# Traffic Signals

The introduction to this issue brief provides an overview of traffic signals (purpose, warrants for signal installation, advantages, disadvantages, and factors to consider) followed by an introduction to the contents of this issue brief (crash reduction factors, presentation of the crash reduction factors, and using the Tables).

## Purpose of Traffic Signals

Traffic signals are used to assign vehicular and pedestrian right-of-way. They are used to promote the orderly movement of vehicular and pedestrian traffic and to prevent excessive delay to traffic.

Traffic signals should not be installed unless one of the warrants specified by the Manual on Uniform Traffic Control Devices (MUTCD) has been satisfied. The satisfaction of a warrant is not in itself justification for a signal. A traffic engineering study must be conducted to determine whether the traffic signal should be installed. The installation of a traffic signal requires sound engineering judgment, and must balance the following, sometimes conflicting, goals:

- Moving traffic in an orderly fashion;
- Minimizing delay to vehicles and pedestrians;
- Reducing crash-producing conflicts; and
- Maximizing capacity for each intersection approach.


## Where Should A Signal Be Installed?

The MUTCD lists eight warrants for the placement of traffic signals. Readers are encouraged to review Part 4 of the MUTCD for more specific information regarding signal warrants. Access management considerations and the spacing of signals on arterial roadways are critical elements of system efficiency and operational safety. The basic question that must be answered is "Will this intersection operate better with or without a traffic signal?"

## Advantages of Signals

Traffic signals that are properly located and operated are likely to:

- Provide for orderly movement of traffic;
- Increase traffic capacity of the intersection;
- Reduce the frequency of certain types of crashes (e.g. right-angle crashes);
- Provide for continuous or nearly continuous movement of traffic along a given route; and
- Interrupt heavy traffic to permit other traffic, vehicular or pedestrian, to cross.

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## Disadvantages of Signals

Traffic control signals are often considered a panacea for all traffic problems at intersections. This belief has led to the installation of traffic control signals at many locations where they are not needed, and where they may adversely affect the safety and efficiency of vehicular, bicycle, and pedestrian traffic.

Even when justified by traffic and roadway conditions, traffic control signals can be ill-designed, ineffectively placed, improperly operated, or poorly maintained. Unjustified or improper traffic control signals can result in one or more of the following disadvantages:

- Excessive delay;
- Excessive disobedience of the signal indications;
- Increased use of less adequate routes as road users attempt to avoid the traffic control signals; and
- Significant increases in the frequency of crashes (especially rear-end crashes).

As angle crashes tend to be more severe than rear-end crashes, traffic engineers are usually willing to trade off an increase in the number of rear-end crashes for a decrease in the number of angle crashes, but if an intersection does not have an angle crash problem, the trade off does not apply, and the installation of traffic signals can actually cause a deterioration in the overall safety at the intersection.

## Factors to Consider when Installing a Signal

A number of factors should be considered when planning to signalize an intersection. These factors include:

- The negative effects of traffic delay. Excessive delay results in significant fuel waste, higher motorist costs and air pollution.
- Potential diversion of arterial traffic into neighborhood streets.
- Red-light running violations and associated crashes.
- Cost. The cost for a signal ranges from $50,000 to more than $200,000 depending on the complexity of the intersection and the characteristics of the traffic using the intersection. In addition, the annual operating cost of each signal ranges from $1,000 to $5,000.

## Signal Improvements that May Decrease Crashes

The following changes may decrease crashes:

- Signal retiming, phasing, and cycle improvements;
- Review and assurance of adequacy of yellow change interval/all-red clearance interval for safer travel through the intersection;
- Use of longer visors, louvers, backplates and reflective borders;
- Installation of 12 inch signal lenses;
- Installation of additional signal heads for increased visibility;
- Provision of advance detection on the approaches so that vehicles are not in the dilemma zone when the signal turns yellow;
- Repositioning of signals to overhead (mast arm) instead of pedestal-mounted;
- Use of double red signal displays; and
- Removal of signals from late night/early morning programmed flash.

## Introduction to the Contents of this Issue Brief

This issue brief documents estimates of the crash reduction that might be expected if a specific countermeasure or group of countermeasures is implemented with respect to traffic signals. The crash reduction estimates are presented as Crash Reduction Factors (CRFs).

Traffic engineers and other transportation professionals can use the information contained in this issue brief when asking the following types of question: Which countermeasures might be considered at the signalized intersection of Maple and Elm streets, an intersection that is experiencing a high number of crashes? What changes in the number of crashes are possible with the various countermeasures?

## Crash Reduction Factors

A CRF is the percentage crash reduction that might be expected after implementing a given countermeasure. In some cases, the CRF is negative, i.e. the implementation of a countermeasure is expected to lead to a percentage increase in crashes.

One CRF estimate is provided for each countermeasure. Where multiple CRF estimates were available from the literature, selection criteria were used to choose which CRFs to include in the issue brief:

- Firstly, CRFs from studies that took into account regression to the mean and changes in traffic volume were preferred over studies that did not.
- Secondly, CRFs from studies that provided additional information about the conditions under which the countermeasure was applied (e.g. road type, area type) were preferred over studies that did not.

Where these criteria could not be met, a CRF may still be provided. In these cases, it is recognized that the reliability of the estimate of the CRF is low, but the estimate is the best available at this time. The CRFs in this issue brief may be periodically updated as new information becomes available.

The *Desktop Reference for Countermeasures* lists all of the CRFs included in this issue brief, and adds many other CRFs available in the literature. A few CRFs found in the literature were not included in the *Desktop Reference*. These CRFs were considered to have too large a range or too large a standard error to be meaningful, or the original research did not provide sufficient detail for the CRF to be useful.

*A CRF should be regarded as a generic estimate of the effectiveness of a countermeasure. The estimate is a useful guide, but it remains necessary to apply engineering judgment and to consider site-specific environmental, traffic volume, traffic mix, geometric, and operational conditions which will affect the safety impact of a countermeasure.* The user must ensure that a countermeasure applies to the particular conditions being considered. The reader is also encouraged to obtain and review the original source documents for more detailed information, and to search databases such as the National Transportation Library (ntlsearch.bts.gov) for information that becomes available after the publication of this issue brief.

## Presentation of the Crash Reduction Factors

In the Table presented in this issue brief, the crash reduction estimates are provided in the following format:

CRF(standard error)[REF]

The CRF is the value selected from the literature.

The standard error is given where available. The standard error is the standard deviation of the error in the estimate of the CRF. The true value of the CRF is unknown. The standard error provides a measure of the accuracy of estimate of the true value of the CRF. A relatively small standard error indicates that a CRF is relatively accurately known. A relatively large standard error indicates that a CRF is not accurately known. The standard error may be used to estimate a confidence interval of the true value of the CRF. (An example of a confidence interval calculation is given below.)

The REF is the reference number for the source information.

As an example, the CRF for the countermeasure *provide protected left-turn phase* for left-turn fatal/injury crashes is:

**16**(2)[9]

The following points should be noted:

- The CRF of 16 means that a 16% reduction in fatal and injury crashes combined is expected after providing a protected left-turn phase.
- This CRF is bolded which means that a) a rigorous study methodology was used to estimate the CRF, and b) the standard error is relatively small. A CRF which is not bolded indicates that a less rigorous methodology (e.g. a simple before-after study) was used to estimate the CRF and/or the standard error is large compared with the CRF.
- The standard error for this CRF is 2. Using the standard error, it is possible to calculate the 95% confidence interval for the potential crash reduction that might be achieved by implementing the countermeasure. The 95% confidence interval is ±2 standard errors from the CRF. Therefore, the 95% confidence interval for providing a protected left-turn phase is between 12% and 20% (16 - 2×2 = 12%, and 16 + 2×2 = 20%).
- The reference number is 9 (Lyon et al., as listed in the References at the end of this issue brief).

## Using the Table

The CRFs for traffic signal related crashes are presented in the Signalization Countermeasures Table that summarizes the available information.

Readers familiar with the previous edition of this issue brief will notice the following changes:

- Countermeasure cost estimates of low, medium, high are no longer provided as most agencies have readily available cost estimate information with actual dollar amounts.
- Countermeasures that do not have an estimate of crash reduction effectiveness are no longer included.
- Table 1, Signalization Countermeasures is divided into three sections: signal operations countermeasures; signal hardware countermeasures; and combination signal and other countermeasures. This table is also found in Issue Brief No.8, which includes a more comprehensive toolbox of countermeasures for consideration at intersections.

The following points should be noted:

- Where available, separate CRFs are provided for different crash severities. The crash severities are: all, fatal/injury, fatal, injury, or property damage only (PDO).
- Where available, existing traffic control information is provided (i.e. the conditions existing before implementation of a countermeasure). The control information is signal where the countermeasure involved a change to existing signalization. The control information is no signal or stop where the countermeasure involved a change from an unsignalized intersection to a signalized intersection.
- Where available, configuration information is provided. Two types of configuration are identified in the studies used for the CRFs: 3-leg and 4-leg.
- Where available, the Table provides daily traffic volume (vehicles/day) information for the major and minor roads of the intersection where the potential effectiveness of the countermeasure was measured. Where only one volume is provided, this volume refers to the traffic volume on the major road, unless otherwise specified.
- Blank cells mean that no information is reported in the source document.
- For additional information, please visit the FHWA Office of Safety website (safety.fhwa.dot.gov).

## Legend

**CRF(standard error)REF**

**CRF is a crash reduction factor, which is an estimate of the percentage reduction that might be expected after implementing a given countermeasure. A number in bold indicates a rigorous study methodology and a small standard error in the value of the CRF. Standard error, where available, is the standard deviation of the error in the estimate of the CRF. REF is the reference number for the source information.**

**Additional crash types identified in the *Other Crashes* column:**
**a: Head-on b: Run-off-road c: Overturn d: Night e: Day f: Multiple-vehicle g: Fixed-object h: Older-driver i: Younger-driver j: Right-turn k: Pedestrian l: Emergency vehicle**

# Table 1: Signalization Countermeasures

| Countermeasure(s) | Crash Severity | Control | Area Type | Configuration | All Crashes | Left-turn Crashes | Rt-angle Crashes | Rear-end Crashes | Sideswipe Crashes | Other Crashes | Major/Minor Daily Traffic Volume (vehicles/day) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SIGNAL OPERATIONS COUNTERMEASURES** | | | | | | | | | | | |
| Add all-red clearance interval (from 0 to 1 second) | All | Signal | Urban | | | | 0(44)[14] | | | | |
| Add exclusive pedestrian phasing | All | Signal | | | | | | | | k 34[7] | |
| Convert exclusive leading protected to exclusive lagging protected | All | Signal | | | -15(19)[6] | -49(54)[6] | | | | | |
| Convert permissive or permissive/protected to protected only left-turn phasing | All | | | | | 99[20] | | | | | |
| Convert permissive to permissive/protected left-turn phasing | All | | | | | 16[20] | | | | | |
| Convert protected left-turn phase to protected/permissive | All | Signal | | | -20(17)[6] | -65(71)[6] | | 4(22)[6] | | | |
| | Fatal/Injury | Signal | | | -10(25)[6] | | | | | | |
| Convert protected/permissive left-turn phase to permissive/protected | All | Signal | | | 13(19)[8] | 33(22)[8] | | | | | |
| Improve signal timing [to intervals specified by the ITE *Determining Vehicle Change Intervals: A Proposed Recommended Practice (1985)*] | All | Signal | | 4-Leg | **8**(9)[15] | | 4(18)[15] | -12(16)[15] | | h 42[12] | |
| | All | Signal | All | | | | | | | f 5[5] | |
| | All | Signal | | | | 75[4] | | | | | |
| | Fatal/Injury | Signal | | | | 55[4] | 30[4] | | | a 75[4] | |
| | Fatal/Injury | Signal | | | | | | | | b 62[4] | |
| | Fatal/Injury | Signal | | 4-Leg | 12(9)[15] | | -6(22)[15] | -8(17)[15] | | | |
| | Fatal/Injury | Signal | All | | | | | | | f 9[5] | |
| | Fatal/Injury | Signal | | | | | | | | k 37[15] | |
| | PDO | Signal | | | | 63[4] | 46[4] | 17[4] | | b 28[4] | |
| Increase yellow change interval | All | Signal | | | 15[4] | | 30[4] | | | | |
| Install emergency vehicle pre-emption systems | All | | | | | | | | | l 70[16] | |
| Modify signal phasing (implement a leading pedestrian interval) | All | Signal | | | | | | | | k 5[7] | |
| Provide actuated signals | All | Signal | | | | 80[4] | 10[4] | | | | |
| Provide Advanced Dilemma Zone Detection for rural high speed approaches | Fatal/Injury | Signal | Rural | 4-Leg (1 app) | 39[19] | | | | | | |
| Provide protected left-turn phase | Fatal/Injury | Signal | Urban | | | **16**(2)[9] | **19**(2)[9] | | | | |
| | All | Signal | | | 30[4] | 41[4] | 54[4] | 27[4] | | c 27[4] | <5,000/ lane(Total) |
| | All | Signal | | | 36[4] | 46[4] | 56[4] | 35[4] | | c 35[4] | >5,000/ lane(Total) |
| | All | Signal | | | 27[4] | 48[4] | 63[4] | 31[4] | | c 31[4] | |
| Provide protected/permissive left-turn phase (leading flashing green) (Request MUTCD Experimentation) | Fatal/Injury | Signal | Urban | | | **16**(4)[9] | **12**(4)[9] | | | | |
| Provide protected/permissive left-turn phase (leading green arrow) | Fatal/Injury | Signal | Urban | | | **17**(2)[9] | **25**(2)[9] | | | | |
| Provide signal coordination | All | Signal | | | | | 32[7] | | | | |
| Provide split phases | All | Signal | | | 25[7] | | | | | | |

**Table 1 (continued on page 6)**

## Table 1 (continued) Signalization Countermeasures

| Countermeasure(s) | Crash Severity | Control | Area Type | Configuration | All Crashes | Left-turn Crashes | Rt-angle Crashes | Rear-end Crashes | Sideswipe Crashes | Other Crashes | Major/Minor Daily Traffic Volume (vehicles/day) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SIGNAL OPERATIONS COUNTERMEASURES (CONTINUED)** | | | | | | | | | | | |
| Remove flash mode (late night/ early morning) | All | Signal | | | 29[7] | | 75(19)[14] | | | | |
| Replace existing WALK / DON'T WALK signals with pedestrian countdown signal heads | All | Signal | Urban | | | | | | | k 25[10] | |
| **SIGNAL HARDWARE COUNTERMEASURES** | | | | | | | | | | | |
| Add 3-inch yellow retroreflective sheeting to signal backplates | All | Signal | Urban | | 15(51)[17] | | | | | | |
| Add additional signal and upgrade to 12-inch lenses | All | Signal | | 4-Leg | | | | | | h 31[12] | |
| | All | Signal | | 4-Leg | | | | | | i 17[12] | |
| Add signal (additional primary head) | All | Signal | Urban | 4-Leg | 28[2] | | 35[2] | 28[2] | | | |
| | Fatal/Injury | Signal | Urban | 4-Leg | 17[2] | | | | | | |
| | PDO | Signal | Urban | 4-Leg | 31[2] | | | | | | |
| Convert signal from pedestal-mounted to mast arm | All | Signal | | | 49[16] | 12[16] | 74[16] | 41[16] | | | |
| | Fatal/Injury | Signal | | | 44[16] | | | | | | |
| | PDO | Signal | | | 51[16] | | | | | | |
| Improve visibility of signal heads (increase signal lens size, install new backboards, add reflective tape to existing backboards, and/or install additional signal heads) | All | Signal | Urban | | 7[18] | | | | | d 6[18] | |
| | All | Signal | Urban | | | | | | | e 6[18] | |
| | Fatal/Injury | Signal | Urban | | 3[18] | | | | | | |
| | PDO | Signal | Urban | | 9[18] | | | | | | |
| Improve visibility of signal heads (install two red displays in each head) | All | Signal | | | 9[7] | | 36[7] | | | | |
| Install larger signal lenses (12 inch) | All | Signal | | | 11[7] | | 46[14] | | | | |
| | All | Signal | Urban | | 24[17] | | | | | | |
| | Fatal/Injury | Signal | Urban | | 16[17] | | | | | | |
| Install signal backplates only | All | Signal | | | 13[7] | | 50[7] | | | | |
| Install signal backplates (or visors) | All | Signal | | | | | 20[4] | | | | |
| Install signals | All | No Signal | | | 33[7] | 38[13] | | | | j 50[13] | |
| | All | No Signal | | | 38[4] | | 74[4] | 22[4] | | c 22[4] | <5,000/ lane(Total) |
| | All | No Signal | | | 20[4] | | 43[4] | 20[4] | | c 20[4] | >5,000/ lane(Total) |
| | All | No Signal | Rural | | 15[13] | | | | | | |
| | Fatal | No Signal | | | 38[13] | | | | | | |
| | Fatal/Injury | Stop | Urban | 3-Leg | 14(32)[11] | | 34(45)[11] | -50(51)[11] | | | 11,750-42,000 / 900-4,000 |
| | Fatal/Injury | Stop | Urban | 4-Leg | 23(22)[11] | | **67**(20)[11] | -38(39)[11] | | | 12,650-22,400 / 2,400-3,625 |
| | PDO | No Signal | | | -15[13] | | | | | | |
| Install signals (temporary) | Fatal/Injury | No Signal | | | | | 39[4] | | 50[4] | | |
| | PDO | No Signal | | | | 11[4] | 73[4] | | | a 83[4] | |
| Install signals (to have one over each approach lane) | All | | All | | | | 46[3] | | | | |
| Remove unwarranted signals | All | Signal | Urban | | 24[5] | | 24[5] | 29[5] | | d 30[5] | |
| | All | Signal | Urban | | | | | | | e 22[5] | |
| | All | Signal | Urban | | | | | | | g 31[5] | |
| | Fatal/Injury | Signal | Urban | | 53[5] | | | | | | |
| | PDO | Signal | Urban | | 24[5] | | | | | | |
| Replace signal lenses with optical lenses | All | Signal | | | 17[7] | 10[4] | 10[4] | 10[4] | | a 20[4] | |
| **COMBINATION SIGNAL AND OTHER COUNTERMEASURES** | | | | | | | | | | | |
| Install left-turn lane and add turn phase | All | Signal | | | 58[7] | | | | | | |
| Install signals and add channelization | Fatal/Injury | No Signal | | | | | 67[4] | | 54[4] | b 35[4] | |
| | PDO | No Signal | | | | 24[4] | 63[4] | | | a 27[4] | |

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