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Evaluation of Engineering Factors Affecting Traffic Signal Change Interval

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ABSTRACT

Engineering factors affecting traffic signal change interval (yellow and all-red) are reviewed, particularly in terms of drivers' perception and brake reaction time (t), and deceleration rate (d). Using driver behavior data collected from time-lapse cameras, two hypotheses were tested: (a) t and d are dependent on speed and (b) there is an interactive effect of t (prebraking) and d (postbraking) on drivers' braking distance. All hypotheses from statistical analysis results were accepted. It is concluded that joint consideration instead of independent consideration should be given to t and d when selecting their values. Furthermore, it is recommended that different t's and d's for different approach speeds should be used rather than a single value (as used in current practice) for all approach speeds in signal change interval design.

To stop or not to stop? That is the question asked when drivers see a green light ahead change to yellow and then to red. If the driver fails to respond safely, a major right-angle collision at the intersection is possible. On the other hand, if the driver overreacts, a hazardous rear-end collision is likely. Because of the complexity of the driver-vehicle-traffic control system involved and the potential severe consequences of system failure (a fatal accident), the design of the traffic signal yellow time and any following all-red interval should be optimized based on the best understanding of the engineering factors involved. The magnitude of the problem requires that traffic engineers do no less.

PERCEPTION AND BRAKE REACTION TIME (t)

AASHO (1) recommends a total of 2.5 sec for perception and brake reaction time. The Institute of Traffic Engineers (ITE) Handbook (2,3) assumed a perception-brake reaction time for a yellow signal of 1 sec. Actual drivers' stopping distance data reported by Williams (4) and Sheffi (5) are analyzed using different deceleration rates from 8 to 15 feet per second per second (fps²). The results, which indicate three categories of t under normal driving behavior, are as follows:

1. Forced stopping: When more than 85 percent of the drivers go through the intersection, those 15 percent or less of the drivers who decide to stop take less than 1 sec of perception and brake reaction time.
2. Indecision stopping: When half of the drivers decide to stop, the perception and brake reaction time is 1 to 1.5 sec.
3. Comfortable stopping: When the majority of drivers decides to stop, their perception and brake reaction time is 1.5 to 3.0 sec.

An analysis of Williams' (4) and Sheffi's (5) results also indicates that perception and brake reaction time at high speeds may be less than that at low speeds. It also appears that, when a driver's position is farther away from the intersection, the perception and brake reaction time to the yellow onset may be longer than for drivers closer to the intersection. In addition, at a given speed, less variation in time t is presumed to exist for drivers closer to the intersection than for those farther away. These developments are based on drivers' physical limitations and lag time, which appears to fall between perception and brake reaction time.

DECELERATION RATE (d)

The ITE Handbook in 1976 (2) used 15 fps^2 as the deceleration rate. Bissell and Warren (6) and Parsonson and Santiago (7) suggested 10 fps^2 for the deceleration rate. AASHO (1) recommended 18.0 fps^2 at design speed of 60 mph and 20.0 fps^2 at design speed of 30 mph for dry pavements. For wet pavements, it recommended 9.7 fps^2 at 60 mph and 11.6 fps^2 at 30 mph, respectively.

It appears that the deceleration rates used by the ITE Handbook in 1976 and by AASHO for dry pavements are unrealistically high. Using data from Williams (4) and Sheffi (5), the required deceleration rates were analyzed using a perception-brake reaction time of 1 sec. The analysis indicates that the majority of drivers who stopped experienced deceleration rates of 5 to 11 fps^2 for approach speeds of from 25 to 55 mph. Only in the case of a few forced stops was a deceleration rate of 15 fps^2 observed. Furthermore, the results indicate the presence of different deceleration rates for different approach speeds. It is noted that the ITE Handbook in 1982 (3) suggested, without acknowledgment, the use of 10 fps^2 as the deceleration rate.

STUDY OBJECTIVE

It is noted that no previous study hypothesized the possible pair of t and d for different approach speeds. One value of t and d is used for all approach speeds. Further, no study examined the potential interaction of t and d. In other words, it can be hypothesized that braking distance and subsequent d are affected by t.

In this paper these problems are addressed using data collected at one intersection in College Station, Texas. Specifically, the objectives of this paper are to examine whether t and d are dependent on speed, and if there is an interactive effect of t and d on drivers' selected braking distance.

DATA COLLECTION

Two time-lapse cameras were used to collect data. Each camera was mounted, using a ladder up a utility pole, on one approach of each street. Both time-lapse cameras were connected to remote control units that could be operated from inconspicuous locations. Both remote cameras were operated approximately 3 sec before yellow and continued operating until the first stopping car in each lane had made a complete stop. The film was shot at nine frames per second. Data collection activity specifically covered peak, off-peak, nighttime, and wet weather conditions. The study collected operational and physical data necessary to evaluate the engineering factors and driver responses affecting change interval design. The perception and brake reaction time is measured as the time elapsed from the onset of yellow until the brake light is observed to come on. Thus t will also include response lag time, which falls between perception and brake reaction.

BOUNDARY AND POPULATION VEHICLES

The vehicles within the observation distance from the stop line to the upstream outer boundary at the onset of yellow are the "boundary vehicles." All vehicles beyond the stop line and preceeding the upstream outer boundary at the onset of yellow are ignored. Further, vehicles turning right are excluded because their response is anticipatory and not a random response.

Among boundary vehicles, those vehicles that go through the intersection and those first vehicles stopped in each lane are the "population vehicles." Vehicles stopping second in each lane are excluded because their behavior is constrained by the first vehicle stopped in each lane (i.e., their probability of stopping = 1). Further, within the sample vehicles stopped in each lane, motorists braking during green through yellow, or braking coincident with the yellow onset, should also be excluded because their behavior is not a random response to the yellow signal but anticipatory or coincidental.

TEST OF HYPOTHESES

In this presentation, the coefficients of variables found from models are intentionally omitted and only graphic results are presented. Because they represent only effects based on mean values and their misuse may cause significant consequences, the coefficients will be presented in a subsequent paper after more data have been collected. It is noted that no high correlation was found between independent variables throughout the models presented.

Hypothesis 1

Drivers' perception and brake reaction time is affected by approach speed (V), distance at yellow onset (D), and the interaction of these two.

The best model obtained from stepwise regression procedure revealed that a driver's perception and brake reaction time is affected by approach speed, distance from the intersection at yellow onset, and the interaction of approach speed and distance. Specifically, it was found that

$$t = f(-v, D, -V \times d, V^2, D^2) \quad (1)$$

The model and all variables were significant at $\alpha = 0.01$ and the R^2 was 0.47. Although $R^2 = 0.47$ is not overwhelmingly high, the model confirmed the fundamental factors affecting drivers' perception and brake reaction time.

Graphic presentation of the model (Figure 1) shows that a driver's perception and brake reaction time decreases as approach speed increases. Note that the approach speed is derived during green just before yellow onset. For the cases of high t the speed between yellow onset and brake actuation should be discounted because of coasting.

Hypothesis 2

Drivers' deceleration rates are affected by approach speed, distance from intersection at yellow onset, and perception and brake reaction time.

Similarly, stepwise regression was used and the

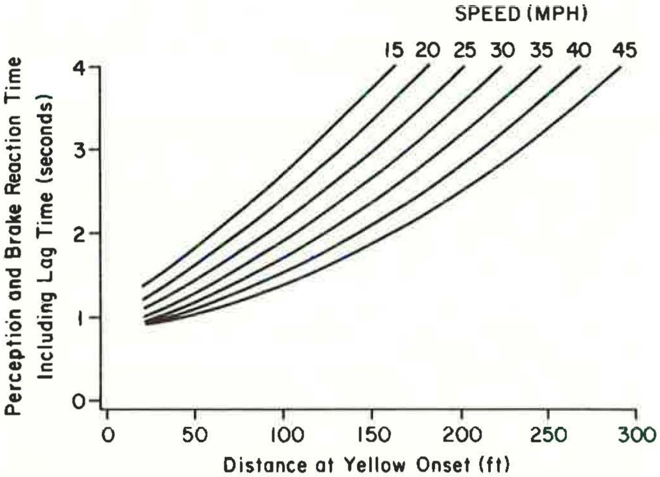

FIGURE 1 Perception and brake reaction time as a function of approach speed and distance at yellow onset.

model revealed that deceleration rate is a function of approach speed, distance at yellow onset, and interaction of distance at yellow onset and t. Specifically, it was found that

$$d = f(V,\ D \times t,\ -D^2) \qquad (2)$$

The R^2 was 0.08 and the model was significant at α = 0.01. The interaction of D and t was significant at α = 0.05, and other variables were significant at α = 0.01. Even if the model is significant, no definite conclusion may be drawn from the data because of a weak relationship. However, the model is noteworthy and will be retested as more data become available.

Hypothesis 3

Braking distance is affected by approach speed and perception and brake reaction time. The interaction of prebraking (t) and postbraking (d) affects braking distance.

The best model found from stepwise regression procedure revealed that a driver's braking distance (B) is a function of the following variables:

$$B = f(V,\ t \times d,\ -V^2,\ -t^2,\ -d^2) \qquad (3)$$

The R^2 was 0.51 and the model was significant at α = 0.01. The interaction of t and d was significant at α = 0.10 and the square of t was significant at α = 0.05. Other variables were significant at α = 0 01.

Graphic presentation of the model (Figure 2) indicates that

1. Drivers' braking distance increases as approach speed increases.
2. Drivers' braking distance decreases quadratically as deceleration rate increases. It is noted that the law of motion stating that braking distance is inversly proportional to deceleration rates is not applicable here because of the influence of t.
3. At low deceleration rates and at relatively farther distances from the intersection, slow-reacting drivers experienced the same comfortable deceleration rate as quick-reacting drivers even if their braking distances were shorter than those of the quick-reacting drivers. This is probably due to the speed reduction from coasting during the longer t periods of slow-reacting drivers.

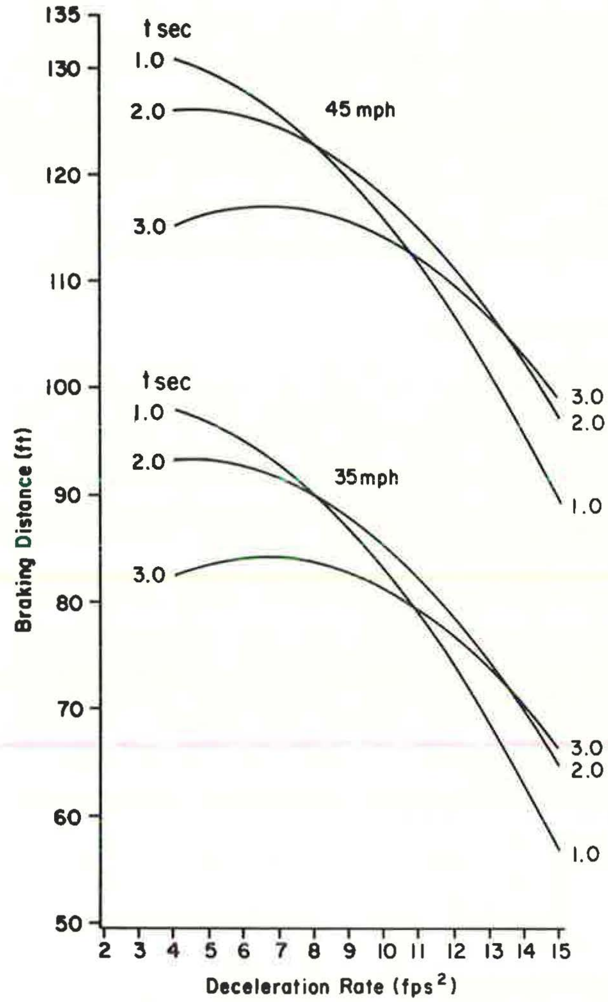

FIGURE 2 Breaking distance as a function of deceleration rate, approach speed, and perception and brake reaction time.

4. At high deceleration rates and at relatively closer distances from the intersection, the slow-reacting drivers experienced the same high deceleration rates as the quick-reacting drivers even though their braking distances were longer than those of the quick-reacting drivers. This is probably due to the human psychology of reducing accident risk by applying high deceleration rates very close to the intersection to compensate for slow reactions.

FURTHER STUDY

The Texas Transportation Institute (TTI), Texas A&M University, is analyzing more data obtained from six other sites. The study will address questions, including the probability of stopping or entering as a function of factors, involving signal change interval design.

CONCLUSIONS

The following conclusions were drawn from the data collected and apply to the experience with local intersections.

1. There was high variability in drivers' perception and brake reaction time (t). Higher t was observed not only for vehicles farther from the

intersection but also for vehicles closer to the intersection. Seventy-five percent of the drivers experienced 2 sec or less of t.

2. Median deceleration rates were found to be 12.5 and 10.5 fps^2 for each approach. The 85 percentile deceleration rates in descending order were 10.0 and 8.0 fps^2 for each approach.

3. Eighty-five percent of the drivers at the site applied the brakes within 240 ft of the intersection stop line.

4. Perception and brake reaction time is affected by approach speed, distance from the intersection at the onset of yellow, and the interaction of these two. Specifically, t decreases as approach speed increases at a given distance at yellow onset.

5. The deceleration rate appears to be affected by approach speed, distance at yellow onset, and perception and brake reaction time.

6. Braking distance is affected by approach speed, perception and brake reaction time, deceleration rate, and the interaction of t and d. Because braking distance is affected by the interaction of prebraking (t factor) and postbraking (d factor), joint consideration should be given the two in selecting the pair of t and d.

7. Because of conclusions 4-6, a different pair of t and d values for different approach speeds should be considered in designing change interval duration.

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