,000,000
A	224,000	1439	4	2047	$458,000,000
B	45,000	5493	15	8987	$404,000,000
C	24,000	11,798	31	24,802	$595,000,000
PDO	2500	18,851	50	0	$94,000,000
Total:	--	**37,702**	**100**	**35,969**	**$1,982,000,000**
Average Cost per Red-Light-Related Crash:					**$52,600**

Notes:

1 - K: fatal injury. A: Incapacitating injury. B: Non-incapacitating injury. C: Possible injury. PDO: property-damage-only crash.

2 - Costs from *Motor Vehicle Accident Costs* (*19*) and updated to 2003. Costs for K, A, B, and C crashes have units of "$ per person injured or killed;" those for PDO crashes have units of "$ per vehicle."

Factors Correlated with Red-Light-Related Crash Frequency

This section describes several factors that are correlated with red-light-related crash frequency. The factors vary depending on the spatial extent of the evaluation unit (i.e., area-wide or local intersection). As a result, the discussion of these factors is separated into two sections based on the evaluation unit.

Area-Wide Factors

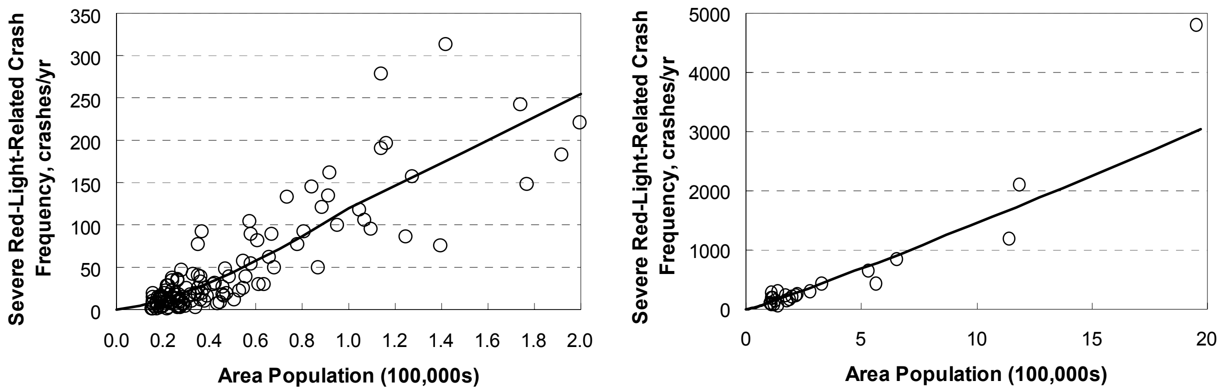
On an area-wide basis, there is a logical relationship between crash frequency and population. Areas (i.e., county, city, municipality, town) with higher populations have more red-light-related crashes. The relationship between population and severe crashes is shown in Figure 5, as developed by Bonneson and Zimmerman (*8*) using 4 years of crash data for each of 135 Texas cities. Severe crashes are defined as those crashes where an injury or fatality are reported.

Each data point in Figure 5 represents one Texas city. The trend line shown in this figure represents a "best fit" to the data. It should not be inferred from this figure that "population" is a cause for red-light-related crashes. Rather, population is a surrogate for the driver behavior, traffic conditions, road network capacity, and level of enforcement present in each city. The scatter of data about the trend line indicates that some cities have fewer red-light-related crashes than others, given similar populations. Presumably, those cities experiencing crash frequencies that are well above the trend line would realize the most benefit (in terms of reduced crashes) from the implementation of a program of red-light-running treatment.

Local Intersection Factors

On an individual intersection approach basis, several factors are correlated with red-light-related crashes; they include: traffic volume, speed, yellow interval duration, and intersection width.

In general, the effect of these "approach-based" factors on crashes is the same as that on violations, as summarized previously in Table 2.



a. Population between 20,000 and 200,000. **b. Population over 200,000.**

Figure 5. Relationship between Area Population and Severe Red-Light-Related Crashes.

Traffic Volume. The frequency of red-light-related crashes is generally recognized to increase with traffic volume. The relationship found by Bonneson and Zimmerman (*8*) is shown in Figure 6. It is based on 3 years of crash data for each of 181 intersection approaches in three Texas cities. The trend line indicates that the frequency of crashes on an intersection approach increases with the average annual daily traffic volume (AADT) of the approach leg. The curved nature of the trend line is a reminder that crashes are not linear with respect to volume and, as such, crash rates can be misleading when used to evaluate the safety of a group of intersections.

Yellow Duration. As noted in a previous section, the yellow interval duration is generally recognized as a key factor that affects the frequency of violations occurring just after the onset of the red indication. Logically, it follows that yellow interval duration should also affect red-light-related crash frequency, especially those crashes occurring in the first few seconds of red.

The validity of Equation 1 was evaluated by Bonneson and Zimmerman (*8*) using crash data. They estimated a "yellow interval difference" by subtracting the yellow interval computed with Equation 1 from the observed yellow interval at 181 intersection approaches in three Texas cities. The relationship between this difference and the observed approach crash frequency is shown in Figure 7. The trend line in this figure indicates that there is a trend toward fewer red-light-related crashes when the observed yellow duration is longer than the computed duration (and possibly more crashes when it is shorter than the computed duration). It should be noted that none of the approaches studied had a yellow indication longer than 5.3 s.

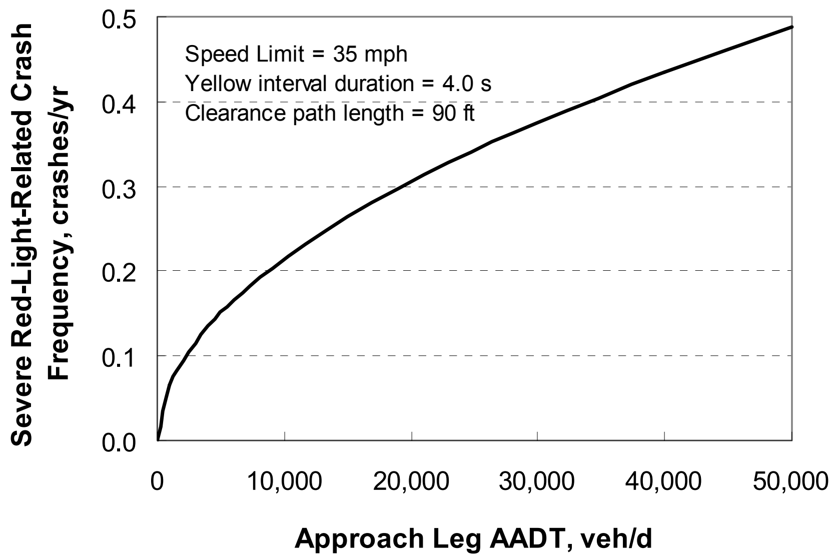


Figure 6. Relationship between Traffic Volume and Red-Light-Related Crashes.

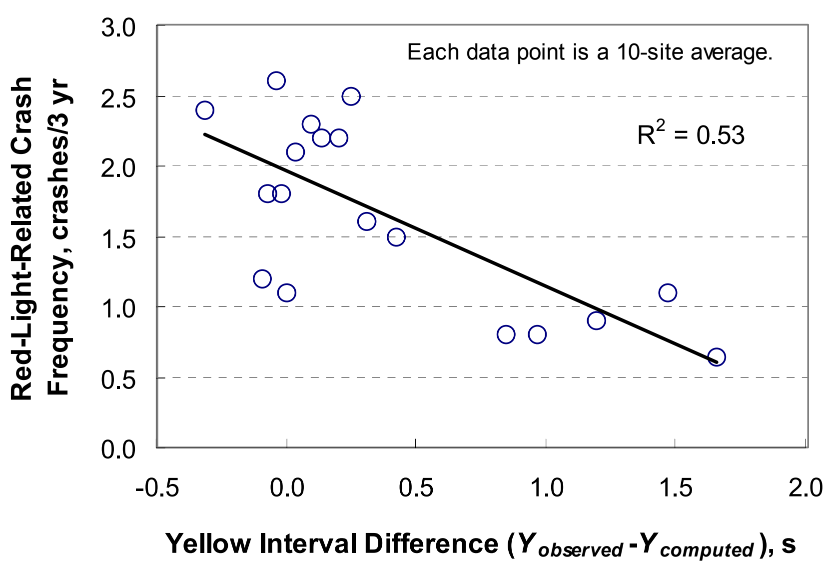


Figure 7. Effect of Yellow Interval Difference on Red-Light-Related Crashes.

Time of Crash

This section examines the characteristics of red-light crashes as they relate to the duration of time the signal indication was red prior to the violation (i.e., "time-into-red"). This time indirectly provides important clues to the selection of countermeasures that will be effective at reducing red-light violations and related crashes.

To evaluate the relationship between time-into-red and crashes, Bonneson and Zimmerman (*8*) obtained data for 63 crashes captured by red-light enforcement cameras. An analysis of these data indicated that red-light-related crashes that occur within the first few seconds of red are almost always between permitted left-turning vehicles and opposing through vehicles (i.e., left-turn-opposed crashes). In these situations, the left-turning driver is attempting to clear the intersection at the end of the adjacent through phase and an opposing through driver runs the red indication (this scenario does not exist when protected-only left-turn phasing is provided). After the first few seconds of red, the right-angle crash type is the more common red-light-related crash. The distribution of these crashes by time-into-red is shown in Figure 8.

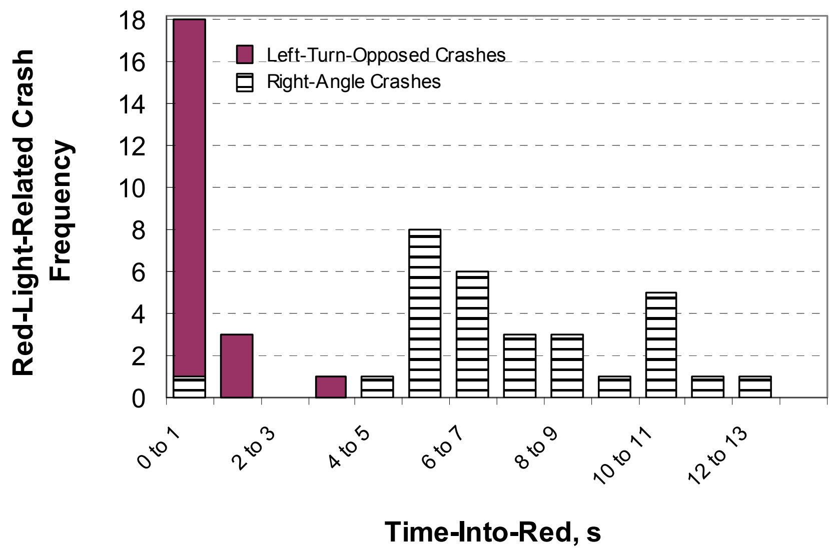


Figure 8. Relationship between Time-Into-Red and Red-Light-Related Crashes.

The trends in Figure 8 confirm the tendency of left-turn-opposed crashes to occur in the first few seconds of red. With one exception, all of the right-angle crashes occurred after 5.0 s or more of red. Closer inspection of this one crash revealed that it occurred very late at night with *both* vehicles simultaneously violating their respective red indications.

The trends in Figure 8 indicate that the frequency of red-light-related crashes tends to be highest in the first couple of seconds of red due to permitted left-turn activity. It is relatively high again between 5.0 and 11.0 s due to the discharge of queued vehicles during the conflicting signal phase. Crash frequency declines thereafter, reaching a nominally small but constant frequency after about 15 s of red due to the randomness of cross street arrivals and red-light violators.

Summary of Crash Characteristics

The points made in this section are summarized in Table 7 as they relate to a large majority of crashes. The information in this table is consistent with that previously offered in Table 3. Specifically, over-represented left-turn-opposed crashes are a likely indication that the violations that occur in the first few seconds of red should be the focus of countermeasure selection. These violations are most likely related to congestion, dense traffic streams, or conditions that make it difficult for drivers to stop. On the other hand, if right-angle crashes are over-represented at the intersection but left-turn-opposed crashes are not over-represented, then the violations occurring later into the red should be the focus of countermeasure selection. These violations are most likely related to driver desire to avoid unnecessary delay or the inability of drivers to detect the controlling signal indications in a timely manner.

Table 7. Relationship between Time of Crash and Crash Characteristics.

Time of Crash	Left-Turn Phasing	Most Likely Crash	Cause of Violation Leading to Crash
Early in red	Protected-only	None	--
	Permitted or Prot./Perm.	Left-turn-opposed	Congestion, dense traffic, incapable of stop
Any time in red	Any	Right-angle	Unnecessary delay, inattentive

COUNTERMEASURES

This section describes countermeasures that are likely to reduce red-light violations or related crashes. Initially, engineering countermeasures are described. These countermeasures typically address modifications to the signal operation, the motorist information system associated with the signal, or the intersection geometry. Next, the public awareness campaign as a countermeasure is described. Finally, enforcement countermeasures are described.

Engineering Countermeasures

Table 8 lists most of the engineering countermeasures cited in the literature as having some ability to reduce red-light violations, related crashes, or both. The reported effectiveness of many of these factors is also presented in the table. These reduction factors reflect the findings from several research projects, as identified in the last column of the table. The effectiveness of education and enforcement are also shown and will be discussed in subsequent sections.

A reduction factor is not provided for some countermeasures listed in Table 8. Any such omission reflects the fact that some countermeasures have not been formally studied. Nevertheless, their ability to reduce red-light violations and related crashes is intuitive and widely recognized, especially when operations or visibility are improved by their implementation. A fairly detailed discussion of many of these countermeasures is provided in the *Toolbox* (*9*).

Table 8. Red-Light Violation Countermeasure Effectiveness.

Category	Countermeasure	Reported Reductions, % [1, 2, 3]		
		Violations	Crashes	Reference [4]
Traffic char.	Reduce approach speed by 5 mph	30	25 to 30	*8*, *8*
Signal operation	Increase signal cycle length by 10 s, if *v/c* ratio < 0.60	15	--	*8*
	Increase yellow interval duration by 0.5 s	40	20 to 25	*8*, *8*
	Provide green extension (advance detection) [5]	65	--	*23*
	Add protected-only left-turn phasing [6]	--	70	*22*
Motorist information	Improve signal visibility via better signal head location	--	--	--
	Improve signal visibility via additional signal head	--	<u>47</u>	*20*
	Improve signal visibility by clearing sight lines to signal	--	--	--
	Improve signal conspicuity by upgrading to 12" lenses	--	<u>47</u>	*20*
	Improve signal conspicuity by using yellow LEDs	13	--	*14*
	Improve signal conspicuity by using red LEDs	--	--	--
	Improve signal conspicuity by using back plates	25	<u>32</u>	*8*, *20*
	Improve signal conspicuity by using dual red indications	--	<u>33</u>	*20*
	Add advance warning signs (no active flashers) [7]	--	<u>44</u>	*20*
	Add advance warning signs with active flashers [7]	29	--	*21*
Traffic operation	Reduce delay through re-timing if *v/c* ratio > 0.70	10 to 50	--	*8*
	Reduce unnecessary delay through signal re-timing	--	--	--
	Improve signal coordination [8]	--	--	--
Geometry	Remove unneeded signals	100	100	--
	Add capacity with additional lanes or turn bays	--	--	--
Education	Implement public awareness campaign	--	--	--
Enforcement	Implement officer enforcement program [9]	16 (--)	-- (6.4)	*25*, *8*
	Implement camera enforcement [10]	40 (--)	36 (10)	*24*, *3*

Notes:

1 - Values listed are for the specific intersection approach to which the countermeasure is applied.

2 - Values in parentheses apply to the entire city or area influenced by the enforcement program.

3 - <u>Underlined</u> factors are based on a simple before-after study without comparison. Hence, values listed may overstate the true effect of the countermeasure. They are shown only to illustrate the potential benefit of the countermeasure.

4 - When two references are listed, they are listed in the order of "violation reference," "crash reference." Numbers in italics identify published reports listed in Chapter 4.

5 - Green extension using advance detection should reduce red-light violations provided it does not max-out frequently.

6 - Crash reduction factor applies only to left-turn-opposed crashes.

7 - Active flashers accompany the advance warning sign and are activated during the last few seconds of green.

8 - Improvements to signal coordination will be most effective in reducing red-light violations if they result in: (1) lower delay, (2) longer cycle lengths, and (3) progression bands that are not constrained by the end of the phase such that platoons traveling through the intersection are repeatedly caught by the change to red.

9 - A citywide officer enforcement program should emphasize the enforcement of intersection traffic control violations. Enforcement should be repeated for 1 or 2 hours each day to retain its effectiveness. The 16 percent reduction listed is based on 28 percent reduction for continuous officer presence but adjusted to represent a daily average for the situation where enforcement is applied only 1 hour each day. Adjustment is based on reported data (*25*).

10- Camera enforcement is generally recognized to result in an increase in rear-end crashes; however, most studies indicate that this increase does not negate the greater reduction in red-light-related crashes (*26*).

"--" - data not available.

Public Awareness Campaign

There are generally three main themes of an effective public awareness campaign. These themes and their associated objectives are:

- Educate drivers on red-light-running hazards (objective: stimulate a voluntarily change in the driver's behavior).
- Use the media to open communications between elected officials and the public about the extent of the problem and the need for treatment (objective: gain public support for treatment).
- Provide advance warning that additional enforcement is being implemented to improve traffic safety (objective: minimize negative public reaction and avoid accusations of deception).

A wide range of methods are often used to convey the campaign message and heighten motorist awareness. Some of the more commonly used methods include: posters, mass mailings, hand outs, electronic media commercials, billboards, warning signs, and bumper stickers (*27*). Methods less commonly used, but recommended, include: (1) outreach efforts to schools, driver education, and community groups; (2) maintenance of a website with program information and answers to frequently-asked questions; and (3) regular surveys of public opinion, support, and awareness of the program.

A review of the literature indicates that the effectiveness of public awareness campaigns is rarely quantified and reported. This limitation is likely due to the fact that campaigns are almost always conducted in parallel with heightened enforcement. In this situation, it is difficult to separate the effect of the public awareness campaign from that of the enforcement program.

Enforcement Countermeasures

This section describes the enforcement programs being used to address red-light-related safety problems. Initially, the various goals of these programs are reviewed. Then, the characteristics of the officer enforcement program and the camera enforcement program are described. Finally, the effectiveness of these two programs are synthesized from findings reported in the research literature.

Program Goals

The need to establish specific goals for an enforcement program is an important, and early, step in the process of treating problem intersections. These goals provide a benchmark by which program success can be measured. They should be based on achieving a level of reduction in crashes or violations that: (1) is cost-effective in its use of enforcement, (2) recognizes that a small number of violations will always occur, and (3) is reasonable and acceptable to both the engineer and the public. The use of citation data as a measure of program effectiveness should be avoided because the number of citations issued in a period of time is strongly correlated with enforcement strategy and effort expended (i.e., productivity). It is not a strong indicator of a change in driver behavior.

There is little doubt that increasing enforcement will reduce red-light violations and related crashes. However, it is also likely that there is a point of diminishing returns where further increases in enforcement effort bring little additional safety benefit. In this context, the cost of providing sufficient enforcement to eliminate red-light violations could exceed the financial resources of most cities. Even if these resources were available, it could be reasonably argued that they could be more cost-effectively applied to other road safety problems. This argument suggests that elimination of red-light violations may be an unreasonable goal for most cities.

Types of Enforcement

Enforcement activities used to treat safety problems can be categorized as one of two types: officer and camera. Typical methods by which each of these two types are used to deal with red-light violations is described in this section.

Officer Enforcement. Many enforcement agencies use a team enforcement technique to address red-light violations and other intersection traffic control violations. With this technique, one officer is stationed upstream of the signalized intersection, and a second officer is located downstream of the intersection. When the "upstream" officer observes a violation, he or she sends a radio message to the "downstream" officer, who then proceeds to stop and cite the violator. This technique is generally regarded as successful in reducing violations but is labor-intensive.

As an alternative to team enforcement, some jurisdictions use enforcement lights. An enforcement light can be attached to the signal head or to the signal mast arm. The latter type of installation is shown in Figure 9. These lights are illuminated while the traffic signal indication is red. They allow a single officer stationed downstream of the signal to observe vehicles entering the intersection and note whether the signal indication is red. Enforcement lights eliminate the need for team enforcement and, therefore, have a lower operating cost.

Camera Enforcement. Red-light enforcement cameras are typically deployed upstream of, and facing toward, the intersection. Figure 10 illustrates a typical camera location. Pavement sensors detect the speed of the vehicle as it crosses the stop line. If its speed exceeds a specified threshold value during the red indication, it is assumed that it is in violation, and the camera takes a sequence of two photos of the vehicle. A red-light camera at a typical intersection can cost from \$50,000 to \$60,000, with installation adding from \$10,000 to \$25,000 (*28*). Operating costs are reported by Maccubbin et al. (*29*) to be in the vicinity of \$5000 per month.

A red-light violation may be treated as a civil or criminal offense, depending on the relevant state statutes (it is a criminal offense in Texas). Tickets for civil offenses can be sent by mail to violators. Prosecution of the violation as a criminal offense requires proof that the individual committed the offense (e.g., a frontal photograph of the driver at the time of the violation) and is adjudicated in a criminal court with a fine levied by a judge. Fines can range from \$50 to \$270 (*29*).

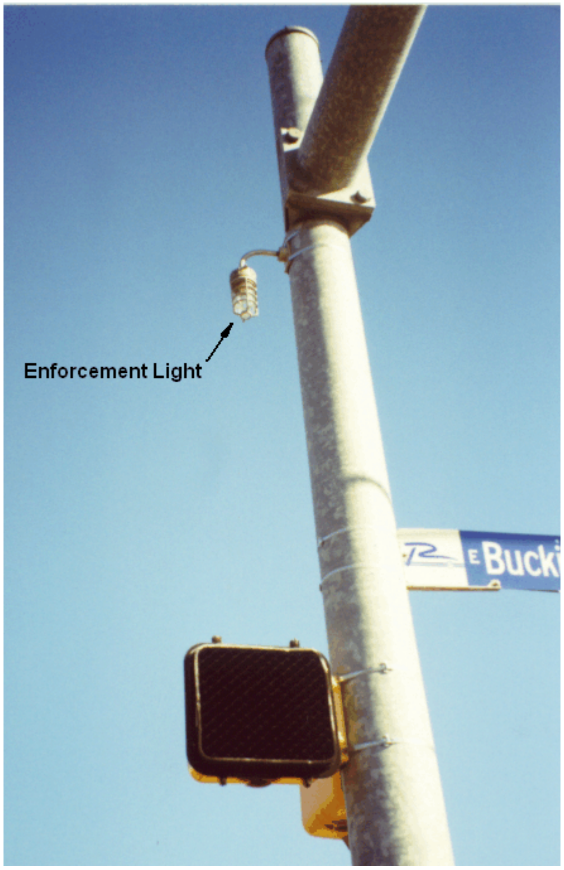


Figure 9. Enforcement Light. **Figure 10. Enforcement Camera.**

A short period of time is often allowed to lapse between the start of red and camera activation. This time is referred to herein as the "grace period." A recent review of grace period values used throughout the world revealed that 0.5 s is the "international standard" and that 0.3 s is commonly used in the U.S. (*3*). A similar review by Milazzo et al. (*4*) of U.S. practice indicated a range of 0.1 to 0.3 s. They recommended the use of a 0.4-s grace period, with a possible increase for intersection approaches having significant downgrade.

Program Effectiveness

Officer Enforcement Effectiveness. Officer enforcement is generally recognized as having an immediate, positive effect of reducing red-light violations. The extent of this impact varies depending on whether the officer (and vehicle) is visible to potential offenders (i.e., overt/visible vs. covert/hidden deployment). The impact also varies depending on whether the enforcement is targeting specific, problem locations or it is deployed at random times and locations (i.e., targeted vs. random enforcement tactic).

Following a review of the literature, Bonneson et al. (*7*) concluded that: (1) targeted officer enforcement of specific intersections reduces crashes by only a few percentage points, (2) covert deployments are largely ineffective in reducing violations, and (3) the reductions due to targeted enforcement are often short-lived (i.e.,violation rates return to pre-enforcement levels within a day or so after the officer leaves the intersection). The more successful officer enforcement efforts were found to be those that: (1) were implemented on an "area-wide" basis with innovative enforcement strategies (e.g., visible officer presence, random location selection), and (2) included a public awareness campaign (e.g., media advertisement, public meetings, posters, etc.).

Bonneson and Zimmerman (*8*) evaluated the effectiveness of an "area-wide" enforcement program undertaken by each of eight Texas cities. These cities participated in TxDOT's Selective Traffic Enforcement Projects - Intersection Traffic Control (STEP-ITC) program. In addition to area-wide enforcement, the program included a public awareness campaign. A before-during analysis was conducted using crash data for 2 years before the program was started and 1 year during which it was implemented. They found that red-light-related crashes were reduced 6.4 percent as a result of city implementation of this enforcement program.

Camera Enforcement Effectiveness. The effectiveness of camera enforcement at reducing red-light violations has been widely reported. A review of this literature by Bonneson et al. (*7*) indicates that camera enforcement reduces red-light violations at the treated intersection between 40 and 59 percent. Camera enforcement reduces red-light-related crashes between 20 and 36 percent at the treated intersection. However, rear-end crashes have been found to increase between 20 and 37 percent at these intersections. A comprehensive study of the impact of camera enforcement on total crashes (including right-angle and rear-end crashes) found that camera enforcement reduced total crashes by 7 percent on a citywide basis (*26*).

Several studies have examined the effect of camera enforcement on other, non-camera-enforced intersections in the same city. Data reported by the California state auditor indicated that the application of camera enforcement at selected intersections in six cities coincided with a 10 percent reduction in red-light-related crashes on a citywide basis (*3*).

CHAPTER 3. PROCEDURE FOR EVALUATING POTENTIAL PROBLEM LOCATIONS

OVERVIEW

This chapter describes a procedure for treating safety problems associated with red-light-running. The procedure uses an engineering study process to identify the nature and extent of the red-light problem and then uses a sequence of engineering, education, and enforcement-based countermeasures to treat the problem. An overview of the procedure is provided in this section. Procedures for local intersection and area-wide evaluation are provided in subsequent sections.

TREAT Software

The analytic procedures described in this chapter have been implemented in a spreadsheet to facilitate their application. This spreadsheet is referred to herein as TREAT. It is an acronym for Texas Red-light-running Evaluation and Analysis Tool. The background for the development of the equations in this spreadsheet is documented in a report by Bonneson and Zimmerman (*8*).

The "Welcome" screen for TREAT is shown in Figure 11. When the button in the bottom center of the screen is selected, the analyst is taken to a menu sheet where the type of evaluation is specified (i.e., area-wide or local intersection). Once this selection is made, the analyst is sent to the appropriate analysis spreadsheet.

Defining the Scope of the Evaluation

A fundamental question in the evaluation of red-light-related problems is, "What is the evaluation unit?" This unit can be a specific intersection approach or a large area within (if not all of) the analyst's jurisdiction. The type of countermeasures selected to treat a red-light problem should be based on the evaluation unit. Some countermeasures are more appropriate for application at a specific intersection (e.g., "remove unneeded signal") while others may be more appropriate for application to an entire area (e.g., public awareness campaign).

Oftentimes, the choice of evaluation unit is clear based on the manner in which the red-light-problems are made known to the engineer. However, if the engineer is uncertain whether the problem is area-wide or intersection-specific, the more conservative decision is to assume that the evaluation unit is the entire jurisdiction. The engineer should proceed with this assumption until the evaluation indicates that the problem does not exist on an area-wide basis.

An exception to the aforementioned guidance on selection of an evaluation unit applies to jurisdictions that are relatively small (i.e., less than 20,000 persons). The number of signalized intersections in small jurisdictions is likely to be sufficiently low that the individual intersections can be evaluated with reasonable effort and with treatments tailored for each intersection.

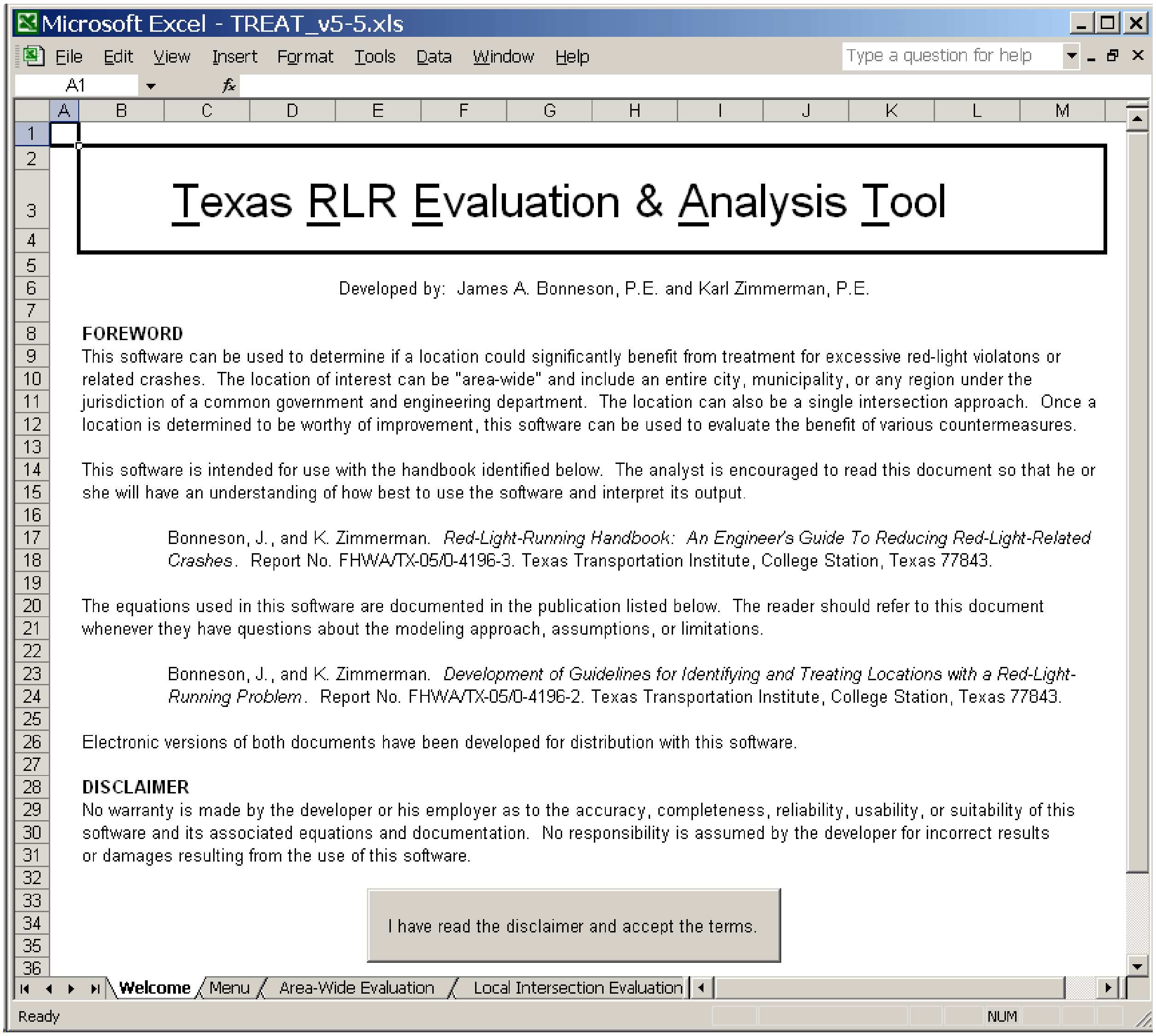


Figure 11. TREAT Spreadsheet Welcome Screen.

The evaluation procedure for each evaluation unit is automated in TREAT. It requires red-light-related crash data for one or more of the most recent years for which such data are available. To determine if an area-wide problem exists, crash data for the subject jurisdiction are compared with the average annual crash frequency of similarly sized jurisdictions. If the subject jurisdiction has significantly more crashes than other jurisdictions of similar size, then it is identified as having potential for benefit from treatment.

To determine if a specific intersection approach has a red-light-related safety problem, crash data for that approach are compared with the average annual crash frequency of similar intersection approaches. If the subject approach has significantly more crashes than similar approaches, then it is identified as having potential for benefit from treatment.

Serial Versus Parallel Treatment Approaches

The best approach in dealing with red-light-related safety problems is generally recognized as one that combines engineering, education, and enforcement. However, there is some debate as to how and when to use countermeasures in any one of these three categories. Many agencies prefer a "serial" treatment approach where engineering countermeasures are considered first, followed by education (via a public information campaign), and then enforcement (*3*). The alternative to the serial approach is the "parallel" approach. It applies countermeasures in each category at the same time. The advantages of each approach are discussed in the remaining paragraphs of this subsection.

The serial approach to countermeasure implementation is shown in Figure 12. The first step in this approach is to confirm that a problem exists. Evidence of a problem might be an exceptionally large frequency of red-light violations, related crashes, or both. Next, the engineer considers engineering countermeasures before resorting to enforcement. If it is found that engineering countermeasures are not effective or feasible, then officer enforcement is tried. Camera enforcement is only considered as a last resort and then only when accompanied by a public information campaign and follow-up evaluation. The serial approach is recommended in this handbook.

Some engineers believe that a parallel treatment approach that combines engineering, education, and enforcement has a more immediate and significant impact on red-light problems than a serial approach. This approach was recently recommended in a published guideline document describing a 10-step process for implementing a red-light camera program (*27*).

One benefit of the parallel approach is that a wide array of resources is immediately brought to bear on one traffic problem. The disadvantages of this approach are: (1) its implementation is expensive (relative to a serial approach), and (2) if a reduction in crashes is realized, it is very difficult to determine whether engineering countermeasures alone could have effectively treated the problem. If this effectiveness were known, it would be possible for an agency to optimize the cost-effectiveness of its treatment program and possibly fund it for a longer period of time.

A Framework for Evaluation

A framework is described in this section that explains the steps required to exercise the serial treatment approach. This framework consists of a series of steps that can be followed to confirm that a problem exists, diagnose its likely cause (or causes), and treat it through application of countermeasures.

Serial Approach for Area-Wide Treatment

1. Conduct a traffic engineering study to verify the extent and cause of the problem. Also, verify that it is an "area-wide" problem.
2. If feasible, implement engineering countermeasures on an area-wide basis.
3. If engineering countermeasures are unsuccessful, consider an area-wide implementation of officer enforcement focused on intersection traffic control violations.
4. If previous countermeasures are unsuccessful or infeasible, consider camera enforcement.
   a. Ensure public safety is the primary goal when making financial arrangements.
   b. Conduct a public information campaign regarding the camera enforcement program.
   c. Implement systems at intersections with the highest potential for crash reduction.
   d. Monitor system effectiveness to verify benefits.

Serial Approach for Local Intersection Treatment

1. Conduct a traffic engineering study to verify the extent and cause of the problem. Also, verify that it is a "local" problem.
2. If feasible, implement engineering countermeasures at the intersection.
3. If engineering countermeasures are unsuccessful, consider implementation of a visible, targeted officer enforcement activity that focuses on traffic control violations at the subject intersection.
4. If previous countermeasures are unsuccessful or infeasible, consider camera enforcement at the subject intersection.
   a. Monitor system effectiveness to verify benefits.

Figure 12. Serial Approach to Treating Red-Light-Related Safety Problems.

The framework is generic to both area-wide and local intersection evaluation. It includes the following tasks:

- Gather information,
- Confirm extent of problem,
- Identify causes and countermeasures,
- Evaluate countermeasures, and
- Implement selected countermeasures and monitor.

The general activities associated with each task are described in the remainder of this subsection.

Gather Information

This task follows the initial notification of a possible red-light-related problem. This notification could come from a variety of sources, including: citizens (possibly via an elected official), peace officers, or the traffic engineering staff. Following this notification, the engineer would gather the necessary information to make a preliminary assessment as to the extent of the problem and whether it requires a solution. Information sources solicited at this step include: crash history, insight of local enforcement officials, and first-hand observation of the suspect intersection (or intersections). If an intersection is suspected to be problematic, then a survey of site conditions (e.g., signal timing, control devices, traffic volumes) is appropriate.

Confirm Extent of Problem

During this task, the engineer would evaluate the information gathered and make a determination of the extent of the red-light-related safety problem. Statistical tests are provided in the TREAT spreadsheet for making this determination. The tests are based primarily on crash history and, for a local intersection, the observed frequency of red-light violations. The findings from this analysis are then used to determine the extent of the problem and whether its treatment will be cost-effective to the agency.

Identify Causes and Countermeasures

The successful treatment of a red-light problem requires a careful diagnosis of the underlying causes and a thoughtful selection of countermeasures. The countermeasures selected should be capable of addressing the diagnosed problems. A flow chart has been developed to help the engineer pool the available information and make a reasonable determination of likely causes and appropriate countermeasures.

Evaluate Countermeasures

During this task, the range of candidate countermeasures identified in the previous task should be evaluated for their effectiveness in treating the subject location (i.e., either local intersection or entire jurisdiction). A list of countermeasures was previously provided in Table 8. In many instances, the ability of these countermeasures to reduce crashes and/or violations has been identified in this table. The effectiveness of a countermeasure should be evaluated in terms of its ability to reduce red-light crashes and/or related violations by an amount that is reasoned to be cost-effective, relative to the resource investment required to implement the countermeasure. The effectiveness of many countermeasures can be evaluated using the TREAT spreadsheet.

Implement Selected Countermeasures and Monitor

The most cost-effective countermeasures should be implemented during this task. If the countermeasures identified include both engineering and enforcement, then the engineering countermeasures should be implemented first and monitored for effectiveness. If the combined effect of all viable engineering countermeasures is determined to be inadequate, then officer enforcement countermeasures should be considered. If officer enforcement is unsuccessful or ineffective, then camera enforcement can be considered. This sequence of countermeasure implementation is summarized in Figure 12.

PROCEDURE FOR LOCAL INTERSECTION EVALUATION

The procedure described in this section is intended to help the engineer select and evaluate engineering countermeasures to reduce red-light violations at a specified intersection. The procedure is presented as a series of tasks where data are gathered, statistics are quantified, and decisions are made. To simplify the presentation of the material, the equations and statistical tests that underlie the evaluations are not presented herein. Instead, they have been coded into a spreadsheet (i.e., TREAT) to facilitate their implementation. The engineer is referred to the research report by Bonneson and Zimmerman (*8*) for a description of the equations and statistical tests.

Scope

This procedure is appropriate for the evaluation of a specified intersection approach. Each of the approaches to an intersection would need to be separately evaluated to obtain an assessment of the entire intersection. Some of the prediction equations developed for this procedure were calibrated using data for intersections located in urban areas. As such, the procedures are most applicable to the following conditions:

- drivers traveling through the intersection (as opposed to turning at it), and
- urban or suburban intersections.

Nevertheless, they can be extended to the evaluation of rural intersections with reasonable accuracy.

Gather Information

Following notification of a possible red-light-related safety problem, the engineer should make a preliminary assessment to determine the extent of the problem and whether it requires a solution. This assessment involves gathering information about the intersection approach so that the problem can be confirmed and its cause identified. Information sources include: crash history, first-hand observation, and a site survey. Table 9 identifies the specific data needed for a complete investigation of red-light problems. These data are discussed in the following paragraphs.

If it is suspected that the intersection does not meet the warrants for signalization defined in the *Manual on Uniform Traffic Control Devices* (*MUTCD*) (*30*), then data will need to be collected to check the appropriate *MUTCD* warrants. These data are not listed in Table 9; however, they are identified in Chapter 4C of the *MUTCD*.

Crash History

As a first step, the analyst should review the crash history of the subject intersection. One goal of this review is to identify the number of severe red-light-related crashes that have occurred on the subject approach. Another goal is to identify potential red-light-related safety problems at the intersection through an interview with local law enforcement officials.

Table 9. Data Needed for the Evaluation of a Specific Intersection Approach.

Category	Data [1]	Description	Units
Traffic characteristics	Traffic volume	Through vehicle count during violation analysis period	vehicles
		Intersection leg AADT (2-way)	veh/d
	85^{th} percentile approach speed		mph
	Heavy-vehicle percentage		%
Traffic control	Posted speed limit		mph
Signal operation	Signal cycle length	(average if actuated)	seconds
	Green phase duration	(average if actuated)	seconds
	Yellow interval duration		seconds
	Multi-loop advance detection	Distance to leading edge of most distant detector	feet
	Approach control mode	Pretimed or actuated	--
	Left-turn phasing	Protected, protected+permitted, permitted-only	--
Motorist information	Signal visibility	Signal head location (distance from stop line)	feet
		Signal head offset relative to traffic lane (distance)	feet
		Number of signal heads controlling through mvmt.	number
		Sight distance to signals	feet
	Signal conspicuity	Signal head lens size (8 or 12 inch)	inches
		Use of yellow LED signal indications	--
		Use of red LED signal indications	--
		Use of back plates on signal heads	--
		Use of double red indications	--
	Advance warning signs	Advance warning (Signal Ahead) sign	--
		Advance warning sign with active flashers [2]	--
Traffic operation	Approach delay	Subjective estimate of level-of-service (A, B, etc.)	--
	Signal coordination	Observation of platoon arrival time and end of green	--
Geometry	Approach through lanes		number
	Approach grade		%
	Clearance path length		feet
Red-light violations	Violation analysis time period		hours
	Through-vehicle violations during study period		vehicles
Crash history	Crash analysis time period		years
	Crash distribution	Severe red-light-related left-turn-opposed crashes	crashes
		Severe red-light-related right-angle and other crashes [3]	crashes
		Severe rear-end crashes	crashes

Notes:
1 - "Severe crash," "red-light-related crash," and "red-light violation" are defined in the text following this table.
2 - Active flashers accompany the advance warning sign and are activated during the last few seconds of green.
3 - "Right-angle and other crashes" include all red-light-related crashes not identified as left-turn-opposed.

Number of Years of Crash Data. The crash data should represent the most recent period of time for which crash data are available and during which there were no substantial changes in intersection geometry, signal display, or signal timing. The number of years in this time period should range from 1 to 5 years. Desirably, the database would include the details of at least six severe red-light-related crashes; hence, the crash analysis period should extend enough years to obtain this desirable minimum crash sample.

Crashes for the Subject Approach. A crash is assigned to the subject approach if the direction of travel of the driver believed responsible for the crash (often the first vehicle listed on the crash report) is the same as that supported by the subject approach.

Severe Crash. Severe crashes are those where one or more persons are injured or killed (i.e., injury codes: K, A, B, or C). Property-damage-only crashes are not used in subsequent analyses because of inconsistent reporting thresholds among enforcement agencies; however, the reports for these crashes may provide useful information of a more general nature about a specific location.

Red-Light-Related Crash. Desirably, the printed crash reports would be acquired for the subject intersection and manually reviewed to identify the true red-light-related crashes. This determination requires a review of several of the information fields in the report, including the officer narrative and crash diagram. To expedite the manual review, an electronic database may be initially screened for all crashes at the intersection designated as having the following attributes:

- intersection relationship: "at" the intersection, and any one of the following:
- crash type: "right-angle,"or
- crash type: "left-turn-opposed," or
- first contributing factor: "disregard of stop and go signal," or
- first contributing factor: "disregard of stop sign or light."

This initial screening significantly reduces the number of crash reports that need to be "pulled" and manually reviewed, without eliminating a significant number of truly red-light-related crashes.

If the reports are not available or cannot be manually reviewed, then the red-light-related crashes can be screened from an electronic crash database. If this approach is used, the following attributes should be used as screens:

- intersection relationship: "at" the intersection, and
- first contributing factor: "disregard of stop and go signal" or "disregard of stop sign or light."

When used in this manner, these attributes can identify almost all red-light-related crashes (*7*).

Left-Turn-Opposed Crashes. A tabulation of severe, red-light-related left-turn-opposed crashes allows for an examination of crash-type distribution. This examination can provide important clues as to the cause of the red-light problem and the selection of countermeasures.

Rear-End Crashes. The number of severe, intersection-related rear-end crashes should also be quantified for the subject approach. The aforementioned screening techniques should *not* be used to estimate this number. Frequent rear-end crashes may be an indicator of driver inattentiveness or inability to stop.

Peace Officer Interview. An important element of the crash history investigation of the subject location is the peace officer interview. Traffic enforcement officers with the local law enforcement agency should be contacted and asked about their experience with traffic violations and crashes at the subject intersection. If they have detected a problem related to red-light-running, they should be asked about their perception of possible causes and treatments.

Observational Study

An important part of the information gathering task is the first-hand observation of conditions at the subject intersection. This observation should be scheduled to coincide with the occurrence of the reported problems (e.g., hour of peak traffic demand). Initially, the engineer should drive through the subject approach to experience traffic conditions and to assess signal head visibility. Then, the engineer should observe intersection operation from a curb-side vantage point.

While at the intersection, the engineer should use judgment to assess the following:

- delay incurred by approach traffic (Is it excessive?);
- platoon arrival time and end of the green (Is the trailing edge repeatedly receiving a yellow?);
- approach speeds (Are speeds routinely in excess of the posted limit?);
- yellow duration (Is it consistent with agency policy and appropriate for the observed speed?);
- advance multi-loop detection (If provided, are all loops working properly?);
- signal conspicuity (Is the correct signal head clearly discernable by motorists?); and
- signal head visibility (Is at least one signal head in view for the minimum sight distance?).

With regard to the last item listed, the MUTCD (*30*) offers minimum sight distance criteria for signal heads. This distance is listed in Table 10 as a function of speed. It is measured back from the stop line. Within this distance, at least one signal head should be continuously visible to approaching drivers. The MUTCD requires the use of an advance warning sign if the distance listed in Table 10 is not available.

Table 10. Minimum Sight Distance to Signal Head.

	85th Percentile Speed, mph								
	20	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
Minimum sight distance [1], ft	175	215	270	325	390	460	540	625	715

Note:
1 - Distances listed do not consider the effect of grade. Longer distances may be needed on downgrade approaches.

Also while at the intersection, the engineer should attempt to observe several red-light violations. Through these observations, the engineer should identify the traffic movements experiencing the problem and possible causes for the violations.

At the conclusion of this study, the engineer should form an opinion as to the need for further study. If there appears to be some deficiencies that may be contributing to the reported red-light problem, or if several violations were observed, then the engineer should schedule the conduct of a site survey. The insights obtained during the observational study will help the engineer identify the data that need to be collected during the site survey.

The engineer may want to consult Chapter 4 of the *Toolbox* (*9*) for additional discussion regarding the site conditions that should be checked or measured during the site survey.

Site Survey

The objective of the site survey is to obtain the information needed to accurately evaluate the extent of the red-light problem. A complete study would collect all of the data identified in Table 9 and include a condition diagram. This diagram would consist of a scale drawing of the intersection in plan-view as well as the location of other physical features and control devices on the subject approach. An example condition diagram is shown in Figure 13. In this example, the eastbound approach is the "subject approach." A blank condition diagram is provided in the Appendix.

Geometric Data. The surveyor should record the physical features of the entire intersection on the condition diagram. In addition, the following two distances need to be measured for the subject approach:

- clearance path length (measured from the stop line of the subject approach to the furthest edge of the last conflicting lane crossed) L_p, ft; and
- distance from the stop line to the upstream edge of the most distant detector D, ft. If detectors are not provided, then D is 0.0 ft. If just stop-line detection is provided, then D is 0.0 ft. If advance detectors are provided, then D is measured as the distance from the stop line to the most distant detector.

The approach grade and lane assignments should also be recorded on the diagram.

Traffic Characteristics, Signal Operation, and Violation Data. The survey of traffic characteristics and signal conditions should take place during a time period that is coincident with the time that red-light violations are most notable. Typically, this time period coincides with the peak traffic hours. As a minimum, the study should be 1 hour in duration. Desirably, it would include 1 or 2 hours during each of the following traffic periods: morning peak, afternoon off-peak, and evening peak.

CONDITION DIAGRAM & DATA SUMMARY

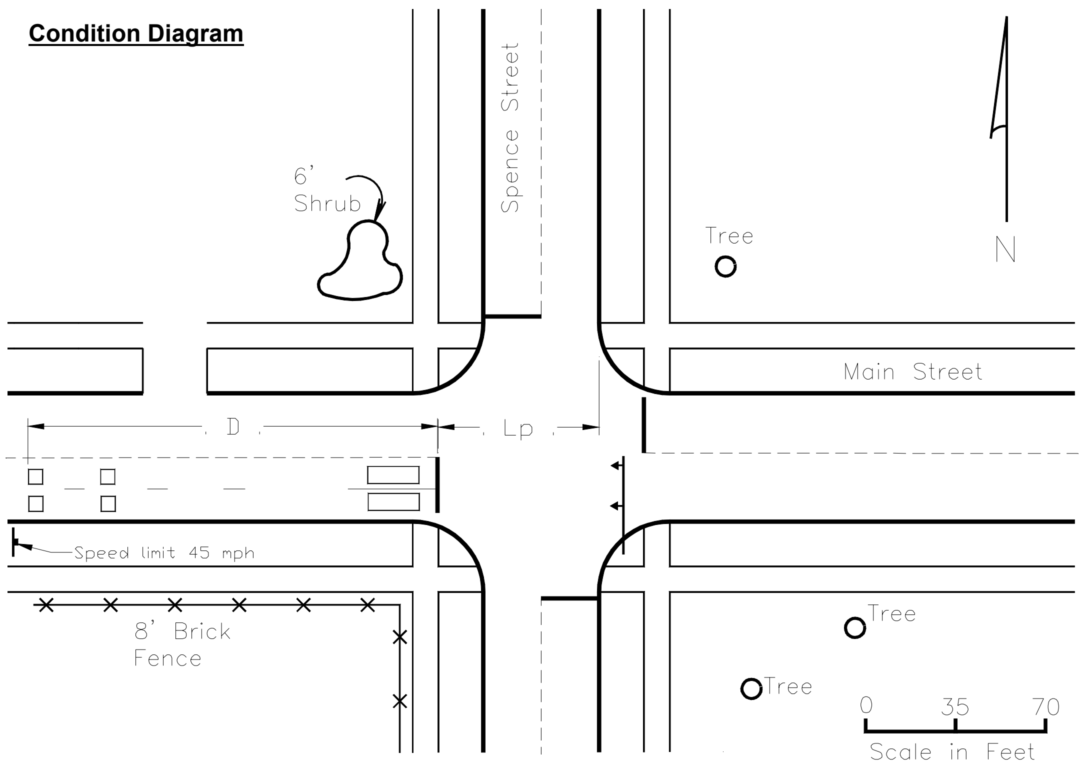
Intersection: *Main Street & Spence Street* **Date:** *38048*

Subject Approach: *Eastbound Main Street* **Surveyor:** *KHZ*

Time Period	Hours	Hours	Thru. Veh. Count	Thru. Truck Count	Thru. Violation Count
Morning peak	*7:00 - 9:00*	*2*	*983*	*49*	*9*
Off-peak	*1:30 - 3:30*	*2*	*343*	*17*	*7*
Evening peak	*4:00 - 6:00*	*2*	*1422*	*71*	*13*
Total:		*6*	*2748*	*137*	*29*

Approach control mode:	Act__ Pre ✔	Intersection leg AADT, veh/d:	*20000*
Posted speed limit, mph:	*45*	12" signal head lens size:	G ✔ Y ✔ R ✔
Lenses with LED indications:	G__ Y__ R__	Back plates on signal heads?:	Yes__ No ✔
Dual red indications?:	Yes__ No ✔	Protected-only left-turn phasing?	Yes__ No ✔
Advance warning signs?:	Yes__ No ✔	Adv. warning signs w/active flashers?:	Yes__ No ✔

Condition Diagram



Signal cycle length, s:	*100*	Number of through lanes:	*2*
Green phase duration, s:	*45*	Approach grade, % (+ for uphill):	*0*
Yellow interval duration, s:	*4*	Clearance path length (L_p), ft:	*90*
85th percentile speed, mph:	*51*	Distance to advance det. (D), ft:	*not applicable*

Figure 13. Sample Condition Diagram.

The field study should include the use of a tripod-mounted camcorder positioned on the subject approach, about 150 ft upstream of the intersection, just behind the curb, and facing the intersection. It would be positioned so that the following traffic data could be extracted from the videotape during its replay back at the office:

- count of through vehicles (and any turn vehicles sharing a through lane) crossing the stop line;
- count of heavy vehicles (i.e., vehicles with more than four tires, excluding 1-ton pickup trucks with dual tires on the rear axle);
- duration of the yellow interval;
- duration of the green interval and cycle length (average values if control is actuated); and
- count of red-light violators (i.e., through vehicles crossing the stop line *after* the onset of red).

Red-light violations by drivers turning in exclusive turn lanes should not be included in the count of violators. Drivers legally turning "right on red" should not be included in the count of violations.

If directed by the engineer, the surveyor may need to collect additional traffic data to facilitate a check of the *MUTCD* signal warrants. These data are identified in Chapter 4C of the *MUTCD* (*30*).

Traffic Control Device Data. The survey of traffic control devices should include an inventory of the devices applicable to drivers on the subject approach. These devices and their relevant characteristics are listed in Table 9. The characteristics of each device should be recorded on the condition diagram.

Approach Control Mode. Two choices are possible for control mode: pretimed and actuated. "Actuated" should be used to denote a phase whose duration is controlled by vehicle presence on the approach detectors (i.e., full-actuated). "Pretimed" should be used for any other type of phase operation. Hence, a coordinated phase serving major-street traffic with a fixed yield point and fixed cycle length should also be identified as "pretimed."

Intersection Leg AADT. The AADT for the intersection leg containing the subject approach should be obtained from the agency's planning department (or local metropolitan planning organization). This AADT should be representative of the same period of time as the crash data. It should represent the count of traffic in *both* travel directions.

85th Percentile Approach Speed. The 85th percentile speed should be measured in the field for the subject approach. The speeds should be measured at a mid-block location, sufficiently distant from the intersection that it does not influence driver speed. A sample of 100 speed observations should be sufficient. If resources do not allow for the conduct of a speed study, common practice is to assume the 85th percentile speed is the same as the posted speed limit. However, research indicates that this assumption is not always valid. An analysis of data at numerous intersection approaches indicated that the 85th percentile speed often exceeds the speed limit by as much as 6 mph (*8*).

Confirm Extent of Problem

During this task, the information gathered in the previous task is evaluated to determine if a red-light-related safety problem exists for the subject traffic movement. Initially, existing conditions should be compared with agency policy to determine if changes are needed. Then, the intersection traffic control devices should be checked against the standards and guidelines in the *MUTCD* (*30*). Finally, the field data should be entered into the TREAT spreadsheet and evaluated to determine if there is an excessive number of violations, crashes, or both at the subject intersection.

Check of Agency Policy

As a first step, the existing conditions should be compared to agency policy, where applicable and available. As a minimum, agency policy should be identified for the following intersection features, as applied to intersection approaches within the jurisdiction that are similar to the subject approach:

- speed limit,
- use of signal head back plates,
- use of LED indications,
- use of advance warning signs with active flashers,
- use of protected-only left-turn phasing,
- distance to the most distant advance loop detector (for green extension),
- yellow interval duration,
- cycle length (if fixed), and
- phase green duration (if pretimed).

If agency policy is not specific on yellow interval duration, then Equation 1 in this handbook should be used to determine an appropriate yellow duration for the subject approach.

Check of MUTCD Standards and Guidelines

The traffic control devices used at the intersection should be checked against the standards and guidelines in the *MUTCD*. Information in this manual addresses the following topics: signal visibility distance, Signal Ahead signs, advance warning flashers, supplemental signal heads, signal head location, signal lens size, back plates, dual red indications, and red LED lenses. It should be noted that yellow LED lenses currently do not meet ITE standards that address the intensity and distribution of light from a traffic signal (*31*). The *Toolbox* (*9*) provides a useful summary of these standards and guidelines.

Finally, if there is a question as to whether the signal is needed at the intersection, the signal warrants provided in Part 4 of the MUTCD should be checked for the subject approach. If none of the warrants are satisfied, then removal of the signal should be considered. Unwarranted signals are likely to be perceived as causing "unnecessary" delay and may promote disrespect for the signal. This disrespect may be exhibited by frequent red-light violations.

Enter Existing Conditions in TREAT

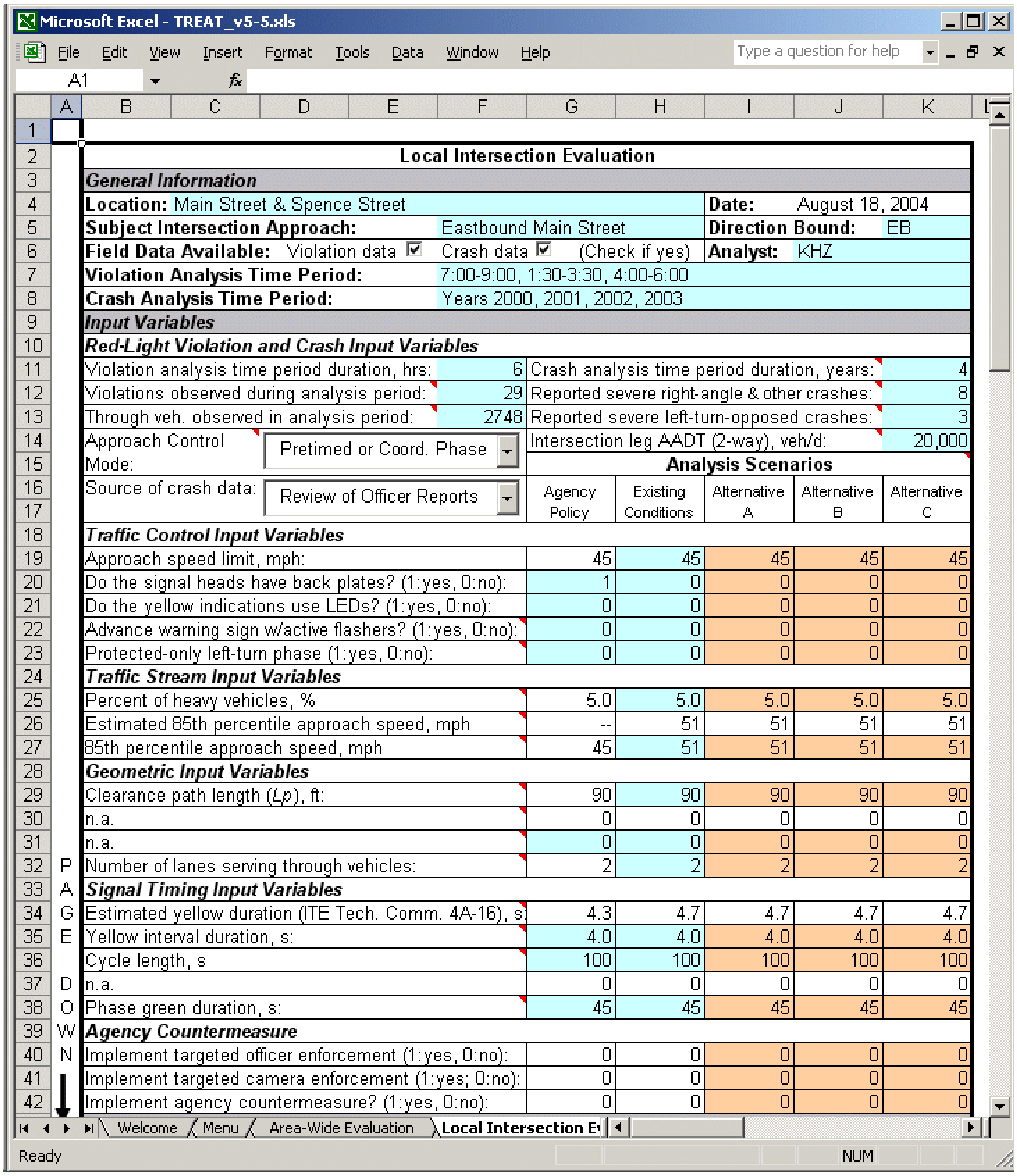
During this step, the information gathered during the previous task is used with the TREAT spreadsheet to evaluate the subject approach. Unlike capacity analysis, separate evaluations for each time period are *not* conducted. Instead, all of the data should be aggregated to represent one, all-inclusive, time period. Thus, the traffic count and violation data for each time period should be added together and entered into the spreadsheet. If the cycle length or green phase duration varies among these time intervals, then an average value should be computed (or estimated) and entered into the spreadsheet. The count of trucks should be used to compute the "percent of heavy vehicles."

The data entry portion of the TREAT spreadsheet is shown in Figure 14. The shaded cells represent data entry fields. The data collected during the site survey have been entered into the spreadsheet shown in the figure. Also shown in the middle of this figure are five columns representing the "analysis scenarios." The scenario headed "Agency Policy" is used to record the various inputs that reflect what agency policy would suggest is appropriate for intersection approaches like the subject approach. The red-light violations and related crashes associated with the "agency policy" intersection represent the basis for evaluating the subject approach.

85th Percentile Speed. The column headed "Existing Conditions" is used to record the various data obtained during the site survey. An estimate of the 85th percentile speed (based on the posted speed limit) is provided in row 26 of the spreadsheet. This estimate is made available in the event that resources did not allow for measurement of the 85th percentile speed during the site survey. It is based on a statistical analysis of speeds measured at 48 intersections in three Texas cities.

Yellow Interval Duration. The yellow interval duration is recorded in row 35. The yellow interval duration obtained from Equation 1 is provided in row 34. This yellow duration is provided only for convenience, as a point of reference for the analyst. Several different approaches are used in practice for establishing yellow durations; however, Equation 1 is the one that is most commonly referenced in authoritative traffic engineering reference documents. Analysts are encouraged to use the policy established by their agency when selecting a yellow interval duration.

Multi-Loop Advance Detection. There are three rows with "n.a." shown in Figure 14. This notation indicates the input field is "not applicable." If actuated control is selected in row 14, then alternative text will replace the "n.a." in rows 30, 31, and 37. It will also replace the text in rows 36 and 38. The revised text in row 31 will request input about the distance to the leading edge of the most distant detector. If multi-loop advance detection is used for green extension on this approach, then this distance should be entered in this row. If multi-loop advance detection is not provided, 0.0 should be entered in this row. Row 30 provides an estimate of this distance if it cannot be measured in the field. Also, the distance shown in row 30 can be used if green extension is being considered as a countermeasure and agency policy does not address multi-loop design.



Local Intersection Evaluation

General Information

Location: Main Street & Spence Street	**Date:** August 18, 2004
Subject Intersection Approach: Eastbound Main Street	**Direction Bound:** EB
Field Data Available: Violation data ☑ Crash data ☑ (Check if yes)	**Analyst:** KHZ
Violation Analysis Time Period: 7:00-9:00, 1:30-3:30, 4:00-6:00	
Crash Analysis Time Period: Years 2000, 2001, 2002, 2003	

Input Variables

Red-Light Violation and Crash Input Variables

Violation analysis time period duration, hrs:	6	Crash analysis time period duration, years:	4
Violations observed during analysis period:	29	Reported severe right-angle & other crashes:	8
Through veh. observed in analysis period:	2748	Reported severe left-turn-opposed crashes:	3
Approach Control Mode:	Pretimed or Coord. Phase	Intersection leg AADT (2-way), veh/d:	20,000
Source of crash data:	Review of Officer Reports		

Analysis Scenarios	Agency Policy	Existing Conditions	Alternative A	Alternative B	Alternative C
Traffic Control Input Variables					
Approach speed limit, mph:	45	45	45	45	45
Do the signal heads have back plates? (1:yes, 0:no):	1	0	0	0	0
Do the yellow indications use LEDs? (1:yes, 0:no):	0	0	0	0	0
Advance warning sign w/active flashers? (1:yes, 0:no):	0	0	0	0	0
Protected-only left-turn phase (1:yes, 0:no):	0	0	0	0	0
Traffic Stream Input Variables					
Percent of heavy vehicles, %	5.0	5.0	5.0	5.0	5.0
Estimated 85th percentile approach speed, mph	--	51	51	51	51
85th percentile approach speed, mph	45	51	51	51	51
Geometric Input Variables					
Clearance path length (*Lp*), ft:	90	90	90	90	90
n.a.	0	0	0	0	0
n.a.	0	0	0	0	0
Number of lanes serving through vehicles:	2	2	2	2	2
Signal Timing Input Variables					
Estimated yellow duration (ITE Tech. Comm. 4A-16), s:	4.3	4.7	4.7	4.7	4.7
Yellow interval duration, s:	4.0	4.0	4.0	4.0	4.0
Cycle length, s	100	100	100	100	100
n.a.	0	0	0	0	0
Phase green duration, s:	45	45	45	45	45
Agency Countermeasure					
Implement targeted officer enforcement (1:yes, 0:no):	0	0	0	0	0
Implement targeted camera enforcement (1:yes; 0:no):	0	0	0	0	0
Implement agency countermeasure? (1:yes, 0:no):	0	0	0	0	0

Figure 14. TREAT Input Variables, Local Intersection Evaluation.

Approach Control Mode. This input describes the control mode of the subject intersection approach. If full-actuated control is used (with or without multi-loop advance detection), then the cycle length is likely to vary during the analysis period. If it does, a sample of cycle lengths should be obtained from the videotape recorded during the site survey. The average cycle length should then be entered in row 36. Row 37 provides an estimate of the average phase green duration based on specified values of controller passage time, minimum green interval, and maximum green interval. Default values of these settings are 2.0 s, 10 s, and 45 s, respectively. These three settings can be changed in rows 71 and 72 (not shown).

If the green phase duration is constant or it serves the coordinated major-street through traffic movement and has a fixed yield point and a fixed cycle length (i.e., semi-actuated), then the "Control Mode" should be entered as "Pretimed." If the phase is semi-actuated, a sample of phase green durations should be obtained from the videotape recorded during the site survey. The average phase green duration should then be entered in row 38.

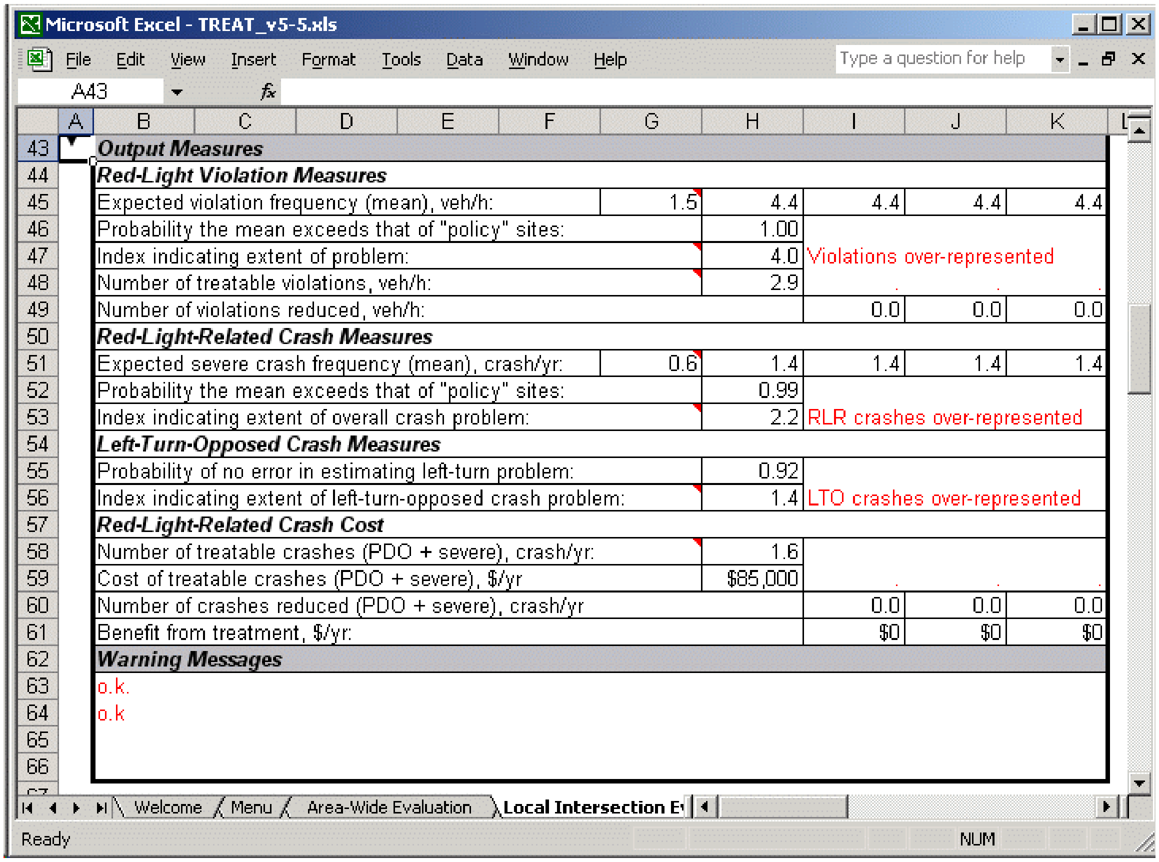
Agency Countermeasure. The spreadsheet automates the evaluation of many of the countermeasures listed in Table 8. However, the reported effectiveness of some countermeasures were noted to be of suspect accuracy and no information is currently available about others. Row 42 provides a place for the agency to evaluate a countermeasure for which they have confidence in its violation and crash reduction potential. The corresponding reduction factors would be entered in row 77 (not shown).

Evaluate Existing Conditions

Figure 15 shows the output measures of effectiveness computed by the TREAT spreadsheet. As indicated in this figure, there are separate sections for the red-light violation evaluation, the red-light-related crash evaluation, the left-turn-opposed crash evaluation, and a crash cost analysis. The interpretation of the various measures in each section is described in the following paragraphs. For this discussion, it should be remembered that columns G and H correspond to the "Agency Policy" and the "Existing Conditions" scenarios, respectively.

Red-Light Violation Measures. The expected violation frequency for each scenario is shown in row 45 of Figure 15. This statistic represents the best estimate of the average number of violations per hour for an intersection approach, as averaged over the time periods studied. Thus, the typical intersection approach operating in accordance with agency policy should experience 1.5 violations/h. In comparison, the subject approach is expected to average 4.4 violations/h. The difference between these two numbers represents the "treatable" number of violations at the subject location; it is shown in row 48. Treatable violations represent those violations that are in excess of the average for the typical approach operating in accordance with agency policy.

The index in row 47 is based on a statistical analysis of the expected violation frequency and the underlying uncertainty associated with its estimate. An index of 1.0 or more is an indication that the treatable red-light violations on the subject approach are sufficiently large that the approach is likely to have a red-light problem. The degree of confidence that can be placed in this claim is reflected in the "probability" provided in row 46. In this instance, there is a probability of 1.0 (i.e., relative certainty) that the approach has a violation problem.



Microsoft Excel - TREAT_v5-5.xls

		G	H	I	J	K
43	***Output Measures***					
44	***Red-Light Violation Measures***					
45	Expected violation frequency (mean), veh/h:	1.5	4.4	4.4	4.4	4.4
46	Probability the mean exceeds that of "policy" sites:		1.00			
47	Index indicating extent of problem:		4.0	Violations over-represented		
48	Number of treatable violations, veh/h:		2.9			
49	Number of violations reduced, veh/h:			0.0	0.0	0.0
50	***Red-Light-Related Crash Measures***					
51	Expected severe crash frequency (mean), crash/yr:	0.6	1.4	1.4	1.4	1.4
52	Probability the mean exceeds that of "policy" sites:		0.99			
53	Index indicating extent of overall crash problem:		2.2	RLR crashes over-represented		
54	***Left-Turn-Opposed Crash Measures***					
55	Probability of no error in estimating left-turn problem:		0.92			
56	Index indicating extent of left-turn-opposed crash problem:		1.4	LTO crashes over-represented		
57	***Red-Light-Related Crash Cost***					
58	Number of treatable crashes (PDO + severe), crash/yr:		1.6			
59	Cost of treatable crashes (PDO + severe), $/yr		$85,000			
60	Number of crashes reduced (PDO + severe), crash/yr			0.0	0.0	0.0
61	Benefit from treatment, $/yr:			$0	$0	$0
62	***Warning Messages***					
63	o.k.					
64	o.k					
65						
66						

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Figure 15. TREAT Output Measures, Local Intersection Evaluation.

Red-Light-Related Crash Measures. The expected severe crash frequency for each scenario is shown in row 51. As with violations, the corresponding index value and probability compare the subject intersection approach with the "agency policy" approach. These values are interpreted in the same manner as for their violation counterparts. For the example site, the index value of 2.2 exceeds 1.0, which indicates that the site is likely a "problem" location. The probability in row 52 indicates that the analyst should have a high degree of confidence in this claim.

Left-Turn-Opposed Crash Measures. The number of severe left-turn-opposed crashes that occurred on the subject approach were also evaluated. In row 56, the index of 1.4 exceeds 1.0, which indicates that there is likely a left-turn-opposed crash problem at this location. The probability of 0.92 in row 55 indicates that there is a small chance (i.e., 8 of 100 trials) that the over-representation of left-turn crashes in the crash history is a result of random variation. Nevertheless, the fact that the index exceeds 1.0 should be sufficient for the analyst to conservatively assume that there is a left-turn-opposed crash problem and to act accordingly in the selection of countermeasures.

Red-Light-Related Crash Cost. The expected number of severe crashes for the subject approach and the "agency policy" site are used to estimate the number of treatable *total* crashes (including both severe and property-damage-only crashes). This number is shown in row 58. The societal cost of these crashes is provided in row 59. It is based on the average crash cost provided in row 69 (not shown). For the example site, the treatable crashes represent an annual societal cost of $85,000. In this instance, if the countermeasures that are applied to this site cost $85,000 or less, then the benefit-cost ratio of the treatment will be 1.0 or larger.

Identify Causes and Countermeasures

The successful treatment of an intersection approach with a red-light-related safety problem requires the thoughtful selection of effective countermeasures. The selection process should include the following considerations:

- frequency of red-light violations (see Table 3),
- cause of the typical red-light violation (see Table 4),
- frequency of red-light-related crashes, and
- crash-type distribution (see Table 7).

As noted previously, many of the countermeasures listed in Table 8 tend to be effective in treating specific types of red-light violations and related crashes. The information cited in Chapter 2 that characterized the red-light violation, the driver, and the crash was used to identify logical relationships between the countermeasures and the cause of the violation that precipitated the crash. These relationships are shown in Table 11.

Four "cause categories" are identified in columns 3 through 6 of Table 11. For simplicity of reference, they are labeled categories "A," "B," "C," and "D." These categories were previously discussed in the text associated with Tables 3, 4, and 7. A check (✔) denotes countermeasures likely to be effective in reducing red-light violations and related crashes for a specific category. An outlined check (✅) denotes countermeasures that may be effective in certain specific instances.

A flow chart that can be used to guide the selection of the appropriate countermeasure category is provided in Figure 16. The steps taken to apply this flow chart are described in the following paragraphs.

Step 1. Over-Representation of Crashes

As indicated by the flow chart, the first step is to determine if crashes are over-represented at the subject approach. Information is provided in the TREAT spreadsheet for making this determination. Specifically, the index value provided for red-light-related crashes can be used for this purpose. An index of 1.0 or larger indicates over-representation of red-light-related crashes.

Table 11. Local Intersection Countermeasure Selection Based on Cause of Violation.

Category	Countermeasure	Cause of Violation in Typical Crash [1]			
		Inattentive (A)	Unnecessary Delay (B)	Congestion, Dense Traffic (C)	Incapable of Stop (D)
Traffic char.	Reduce approach speed	✔			✔
Signal operation	Increase signal cycle length if *v/c* ratio < 0.60		✔		
	Increase yellow interval duration (not to exceed 5.5 s)				✔
	Provide green extension (advance detection) [2]				✔
	Add protected-only left-turn phasing				✔
Motorist information	Improve signal visibility via better signal head location	✔			✓
	Improve signal visibility via additional signal head	✔			✓
	Improve signal visibility by clearing sight lines to signal	✔			✓
	Improve signal conspicuity by upgrading to 12" lenses [3]	✔			✔
	Improve signal conspicuity by using yellow LEDs				✔
	Improve signal conspicuity by using red LEDs	✔			
	Improve signal conspicuity by using back plates	✔			✔
	Improve signal conspicuity by using dual red indications	✔			
	Add advance warning signs (no flashers)	✔			
	Add advance warning signs with active flashers [4]	✔			
Traffic operation	Reduce delay through re-timing if *v/c* ratio > 0.70			✔	
	Reduce unnecessary delay through signal re-timing		✔		
	Improve signal coordination [5]			✔	
Geometry	Remove unneeded signals	✔	✔		
	Add capacity with additional lanes or turn bays			✔	
Education	Implement public awareness campaign		✔	✔	
Enforcement	Implement officer enforcement program		✓	✔	
	Implement camera enforcement		✔	✔	

Notes:

1 - Cause category (A, B, C, D) shown in parentheses. ✔: likely countermeasure. ✓: possible countermeasure.

2 - Green extension using advance detection should reduce red-light violations provided it does not max-out frequently.

3 - Increasing the red lens size from 8" to 12" should have more impact on inattentive drivers. Increasing the yellow lens size from 8" to 12" should have more impact on drivers that report being incapable of stopping at yellow onset.

4 - Active flashers accompany the advance warning sign and are activated during the last few seconds of green.

5 - Improvements to signal coordination will be most effective in reducing red-light violations if they result in: (1) lower delay, (2) longer cycle lengths, and (3) progression bands that are not constrained by the end of the phase such that platoons traveling through the intersection are repeatedly caught by the change to red.

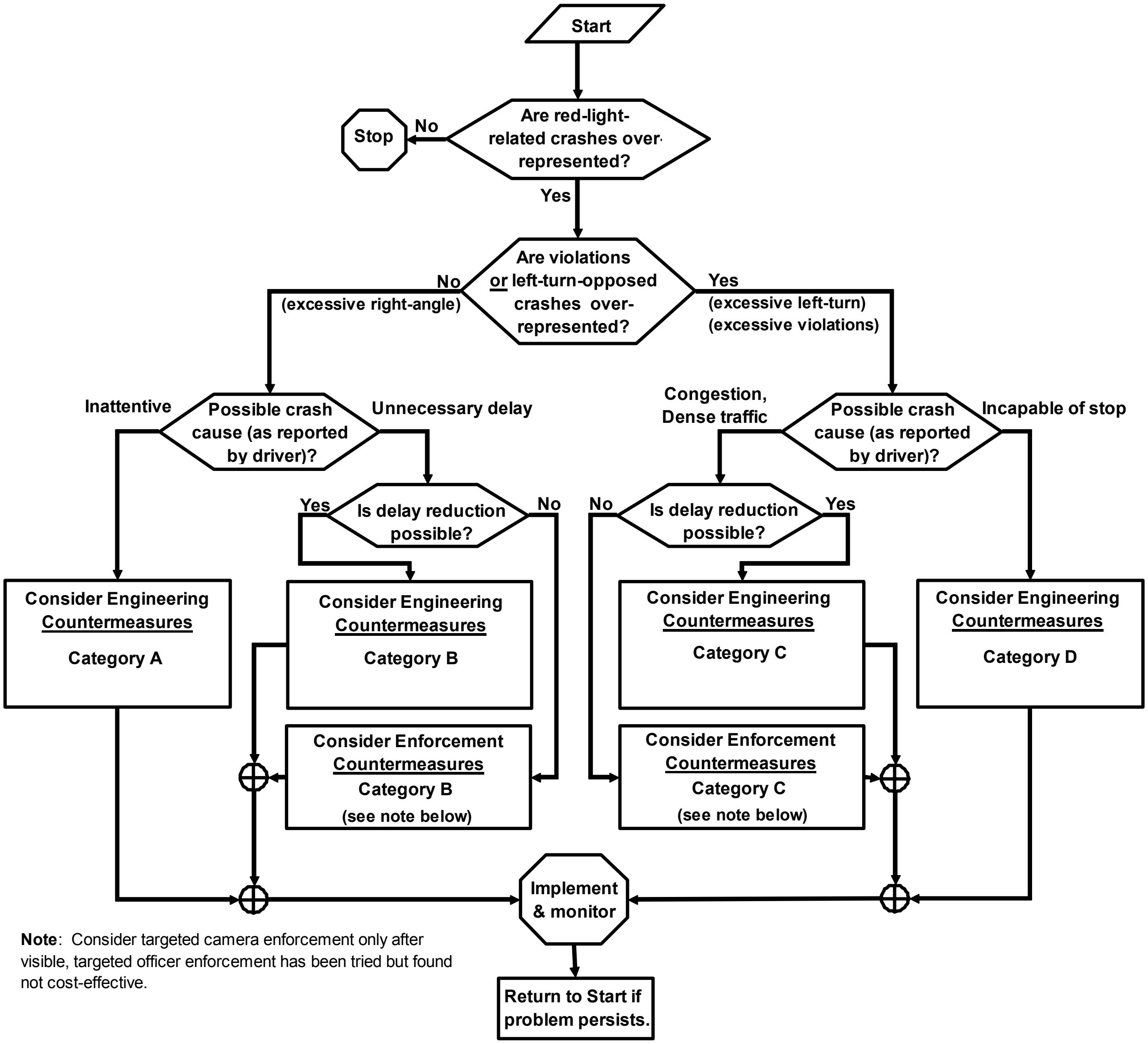


Figure 16. Countermeasure Selection Guidelines, Local Intersection Evaluation.

Step 2. Over-Representation of Violations or Left-Turn-Opposed Crashes

If crashes are over-represented, the next step is to determine whether red-light violations or red-light-related left-turn-opposed crashes are over represented. Again, the TREAT software provides an index value that can be used to make this assessment. An index of 1.0 or larger is an indication of over-representation for the purpose of countermeasure selection. Excessive violations or left-turn-opposed crashes are an indication that countermeasure selection should focus on treatment of violations occurring during the first few seconds of red.

Step 3. Possible Crash Cause

The determination of crash cause requires the application of engineering judgment based on the information obtained from the peace officer interview, observational study, and site survey. An important piece of information is the printed officer report. A review of the narratives on these reports may provide important clues indicating the range of crash causes. The engineer should evaluate all the information and make a determination of the cause of the "typical" (or most frequent) crash. This determination should result in the engineer designating one of the following crash categories as being the most likely cause of the typical crash:

- inattentive (Category A countermeasures),
- unnecessary delay (Category B countermeasures),
- congestion or dense traffic (Category C countermeasures), and
- incapable of stop (Category D countermeasures).

Crashes due to "inattentive" drivers or "unnecessary delay" may not be associated with a high frequency of red-light violations. These crashes often occur randomly during the later portion of the red indication, while almost all violations tend to occur in the first few seconds of red.

The frequency of severe rear-end crashes may also offer some clue as to the cause of the typical crash. If these crashes are over-represented on the subject intersection approach, it may be an indication that crash cause may be related to driver inattentiveness or inability to stop.

Step 4. Feasibility of Delay Reduction Countermeasures

If the typical crash cause is determined to be due to "unnecessary delay," "congestion," or "dense traffic," then countermeasures that improve intersection operation and reduce delay should be considered. During this step, the feasibility of delay reduction countermeasures is evaluated using engineering judgment based on information from the observational study. If it is determined that improvements to the intersection operation are not available, affordable, or feasible, then enforcement countermeasures should be considered.

Step 5. Identify Candidate Countermeasures

The last step associated with this task is to identify the candidate countermeasures. These countermeasures should be selected from Table 11 based on the "cause category" identified in the previous steps. Again, engineering judgment should be used to screen out those countermeasures that are not appropriate for the subject location.

Example Application

The example shown in Figure 14 was evaluated using the flow chart in Figure 16 and the findings from the statistical analysis (as shown in Figure 15). The results indicated that both red-light-related crashes and violations are over-represented at the subject approach. It was also determined that left-turn-opposed crashes are also likely to be over-represented at this location.

The findings from the observational study, site survey, and review of printed crash reports indicated that the crashes are likely being caused by driver inability to stop (i.e., Category D). Using engineering judgment based on the observational study, it was determined that the following engineering countermeasures should be evaluated: add back plates, increase yellow duration, and clear driver line of sight. The following alternatives were generated for evaluation with TREAT:

- Alternative A: add back plates,
- Alternative B: add back plates and increase yellow duration, and
- Alternative C: add back plates, increase yellow duration, and clear driver line of sight.

The entry of these alternatives into TREAT is shown in rows 20, 35, and 42 of Figure 17.

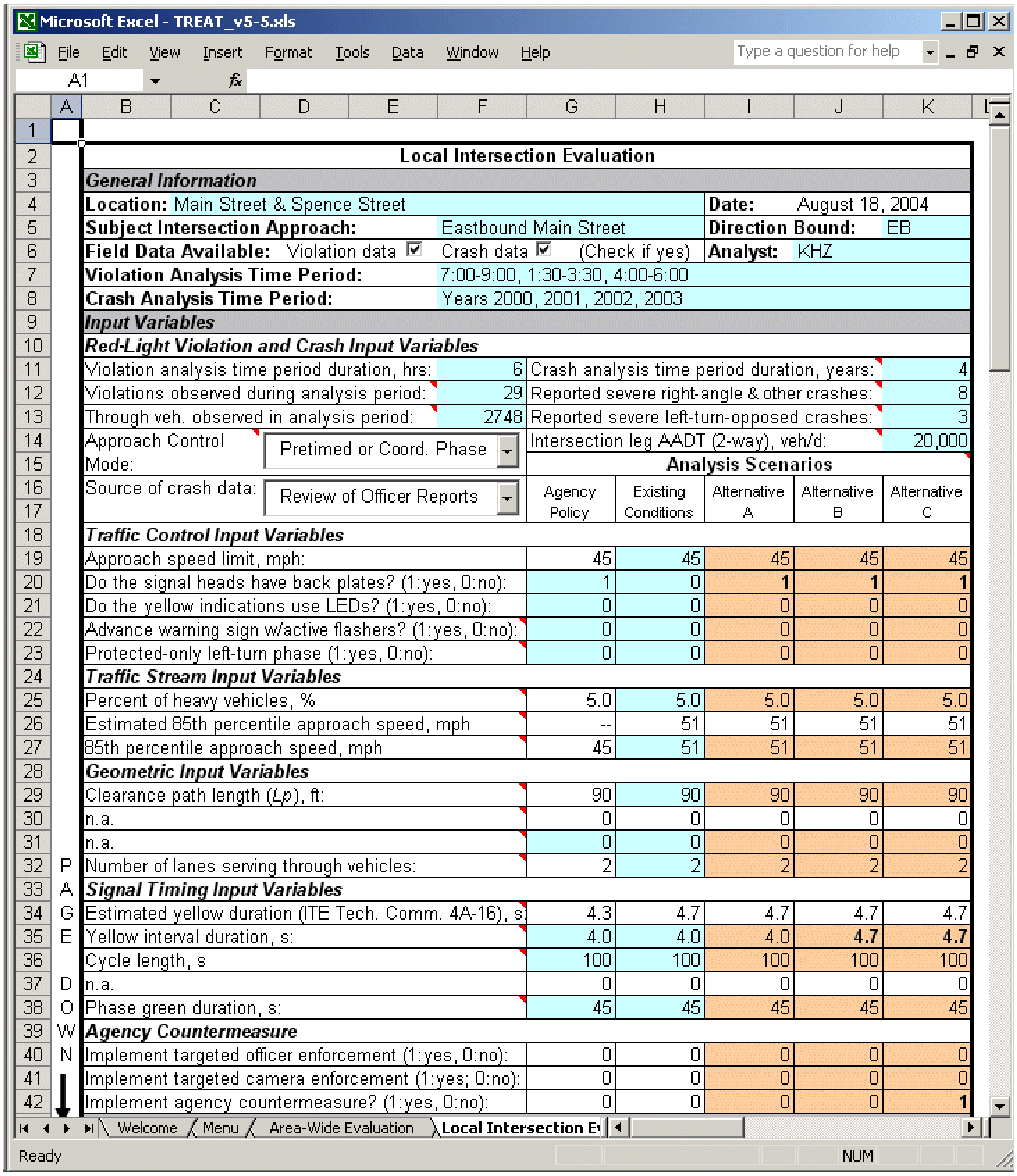
Violation and crash reduction factors were not available in Table 8 for the "clear driver line of sight" countermeasure. However, agency experience with this treatment at other intersection approaches indicates that it reduces violations and crashes by 20 percent (these values are entered in row 77 of TREAT).

Evaluate Countermeasures

During this task, the range of candidate countermeasures identified in the previous task are evaluated for their effectiveness in treating the subject approach. The effectiveness of a countermeasure is evaluated in terms of its ability to reduce red-light crashes and/or related violations by an amount that is reasoned to be cost-effective, relative to the resource investment required to implement the countermeasure. The effectiveness of most countermeasures can be evaluated using the TREAT spreadsheet.

Alternative Evaluation

To illustrate the decisions made during this task, consider the example application introduced previously. The findings from the evaluation of the three alternatives are shown in Figure 18. It should be remembered that the output measures corresponding to Alternatives A, B, and C are shown in columns I, J, and K, respectively.



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Local Intersection Evaluation

General Information

Location: Main Street & Spence Street		**Date:**	August 18, 2004
Subject Intersection Approach:	Eastbound Main Street	**Direction Bound:**	EB
Field Data Available: Violation data ☑	Crash data ☑ (Check if yes)	**Analyst:**	KHZ
Violation Analysis Time Period:	7:00-9:00, 1:30-3:30, 4:00-6:00		
Crash Analysis Time Period:	Years 2000, 2001, 2002, 2003		

Input Variables

Red-Light Violation and Crash Input Variables

Violation analysis time period duration, hrs:	6	Crash analysis time period duration, years:	4
Violations observed during analysis period:	29	Reported severe right-angle & other crashes:	8
Through veh. observed in analysis period:	2748	Reported severe left-turn-opposed crashes:	3
Approach Control Mode:	Pretimed or Coord. Phase	Intersection leg AADT (2-way), veh/d:	20,000
Source of crash data:	Review of Officer Reports		

	Analysis Scenarios				
	Agency Policy	Existing Conditions	Alternative A	Alternative B	Alternative C
Traffic Control Input Variables					
Approach speed limit, mph:	45	45	45	45	45
Do the signal heads have back plates? (1:yes, 0:no):	1	0	**1**	**1**	**1**
Do the yellow indications use LEDs? (1:yes, 0:no):	0	0	0	0	0
Advance warning sign w/active flashers? (1:yes, 0:no):	0	0	0	0	0
Protected-only left-turn phase (1:yes, 0:no):	0	0	0	0	0
Traffic Stream Input Variables					
Percent of heavy vehicles, %	5.0	5.0	5.0	5.0	5.0
Estimated 85th percentile approach speed, mph	--	51	51	51	51
85th percentile approach speed, mph	45	51	51	51	51
Geometric Input Variables					
Clearance path length (Lp), ft:	90	90	90	90	90
n.a.	0	0	0	0	0
n.a.	0	0	0	0	0
Number of lanes serving through vehicles:	2	2	2	2	2
Signal Timing Input Variables					
Estimated yellow duration (ITE Tech. Comm. 4A-16), s:	4.3	4.7	4.7	4.7	4.7
Yellow interval duration, s:	4.0	4.0	4.0	**4.7**	**4.7**
Cycle length, s	100	100	100	100	100
n.a.	0	0	0	0	0
Phase green duration, s:	45	45	45	45	45
Agency Countermeasure					
Implement targeted officer enforcement (1:yes, 0:no):	0	0	0	0	0
Implement targeted camera enforcement (1:yes; 0:no):	0	0	0	0	0
Implement agency countermeasure? (1:yes, 0:no):	0	0	0	0	**1**

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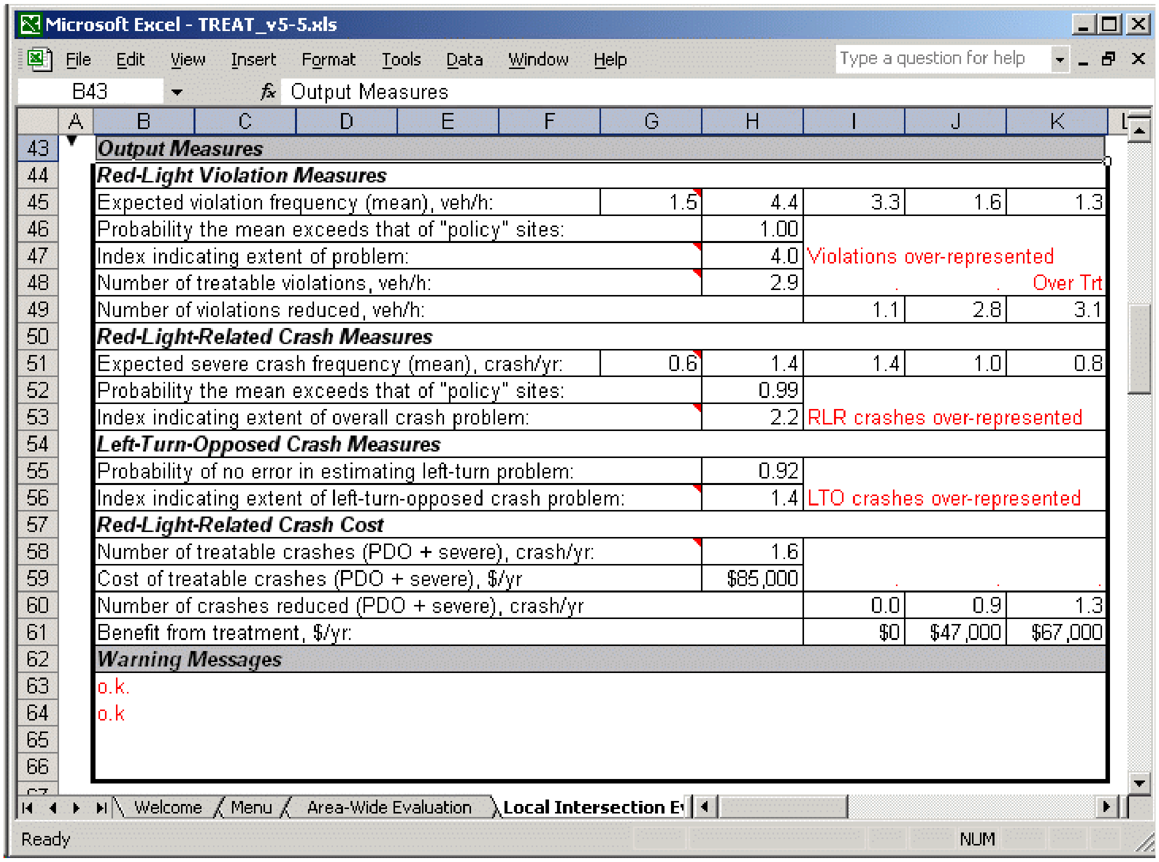
Figure 17. Input Variables for Example Application, Local Intersection Evaluation.



	B	G	H	I	J	K
43	***Output Measures***					
44	***Red-Light Violation Measures***					
45	Expected violation frequency (mean), veh/h:	1.5	4.4	3.3	1.6	1.3
46	Probability the mean exceeds that of "policy" sites:		1.00			
47	Index indicating extent of problem:		4.0	Violations over-represented		
48	Number of treatable violations, veh/h:		2.9			Over Trt
49	Number of violations reduced, veh/h:			1.1	2.8	3.1
50	***Red-Light-Related Crash Measures***					
51	Expected severe crash frequency (mean), crash/yr:	0.6	1.4	1.4	1.0	0.8
52	Probability the mean exceeds that of "policy" sites:		0.99			
53	Index indicating extent of overall crash problem:		2.2	RLR crashes over-represented		
54	***Left-Turn-Opposed Crash Measures***					
55	Probability of no error in estimating left-turn problem:		0.92			
56	Index indicating extent of left-turn-opposed crash problem:		1.4	LTO crashes over-represented		
57	***Red-Light-Related Crash Cost***					
58	Number of treatable crashes (PDO + severe), crash/yr:		1.6			
59	Cost of treatable crashes (PDO + severe), $/yr		$85,000			
60	Number of crashes reduced (PDO + severe), crash/yr			0.0	0.9	1.3
61	Benefit from treatment, $/yr:			$0	$47,000	$67,000
62	***Warning Messages***					
63	o.k.					
64	o.k					

Figure 18. Output Measures for Example Application, Local Intersection Evaluation.

As indicated in Figure 18, Alternative A (i.e., add back plates) should yield an expected red-light violation frequency of 3.3 violations/h (row 45). As indicated by row 49, this frequency is 1.1 violations/h less than the existing condition. Row 60 indicates no reduction in related crashes. This lack of a reduction in crashes is merely a reflection of the lack of information about the crash reduction potential of this alternative (as noted in Table 8). Additional research is needed to quantify the effect of signal head back plates on red-light-related crashes.

The findings from the evaluation of Alternative B (i.e., add back plates and increase yellow duration) are shown in column J. Row 49 indicates that this alternative should reduce violations by 2.8 violations/h. Row 60 indicates that the increase in yellow duration should reduce crashes by 0.9 crashes/yr for a net annual benefit of $47,000.

The findings from the evaluation of Alternative C (i.e., add back plates, increase yellow duration, and clear driver line of sight) are shown in column K. Row 49 indicates that this alternative should reduce violations by 3.1 violations/h. Row 60 indicates that crashes should be reduced by 1.3 crashes/yr for a net annual benefit of $67,000.

Techniques to Avoid Over-Treatment

It is useful to evaluate the effectiveness of the alternatives relative to the number of treatable violations (row 48) and the number of treatable crashes (row 58). The reduction in violations associated with Alternative C (i.e., 3.1 violations/h) exceeds the treatable violations of 2.9 violations/h. This is an indication that Alternative C may be "over-treating" the subject approach. In general, it is advisable that the countermeasure selection process does not result in over-treatment as the predicted benefits may not be realized. Hence, in this example, all three countermeasures should not be applied simultaneously. Rather, one or two countermeasures should be applied and, after a reasonable acclimation period, reevaluated to determine if the red-light problem still exists.

The crash analysis associated with Alternative C did not indicate over-treatment (i.e., 1.3 crashes/yr reduced does not exceed the treatable 1.61 crashes/yr). However, the crash reduction potential of signal back plates is not reflected in the crash analysis. Hence, the violation analysis is probably a more accurate indicator of "over-treatment" in this instance because it does include a sensitivity to the effectiveness of back plates.

Implement Selected Countermeasures and Monitor

The most cost-effective countermeasures should be implemented during this task. To assist in making this determination, the crash reduction benefits reported in TREAT for each alternative can be compared with the cost of implementing the associated countermeasures. The difference between this benefit and cost represents the net-benefit associated with an alternative. All other considerations being equal, the alternative associated with the largest net-benefit should be considered for implementation.

The recommended sequence of countermeasure implementation is summarized in Figure 12. In general, if the countermeasures identified include both engineering and enforcement, then the engineering countermeasures should be implemented first and monitored for effectiveness.

If all the viable engineering countermeasures have been implemented but the problem persists, then officer enforcement countermeasures should be considered. Officer enforcement should target the subject approach. It should be sustained for at least 1 hour each day. The officers should be visible during the enforcement activity. The length of time for which this enforcement activity is sustained should be based on the judgment of the engineer and the enforcement officials. The findings from a study of the effectiveness of this activity should be considered in the decision.

If officer enforcement is determined to be unsuccessful or ineffective, then camera enforcement can be considered. If camera enforcement is implemented, rear-end crash frequency should be monitored at the intersection and remedial action taken if a sustained increase in crashes is observed. The FHWA report *Guidance for Using Red Light Cameras* (*10*) is a useful resource for agencies considering camera enforcement.

PROCEDURE FOR AREA-WIDE EVALUATION

The procedure described in this section is intended to help the engineer select and evaluate engineering countermeasures to reduce red-light-related safety problems in a specified jurisdiction. The procedure is presented as a series of tasks where data are gathered, statistics are quantified, and decisions are made. To simplify the presentation of the material, the equations and statistical tests that underlie the evaluations are not presented herein. Instead, they have been coded into a spreadsheet (i.e., TREAT) to facilitate their implementation. The engineer is referred to the research report by Bonneson and Zimmerman (*8*) for a description of the equations and statistical tests.

Scope

This procedure is appropriate for the evaluation of a specified jurisdiction (e.g., city) or portion thereof. The prediction equations developed for this procedure were calibrated using crash data for intersections located in cities with a population of 20,000 or more. Nevertheless, the procedures can be extended, with reasonable accuracy, to the evaluation of a portion of a large city or to a city having a population less than 20,000 persons.

Gather Information

If a possible red-light-related safety problem is believed to exist in a jurisdiction, the engineer should make a preliminary assessment of the problem to determine its extent and whether it requires a solution. This assessment involves gathering information about the jurisdiction so that the problem can be confirmed and its cause identified. The primary source of information is the crash history for the jurisdiction; however, the first-hand observation of typical intersections in the jurisdiction may provide useful insight into the problem.

Table 12 identifies the specific data that need to be gathered for a complete investigation of red-light problems. The data identified in this table are discussed in the following paragraphs.

Table 12. Data Needed for the Evaluation of a Specific Jurisdiction.

Category	Data [1]	Description	Units
Population	Census-based population estimate for the jurisdiction		persons
Red-light-related crash history	Crash analysis time period		years
	Crash distribution	Severe left-turn-opposed crashes	crashes
		Severe right-angle and other crashes [2]	crashes

Notes:
1 - "Severe crash," "red-light-related crash," and "red-light violation" are defined in the text following this table.
2 - "Right-angle and other crashes" include all red-light-related crashes not identified as left-turn-opposed.

The population estimate for the jurisdiction is needed to estimate the number of severe red-light-related crashes for jurisdictions similar to the subject jurisdiction. This population estimate should be based on U.S. census estimates for the jurisdiction. It should be representative of the years for which the crash data are obtained (as described in the next section).

Crash History

As a first step in the information gathering process, the analyst should review the crash history of the signalized intersections in the jurisdiction. One goal of this review is to identify the number of severe red-light-related crashes that have occurred at these intersections. Another goal is to identify potential red-light-related safety problems at these intersections through an interview with the local law enforcement officials.

Number of Years of Crash Data. The crash data should represent the most recent period of time for which crash data are available. The number of years in this time period should range from 1 to 5 years. Desirably, the database would include the details of at least six severe red-light-related crashes; hence, the crash analysis period should extend enough years to obtain this desirable minimum crash sample.

Severe Crash. Severe crashes are those where one or more persons are injured or killed (i.e., injury codes: K, A, B, or C). Property-damage-only crashes are not used in subsequent analyses because of inconsistent reporting thresholds among enforcement agencies; however, the reports for these crashes may provide useful information of a more general nature about a specific location.

Red-Light-Related Crash. Desirably, the printed crash reports would be acquired for all crashes in the jurisdiction and manually reviewed to identify the red-light-related crashes. This determination requires a review of several of the information fields in the report, including the officer narrative and crash diagram. For larger cities, this approach is probably not feasible due to the number of crashes that occur. Therefore, if the reports cannot be manually reviewed, the red-light-related crashes should be screened from an electronic crash database with the following attributes used as screens:

- traffic control: "stop and go signal,"
- intersection relationship: "at" the intersection, and
- first contributing factor: "disregard of stop and go signal" or "disregard of stop sign or light."

When used in this manner, these attributes can identify almost all red-light-related crashes (*7*).

Desirably, the printed crash reports would be acquired for a randomly selected sample of 20 or more red-light-related crashes and manually reviewed to determine if there are any patterns or trends in the stated crash causes. The intersections represented in the sample reports should reflect a reasonable degree of geographic distribution throughout the jurisdiction.

Left-Turn-Opposed Crashes. The number of severe red-light-related crashes should be separated into two categories: "left-turn-opposed" and "right-angle and other." The separate tabulation of left-turn-opposed crashes allows for an examination of crash-type distribution. This examination can provide important clues as to the cause of the red-light problem and the selection of countermeasures.

Rear-End Crashes. The number of severe, intersection-related rear-end crashes should also be quantified for the subject approach. The aforementioned screening techniques should *not* be used to estimate this number. Frequent rear-end crashes may be an indicator of driver inattentiveness or inability to stop.

Peace Officer Interview. An important element of the crash history investigation is the peace officer interview. Traffic enforcement officers with the local law enforcement agency should be contacted and asked about their experience with traffic violations and crashes at signalized intersections in their jurisdiction. If they have detected a problem related to red-light-running, they should be asked about their perception of possible causes and treatments.

Observational Study

An important part of this task is the first-hand observation of conditions at intersections in the jurisdiction. This observation should be scheduled to coincide with the occurrence of the reported problems (e.g., hour of peak traffic demand). Over a period of several days, the engineer should evaluate several signalized intersections in the city (preferably the same ones for which the printed crash reports were reviewed). This evaluation should include a "drive through" at each intersection as well as some time spent observing its operation from a curb-side vantage point.

While at the intersection, the engineer should use judgment to assess the following:

- delay incurred by approach traffic (Is it excessive?);
- platoon arrival time and end of the green (Is the trailing edge repeatedly receiving a yellow?);
- yellow duration (Is it consistent with agency policy and appropriate for the observed speed?);
- approach speeds (Are speeds routinely in excess of the posted limit?); and
- signal conspicuity (Is the correct signal head clearly discernable by motorists?).

Also, while at the intersection, the engineer should attempt to observe several red-light violations. Through these observations, the engineer should identify the traffic movements experiencing the problem and possible causes for the violations.

At the conclusion of this study, the engineer should form an opinion as to the possible existence of an "area-wide" red-light problem. If an area-wide problem is thought to exist, then the evaluation should proceed to the next task. If it appears that only a few intersections in the jurisdiction that are experiencing red-light problems, then the engineer should consider a focused evaluation of these few intersections using the "local intersection" procedure described elsewhere in this handbook.

Confirm Extent of Problem

During this task, the information gathered in the previous task is evaluated to determine if a red-light-related safety problem exists in the jurisdiction. Initially, the population and crash history should be entered into the TREAT spreadsheet. Then, the output measures should be evaluated to determine if there is an excessive number of crashes in the subject jurisdiction.

Enter Existing Conditions in TREAT

During this step, the information gathered during the previous task is used with the TREAT spreadsheet to evaluate the subject approach. The count of "right-angle and other" and the count of "left-turn-opposed" crashes should be entered into the spreadsheet. The population of the jurisdiction should also be entered.

Population and Crash Data. The data entry portion of the TREAT spreadsheet is shown in Figure 19. The shaded cells represent data entry fields. The population is entered in row 8. The crash data are entered in rows 9 and 10. In middle of this figure are three columns representing the "analysis scenarios." The scenario headed "existing conditions" does not include any additional inputs. The output measures (discussed next) for this scenario represent the safety record of the jurisdiction at the time of the evaluation. They form the basis for evaluating the alternatives.

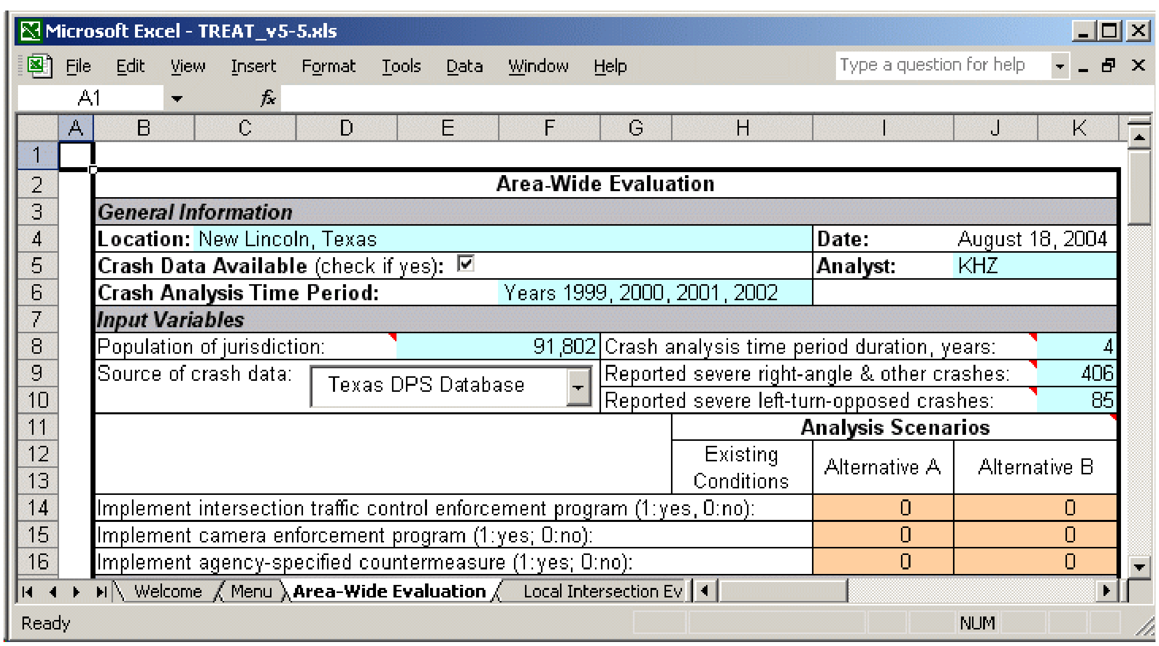
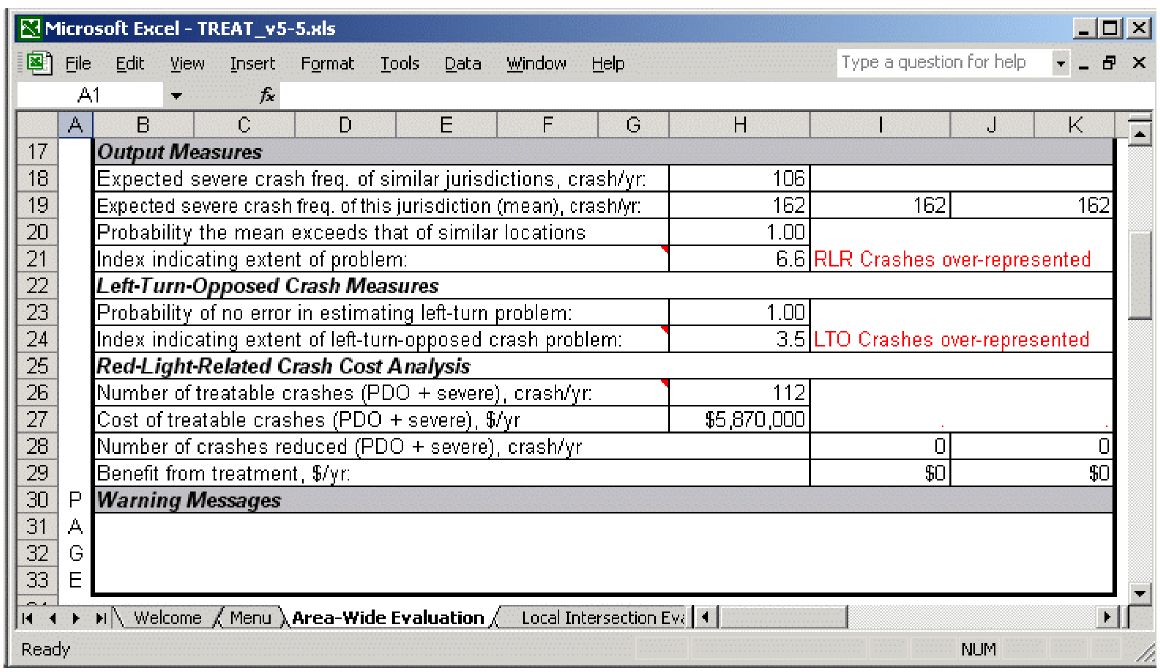


Figure 19. TREAT Input Variables, Area-Wide Evaluation.

Agency Countermeasure. The spreadsheet automates the evaluation of the area-wide enforcement countermeasures listed in Table 8. Crash reduction factors attributable to the area-wide implementation of engineering countermeasures were not available in the literature at the time of publication of this handbook. Row 16 provides a place for the agency to evaluate a countermeasure for which they have confidence in its crash reduction potential. The corresponding reduction factors would be entered in row 39 (not shown).

Evaluate Existing Conditions

Figure 20 shows the output measures of effectiveness computed by the TREAT spreadsheet. As indicated in this figure, there are separate sections for the red-light-related crash evaluation, the left-turn-opposed crash evaluation, and a crash cost analysis. The interpretation of the various measures in each section is described in the following paragraphs. For this discussion, it should be remembered that column H corresponds to the "Existing Conditions" scenario. It should also be noted that rows 18 and 20 refer to "location" instead of "jurisdiction." The term "location" is used generically here because an evaluation can apply to an entire jurisdiction or to just a portion of it.



	A	B–G	H	I	J–K
17		***Output Measures***			
18		Expected severe crash freq. of similar jurisdictions, crash/yr:	106		
19		Expected severe crash freq. of this jurisdiction (mean), crash/yr:	162	162	162
20		Probability the mean exceeds that of similar locations	1.00		
21		Index indicating extent of problem:	6.6	RLR Crashes over-represented	
22		***Left-Turn-Opposed Crash Measures***			
23		Probability of no error in estimating left-turn problem:	1.00		
24		Index indicating extent of left-turn-opposed crash problem:	3.5	LTO Crashes over-represented	
25		***Red-Light-Related Crash Cost Analysis***			
26		Number of treatable crashes (PDO + severe), crash/yr:	112		
27		Cost of treatable crashes (PDO + severe), $/yr	$5,870,000		
28		Number of crashes reduced (PDO + severe), crash/yr		0	0
29		Benefit from treatment, $/yr:		$0	$0
30	P	***Warning Messages***			
31	A				
32	G				
33	E				

Figure 20. TREAT Output Measures, Area-Wide Evaluation.

Red-Light-Related Crash Measures. The expected severe crash frequency for a typical jurisdiction of similar population to that of the subject jurisdiction is provided in row 18 of Figure 20. The statistics shown indicate that cities similar in population to the example city should experience an annual average of 106 severe red-light-related crashes.

An estimate of the expected crash frequency for the subject jurisdiction, given its crash history, is provided in row 19. This statistic represents the best estimate of the average number of crashes occurring annually in the jurisdiction, as averaged over the time periods studied. The output indicates that the example subject city should experience an annual average of 162 severe red-light-related crashes. The difference between this average and that for the "similar" cities represents the "treatable" number of crashes in the subject jurisdiction. This difference, adjusted upward to include the likely number of property-damage-only crashes, is shown in row 26.

The index in row 21 is based on a statistical analysis of the expected crash frequency and the underlying uncertainty associated with its estimate. An index of 1.0 or more is an indication that the treatable red-light crashes in the jurisdiction are sufficiently large that a red-light-related problem exists. The degree of confidence that can be placed in this claim is reflected in the "probability" provided in row 20. In this instance, there is a probability of 1.0 (i.e., relative certainty) that the jurisdiction has a red-light-related problem.

Left-Turn-Opposed Crash Measures. The number of severe left-turn-opposed crashes that occurred in the jurisdiction were also evaluated. The index in row 24 of 3.5 exceeds 1.0, which indicates that there is likely a left-turn-opposed crash problem in this jurisdiction. The associated probability of 1.0 in row 23 indicates that the existence of this problem is fairly certain (i.e., that the observed over-representation of left-turn crashes is probably not a result of random variation).

Red-Light-Related Crash Cost. The expected number of severe crashes for the subject jurisdiction and the "similar" jurisdiction are used to estimate the number of treatable severe crashes. This estimate is then converted into the number of treatable *total* crashes (including both severe and PDO crashes). The number of treatable total crashes is provided in row 26. The societal cost of these crashes is provided in row 27. It is based on the average crash cost provided in row 36 (not shown). For the example city, the treatable crashes represent an annual societal cost of $5,870,000. In this instance, if the countermeasures that are applied to this jurisdiction cost $5,870,000 or less, then the benefit-cost ratio of the treatment will be 1.0 or larger.

Identify Causes and Countermeasures

The successful treatment of red-light-related safety problems within a jurisdiction is likely to require treatment at both the area-wide and local-intersection levels. This section addresses area-wide treatments. The identification of problem intersections and their treatment is discussed in the section titled Procedures for Local Intersection Evaluation. The countermeasure selection process for area-wide treatment should include an evaluation of the following crash data:

- frequency of red-light-related crashes, and
- crash-type distribution.

The aforementioned crash data should be used to determine if a pattern exists in the red-light-related crashes. Specifically, the engineer should attempt to sort the crashes into the four "violation cause" categories listed in Table 4. The category representing the most frequent cause of violation is combined in a later task with other information to identify the most appropriate countermeasures.

Many of the countermeasures listed in Table 8 are effective in treating specific types of red-light-related crashes. The information cited in Chapter 2 that characterized the red-light violation, the driver, and the crash was used to identify logical relationships between the countermeasures and the cause of the violation that precipitated the crash. These relationships are shown in Table 13.

Table 13. Area-Wide Countermeasure Selection Based on Cause of Violation.

Category	Countermeasure	Cause of Violation in Typical Crash [1]			
		Inattentive (A)	Unnecessary Delay (B)	Congestion, Dense Traffic (C)	Incapable of Stop (D)
Signal operation	Bring yellow durations into compliance with policy				✔
	Add protected-only left-turn phasing				✔
Motorist information	Improve signal conspicuity by upgrading to 12" lenses [2]	✔			✔
	Improve signal conspicuity by using yellow LEDs				✔
	Improve signal conspicuity by using red LEDs	✔			
	Improve signal conspicuity by using back plates	✔			✔
	Improve signal conspicuity by using dual red indications	✔			
Traffic operation	Reduce delay through signal re-timing			✔	
	Reduce unnecessary delay through signal re-timing		✔		
	Improve signal coordination [3]			✔	
Education	Implement public awareness campaign		✔	✔	
Enforcement	Increase officer enforcement		✐ (outlined check)	✔	
	Implement camera enforcement		✔	✔	

Notes:
1 - Cause category (A, B, C, D) shown in parentheses. ✔: likely countermeasure. ✅: possible countermeasure.
2 - Increasing the red lens size from 8" to 12" should have more impact on inattentive drivers. Increasing the yellow lens size from 8" to 12" should have more impact on drivers that report being incapable of stopping at yellow onset.
3 - Improvements to signal coordination will be most effective in reducing red-light violations if they result in: (1) lower delay, (2) longer cycle lengths, and (3) progression bands that are not constrained by the end of the phase such that platoons traveling through the intersection are repeatedly caught by the change to red.

Four "violation cause" categories are identified in columns 3 through 6 of Table 13. They are labeled categories "A," "B," "C," and "D." These categories were previously discussed in the text associated with Tables 3, 4, and 7. A check (✔) is used to denote countermeasures likely to be effective in reducing red-light-related crashes for a specific category. An outlined check (✅) is used to denote countermeasures that may be effective in certain specific instances.

A flow chart that can be used to guide the selection of the appropriate countermeasure category is provided in Figure 21. The steps taken to apply this flow chart are described in the following paragraphs.

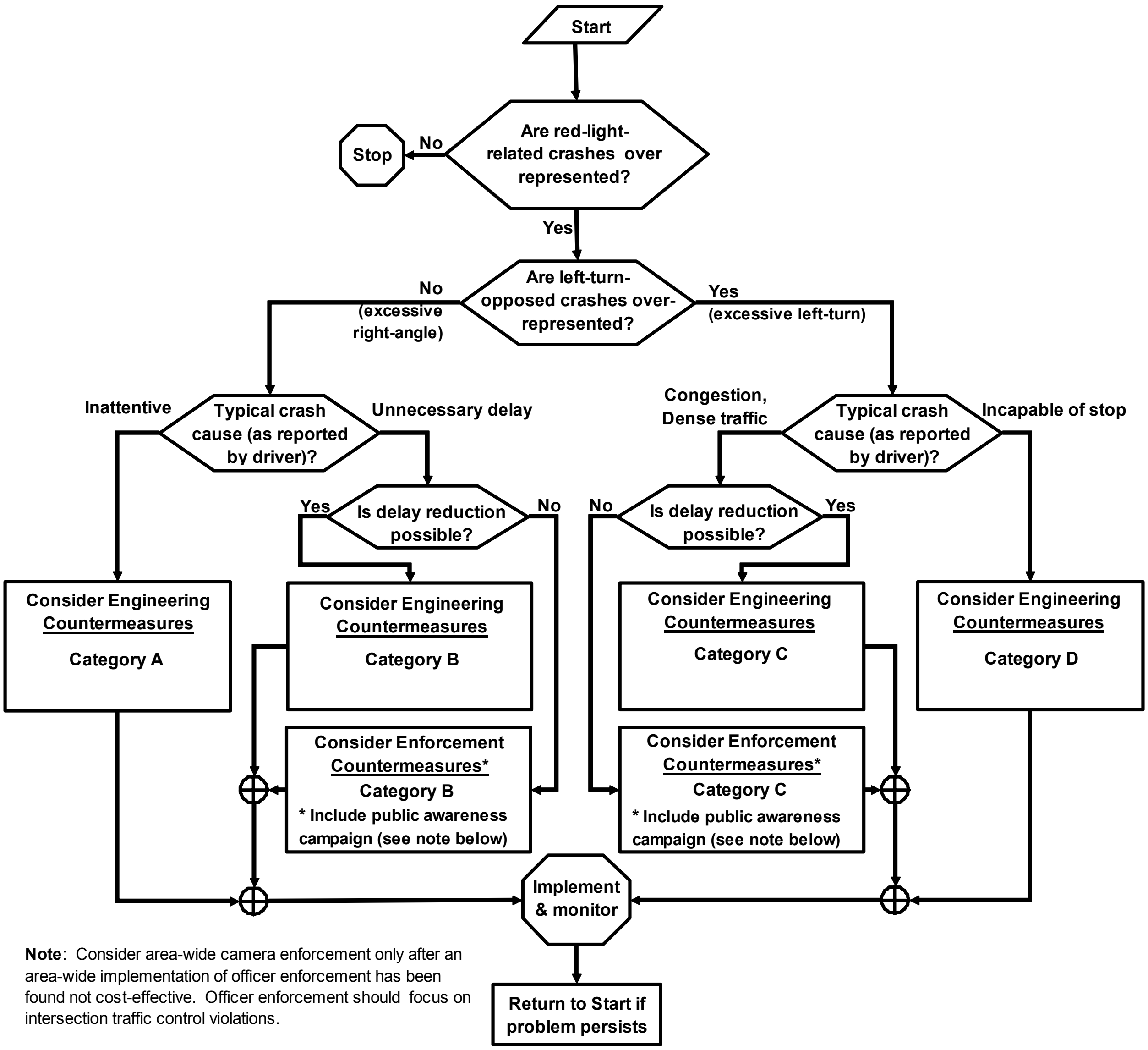


Figure 21. Countermeasure Selection Guidelines, Area-Wide Evaluation.

Step 1. Over-Representation of Crashes

As indicated by the flow chart, the first step is to determine if crashes are over-represented in the jurisdiction. Information is provided in the TREAT spreadsheet for making this determination. Specifically, the index value provided for red-light-related crashes can be used for this purpose. An index of 1.0 or larger indicates over-representation of crashes in the jurisdiction.

Step 2. Over-Representation of Left-Turn-Opposed Crashes

If crashes are over-represented, the next step is to determine whether left-turn-opposed crashes are over-represented. Again, the TREAT software provides an index value that can be used to make this assessment. An index of 1.0 or larger should be considered an indication of over-representation for the purpose of countermeasure selection. Excessive left-turn-opposed crashes are an indication that the red-light violations occurring just after the onset of red are problematic.

Step 3. Possible Crash Cause

The determination of crash cause requires the application of engineering judgment based on the information obtained from the peace officer interview and observational study. An important piece of information is the printed officer report. A review of the narratives on a sample of these reports may provide important clues indicating the range of crash causes. The engineer should evaluate all the information and make a determination of the cause of the "typical" (or most frequent) crash. This determination should result in the engineer designating one of the following crash categories as being the most likely cause of the typical crash:

- inattentive (Category A countermeasures),
- unnecessary delay (Category B countermeasures),
- congestion or dense traffic (Category C countermeasures), and
- incapable of stop (Category D countermeasures).

Crashes due to "inattentive" drivers may not be associated with a high frequency of red-light violations. These crashes often occur randomly during the later portion of the red indication, while almost all violations tend to occur in the first few seconds of red.

The frequency of severe rear-end crashes may also offer some clue as to the cause of the typical crash. If these crashes are over-represented in the jurisdiction, it may be an indication that crash cause may be related to driver inattentiveness or inability to stop. Rear-end crashes typically represent about 45 percent of all intersection-related crashes (*7*).

Step 4. Feasibility of Delay Reduction Countermeasures

If the typical crash cause is determined to be due to "unnecessary delay," "congestion," or "dense traffic," then countermeasures that improve intersection operations on an area-wide basis should be considered. During this step, the feasibility of delay reduction countermeasures is evaluated using engineering judgment based on information from the observational study. If it is determined that area-wide improvements to intersection operations are not available, affordable, or feasible, then enforcement countermeasures should be considered.

Step 5. Identify Candidate Countermeasures

The last step associated with this task is to identify the candidate countermeasures. These countermeasures should be selected from Table 13 based on the "cause category" identified in the previous steps. Again, engineering judgment should be used to screen out those countermeasures that are not appropriate for the jurisdiction.

Example Application

The example shown in Figure 19 was evaluated using the flow chart in Figure 21 and the findings from the statistical analysis (as shown in Figure 20). The results indicated that both red-light-related and left-turn-opposed crashes are over-represented in the jurisdiction.

The findings from the officer interview, observational study, and review of printed crash reports indicated that the crashes are likely being caused by a mix of congestion and "dense traffic" in the context of poor signal progression on several of the city's arterial streets (i.e., Category C). It was determined that the following engineering countermeasures should be evaluated:

- Alternative A: Improve signal coordination along the city's major arterial streets, and
- Alternative B: Implement intersection traffic control enforcement program.

The entry of these alternatives into TREAT is shown in rows 14 and 16 of Figure 22.

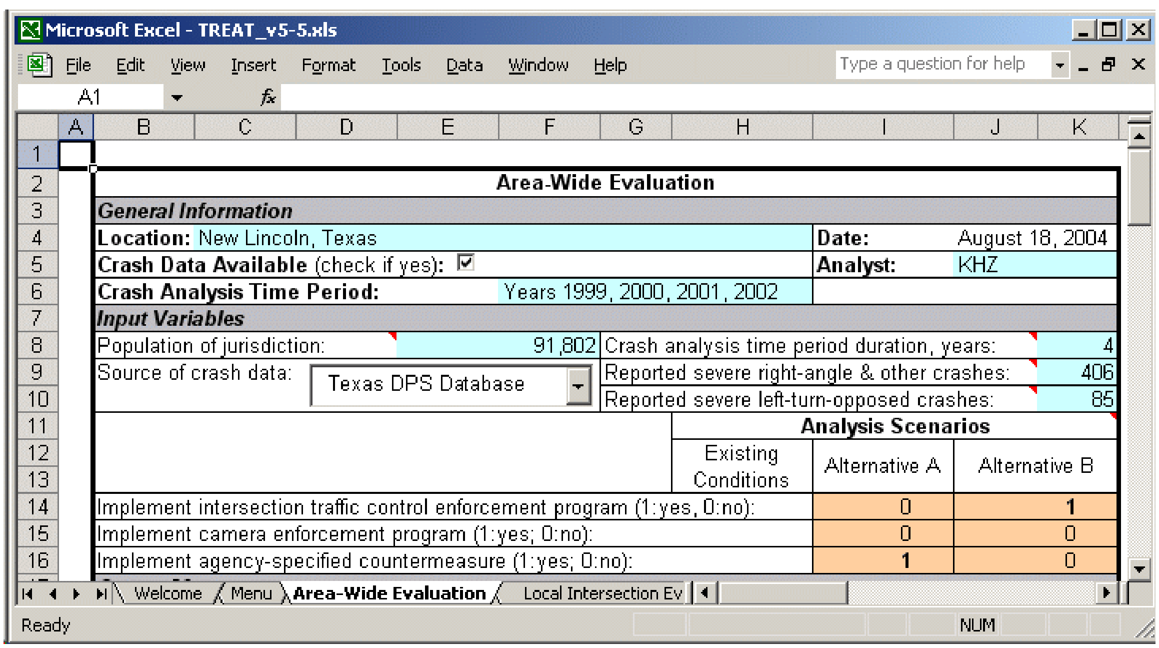


Figure 22. Input Variables for Example Application, Area-Wide Evaluation.

Crash reduction factors were not available in Table 8 for the "improve signal coordination" countermeasure. However, experience with this treatment at neighboring jurisdictions indicated that it reduced crashes by 8.0 percent (this value is entered in row 39 of TREAT).

Evaluate Countermeasures

During this task, the range of candidate countermeasures identified in the previous task are evaluated for their effectiveness in treating the subject approach. The effectiveness of a countermeasure is evaluated in terms of its ability to reduce red-light crashes by an amount that is reasoned to be cost-effective, relative to the resource investment required to implement the countermeasure. The effectiveness of several countermeasures can be evaluated using the TREAT spreadsheet.

Alternative Evaluation

To illustrate the decisions made during this task, consider the example application introduced previously. The findings from the evaluation of the two alternatives are shown in Figure 23. It should be remembered that the output measures corresponding to Alternatives A and B are shown in columns I and J/K, respectively.

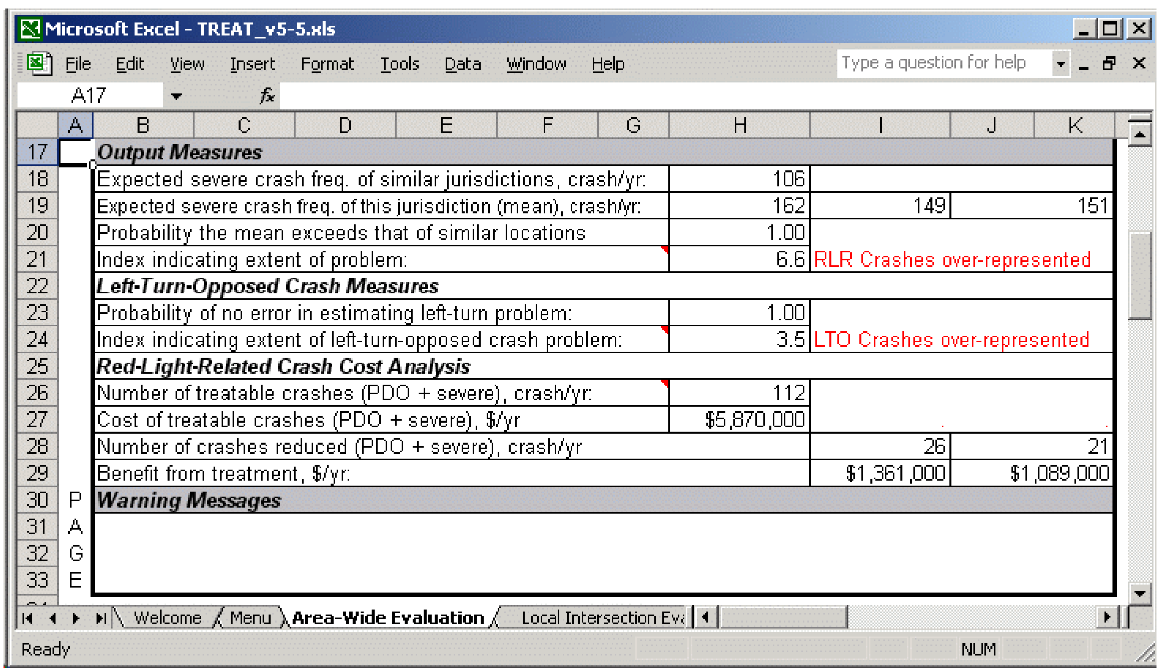


Figure 23. Output Measures for Example Application, Area-Wide Evaluation.

As indicated in Figure 23, Alternative A (i.e., improve signal coordination) is associated with an expected annual severe red-light crash frequency of 149 crashes (row 19). This value compares to the 162 crashes/yr currently experienced in the jurisdiction. As indicated by row 28, this frequency translates into a crash reduction of 26 crashes/yr (including both severe and PDO crashes). Row 29 indicates that this reduction results in a net annual benefit of $1,361,000.

The findings from the evaluation of Alternative B (i.e., implement enforcement program) are shown in column J/K. Row 28 indicates that this alternative should reduce crashes by 21 crashes/yr. Row 29 indicates that this reduction results in a net annual benefit of $1,089,000.

Techniques to Avoid Over-Treatment

It is useful to evaluate the effectiveness of the alternatives relative to the number of treatable crashes (row 26). In this instance, the reduction in crashes associated with Alternatives A or B do not exceed the treatable 112 crashes/yr. Hence, both countermeasures are viable. In general, any combination of countermeasures that yield a crash reduction that does not exceed the treatable number can be considered viable. Countermeasure combinations that reduce crashes beyond the treatable number represent "over-treating" and may not yield the predicted benefits. If TREAT indicates that a specific combination of countermeasures will over-treat the problem, their number should be reduced until over-treating is not expected to occur. The subset of countermeasures obtained in this manner should be implemented and, after a reasonable acclimation period, their effectiveness should be reevaluated to determine if the red-light problem still exists.

Incorporating Local Intersection Treatments in the Area-Wide Evaluation

As shown in Figure 23, the crash analysis for Alternatives A and B only reduced a small portion of the treatable crashes. This result is common for area-wide treatments. It is a reminder that area-wide countermeasures are not likely to eliminate the majority of red-light violations or related crashes. Further reduction of red-light violations will likely require the spot treatment of problem intersection approaches. Hence, the identification and treatment of specific problem intersections should be included in any area-wide evaluation for maximum safety improvement.

Implement Selected Countermeasures and Monitor

The most cost-effective countermeasures should be implemented during this task. To assist in making this determination, the crash reduction benefits reported in TREAT for each alternative can be compared with the cost of implementing the associated countermeasures. The difference between this benefit and cost represents the net-benefit associated with an alternative. All other considerations being equal, the alternative associated with the largest net-benefit should be considered for implementation.

The recommended sequence of countermeasure implementation is summarized in Figure 12. In general, if the countermeasures identified include both engineering and enforcement, then the engineering countermeasures should be implemented first and monitored for effectiveness.

If the resulting effect of the engineering countermeasures is determined to be inadequate, then officer enforcement should be considered. For area-wide treatment, officer enforcement should represent a long-term program of enforcement activity that focuses on intersection traffic control violations. The program should last for a period of 6 to 12 months and include a public awareness campaign. Officers should be deployed daily to randomly selected intersections for short-term intervals (i.e., 1 or 2 hours). The officers should be visible during the enforcement activity. The TxDOT STEP-ITC program is an example of this type of enforcement program.

The effectiveness of the enforcement program should be evaluated by comparing red-light-related crashes before and during the program. If, after the program has ended, crashes are believed to have returned to pre-enforcement levels, then the engineer and the enforcement agency should meet and decide whether to reinitiate the enforcement activity.

If officer enforcement is determined to be unsuccessful or ineffective, then camera enforcement can be considered. If camera enforcement is implemented, it should be accompanied by a public awareness campaign. Also, rear-end crash frequency should be monitored at the camera-enforced intersections and remedial action taken if a sustained increase in crashes is observed. The FHWA report *Guidance for Using Red Light Cameras* (*10*) is a useful resource for agencies considering camera enforcement.

CHAPTER 4. REFERENCES

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APPENDIX

TABLE OF YELLOW INTERVAL DURATIONS
CONDITION DIAGRAM & DATA SUMMARY SHEET
MODEL CALIBRATION PROCEDURE

TABLE OF YELLOW INTERVAL DURATIONS

85th Percentile Speed, mph	**Yellow Interval Duration [1], s**								
	Approach Grade [2], %								
	-4	**-3**	**-2**	**-1**	**0**	**1**	**2**	**3**	**4**
30	3.5	3.4	3.4	3.3	3.2	3.1	3.1	3.0	3.0
35	3.9	3.8	3.7	3.7	3.6	3.5	3.4	3.3	3.3
40	4.4	4.2	4.1	4.0	3.9	3.8	3.8	3.7	3.6
45	4.8	4.7	4.5	4.4	4.3	4.2	4.1	4.0	3.9
50	5.2	5.1	4.9	4.8	4.7	4.6	4.4	4.3	4.2
55	5.6	5.5	5.3	5.2	5.0	4.9	4.8	4.7	4.6
60	6.0	5.9	5.7	5.5	5.4	5.3	5.1	5.0	4.9

Notes:
1 - Yellow interval durations computed using Equation 1.
2 - Negative grade represents a "downhill" condition. Positive grade represents an "uphill" condition.

CONDITION DIAGRAM & DATA SUMMARY

Intersection: ______________________________ **Date:** ____________

Subject Approach: ______________________________ **Surveyor:** ____________

Time Period	Hours	Hours	Thru. Veh. Count	Thru. Truck Count	Thru. Violation Count
Morning peak					
Off-peak					
Evening peak					
Total:					

Approach control mode:	Act___ Pre___	Intersection leg AADT, veh/d:	
Posted speed limit, mph:		12" signal head lens size:	G__ Y__ R__
Lenses with LED indications:	G__ Y__ R__	Back plates on signal heads?:	Yes___ No___
Dual red indications?:	Yes___ No___	Protected-only left-turn phasing?	Yes___ No___
Advance warning signs?:	Yes___ No___	Adv. warning signs w/active flashers?:	Yes___ No___

Condition Diagram

Signal cycle length, s:		Number of through lanes:	
Green phase duration, s:		Approach grade, % (+ for uphill):	

MODEL CALIBRATION PROCEDURE

INTRODUCTION

The violation and crash prediction models included in TREAT were developed using data collected in Texas; however, they can be used by transportation agencies located throughout the U.S. Regardless of where it is used, TREAT models must be calibrated before they can be reliably used for selecting and evaluating countermeasures. This need stems from differences that exist in levels of enforcement and driver behavior among jurisdictions. This requirement is especially true for the application of TREAT in states other than Texas.

The TREAT spreadsheet includes three models that require calibration; they are:

- violation prediction model for local intersection evaluation,
- crash prediction model for local intersection evaluation, and
- crash prediction model for area-wide evaluation.

A description of the calibration procedure for each of these models is presented in the following sections in the order listed above.

TREAT includes several default parameters. These parameters are identified in the Area-Wide Evaluation worksheet and the Local Intersection Evaluation worksheet. A section titled Default Parameters is highlighted in each worksheet. The analyst should also adjust these parameters to adapt TREAT to local conditions.

CALIBRATION PROCEDURE

Local Intersection Violation Model

The calibration process is essentially one of determining the value of the calibration factor C_f that, when used with the prediction model, facilitates the accurate estimation of the red-light violation frequency that is consistent with the typical intersection approach. It is anticipated that the calibration process will be completed once by the agency, prior to first use of the TREAT spreadsheet. However, the agency may find it useful to update the calibration factor periodically, especially if regional programs have been implemented that reduce red-light violations through enforcement or driver education.

The calibration process is focused on the individual intersection approach. The calibration factor should be developed for the through movement (and any turn movements that share a lane with the through movement) because this is the movement modeled in TREAT.

The calibration process consists of the following steps:

1. **Identify Typical Intersection Approaches.** Several intersections should be selected for use in the calibration process. These intersections must not be known to have an unusually large frequency of red-light violations. Moreover, their traffic volume, signalization, and geometry should be considered typical and should reflect some range in volume level, cycle length, and number of lanes. A minimum of six intersection approaches at three or more intersections should be selected. The selection of more than six intersection approaches and more than three intersections is desirable. Red-light violations for the through movement on each approach should be tabulated for 1 hour. The studies should focus on the peak traffic period during typical weekdays.

2. **Collect Data at Selected Intersections.** A site survey (as described in Chapter 3) should be conducted for each of the subject approaches selected in Step 1.

3. **Compute Expected Frequency of Red-Light-Running.** The TREAT spreadsheet is used (with $C_f = 1.0$) to compute the expected red-light violation frequency $E[R]$ for each subject approach. Specifically, the "Existing Conditions" column (i.e., column H) is used to enter the data corresponding to the subject approach. The analysis period duration, violation count, and traffic volume are entered in column F, rows 11, 12, and 13, respectively. The expected red-light violation frequency $E[R]$ for this approach is obtained from row 108, column H.

4. **Compute Calibration Factor.** The following equation is used to compute the calibration factor C_f:

$$C_f = \frac{x_1 + x_2 + x_3 + \ldots + x_n}{E[R]_1 + E[R]_2 + E[R]_3 + \ldots + E[R]_n} \qquad \textbf{(A-1)}$$

   where, x_i is the observed red-light violation frequency for subject approach i, and $E[R]_i$ is the expected red-light violation frequency for this same approach. The values of x_i were obtained during Step 2. The values of $E[R]_i$ were computed in Step 3. The calibration factor obtained from Equation A-1 is then entered into row 73, column F of the TREAT spreadsheet. The spreadsheet file should be "saved" to disk to retain this calibration constant.

Local Intersection Crash Model

The calibration process for the local intersection crash model is similar to that for the violation model. It is essentially one of determining the value of the calibration factor that, when used with the prediction model, facilitates the accurate estimation of the red-light crash frequency consistent with the typical intersection approach in the jurisdiction of interest. It is anticipated that the calibration process will be completed once by the agency, prior to first use of the TREAT spreadsheet. However, the agency may find it useful to update the calibration factor periodically, especially if regional programs have been implemented that reduce red-light crashes through enforcement or driver education.

The calibration process is focused on the individual intersection approach. The calibration factor should be developed for the through movement (and any turn movements that share a lane with the through movement) because this is the movement modeled in TREAT.

The calibration process consists of the following steps:

1. **Identify Typical Intersection Approaches.** Several intersections should be selected for use in the calibration process. These intersections must not be known to have an unusually large frequency of red-light crashes. Moreover, their traffic volume, signalization, and geometry should be considered typical and should reflect some range in volume level, cycle length, and number of lanes. A minimum of 20 intersection approaches at 10 or more intersections should be selected. The selection of more than 20 intersection approaches and more than 10 intersections is desirable.

2. **Collect Data at Selected Intersections.** A site survey (as described previously in Chapter 3) is conducted for each of the subject approaches selected in Step 1. Measurement of red-light violations is not needed for this calibration activity. The crash history of each intersection approach) should be obtained for the most recent 3 years for which data are available.

   Desirably, the printed crash reports would be acquired for each intersection and manually reviewed to identify the true red-light-related crashes associated with the subject intersection approaches. This determination requires a review of several of the information fields in the report, including the officer narrative and crash diagram. To expedite the manual review, an electronic database may be initially screened for all crashes at the intersection designated as having the following attributes:

   - intersection relationship: "at" the intersection, and any one of the following:
   - crash type: "right-angle,"or
   - crash type: "left-turn-opposed," or
   - first contributing factor: "disregard of stop and go signal," or
   - first contributing factor: "disregard of stop sign or light."

   This initial screening will significantly reduce the number of crash reports that need to be "pulled" from agency files and manually reviewed without eliminating a significant number of truly red-light-related crashes.

If the reports are not available or cannot be manually reviewed, then the red-light-related crashes can be screened from an electronic crash database. If this approach is used, the following attributes should be used as screens:

- intersection relationship: "at" the intersection, and
- first contributing factor: "disregard of stop and go signal" or "disregard of stop sign or light."

3. **Compute Expected Frequency of Red-Light-Related Crashes.** The TREAT spreadsheet is used (with $C_f = 1.0$) to compute the expected annual red-light crash frequency *E[r]* for each subject approach. Specifically, the "Existing Conditions" column (i.e., column H) is used to enter the data corresponding to the subject approach. The crash data are entered in column K, rows 11, 12, and 13. The expected red-light crash frequency *E[r]* for this approach is obtained from row 129, column H.

4. **Compute Calibration Factor.** The following equation is used to compute the calibration factor C_f:

$$C_f = \frac{1}{3} \frac{c_1 + c_2 + c_3 + \ldots + c_n}{E[r]_1 + E[r]_2 + E[r]_3 + \ldots + E[r]_n} \qquad \textbf{(A-2)}$$

where, c_i is the observed 3-year red-light-related crash frequency for subject approach *i*, and $E[r]_i$ is the expected annual red-light-related crash frequency for this same approach. The values of c_i were obtained during Step 2. The values of $E[r]_i$ were computed in Step 3. The calibration factor obtained from Equation A-2 is then entered into row 73, column K of the TREAT spreadsheet. The spreadsheet file should be "saved" to disk to retain this calibration constant.

Area-Wide Crash Model

The calibration process for the area-wide crash model is similar to that for the violation model. It is essentially one of determining the value of the calibration factor that, when used with the prediction model, facilitates the accurate estimation of the red-light crash frequency consistent with the typical jurisdiction of similar population. It is anticipated that the calibration process will be completed once by agencies outside of Texas, prior to first use of the TREAT spreadsheet. It does not need to be receive an initial calibration for use in Texas because it was developed using crash data representing 135 Texas cities.

Agencies in Texas, and those in other states, may find it useful to update the calibration factor periodically, especially if regional programs have been implemented that reduce red-light crashes through enforcement or driver education.

The calibration process consists of the following steps:

1. **Identify Calibration Jurisdictions.** Several cities in the state should be selected for use in the calibration process. These cities must not be known to have an unusually large frequency of red-light crashes. Moreover, their demographics should be considered typical and should reflect some range in location within the state and in population. A minimum of 20 cities should be selected. The selection of more than 20 cities is desirable. It is also desirable that the cities selected all have a population of 20,000 or more persons.

2. **Collect Data at Selected Jurisdictions.** The crash history of each city should be obtained by screening the crash database and making an accurate identification of severe red-light-related crashes (as defined in Chapter 3). The most recent 3 years for which crash data are available are needed for each city.

   Desirably, the printed crash reports would be acquired for all crashes in each city and manually reviewed to identify the red-light-related crashes. This determination requires a review of several of the information fields in the report, including the officer narrative and crash diagram. For larger cities, this approach is probably not feasible due to the number of crashes that occur. Therefore, if the reports cannot be manually reviewed, the red-light-related crashes should be screened from an electronic crash database with the following attributes used as screens:

   - traffic control: "stop and go signal,"
   - intersection relationship: "at" the intersection, and
   - first contributing factor: "disregard of stop and go signal" or "disregard of stop sign or light."

3. **Compute Expected Frequency of Red-Light-Related Crashes.** The TREAT spreadsheet is used (with $C_f = 1.0$) to compute the expected annual red-light crash frequency *E[r]* for each subject approach. The crash data are entered in column K, rows 8, 9, and 10. The expected annual red-light crash frequency *E[r]* for this approach is obtained from row 49, column H.

4. **Compute Calibration Factor.** The following equation is used to compute the calibration factor C_f:

$$C_f = \frac{1}{3} \frac{c_1 + c_2 + c_3 + \ldots + c_n}{E[r]_1 + E[r]_2 + E[r]_3 + \ldots + E[r]_n} \qquad \textbf{(A-3)}$$

   where, c_i is the observed 3-year red-light-related crash frequency for city i, and $E[r]_i$ is the expected annual red-light-related crash frequency for this same jurisdiction. The values of

c_i were obtained during Step 2. The values of $E[r]_i$ were computed in Step 3. The calibration factor obtained from Equation A-3 is then entered into row 39, column F of the TREAT spreadsheet. The spreadsheet file should be “saved” to disk to retain this calibration constant.