

# **LEVEL OF SERVICE CRITERIA FOR ACTIVE WARNING DEVICES AT RAILROAD-HIGHWAY CROSSINGS**

**BY**

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## **LEVELS OF SERVICE CRITERIA FOR ACTIVE WARNING DEVICES AT RAILROAD-HIGHWAY GRADE CROSSINGS**

In the past two decades, over \$2 billion has been allocated for improvements at the 192,454 public grade crossing locations in this country. The majority of these improvements involved converting passive crossings to active ones -- 22,066 grade crossings were equipped with automatic gates and 32,778 were equipped with flashing light signals. The upgrading of crossings to active control no doubt has contributed to improved crossing safety. Between 1977 and 1986, fatalities at grade crossings dropped from 846 to 501, and injuries decreased from 4,455 to 2,192.

Even with these improvements, however, over 50 percent of all car-train accidents in 1986 occurred at the 30 percent of the total crossings having active warning devices. It is generally recognized that much of the safety problem at active crossings is tied to poor driver response to the traffic control. In fact, a study by the National Transportation Safety Board concluded that most accidents at actively-controlled crossings resulted from drivers intentionally violating the warning device (1). It would seem that driver performance at active grade crossings could be improved.

**Problem Statement.** The poor performance of drivers at active grade crossings is due in part to the lack of system operating credibility by the drivers. That is, drivers may not consider these devices to be accurate or reliable, leading to violation of their warning. The most significant factor relating directly to the issue of driver violation of active warning devices is the amount of time provided between device activation by a train and passage of the train through the crossing (warning time). Specifically, excessive and/or highly variable warning times result in poor driver performance at the crossing. Conversely, extremely short warning times leave little margin of safety and poorly accommodate larger vehicles such as combination trucks and buses, especially if those vehicles must first come to a stop as required by many state laws.

The warning time issue is hardware related -- certain types of train detection devices cannot provide reasonable warning times if train speeds are highly variable. Train predictors, however, can provide a relatively constant warning time at active crossings regardless of train speed. One study found that violations, motorist delay, and accidents were lower at crossings with predictors, presumably due to the reasonable and consistent warning times they provide (2). Another study estimated that up to 13,100 additional crossings can benefit from predictor installation (3). What is missing in the literature, however, is a methodology for assessing the operational performance of existing active warning devices.

**Objective and Scope.** The objective of this paper is to present a level of service methodology for assessing the operational performance of active warning devices at railroad-highway grade crossings. The following sections of the paper discuss the types of active warning devices used at grade crossings; driver behavior in response to active warning devices at grade crossings; and the rationale and criteria for determining level of service for active warning devices at grade crossings.

## **WARNING DEVICES FOR USE AT GRADE CROSSINGS**

There are two basic types of warning devices for use at railroad-highway grade crossings; passive devices and active devices. Passive devices, including signs and pavement markings, provide static warning of a grade crossing. Active devices warn drivers of the approach or presence of a train. Two types of active warning systems are in common use; i.e., flashing light signals and flashing light signals with automatic gates. Both of these systems combine passive signs and pavement markings with active warning devices to warn and regulate traffic at railroad-highway grade crossings.

**Historical Development.** One of the earliest active warning devices used in this country is that shown in Figure 1 - a signalman on horseback preceding the train, waving a flag, and shouting "a train is coming" to warn people away from the tracks (4). From this,

evolved the practice of a signalman standing at the crossing and waving a red flag or paddle during the day and a red-colored lantern at night to warn of approaching trains. The first steps toward replacing flagmen were taken around 1890 when an automatic switch was used to detect the presence of a train and activate a visual device known as a "wig-wag" which simulated the action of a signalman waving his flag or lantern (5). During the next few years, several types of flashing light signals were put into service. Most used a horizontal array of lights and simulated the signalman's swinging lantern by sequential lighting back and forth.



The forerunner of the modern-day flashing light signal was installed in 1913 by the Central Railroad of New Jersey at Woodbridge Avenue, Sewaren, New Jersey (6). Basically, the unit consisted of two alternately-flashing horizontal red lights each with 5 3/8-inch diameter lenses. The use of this light spread rapidly and operational experience soon revealed a need for much stronger lights, and as a result, the 8 3/8-inch diameter lens was introduced in 1923. By 1930, there were over 60 different warning devices being used on different railroads, and it was at this point in time that the American Association of Railroads (AAR) decided that the two most widely favored devices, the wig-wag for new construction has ceased and the two alternately-flashing horizontal lights have become the national standard.

The other type of active warning device in use today is the short-arm automatic gate. Originally, gates were designed for manual operation by a signalman. They would be lowered in advance of a train's arrival and raised after its departure. By 1935, there were about 4,700 manual gates at crossing in the United States (7). In the same year, 26 automatic gates were installed nationwide in an effort to provide more protection and reduce labor costs. Interestingly, both the manual and early automatic gates blocked the entire roadway as is currently done in much of Europe (8). It was not until July 1936 that the first short-arm automatic gate, today's standard, was installed. This concept was quickly accepted and within ten years short-arm gates were being installed approximately 1,000 new crossing per year (7).

**Flashing Light Signals.** A standard flashing light signal assembly is illustrated in Figure 2 (9). It includes a standard crossbuck sign, an auxiliary "number of tracks" sign when there is more than one track, and the flashing light signals. The flashing lights can be either post or cantilever-mounted. They are normally placed to the right of approaching highway traffic on all roadway approaches to the crossing. Additional pairs of lights can be mounted on the same support and directed toward highway traffic approaching from another or opposite direction. Signals on both sides of the street are used at one-way streets and

certain divided highway locations. The signals, as well as other active warning devices, are required to operate in a fail-safe manner; i.e., failures or loss of electrical power cause the warning system to be activated. A trickle-charged 12-volt battery system is used to provide backup power for, in most cases, more than 48 hours of normal operation.





Flashing light signals are activated a minimum of 20 seconds before the train's arrival whereupon the two lights begin to flash alternately at a rate of 35 to 55 times per minute (10). They continue to flash until after the train has cleared the crossing. The two lights are spaced 30 inches apart on a horizontal cross-arm and consist of either two 8 3/8-inch or two 12-inch diameter red lenses, or roundels as they are more commonly called, each surrounded by 20-inch diameter black backgrounds. Inside the lamp housings are located a 10 to 36 watt bulb and a reflector. These low wattages are used because of the limitation of the backup power system. To compensate for this constraint, the reflector and roundel work in conjunction with one another to focus the hot spots of these lights along a relatively narrow-field or view. Therefore, focusing and aiming procedures are extremely critical.

**Flashing Light Signals with Automatic Gates.** An automatic short-arm gate is illustrated in Figure 3 (2). As shown, it is used in conjunction with a flashing light signal and consists of a drive mechanism and a fully reflectorized red and white striped gate arm with three lights. They may be located on the same post as the flashing light signals or separately mounted. When the gate is in the down position, it extends across the approaching lanes of traffic at a height of approximately 4 feet above the pavement's surface. The red and white stripes are 16 inches in length and are cut such that they slope down toward the center of the roadway at a 45-degree angle. The flash pattern of the gate arm lights is steady burn by the end or tip light and alternate flash by the two inside lights. They are activated at the same time as are the flashing light signals; however, the downward motion of the gate arm generally lags the light activation by 5 to 10 seconds. Gate arms can be made of aluminum, fiberglass, or wood and their generally acceptable maximum practical length is 44 feet.

**Guidelines for Use.** Guidelines for the conditions under which different warning devices should be installed are contained in three documents: 1) the Manual of Uniform Traffic Control Devices (MUTCD); 2) the Railroad-Highway Grade Crossing Handbook; and 3) the Traffic Control Devices Handbook (8, 9, 10, 11, 12). The MUTCD has been

adopted as a national standard and as such is a legal requirement whereas the other documents' contents provide guidelines and practical applications thereof. Basically, passive warning devices are required at all grade crossings, and active warning devices are required at all grade crossings, and active warning devices are recommended where increased levels of warning and/or control are needed. Factors used in determining the need for active warning devices are contained in the Railroad-Highway Grade Crossing Handbook.



## **DRIVER BEHAVIOR AT ACTIVE GRADE CROSSINGS**

**Driver Needs.** At railroad-highway grade crossings, the warning system should provide appropriate, timely information in order to enable drivers to make simple decisions about whether or not it is safe to proceed over the crossing. If their informational needs are met, drivers should perform in an acceptable and safe manner. If they are not met, drivers may at times, perform in an erratic manner, and safety problems are likely to result. Driver needs at grade crossings can be broken down into three basic areas:

1. Approaching the crossing;
2. Within the critical stopping distance zone; and
3. Crossing the tracks

When approaching the crossing, drivers need to be made aware of the crossing's presence. This need can be accomplished by advance warning signs, pavement markings, and sometimes by visual observation of either the crossing or the train itself. At some point when approaching the crossing, drivers reach a critical point where a decision must be made to stop if a train is approaching, or to proceed if one is not. Their need at this point is to be able to see either the train or an active warning device far enough away from the crossing to react and stop safely.

When actually crossing the tracks, driver needs are different depending upon whether passive or active warning devices are present. At passive crossings, drivers need to be able to see far enough down the tracks to determine whether or not it is safe to cross the tracks. At active crossings, the active warning device conveys a message to the driver as to whether or not it is safe to cross. If drivers are expected to perform in a reasonable and prudent manner, it is imperative that the credibility of this message be maintained.

In summary, driver informational need at grade crossings are that the warning system and/or train be highly visible and that conditions at the track itself be accurately

represented. Driver performance measures are a means of assessing the adequacy of the warning system in meeting the driver's needs. The challenge of using driver performance measures of this purpose, however, is the definition of what constitutes good driving behavior. The following section describes three active crossings where driver performance measures were recorded; their driver performance measures defined by this study; and summary statistics of driver performance measures at active grade crossings.

**Crossing Site Description.** Recognizing the need to identify and quantify driver performance at active railroad-highway grade crossings, an in-depth evaluation of driver behavior at three crossings with several types of active warning devices was performed as a part of a recently completed Federal Highway Administration (FHWA) study (5). Data for the driver performance evaluation were taken from videotapes of over 600 train arrivals at three crossings in the Knoxville, Tennessee area. One of the crossings had automatic gates with standard flashing light signals, and the other two crossings had standard flashing light signals. Each of the three crossings studied had relatively high train and traffic volumes, and had a history of at least some accidents in the last five years.

*Cherry Street Crossing.* The crossing (Inventory Number 730584K) selected for the evaluation of a four-quadrant gate system is located in the eastern part of Knoxville on Cherry Street. The existing active warning devices at the crossing were automatic gates, standard railroad flashing light signals, and a bell. It was ranked as the 223rd most dangerous crossing in the State. The roadway was four lanes wide and straight and level on both approaches to the crossing. There was a building in the southwest quadrant which could obstruct a northbound driver's view of eastbound trains. The average daily traffic at this site was approximately 14,000 vehicles per day, and the average through train volume was approximately 20 trains per day. The speed limit on Cherry Street was 30 mi/h, and train speeds at the crossing ranged from 20 to 40 mi/h. Although only one car-train accident had occurred at this location in the past 5 years, large numbers of motorists were observed driving around lowered gate arms at this site.

*Ebenezer Road Crossing.* The crossing (Inventory Number 731461C) selected for evaluation of a four-quadrant flashing light signal system is located in the western part of Knox County of Ebenezer Road. The existing active warning devices at the crossing were standard railroad flashing light signals with 8 3/8-inch roundels and a bell. It is ranked as the 276th most dangerous crossing in the State. The roadway was two lanes wide and its horizontal and vertical alignments limited the crossing's visibility from both directions. Several other sight distance obstructions on both approaches also limit the driver's view of approaching trains. The average daily traffic at this site was approximately 10,000 vehicles per day, and the average through train volume was approximately 10 trains per day. The speed limit on Ebenezer Road was 40 mi/h, and train speeds at the crossing ranged from 5 to 55 mi/h. Additionally, one car-train accident had occurred at this location in the past 5 years.

*Cedar Drive Crossing.* The crossing (Inventory Number 730643K) selected for the evaluation of a highway traffic signal system is located in the northern part of Knoxville on Cedar Drive. The existing active warning devices at the crossing were standard railroad flashing light signals with 8 3/8-inch roundels and a bell. It was ranked at the 31st most dangerous crossing in the State. The highway is two lanes wide and straight on both approaches to the crossing. The vertical alignment on the westbound approach limited a motorist's visibility of the crossing itself. In addition, the thick vegetation in the vicinity of the crossing restricted the driver's view of approaching trains. The average daily traffic at this site was approximately 14,000 vehicles per day, and the average through train volume was approximately 10 trains per day. The speed limit on Cedar Drive was 40 mi/h, and train speeds at the crossing ranged from 5 to 40 mi/h. As evidenced by its hazard ranking and the three car-train accidents that occurred at this site in the past 5 years, this was an extremely hazardous location.

**Driver Performance Measures.** The driver performance evaluation focused on quantifying of the effects of warning time length on key driver behavior measures. These measures and their definitions were as follows:

*Warning time* was defined as the difference in time between activation of the flashing light signals and the train's arrival at the crossing. It is the same as the maximum time a motorist would have to wait between activation of the flashing light signals and a train's arrival at the crossing.

*Clearance time* was defined as the difference in time between the last vehicle to cross and the train's arrival at the crossing. Increasing the clearance time, increases the temporal separation between the cars and trains, a definite safety benefit if the clearance times are too short.

*Violations* at a crossing with gates were defined as motorists driving around the gate arms in the down position. Violations at a crossing with flashing light signals were defined as motorists who could reasonably stop in response to activation of the warning device, but failed to do so. Because of the difficulty in determining whether or not a vehicle came to a complete stop, violations were not counted for flashing light signal systems. Violations at a crossing with highway traffic signals were defined as a motorist driving through the crossing while the signal displayed a red indication.

*Vehicles crossing* were defined as the average number of vehicles crossing between activation of the active warning devices and the train's arrival at the crossing. Its magnitude is related to the traffic volume on the roadway and length of the warning time.

*Crossings less than 20 seconds (CL20)* were defined as the average number of vehicles crossing within 20 seconds of a train's arrival at a crossing. It also is an indication

of aggressive behavior; i.e., there is some, but not much, room for driver and/or vehicular error.

*Crossings less than 10 seconds (CL10)* were defined as the vehicle crossings within 10 seconds of the train's arrival at the crossing. It also is an indication of risky behavior; i.e., there is no margin for driver and/or vehicular error.

**Results.** Summary statistics of the driver performance measures in response to the various active warning devices at the crossings are shown in Table 1. Average warning times at the three crossings were approximately 57 seconds at the Cherry Street crossing, 40 seconds at the Ebenezer Road Crossing, 38 seconds at the Cedar Drive crossing with predictors, and 75 seconds at the Cedar Drive crossing without predictors. The driver performance measures in response to these warning times are discussed in the following sections.



**Table 1. Comparison of Driver Performance Measures in Response to Various Active Warning Devices.<sup>1</sup>**

Type of Warning Device	<u>Warning Time</u> Time (sec)	<u>Clearance</u> Time (sec)	<u>Violations</u> Mean/Percent	<u>Crossings</u> Mean/Percent	<u>CL20s</u> Mean/Percent	<u>CL10s</u> Mean/Percent
<u>Cherry Street Crossing</u>						
Two-Quadrant Gates	57.6	24.5	2.60 83.9	4.0 96.8	0.60 40.9	0.05 5.4
Four-Quadrant Gates with skirts	56.1	48.9	0.00 0.0	1.13 54.7	0.00 0.0	0.00 0.0
<u>Ebenezer Road Crossing</u>						
Flashing Light Signals	40.8	20.5	- -	3.43 88.6	1.14 55.3	0.11 10.6
Flashing Light Signals with Strobes (Spring 1986)	36.7	19.1	- -	2.50 90.0	0.05 50.0	0.05 5.0
Flashing Light Signals with Strobes (Summer 1986)	41.6	16.3	- -	4.02 91.8	1.47 71.4	0.22 18.4
<u>Cedar Drive Crossing</u>						
Flashing Light Signals without Predictors	75.2	20.1	- -	10.86 98.8	1.82 63.9	0.39 26.5
Flashing Light Signals with Predictors	41.7	21.4	- -	3.35 86.7	0.78 53.3	0.13 8.9
Highway Traffic Signals with Predictors	36.3	20.9	0.68 35.9	0.73 37.2	0.24 18.0	0.05 5.1

<sup>1</sup>All values involving motor vehicles include only train arrivals in which a motor vehicle was at the crossing.

In regard to clearance times, the average for seven of the eight study conditions was 20 seconds prior to the train's arrival. It should be noted, however, that a number of drivers accepted clearance times shorter than 20 seconds. For the eighth study condition (four-quadrant gates with skirts), the gate and skirt system completely blocked the roadway at least 30 seconds prior to the train's arrival, and thus eliminated the possibility of shorter clearance times.

In regard to violations, the eight studies are not comparable because of the different requirements the various devices placed on the approaching motorists. In regard to the number of vehicle crossings, the eight study conditions are comparable. Interestingly, for six of the seven study conditions with average clearance times of approximately 20 seconds, the average number of vehicle crossings is between 2.5 and 4.0, the average number of CL20s is between 0.6 and 1.5, and the average number of CL10s is between 0.05 and 0.22. For the seventh study condition (flashing light signals without predictors), the average warning time was significantly longer and the number of vehicle crossings was also significantly larger.

## **LEVEL OF SERVICE CRITERIA**

It was hypothesized that the warning times observed at a railroad-highway grade crossing have a major influence on driver performance; i.e., the longer the warning times, the larger the number of drivers who will exhibit dangerous and/or illegal behavior. Unfortunately, there was no method in the literature for assessing the adequacy of the warning times at a railroad-highway grade crossing from the driver's perspective; however level-of-service concepts have been well established in the highway field for the past 30 years. As a result, level-of-service criteria, similar to those for signalized intersections in the 1985 Highway Capacity Manual, were developed for active warning devices at grade crossings.<sup>(48)</sup> The proposed criteria are shown in Table 2. The levels of service are based on the premise that a grade crossing is very similar to a signalized intersection, albeit that one interrupts vehicular flow only a few times each day. This premise is not an

unreasonable assumption given the fact that at both a signalized intersection and a railroad-highway grade crossing, drivers are primarily concerned with how long they have to wait.

**Table 2. Proposed Level of Service Criteria for Railroad Highway Grade Crossing.**

Level of Service	Warning Time Category	Before Train's Arrival <sup>1</sup>
-	Inadequate <sup>2</sup>	<20
A	Desirable	20 to 30
B	Marginal	30 to 40
C	Poor	40 to 50
D	Maximum	50 to 60
F	Unacceptable <sup>3</sup>	>60

<sup>1</sup> Average time (in seconds) between activation of the flashing light signals and the train's arrival at the crossing.

<sup>2</sup> 20 seconds is the minimum warning time allowed by the MUTCD.

<sup>3</sup> 60 seconds is the limit of acceptable delay to most motorists as defined by the 1985 Highway Capacity Manual.

As shown in Table 2, 20 seconds is the minimum warning time currently required by the MUTCD, and 60 seconds is defined by the 1985 Highway Capacity Manual as the limit of acceptable delay to most motorists.<sup>(11,48)</sup> These two points clearly define the limits of adequate or acceptable motorist service; i.e., warning times less than 20 seconds are inadequate (as currently defined by the MUTCD), and warning times greater than 60 seconds are unacceptable and defined as level of service F. The 40-second range between these two limits was subdivided in 10 second increments so as to create four warning time categories for levels of service A, B, C, and D. As can be seen from Table 3, by using these definitions, the majority of the warning times observed in both studies could be classified as level of service D or better -- 65.7 percent in the before study (two-quadrant gates) and 73.5 percent in the after study (four-quadrant gates with skirts). However a much smaller percentage of the warning times observed could be classified as level of service F (unacceptable) might explain why so many motorists drove around the lowered two-quadrant gate arms. In other words the warning times were perceived as unacceptable (too long) and the motorists performed in an unacceptable (dangerous and illegal) manner by driving around the lower two-quadrant gate arms.

It was hypothesized that the warning times observed at a railroad-highway grade crossing have a major influence on driver performance at the crossing; i.e., the longer the warning times, the larger the number of drivers who will exhibit dangerous and/or illegal behavior. By using the level of service definitions developed in Chapter V, approximately 90 percent of the observed warning times for each of the three studies at the Ebenezer Road crossing could be classified as level of service A, B, or C. In fact, over 60 percent of the observed warning times in all three studies could be classified as level of service A or B. Additionally, the very small number of unacceptable (greater than 60 seconds) warning times in the three data sets means that the active warning devices at the Ebenezer Road crossing were operating at a good level of service. Thus, it would be expected that driver behavior at the crossing itself would be relatively good (i.e., few dangerous or illegal

maneuvers) and that, because the warning times did not change between studies, driver behavior at the crossing itself would not change between studies.

As with the other two crossings, it was hypothesized that the warning times observed at the Cedar Drive crossing would have a major influence on driver performance; i.e., the longer the warning time, the larger the number of drivers that would exhibit dangerous and/or ukkegak behavior. By using the level of service criteria previously developed, less than 5 percent of the observed warning times in the first before study (without predictors) were level of service C or better, and over 80 percent of the observed warning times were level of service F (unacceptable). However, after the predictors were installed, 80 percent of the observed warning times were level of service C or better, and only 10 percent were level of service F. In fact, over 68 percent of the observed warning times were level of service B or better. When the highway traffic signals were installed in conjunction with the predictors, over 90 percent of the observed warning times were level of service B or better and only 5.5 percent were level of service F. Clearly, installation of the predictors greatly improved the level of service of the active warning devices at the Cedar Drive crossing, and as a result, should have improved driver behavior at the crossing by reducing the number of dangerous and/or illegal maneuvers that took place.

It was hypothesized that even though warning times have a major influence on driver performance, a small percentage of drivers would exhibit undesirable (dangerous or illegal) behavior no matter how short the warning times were. This type of behavior is similar to that of those drivers who exceed properly set speed limits. In other word, there will always be a few drivers who will take risks at railroad-highway grade crossings just as there will always be a few drivers who take risks at regular intersections as well as on the open highway. The problem then becomes one of the defining risky behavior. To solve this problem, four categories of driver performance and associated clearance times were defined as follows:

- Risky -- less than 10 seconds,
- Aggressive -- from 10 to 20 seconds,
- Normal -- from 20 to 30 seconds, and
- Cautious -- greater than 30 seconds.

Risky behavior represents a level of driver performance in which there is little, if any, room for error. A judgmental mistake by the driver or a mechanical failure by the vehicle will probably result in an accident. Aggressive behavior represents a level of driver performance in which there is some, but not much, room for error. A small misestimation of the train's arrival time at the crossing will probably still allow time for most drivers to clear safely; however, vehicles that stall or have poor acceleration characteristics may be involved in an accident. The MUTCD appears to address this point by currently requiring a minimum warning time of 20 seconds. Normal behavior represents a level of driver performance in which most reasonable and prudent drivers fall. Most minor judgmental mistakes and poorly accelerating vehicles will not result in an accident. Cautious behavior represents a level of driver performance in which drivers probably rely totally on the warning device and not on their own judgment of the train's arrival at the crossing.

Using the preceding definitions, 40.0 percent of the clearance times in the before study (see Table 8) were classified as either risky or aggressive, whereas, in the after study, no clearance times were classified in these categories. In fact, all of the clearance times in the after study were classified as cautious; however, this finding is not a result of a different train or driver population. Instead, as stated previously, it is a result of the four-quadrant gates with skirts prohibiting motorists from driving around the gate arms by completely blocking the road. Thus, all drivers rather than just a few were forced to rely on the warning device. In other words, the potential for drivers to make a judgment as to whether or not it was safe to cross was removed from their possible set of options. Reliance on active warning devices is especially important at crossing with limited sight distance, high-speed trains, and multiple tracks because it is at these locations that drivers often make

mistakes in judgment. However, to avoid unnecessarily delaying drivers at these crossings and to reduce risky and/or aggressive behavior, it is imperative that the warning devices operate reliably and at as high a level of service as possible.

It was also hypothesized that no matter how short the warning times, a small percentage of drivers would exhibit dangerous and/or illegal behavior. To assess the magnitude of this problem at the Ebenezer Road crossing, the observed vehicle clearance times were classified into the four categories previously defined:

- Risky -- less than 10 seconds,
- Aggressive -- from 10 to 20 seconds,
- Normal -- from 20 to 30 seconds, and
- Cautious -- greater than 30 seconds.

By using the definitions, the percentage of the observed clearance times was in all three studies that could be classified as either risky or aggressive, ranged from 55.6 percent to 75.6 percent. In addition, from 6.6 percent to 13.8 percent of the clearance times could be classified as cautious. These data indicate that motorists will drive through a crossing while the signals are flashing as long as a train does not appear to be in close proximity. Interestingly, the frequency with which short clearance times occur indicate that drivers and the MUTCD may have different ideas as to what the necessary warning time should be.<sup>(11)</sup>

As at the other two crossings, it was hypothesized that even though warning times have a major influence on driver behavior, a small percentage of drivers would exhibit undesirable (dangerous or illegal) behavior no matter how short the warning times were. Therefore, it was expected at the Cedar Drive crossing that many dangerous and/or illegal maneuvers would be made during the first before study when the warning times were long and fewer dangerous and/or illegal maneuvers would be made when the warning times were shorter, as in the second before study and the after study.



By using the four categories of driver performance and associated clearance times, 27.7 percent of the clearance times in the first before study would be classified as risky, whereas only 10.3 to 13.8 percent of the clearance times observed in the second before study and the after study, respectively would be classified as risky. Additionally, over 60 percent of the observed clearance times in the first two before studies would be classified as either risky or aggressive, but under 50 percent of the observed clearance times in the after study would be classified as risky or aggressive. This seems to indicate that the shorter warning times which resulted from the installation of the predictors were successful in reducing risky behavior at the Cedar Drive crossing, and the installation of the highway traffic signals in combination with the predictors was able to further reduce aggressive behavior exhibited by motorists at the Cedar Drive crossing.

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