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Driver Perception Response Time During the Signal Change Interval

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Abstract

The importance of perception response time (PRT) values for traffic signal change interval design, and the need to monitor the design PRT value, are challenges facing transportation professionals. However, current methods used to validate the design PRT value from on-site observational studies have failed to yield convincing proof that the 1 second design value is adequate. A modification to on-site data capture and extraction, using a transitional zone (TZ), is used to overcome this deficiency. The TZ allows the systematic identification and exclusion of those drivers who have time to delay their responses. Their inclusion in past studies inflated PRT values. Their exclusion in this study provides a more accurate value.

Road traffic accidents are highly undesirable outcomes in road operations. At junctions with traffic signals, a significant proportion of accidents occur during the signal change interval (comprising pre-red amber and all-red periods). Traffic signal design incorporates several driver performance parameters, and utilisation of realistic performance values can enhance safe signal operations.^[1-3] Driver perception response time (PRT) to the amber signal is a key human performance parameter. The PRT measures how fast a driver responds to the signal change.

Transportation design practices are coming under greater public scrutiny. Well established practices are being questioned in litigation suits, usually following serious or fatal accidents.^[4,5] Modern lifestyles (for example, mobile phones and in-vehicle navigation systems), coupled with an ageing driver population, are expected to affect driver performance characteristics.^[6,7] As driver characteristics are known to be major contributors to accidents,^[8] these changes should be incorporated into traffic system design.^[2,9,10]

Driver performance studies at traffic signals have generated PRT statistics that are greater than the typical design value. This has led to calls to increase the latter.^[11] However, it is our contention that the widely used design PRT value of one second (1 sec) is reproducible and remains applicable. The inconsistencies reported by past studies can be attributed to either the controlled nature of the experiments or methodological flaws. In this article, an im-

proved method for validating the design PRT value is reported, and issues concerning PRT determination are highlighted. The technique used to estimate the PRT value is presented, along with the results, and the implications of the findings are discussed.

Determination of Perception Response Time (PRT)

PRT is defined as the time interval from the appearance of some object or condition in the driver's field of view to the initiation of a response.^[12] In the context of the signal change interval, PRT equals the time between the onset of the amber signal and initiation of braking by the driver. Two approaches, experimental and observational, have been used in studying driver PRT. In the experimental approach, PRT is determined either by simulated conditions in the laboratory or by using informed test subjects under field-controlled conditions. However, the relatively artificial conditions restrict the type and realism of the experiments.^[12] The observational approach relies on unobtrusive, on-site observations to obtain empirical data under actual, on-the-road conditions.

The 1 sec design PRT value^[13] has been adopted by the Institute of Transportation Engineers (ITE). This value is pegged at the 85th percentile point (or higher) of the PRT distribution.^[11] According to Hooper and McGee,^[14] the 1 sec value was established on the basis of findings from studies of informed test subjects^[15,16] and unobtrusive field measurements.^[17,18] The 1 sec value has only

been corroborated in experimental studies where realism was, at best, uncertain. The observational studies^[3,11,19,20] produced higher PRT values. The suitability of the 1 sec design PRT value has thus been questioned.^[11]

We contend that the methodology employed in past observational studies was basically flawed. In those studies, vehicles were sampled over a long approach. Hence, subject vehicles that were a long distance from the stop line (at amber onset) would have had ample leeway to delay initiating the stopping response.^[19] An improved methodology was developed to overcome this flaw in sample selection, using a transitional zone (TZ) to select drivers operating in a (relatively) immediate stopping situation.

Perception Response Time and the Transitional Zone

The TZ was constructed by defining an empirically calibrated range of time headways suitable for identifying drivers with realistic stop-or-cross decisions. The contention is that while all drivers approaching the junction will have to make a choice to either stop or cross, drivers within the TZ are those who are required to make a decision quickly or be forced to cross by default. Outside the TZ, drivers are in clear-cut situations: near vehicles must cross and far vehicles cannot legally cross. In this study, drivers were considered to be operating under a forced-pace situation when they were within the TZ and operating under a free-pace situation when not in the TZ. If they are far away, the driver's decision is clearly to stop, and there is no urgency to initiate stopping action.

PRT values obtained from within the TZ should come close those required for design purposes. They cover the situation of drivers operating in the range where both stopping and crossing are valid options. The methodology developed in this study combines motivational theorising with an observational technique, which is quite rare in transportation and human factors studies.^[21]

Data Collection and Extraction

In Singapore, motorists drive on the left, and there is a uniform 3 sec amber interval at junctions. Field observations were carried out at nine approaches to signalised X- and T-junctions. Some of these had red light surveillance cameras (RLCs) as automated enforcement devices. Right turns are permitted on full green lights. This can involve cutting through on-coming traffic, with an associated collision risk. At the T-junctions, traffic movements were observed only for vehicles travelling from the left along the 'top of the T-junction', which are characterised as having no on-coming traffic turning across them and hence no collision risk. As another dimension, an approach with an RLC installation represents a location of high enforcement risk. The RLC may, therefore, be expected to affect driver behaviour. The experimental design allocated each of the nine approaches to one of the four combinations of high and low collision/enforcement risks.

The required data were the vehicle's distance and approach speed at the onset of the 3 sec amber signal. Traffic movement data were collected using high-definition digital cameras that record video images at 50 fields (or 25 frames) per second. In the field set-up, cameras were inconspicuously mounted on pedestrian bridges. Recording sessions were conducted during morning and late afternoon periods with free-flowing traffic and dry weather conditions. During these periods, it could be assumed that the proportion of impaired drivers (from fatigue, alcohol intoxication) would be low and older (retired) drivers would be well represented. In addition to the video filming, the distance of road markings from the stop line was measured on site using a road distance meter.

Data extracted from the video records included the PRT, vehicle type and vehicle positions (to determine distances and speeds) of first stopping and last crossing vehicles in each lane. The PRT was the time interval from amber onset until the brake lights

Table I. Site characteristics of junction classes

Approach type	No. of approaches	n		Signal timing duration (sec)				Distance (m) ^a
		stop	cross	green	amber	all-red	red	
X-junction								
Without RLC	5	182	362	41–66	3	1	39–94	300–800
With RLC	2	88	82	31–55	3	1	61–81	300–350
T-junction								
Without RLC	1	40	127	100	3	1	27	600
With RLC	1	54	30	93	3	1	34	350

a Distance to upstream junction.

n = number of observed vehicles in the transitional zone; **RLC** = red light surveillance camera.

Table II. Vehicle composition and speed (within transitional zone) at study locations

Approach type	Composition of vehicle groups (%)				Approach speed (km/h)		
	car	motorcycle	light commercial vehicle ^a	heavy vehicle	mean	standard deviation	85th percentile
X-junction							
Without RLC	59.7	7.9	13.4	18.9	59.0	11.6	71.4
With RLC	61.9	10.6	8.1	19.4	50.9	10.3	61.7
T-junction							
Without RLC	69.1	6.0	15.6	17.4	63.4	10.2	73.9
With RLC	69.1	4.8	11.9	14.3	59.0	8.2	67.0

a Light commercial vehicles comprises vans and pickup trucks/utes.

RLC = red light surveillance camera.

became visible. The projected time to stop line (TTSL) at amber onset was computed for every subject vehicle, using the front wheels as the reference. Actual traverse times to cross the stop line were measured for the crossing vehicles. Further details on the data collection and extraction tasks can be found in Wong and Goh.^[22,23]

Sample Characteristics

Altogether, 2506 vehicles were sampled. This gave 965 vehicles within the TZ, with 364 of these stopping. The TZ sample was used for the analysis. Selected site and sample characteristics are shown in table I and table II, respectively.

The subject vehicles comprised mostly cars, followed by heavy vehicles, light commercial vehicles and motorcycles. The vehicle composition was fairly similar across the sites and was representative of the national vehicle population. The sample mean speeds were in the range of 50–60 km/h, with standard deviations of around 8–12 km/h. It should be noted that all the subject vehicles were on straight-through movements.

Analysis and Results

Determining the Transitional Zone

The TZ was established empirically and used to select drivers with a realistic stop-versus-cross decision. The TZ can be defined in terms of either distance at amber onset or time headway.^[22] The time headway approach was used in this study; it has greater intuitive meaning and is less cumbersome to apply. The PRT data were graphed against the projected TTSL for different junction classes (figure 1, figure 2, figure 3, figure 4). The traverse times of crossing vehicles were also plotted. The combined plots of the stopping and crossing vehicles illustrate the progression in the

driver PRT and the traverse time. The following observations can be made:

1. Vehicles with a small TTSL (at amber onset) tended to cross the junction, while vehicles with a large TTSL stopped.
2. The range and variation of PRT values increased with the TTSL.
3. Upper PRTs increased rapidly after a certain TTSL value. Above this value, no vehicles were observed to cross at RLC approaches, and relatively few vehicles were observed crossing at non-RLC approaches.
4. The datapoints within the TZ for RLC and non-RLC approaches were distributed differently, reflecting different site conditions. There was a greater proportion of stopping vehicles at RLC approaches.

The first observation is consistent with the findings made by Chang et al.^[19] However, the second and third observations justify the use of a TZ. Vehicles that stopped with a TTSL value of up to about 4 sec had PRT values within a narrow band of about 1.0 ± 0.6 sec (see, for example, the dashed box in figure 1). Also, the sample for TTSL below 4 sec included both stopping and crossing vehicles, implying a stop-or-cross choice. The 4 sec TTSL value was therefore considered a suitable upper bound for the TZ. The target population was thus made up of stopping vehicles with a TTSL value below 4 sec at amber onset, and their PRT values were analysed.

Above the 4 sec TTSL value, PRT values spread rapidly. It is hypothesised that motorists in this range can engage in free-pace braking. This explained the numerous inflated PRT values for vehicles far away from the stop line. In defining the upper limit of the TZ, care was taken to exclude late red-light runners, who would otherwise inflate the TZ upper bound.

Fig. 1. Perception response time (PRT) and actual time to cross the stop line vs time to stop line (TTSL) for X-junctions without red light surveillance cameras. Dashed box indicates vehicles that stopped with a TTSL value of up to about 4 sec.

PRT Values in the Transitional Zone

The summary statistics for PRT values for vehicles within the TZ are presented in table III. Most importantly, the 85th percentile PRT value was 1.06 sec at X-junctions and 1.08 sec at T-junctions. The mean PRT value ranged from 0.80 sec at X-junctions with RLCs to 0.92 sec for T-junctions without RLCs. The mean value was lower at junctions fitted with RLCs than at non-camera junctions, and at X-junctions than at T-junctions. The standard deviation was quite constant at 0.21–0.23 sec.

The log-normal distribution was found to give the best fit (when tested together with normal and Pearson type III) for modelling the observed PRT values. The probability density function of the log-normal distribution (adapted from Ang and

Tang^[24]) is presented in the following equation, where $t = \text{PRT}$, λ = median, σ = standard deviation and μ = mean:

$$f(t) = \frac{1}{t\zeta\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{\ln t - \ln \lambda}{\zeta}\right)^2\right]$$

where

$$\zeta = \sqrt{\ln\left(1 + \frac{\sigma^2}{\mu^2}\right)}$$

The PRT distributions, together with results from other studies, are shown in figure 5. The profiles among the four types of sites were very similar. The distributions were able to fit the observed PRT values fairly well (within 1% significance using the Kolmogorov-Smirnov test). Notably, the 85th percentile PRT

Fig. 2. Perception response time (PRT) and actual time to cross the stop line vs time to stop line (TTSL) for X-junctions with red light surveillance cameras.

Fig. 3. Perception response time (PRT) and actual time to cross the stop line vs time to stop line (TTSL) for T-junctions without red light surveillance cameras.

values were close to the 1 sec design PRT value recommended by the ITE. In comparison with other studies, the PRT values within the TZ more realistically reflect the driver's ability to respond to the signal change interval. This is because the study approach explicitly recognises and accounts for the steps leading up to the actual stopping action. In contrast, other studies did not exclude vehicles operating under free-pace stopping, and so produced inflated values.

Discussion

This study of on-site driver PRT entailed the definition and calibration of a TZ for sample selection. The resultant mean PRT values (1.0–1.1 sec) were found to correspond very closely to the 1

sec design value. However, this may change with time as the profile of drivers (such as the proportion of older drivers) changes. Such changes should be monitored, using techniques like the one reported in this article, to ensure a proper balance of safety and efficiency.

The distributions of the PRT values were quite similar at junctions with different geometric configurations and/or enforcement risks. This means that collision risks and enforcement risks did not substantially influence driver response time. This lends support for the use of a single design PRT for the different junction configurations. However, the small number of sites in the present study should be noted.

Fig. 4. Perception response time (PRT) and actual time to cross the stop line vs time to stop line (TTSL) for T-junctions with red light surveillance cameras.

Table III. Distribution of perception response time (PRT) [within transitional zone] at X-junctions and T-junctions

Approach type	n	PRT values (sec)				
		15th percentile	median	mean	standard deviation	85th percentile
X-junction						
Without RLC	182	0.64	0.84	0.86	0.23	1.08
With RLC	88	0.58	0.80	0.80	0.21	1.00
Total	270	0.60	0.82	0.84	0.23	1.06
T-junction						
Without RLC	40	0.68	0.90	0.92	0.22	1.13
With RLC	54	0.60	0.82	0.83	0.22	1.04
Total	94	0.62	0.85	0.87	0.22	1.08

n = number of observed vehicles in the transitional zone; **RLC** = red light surveillance camera.

Fitting of the PRT values showed that the log-normal distribution is suitable. This result is similar to the finding by Taoka.^[11] The log-normal distribution is a simple statistical distribution with relatively few data requirements (requiring only mean, median and standard deviation). It should be a valuable modelling tool for evaluating PRT values at a specific junction.

The method described in this article is well suited for selecting motorists operating under a relatively forced-pace situation. However, it is a tedious method, as the vehicle speed and position at amber onset are required for sample selection. The observational approach also restricts the scope to account for driver attributes. The results generated by the method described in this article are nevertheless realistic and very useful for design applications.

Conclusions

This study presented the determination of driver PRT for braking action during the traffic signal change interval. Two potential

challenges to the 1 sec design PRT value currently used were identified and discussed. These are: (a) the inability to provide corroborating results from past on-site studies; and (b) changing driver profiles. Transportation practitioners are increasingly coming under public and professional pressure to justify the values used in design, in this case the 1 sec PRT. A realistic way to evaluate PRT is through on-site observation. Past on-site studies failed to generate corroborating results, but this can be traced to an inherent flaw in sample selection. The method described in this article overcomes this deficiency by defining a TZ. Drivers in the TZ face a feasible stop-versus-cross decision during the signal change interval, and hence operate under forced-pace conditions.

This study produced PRT statistics (85th percentile value of 1.0–1.1 sec) close to the 1 sec design PRT value. This means that the 1 sec design value is not unrealistic. The PRT statistics under different risk exposures were very similar, thus supporting the case

Fig. 5. Cumulative perception response time (PRT) values (modelled) from this study compared with other studies (Chang et al.,^[19] Gazis et al.,^[17] Wortman and Matthias^[3]). **RLC** = red light surveillance camera.

for a single PRT value in design. In addition, the PRT was found to fit the log-normal distribution.

This research also highlights the features of an improved study methodology. The new method outlined in this article entails unobtrusive data collection and sample selection using a TZ. The study technique is suitable for large-scale evaluation of design PRT values. It is also useful in small-scale applications whenever the design PRT value for a specific junction/situation is subject to contention.

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References

1. Arasan VT, Rao DM. Estimation of intergreen interval for maximum safety at traffic signals. Proceedings of the International Conference on Transportation into the Next Millennium; 1998 Sep 9-11; Singapore. Singapore: Nanyang Technological University, 1998
2. Mahalel D, Zaidel D. A probabilistic approach for determining the change interval. *Transport Res Rec* 1986; 1069: 39-45
3. Wortman RH, Matthias JS. Evaluation of driver behavior at signalized intersections. *Transport Res Rec* 1983; 904: 10-21
4. Parsonson PS, Czech WS, Bansley WC. Yellow and red clearance signal timing: drivers and attorneys speak out. *ITE J* 1993; 63: 26-31
5. Indiana County's intersection design may be negligent even when it conformed to engineering standards [online]. *Road Inj Prev Litigation J*. Available from URL: <http://www.usroads.com/journals/p/ri/j/9802/ri980201.htm> [Accessed 2001 Dec 30]
6. Naylor DW, Graham JR. Intersection design and decision-reaction time for older drivers. *Transport Res Rec* 1997; 1573: 68-71
7. Shasheen SA, Niemeier DA. Integrating vehicle design and human factors: minimising elderly driving constraints. *Transport Res Part C* 2001; 9: 155-74
8. Sanders MS, McCormick EJ. Human factors in engineering and design. Singapore: McGraw-Hill Inc., 1993
9. Department of the Environment, Transport and the Regions. Tomorrow's roads: safer for everyone. London: Department of the Environment, Transport and the Regions, 2000
10. Department of Transportation. Safety in numbers: using statistics to make the transportation system safer. Washington, DC: Bureau of Transportation Statistics, Department of Transportation Safety Council, 2000
11. Taoka GT. Brake reaction times of unalerted drivers. *ITE J* 1989; 59: 19-21
12. Olson PL. Forensic aspects of driver perception and response. Tucson (AZ): Lawyers and Judges Publishing Company Inc., 1996
13. Institute of Transportation Engineers. Traffic engineering handbook. Washington, DC: Institute of Transportation Engineers, 1999
14. Hooper KG, McGee HW. Driver perception-reaction time: are revisions to current specification values in order? *Transport Res Rec* 1983; 904: 93-7
15. Johansson G, Rumar K. Driver's brake reaction times. *Hum Factors* 1971; 13 (1): 23-7
16. Massachusetts Institute of Technology. Report on Massachusetts highway accident survey, CWA-ERA project. Cambridge (MA): Massachusetts Institute of Technology, 1934
17. Gazis D, Herman K, Maradudin A. The problem of the amber signal in traffic flow. *Operations Res* 1960; 8: 112-32
18. Olson PL, Rothery RW. Driver response to the amber phase of traffic signals. *Operations Res* 1961; 9: 650-63
19. Chang MS, Messer CJ, Santiago AJ. Timing traffic signal change intervals based on driver behavior. *Transport Res Rec* 1985; 1027: 20-30
20. Wortman RH, Witkowski JM, Fox TC. Traffic characteristics during signal change intervals. *Transport Res Rec* 1985; 1027: 4-6
21. Ranney TA. Models of driving behaviour: a review of their evolution. *Accid Anal Prev* 1994; 26: 733-50
22. Wong YD, Goh PK. Driver perception-response time for braking action during signal change interval. *Road Transport Res* 2000; 9: 17-26
23. Wong YD, Goh PK. Perception-braking response time of unalerted drivers at signalised intersections. *ITE J* 2001; 71: 73-6
24. Ang A, Tang WH. Probability concepts in engineering planning and design. New York: J Wiley, 1975

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