Issues in Flashing Operation for Malfunctioning Traffic Signals

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Current standards and practices have been evaluated for the display to be shown to drivers when control equipment at a signalized intersection malfunctions. Documents setting forth current good engineering practice were reviewed; signalized intersections were inspected in metropolitan Atlanta; and eight traffic engineering agencies were interviewed. The *Manual on Uniform Traffic Control Devices* (MUTCD) describes flashing yellow/red as "normal"; however, two other primary references caution that this may be inappropriate and hazardous if the minor street lacks sight distance or traffic volume on the major street is moderate or heavy. Ten intersections were readily found that failed to meet AASHTO standards for sight distance but were programmed for flashing yellow/red. The agencies stated that flashing red/red during rush hours would produce intolerable congestion during the estimated 10 min needed for a traffic-control police officer to reach the scene. It was recommended that serious consideration be given to changing the MUTCD to acknowledge the potential hazard of flashing yellow/red and to make mention of flashing red/red. Traffic engineering agencies should evaluate all signalized intersections that use flashing yellow/red and identify as "critical" those that would operate with difficulty during rush hours or that have inadequate sight distance for a minor-street approach. Remote monitoring of signal status, selective use of Right Turn Only blank-out signs, and a public information program were recommended. Research is needed on accident rates during malfunction flash.

This research was prompted by the senior author's being consulted about a serious accident that occurred soon after a tripped conflict monitor placed a signalized intersection on flashing yellow for the main street and flashing red for the cross street, just as the *Manual on Uniform Traffic Control Devices* (MUTCD) suggests is normal. A visit to the accident scene made it clear that accidents were quite foreseeable at this location if the intersection were allowed to operate in this flashing mode. If main-street volumes are too heavy for side-street traffic to enter or cross, or if side-street traffic cannot see far enough along the main street for safety, then how should the intersection be operated when a signal malfunction occurs?

Flashing operation at a signalized intersection can be preprogrammed for selected off-peak time periods when traffic is considered too light to require normal green/yellow/red (stop-and-go) operation. Flashing operation will also occur if a stop-and-go signal malfunctions in certain ways, such as by the simultaneous display of green to two conflicting movements. Issues pertaining to off-peak flash are already discussed extensively in the literature (*1*). Therefore, the focus here is on malfunction flash. (However, the section related to sight distance is also pertinent to off-peak flash.)

Agency records reviewed by the authors show that malfunction flash occurs frequently enough to be considered an expected and foreseeable event. Like freeway incidents, malfunction flash is not uncommon but is rather unpredictable as to location. Some causes of malfunction flash are controller failure, load switch failure, and voltage problems such as transients, sags, and brief power outages.

Over the past 20 years of experience with malfunction flash improvements have been made in the electrical design of signal control equipment that have tended to reduce the incidence of malfunction flash. At the same time, however, the industry has expanded the list of faults that can be watched for by the conflict monitor in the cabinet. In the early days of solid-state equipment, the conflict monitor unit was aptly named because it would cause the intersection to go to flash only in the event of green (or yellow) shown simultaneously to two conflicting movements. In 1976 the National Electrical Manufacturers Association (NEMA) expanded the concept of "conflict" to include absence of signal ("dark failure" or "red failure") for a movement (*2*). Currently, at least one manufacturer offers a conflict monitor that can (as an option) cause flashing operation if a load switch fails by turning on two or three colors at once. For example, the intersection will go to flash if one movement is shown a red and a conflicting movement is shown both a green and a yellow. Currently, NEMA is considering requiring a similar load switch monitoring capability (for optional use) for their future design standard TS 2 (*3*). Fault monitoring has expanded over the years to the point that NEMA's draft TS 2 now refers to a conflict monitor as a "malfunction management unit." Plainly these safety-oriented trends in the signal industry could keep malfunction flash at least as frequent an occurrence as it is today.

RESEARCH PROCEDURE

The purpose of this research was to evaluate current standards and practices for the display to be shown to drivers when the control equipment at a signalized intersection malfunctions. The procedure was first to review the documents setting forth current engineering good practice. This step showed that two primary references caution that flashing yellow/red could be inappropriate and hazardous if minor-street drivers waiting on the flashing red cannot see far enough along the main street or are confronted with moderate to heavy volumes on the main street. The latter condition is well known to be

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common during rush hours. The researchers then went to a number of signalized intersections in the Atlanta metropolitan area to determine if sight distance might be a potential problem during flashing yellow/red. Through field observation, 10 intersections lacking adequate sight distance were easily found. A check with the local traffic engineering agencies showed that each intersection was programmed to flash yellow/red. The researchers measured the sight distance available to minor-street drivers who could find themselves waiting on a flashing red. Finally, interviews were conducted with eight traffic engineering agencies to determine opinions and practices with respect to malfunction flash. Conclusions were drawn as to the potential difficulty of ensuring both safety and uncongested flow during periods of malfunction flash. Recommendations for improving safety during malfunction flash and for needed research were developed.

CURRENT ENGINEERING GOOD PRACTICE

The MUTCD, which is published by FHWA, has been adopted by most states as a standard. Section 4B-6(7) states the following:

> When a traffic control signal is put on flashing operation, normally a yellow indication should be used for the major street and a red indication for the other approaches. . . (*4*, p. 4B-6)

FHWA publishes a companion manual, the *Traffic Control Devices Handbook* (TCDH) (*5*), which is "intended to augment the MUTCD by serving an interpretive function. . ." The TCDH states the following:

> Flashing yellow/red may be appropriate at simple, four-legged or three-legged intersections where the minor-street drivers have an unrestricted view of approaching main street traffic, and the traffic volumes are low. (*5*, p. 4-9)

The TCDH in effect cautions that the normal flashing yellow/red operation set forth by the MUTCD could be inappropriate when minor-street drivers cannot see far enough along the main street or cannot find a gap in main-street traffic long enough to avoid collisions.

AASHTO publishes a primary reference titled *A Policy on Geometric Design of Highways and Streets* (*6*). The book is well known to traffic engineers as well as to highway designers and is commonly called the Green Book. This reference includes sight-distance guidelines for intersections under various types (cases) of traffic control. Case III pertains to Stop sign control of traffic on a minor road waiting to enter or cross a major roadway:

> Where traffic on the minor road of an intersection is controlled by stop signs, the driver of the vehicle on the minor road must have sufficient sight distance for a safe departure from the stopped position. . . (*6*)

The Green Book adds the following:

> This principle applies to signalized intersections as well as those with only stop signs, as there may be a malfunction of the signals, or it may be desirable to place the signals periodically in a flashing operation. The latter is the same as stop sign control. (*6*)

The Green Book also states the following:

> Intersections controlled by traffic signals are considered by many not to require sight distance between intersecting traffic flows because the flows move at separate times. However, due to a variety of operational characteristics associated with intersections, sight distance based on the Case III procedures should be available to the driver. This principle is based on the increased driver workload at intersections and the hazard involved when vehicles turn onto or cross the major highway. The hazard associated with unanticipated vehicle conflicts at signalized intersections, such as violation of the signal, right turns on red, malfunction of the signal, or use of flashing red/yellow mode, further substantiate the need for incorporation of Case III sight distance even at signal-controlled intersections. (*6*)

The Green Book is seen to be very specific about the potential hazards of flashing yellow/red, such as during signal malfunction, where entering sight distance falls short of AASHTO guidelines for Case III intersections.

This review of current engineering good practice showed first that the MUTCD simply states that it is normal for a flashing display to be yellow/red. The TCDH and the AASHTO Green Book caution that flashing yellow/red may be inappropriate and hazardous if sight distance is a problem or traffic volume on the main street is moderate or heavy.

FIELD MEASUREMENT OF ENTERING SIGHT DISTANCE

The next step was to apply the AASHTO Case III sight-distance criteria to a number of signalized intersections in the Atlanta metropolitan area. The purpose was to gather information on specific locations with sight-distance problems.

Field observations quickly turned up 10 intersections that were programmed to flash yellow/red upon malfunction and that appeared possibly to be lacking in sight distance from the minor-street stopped positions (*7*). Posted speed limits on the major street varied from 35 to 45 mph. The characteristics of each intersection are detailed by Walker (*7*).

AASHTO sight-distance criteria assume that the minor-street driver will stop with his front bumper 10 ft back from the near edge of the intersecting major-street pavement. However, the senior author has found that, as a practical matter, a court may impose a higher standard for that driver. If edging the car forward will improve the driver's sight distance, a jury may expect the driver to edge out to the extent that it is safe to do so. Therefore, all sight-distance measurements in this research were performed with the front bumper assumed to be located as close as possible to the edge of the major-street pavement. This procedure improved the sight distance of all 10 intersections measured, thus improving their prospects of meeting AASHTO Case III standards. The waiting driver was taken to be 7 ft back from the front bumper as if stopped in a full-sized vehicle.

In the AASHTO Case III procedures, the driver's eye is 3.5 ft above the minor-street pavement, and he/she is looking for an object 4.25 ft above the major-street pavement (*6*). In this research the same height of object was used, but the waiting driver was taken to have a height of eye of 4.0 ft; the extra 0.5 ft of height results in a sight distance slightly longer than AASHTO standard.

Most of the 10 intersections were four-way, allowing checks of all three AASHTO Case III maneuvers, namely crossing (III A), turning left (III B), and turning right (III C). Four of the intersections had possible sight-distance problems in both directions of view from the minor street. In all, for the 10 intersections there were 35 sight-distance checks.

It was found that each intersection failed all of the Case III tests that applied to it, even with the waiting driver taken to be 10 ft closer to the intersection than called for by AASHTO guidelines for Case III measurements. All of the sight-distance restrictions were caused by horizontal or vertical curvature, or buildings, or a combination of these. Deficiencies in sight distance varied from 75 to 630 ft, averaging 312 ft. Of the 35 cases of tested, almost half failed by more than the length of a football field.

AASHTO Case III sight distances are intended to give a minor-street driver enough time to complete the departure maneuver before a vehicle approaching the intersection from just out of view is close enough to create a conflict. The deficiencies in measured sight distances were converted to seconds of travel time along the major street at the posted speed limit. These varied from 1.1 to 9.5 sec, averaging 5.2 sec.

INTERVIEWS WITH TRAFFIC ENGINEERING AGENCIES

Comprehensive interviews were conducted with eight traffic engineering agencies in the Atlanta metropolitan area (*7*). Each engineer was asked the same series of questions, and extensive notes were taken by the interviewer. The eight agencies were about equally divided among categories of large, medium, and small number of signalized intersections operated. The large and medium-sized agencies were able to monitor in real time the flash status of about 25 percent of their signals, on the average, and the two small agencies could continuously monitor about half their signals.

Off-Peak Flash

All eight engineers reported that they do not use off-peak flash. However, each had extensive opinions on the subject. These were reported in detail by Walker (*7*).

Malfunction Flash

Three of the eight traffic engineers reported using only flashing yellow/red, as described by MUTCD Section 4B-6(7), for malfunctioning traffic signals in their jurisdictions. One of these noted that the MUTCD specifies no flashing mode other than flashing yellow/red.

Of the five engineers who sometimes used flashing red/red, four did so at intersections of two major streets or where there is no clear major street. One of these four noted that MUTCD 4B-6(7), which states that flashing yellow/red is normally used, is applicable only to those intersections where a major and a minor street cross. He went on to say that the logic of 4B-6(7) is that flashing red/red is the only acceptable alternative where two major streets cross.

One engineer specified all-way flashing red for intersections of five or more legs, as implied by the TCDH.

Five of the engineers stated that entering sight distance was considered when selecting a particular mode of flashing operation for signal malfunction. Two of these engineers were confident that no signalized intersections in their jurisdictions had sight restrictions from minor-street stopped positions that required flashing red/red. One of the engineers used flashing red/red at some locations because entering sight distance was restricted. One engineer said that his agency was committed to eliminating sight-distance restrictions rather than resorting to flashing red/red. According to another engineer, all of his agency's intersections had been designed or modified to operate safely under two-way stop control, so that flashing red/red is unnecessary.

The engineers who considered sight distance as related to flashing operation relied on engineering judgment, rather than some computational procedure or the AASHTO Case III sight-distance guidelines, when evaluating entering sight distance.

None of the engineers considered the availability of adequate gap to entering minor-street vehicles when selecting the malfunction-flash mode.

Five of the eight engineers relied to some extent on traffic-control police officers to direct traffic at malfunctioning signals. Two of these engineers routinely requested traffic-control police officers to be sent to major intersections (as determined by the engineer) that went to malfunction flash during heavy traffic periods. Another of the five engineers had identified several critical intersections at which police officers were requested if malfunction occurred during a period of peak traffic volume. Two engineers requested police assistance at such malfunctioning signals if the signal-repair technician was delayed in reaching the intersection or in restoring the signal to proper operation.

Local police departments of five jurisdictions were described as generally cooperative when asked to direct traffic at malfunctioning signals. Officers were reported to be well trained in manual traffic control. One engineer noted that his local police department had no clear directive of its responsibility to assist the traffic engineering agency; officers were only provided if available at the time of signal malfunction.

Two engineers described their police departments as less cooperative, possibly because of manpower constraints, when asked to direct traffic at malfunctioning signals. One of these engineers noted that many of his police officers were unskilled in manual traffic control.

In the jurisdictions investigated, many traffic signals at major intersections were part of closed-loop computer systems, allowing the traffic engineers to monitor signal status continuously. Most of the engineers agreed that, if requested, a traffic-control police officer could be at the scene of a malfunctioning traffic signal within 10 min of agency notification. Even if signal status was monitored continuously, seven of the eight engineers believed that a 10-min travel time to a flashing red/red intersection would produce intolerable congestion during rush hours. Depending on the time of malfunction, several of the engineers believed that a flashing red/red signal along an arterial system could soon cause a bottleneck capable of disrupting traffic operations at adjacent intersections.

The engineers were united in the opinion that the flashing red/red mode is too harmful to main-street-traffic flow to select for signal malfunction just because, at some time of the day, traffic volume at a particular intersection may cause difficulty to minor-street vehicles entering under two-way-stop control. Flashing red/red during rush hours could severely delay a traffic-control police officer (and even emergency vehicles) in arriving at the scene.

SUMMARY

The research produced the following principal findings:

- The MUTCD states that it is normal for a flashing display to be yellow/red. The TCDH and the AASHTO Green Book caution that flashing yellow/red may be inappropriate and hazardous if sight distance is lacking or traffic volume on the major street is moderate or heavy.
- Field observations in metropolitan Atlanta readily turned up 10 signalized intersections that failed to meet AASHTO standards for sight distance and that were programmed for flashing yellow/red.
- Interviews with eight traffic engineering agencies in metropolitan Atlanta showed variation in interpretation of the MUTCD. One engineer noted that the MUTCD specifies no flashing mode other than yellow/red. Another understood the MUTCD to mean that flashing red/red is the only acceptable display where two major streets cross.
- Of the five agencies that sometimes used flashing red/red, only one selected it where sight distance was inadequate. (The other four reported no sight-distance problems.)
- The agencies determined sight distance by engineering judgment rather than by some formal procedure.
- When selecting the flash display, none of the agencies considered the availability of adequate gaps to entering minor-street vehicles.
- Seven of the eight agencies judged that flashing red/red during rush hours would produce intolerable congestion during the estimated 10 min needed for a traffic-control police officer to reach the scene.
- All agencies agreed that flashing red/red should not be selected just because, at some time of day, major-street traffic could cause difficulty to vehicles entering from the minor street.

CONCLUSIONS AND RECOMMENDATIONS

It is concluded that there could be a problem here that needs to be addressed by the traffic engineering profession. If major-street volumes are too heavy for minor-street traffic to enter or cross, or if minor-street traffic cannot see far enough along the major street for safety, there appears to be no acceptable mode of flashing operation.

The literature explains the hazard of flashing yellow/red but offers no traffic-operational solution. Flashing red/red, although possibly increasing the likelihood of rear-end collisions, could reduce the risk of serious right-angle collisions. The engineers interviewed clearly believe that flashing red/red could cause intolerable congestion on the major street during rush hours.

Nonetheless, serious consideration should be given to changing Section 4B-6(7) of the MUTCD to acknowledge the potential hazard of flashing yellow/red. Although it is the most common flashing mode, the MUTCD need not characterize it as "normal." Red/red should be stated to be an acceptable mode of flashing operation but not the only acceptable alternative where two major streets cross.

Traffic engineering agencies should evaluate all their signalized intersections that use flashing yellow/red. For each intersection those times of day should be identified when minor-street traffic likely will have difficulty finding long enough gaps in major-street traffic to avoid collisions. The intersection should be considered "critical" when in flashing mode during these times of day, and solutions such as those described next should be considered.

Traffic engineering agencies should identify their minor-street approaches lacking in AASHTO Case III sight distance. These intersections should be characterized as "critical" when in flashing yellow/red and a reasonably safe solution should be sought for each. For example, the signal status could be monitored continuously by a master located at curbside or at the traffic operations center. When flashing operation is detected, a traffic-control police officer (and the signal-repair crew) could be dispatched to the intersection. Another possible solution could be to use a flashing yellow on the major street; other approaches not having safe sight distance conceivably could have their flashing red indication supplemented by a blank-out sign message such as Right Turn Only. There could be a public information program encouraging motorists facing a flashing red to edge out carefully and then turn right if traffic is heavy or they cannot see very far.

More research by the traffic engineering profession is needed into the issues in flashing operation for malfunctioning traffic signals. Total accident rates and accident rates by category during malfunction flash should be studied. Cost-benefit analysis should be applied to accident data to compare the property and injury costs of flashing yellow/red and flashing red/red. The frequency of signal malfunctions in general and the frequency of signal malfunctions relative to types of controllers, conflict monitors, environmental conditions, and so on, should be investigated.

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