

TIME PROXIMITY MEASURES FOR TRAFFIC CONFLICTS SIMULATION

ABSTRACT

This paper uses time proximity to hazard as driver perceived measures of safety to simulate traffic conflicts when defined by time-to-collision. A traffic conflicts observation technique has been developed to determine time-to-collision behavioral responses. Statistics and experimental research have provided insights for reasonable threshold times to use in traffic conflict definition based on driver hazard perception and behavioral response.

In order to extend the research potential, a traffic conflicts computer simulation model, TSC-Sim, and attached graphics display for tee and 4-legged intersections was developed and used to study traffic conflicts, with time-to-collision as the critical traffic event in driver behaviour simulation. Some aspects of gap acceptance criteria and differential effects of driver parameters including age, sex and waiting time tolerance are investigated. The simulation was validated against previous work in the literature and actual conflicts at several intersections with, so far, quite good results.

INTRODUCTION

Traffic crashes are serious road system failures, yet our understanding of the failure mechanism is poor; in particular, we know little about the conceptual linkage between human factors and road safety. More specifically, good design, for both conventional roadways and future "intelligent" vehicle and highway systems requires an intimate knowledge of the relationship between road user risk and road and traffic design criteria. The purpose of this research report is to examine how the time space between the driver and roadway hazard, presumed to be perceived visually, may be used in a simulation model to allow further insights into this relationship.

In past investigations of human behaviour and road safety in the past the time space between a vehicle operator and road hazards has been articulated as gap acceptance in taking action to proceed safely and more recently as the concept of time-to-collision in taking action to avoid collision. In this present research the literature on gap acceptance (see for example, Darzentas, 1981) provides the means for a simulation model of vehicle movement, while the concept of time-to-collision, as a quantitative definition of the severity of traffic conflicts, provides the means to evaluate safety with the simulation model.

Traffic conflicts, defined by time-to-collision measures, may well prove useful to examine the road system failure mechanism, and may provide a measure of driver risk that can be related to roadway and traffic parameters for safe design. But programs to collect traffic conflict data are few because of difficult and costly observational techniques with trained observers. It therefore appears useful to attempt to simulate traffic conflicts for both research and professional objectives.

CONCEPT OF TIME SPACE

The concept presumes that driver perception of hazard and subsequent behavioural response is an automatic control process with little or no cognitive content, and can be explained by visual parameters. First proposed as a theory of visual perception, a moving observer picks up properties of the environment in the form of ambient optical array of visual information which is processed as an optic flow field. Lee (1976) first applied this concept to driver braking responses in which he postulated that a driver does not simply depend upon his spatial proximity to hazard, nor simply on the closing velocity and deceleration, but on some relationship (or synthesis) of these variables which he called temporal proximity, or more specifically time-to-collision (TTC). Lee postulated that visual information alone, in the form of the changing optical array at the driver's eye, is used to register the hazard, when to start braking and how to control the ongoing braking process. Lee specifies the time-to-collision by the visual variable $\alpha/\dot{\alpha}$ in which α is the angle subtended at the eye by two elemental points on the surface of the hazard and $\dot{\alpha}$ is the rate of separation of the image points.

The concept can be extended to the case in which two vehicles approach an intersection on a converging course. In this case the time-to-collision is defined by the remaining time space between the converging vehicle and the trajectory of the subject vehicle on a collision course. If the angle subtended by the remaining time space is Θ , the time-to-collision as a visual perception concept can be described in terms of the visual image of the closing angle Θ . For a vehicle at rest at an intersection waiting to proceed Θ is subtended by the time lag as defined in the literature on gap acceptance.

Several braking and simulated braking experiments appear to support the validity of this concept: Schiff and Detwiler (1979); McLeod and Ross (1983); Carvallo et al. (1986).

The time-to-collision measure is used here as an indicator of the danger or the risk of a collision. In principle, the lower the TTC value during the approach, the higher the risk of a collision. In practice it is defined as the time required for two vehicles to collide if they were to continue at their speed and were to remain on the same path. As long as a collision course is present, TTC is a continuous function of time. If two vehicles are not on a collision course, the value of TTC is infinite. The function is linear when both speed and heading-angle of the two vehicles remain constant. If none of the vehicles changes its speed and/or course, a collision will result and TTC goes to zero. A "near miss" may be described by a minimum value, TTC_{min} , after which TTC increases.

To illustrate, Figure 1 shows what happens when a car approaches a fixed object. Point A indicates TTC when the evasive action is started, t_c , representing the available manoeuvring space at the moment of braking. Point B gives TTC_{min} , reached during the approach.

VALUE OF CRITICAL TTC, t_c

For simulation the value of the critical TTC, referred to here as t_c , needs to be defined. The driver decision rule assumed in collision avoidance is that, if TTC is less than or equal to t_c begin and continue evasive action, but after the point at which TTC is greater than t_{min} revert to normal driving behaviour. If x is the distance between a subject vehicle and a potential point of contact and v is the velocity at the point where evasive action is taken, and if the road users are treated as point sources for simplicity, the time-to-collision is x/v . Assuming that the velocity and heading angle are constant, the critical event will be taken to be the point of evasive action, or $t_c = x_c/v$, with x_c the critical distance. The t_{min} measure presumes the

driver adjusts acceleration rates to maintain a critical time space such that $d_{tc}/d_t = 0$. While this describes the rule on which to value t_c , for simulation evasive action is not possible to replicate and t_c is simply taken as the minimum time space calculated for two vehicles on a collision course.

A number of field and experimental studies using time-based measures of driver risk indicate a desirable time-based driver safety space of 1.5 seconds and a minimum space of 1.0 seconds (Godthelp, 1984; van der Horst, 1990). Van der Horst (1990) has also examined by video analysis the distribution of critical events from two major conflict calibration studies. In these studies conflicts were defined, not by time-to-collision measures but by a combination of objective and subjective indices used by observer teams from several countries. When converted to time measure the mean is very close to 1.5 seconds, as shown in Fig. 2.

To test the t_c and t_{min} values of 1.5 seconds and 1.0 seconds used in this research a field experiment for braking was conducted (van der Horst and Brown, 1989). Twelve student subjects were instructed to drive an instrumented car at various given speeds toward a styrofoam model of a stationary car, and to apply the brakes at the last possible moment to avoid a collision with the styrofoam "car". Driver vision was partially obstructed for some experimental runs. The experimental site was an abandoned airport providing an asphalt test track of 544 metres. Data was logged and downloaded to Toshiba T1100 plus computer. A pulsed infra red detector on the vehicle fired on passing a track side reflector pole 107m from the collision point (that is, the styrofoam "car"). There were 216 experimental runs in all; 18 for each subject at 3 speeds, 2 braking strategies and 3 vision scenarios. The experimental apparatus allowed the following data to be recorded and downloaded; distance with time, longitudinal speed with time, moment of braking action, and moment of passing the reflector. Summary results as shown on Figure 3 give a mean t_c of 1.6 seconds and a mean t_{min} of 1.1 second for the "hard" (emergency) braking instruction.

The field experiment was also designed to test the visual perception hypothesis of driver braking behaviour. For this experiment the 12 male students were instructed to approach the styrofoam mock-up of the rear of the vehicle at different approach velocities and to brake at the last possible moment to avoid a collision with the "car". Stroboscopic visual occlusion, by means of specially designed electronic liquid crystal glasses, was used to monitor braking performance in the absence of continuous visual clues which would normally be available to judge distance and speed. Three levels of occlusion were used; (a) no visual occlusion, (b) 25 Hertz, or where vision was unrestricted for 10 ms periods at a frequency of twenty five openings per second, and (c) 5 Hertz, or where vision was unrestricted for 10ms periods at a frequency of 5 openings per second. These tests provide scenarios of 100%, 25%, and 5% of the flow of optic information to the driver in braking manoeuvres. Figure 3 shows summary results, indicating deterioration of braking performance with visual occlusion with less deterioration at high speed than at low or moderate speed. What is not shown by the figure is the large variation observed across individual drivers, indicating a tendency toward individualization of driving strategies in braking. However with this caveat, the experiment appears to suggest that the subjects' braking strategy could match the safe visual time space, independent speed hypothesis, as shown by Figure 4(b), as opposed to the conventional assumption of uniform deceleration as shown by Figure 4(a).

THE TRAFFIC CONFLICTS SIMULATION MODEL

The model simulates individual vehicles as they approach, proceed through and depart an intersection. This process is quantified as a driver accepting a "gap" or a "lag" in which gap is defined as the time headway between two successive vehicles in the major road traffic stream and a lag is defined as the time remaining between a

vehicle on the major road and a vehicle entering the major road from a minor road. The simulation is meant to emulate this traffic process at unsignalized intersections as follows; (a) vehicles with a random set of characteristics are generated on the approaches; (b) on arriving at the intersection a gap (lag) acceptance criterion is determined based on, a priori, realistic assumptions; (c) a "consistent" behaviour model assumes a minimum gap (lag) which is acceptable to each driver at all times, with variation across drivers based on the type of traffic control, approach speed, driver age and sex, and stopped delay. A traffic conflict is recorded by the simulation when a gap (lag) is accepted by a driver, which given the closing speed of the conflicting vehicles, puts him/her at risk of collision with the other vehicle, using the critical conflict time space criterion t_c . It is assumed that traffic conflicts have the same stochastic event characteristics as vehicle arrivals.

The model uses a micro computer version of the discrete event simulation language, General Purpose Simulation System or GPSS/H, a specialized language described by Schriber, 1974. The simulation model also has some features not normally part of GPSS/H and therefore has been labelled "TSC-Sim," for Traffic Systems Conflict Simulation. (For a full description and results of TSC-Sim, see Sayed, Brown and Navin, forthcoming.)

Actions for vehicles in the model include vehicle generation, approach to the intersection, choosing a gap (lag) and proceeding to depart. The input parameters to the model include: (a) traffic volumes of all traffic streams, (b) percentage of heavy vehicle traffic to the total traffic volume, (c) type of the intersection control (yield or stop), (d) speed limit on the major road, (e) percentage of each driver type in the driver population, (f) number of lanes for both major and minor roads, and (g) total default simulation time. Several other parameters such as: move-up time, minimum allowable headway, turning speed of vehicles, and maximum queue lengths are given as constants to the model. It is possible to change the values of these parameters between simulation runs.

The Gap Acceptance Process

This process takes place when a vehicle has to cross or merge with other traffic streams where different traffic streams have different priority levels according to the rules of the road. Each vehicle is assigned a primary critical gap value by testing the gap acceptance function according to the driver type and the intersection type of control. The primary critical gap value is modified according to the vehicle type and the number of lanes to be crossed. Vehicles trying to cross or merge wait for a gap in the conflicting traffic stream (streams) greater than or equal to their critical gap. The critical gap value is obtained by multiplying the primary critical gap with a delay modification factor. The delay modification factor has an initial value of 1.5 when the vehicle faces no delay and this value decreases as the vehicle's stopped delay increases with a minimum theoretical value of 0.5 when the vehicle faces infinite delay. The model assumes that no driver will accept a gap that he/she thinks will certainly lead to a collision. Therefore, a minimum acceptable gap is used, with a value of 2.0 seconds as a minimum allowable critical gap, based on data provided by Wennel et al. (1981). If the critical gap value is less than the minimum acceptable gap, it is set to the minimum.

Vehicle drivers who decide to enter the intersection are assigned a single lane manoeuvre time. This time is sampled from a truncated normal distribution function. The mean and standard deviation of the function depend on the driver type (Darzentas et al., 1980). The sampled manoeuvre time is then corrected according to the number of lanes to be crossed and the vehicle type.

Traffic Conflict Simulation

A traffic conflict occurs when a driver decides to execute a manoeuvre which puts him/her at risk of collision with another vehicle. Conflicts are classified into six types, as visualized from one approach: left turn opposing (LT/O) ; left turn crossing (LT/C) ; crossing (C) ; right turn (RT) ; rear end ; and weaving (W) . The time-to-collision for the simulation process is taken to be the minimum time space between two converging vehicles during these conflict incidences. The model first estimates whether or not the vehicles are on a collision course. If the vehicles are on a collision course, the TTC value is calculated and compared with the threshold value of t_c . If the TTC is less than or equal to the threshold value the model records the conflict, its type, location, and the TTC value. For this study the threshold value of t_c is 1.5 seconds.

VALIDATION

Validity of the simulation was tested by comparing traffic conflicts observed at four unsignalized intersections with traffic conflicts predicted by the simulation model for these intersections for the same period of time. The validation data base came from studies of traffic conflicts at several intersections in the Greater Vancouver, Canada, area. Although several more intersection studies were reviewed, the majority of the unsignalized intersections covered by the conflict studies were complex layouts, beyond the simple T and four way intersections selected for this analysis. All selected intersections were 4-leg intersections with negligible grades, good visibility and simple layout. Table 1 is a summary of the intersection characteristics.

Table 1. Study Intersections for Simulation Validation

Intersection Type	Lanes	Turn Restrictions	Minor	Peak Hour Traffic
#1 4 approaches	1+1 2+2	none	stop signs	120 vph/80 vph
#2 4 approaches (1+2 lane ramps on major approaches)	2+1	high type	stop signs	500 vph/300 vph
#3 4 approaches	1+1	none	stop signs	460 vph/110 vph
#4 4 approaches	1+1	none	stop signs	360 vph/140 vph

Conflict Observation Method

For 4 legged intersections there are 44 conflicting movements. The observation method used here collapses these movements into the six categories described above. The observer positions himself about 2 seconds from the centre of the intersection so as to be able to observe brake lights or the beginning of evasive action. The method sets up hypothetical TTC zones according to the average approach speed to facilitate accurate recording.

Traffic conflicts were recorded at the study intersections by trained observers. The observation and recording method is an on-site, on-line record of the incidence

and severity of traffic conflicts. Observations were made for two days at each intersection. Two observers were used each day for an 8-hour observation period, giving a total of 32 man-hours/intersection. The severity of traffic conflicts is determined by the sum of two scores: the TTC score and A "Risk of Collision" or ROC score. The ROC score is a subjective measure of the risk of collision and is dependent on the perceived control that the driver has over the conflict situation. The TTC and ROC scales were given equal weighting and combined into a 5-point Likert type scale. The summation of the TTC and ROC scores gives the overall severity score which range between two and six. An overall severity score of two signifies a low risk conflict situation and a score of six is a high risk conflict situation (Table 2). The mid-point of the composite scale registers the critical event, corresponding to a TTC of 1.5 seconds or less with a "moderate" ROC.

Table 2. Time-to-collision and Risk of Collision Scores

TTC and ROC Scores	Time-to-collision (TTC)	Risk Of Collision (ROC)
1	1.6 - 2.0 seconds	Low Risk
2	1.0 - 1.5 seconds	Moderate Risk
3	0.0 - 0.9 seconds	High Risk

Source: Brown, G.R. (1991)

Reliability tests of the observation method gave 77% accuracy with 95% confidence, with a high of 85% accuracy for assessing the correct TTC. In addition, in a study of 13 intersections to test the validity of a $TTC = 1.5$ seconds or less for a measure of safety as defined by the number of accidents, it was found that at 8 of 11 intersections conflicts are significantly correlated with accidents at 95% confidence with $R^2 \geq .64$ with 3 intersections having $R^2 \geq .81$ (Brown, 1994).

Validation Results

Conflict simulation was based on legal speed limits of 50 km/hr, but it was observed that vehicle speeds were by and large higher, so runs were made at 70 km/hr and 60 km/hr depending on estimated actual traffic speed. The model was modified for traffic volume changes for morning, noon and afternoon peaks, and further adjusted to allow the exclusion of a left turn restricted movement from 7-9 a.m. at intersection #2. The overall results are given in Table 3 which shows encouraging results, particularly in the distribution of conflicts by movement type.

Table 3. Observed Versus Predicted Conflicts by Movement Category

	Observed Conflicts*	Predicted Conflicts* @ 50 km/hr	Predicted Conflicts* @ __ km/hr
	O	P ₅₀	P ₇₀
RE	4+1	2+0	4+1
Crossing	1+0	1+1	1+2
LT/C	2	1	2
	8	5	10
	O	P ₅₀	P ₆₀
RE	0	0	1
Crossing	2+2	3+3	3+4
LT/C	10	7	9
LT/O	1+2	2+1	2+1
RT	2	1	1
	19	17	21
	O	P ₅₀	P ₆₀
RE	2+1	1+0	2+1
Crossing	0	0	0
LT/C	3+2	2+1	2+1
LT/O	1	1	1
RT	1	1	1
	10	6	8
	O	P ₅₀	P ₇₀
RE	1	0	1
Crossing	8+4+1	4+3+1	6+3+1
LT/C	1	1	1
	15	9	12

* by approach

CONCLUSIONS AND FURTHER RESEARCH

To gain credibility for application traffic conflicts need to provide a quantitative, observable measure of the systematic variability of road safety, and combined with random effects serve to describe road user risk. In this study the systematic component of risk is described by the traffic process critical event, t_c . The notion of driver risk intended here follows Zeidel's ergonomic model of the driver as a self-paced vehicle operator in a complex and multi-dimensional environment, dependent upon his abilities and limitations to control the vehicle and on the information and uncertainty about what lies ahead (Zeidel, 1985). A traffic conflict is viewed as a unique, independent critical event in the traffic process which signals a hazard, and combined with a severity level of the conflict event represents some discrete risk. Thus defined, the traffic conflict meets at least one definition of risk in a driver behaviour context; the probability and consequences of a hazardous event (Kalbfleisch, Lawless and MacKay, 1988).

The research attempts to contribute to road safety studies in two ways. The measure used to delineate the conflict has been quantified as a time proximity value, allowing road safety to be studied in the context of gap acceptance research; and the resultant simulation model using this measure appears to replicate, with some degree of accuracy, field observations of traffic conflict behaviour. However, the

study has pointed to several areas of further research. Firstly, the severity definition used is specific to the field procedure, and this constrains the wider evaluation of the model. A larger inventory of conflict studies, using the time proximity definition, is needed. Secondly, more research is needed to confirm the conceptual linkage of traffic conflicts to safety and risk. The model simulates conflicts (as defined here) and cannot be evaluated against accident statistics. The authors are reasonably confident that the time proximity definition of traffic conflict will prove to be a measure of driver risk, but to date, this contention is still tentative. Lastly, simulation has been suggested as a tool to study road safety. Until the road safety problem can be described unambiguously, and the complex relationship between driver behaviour and roadway and traffic parameters delineating driver risk is known, perhaps computer simulation will prove useful for road safety evaluation.

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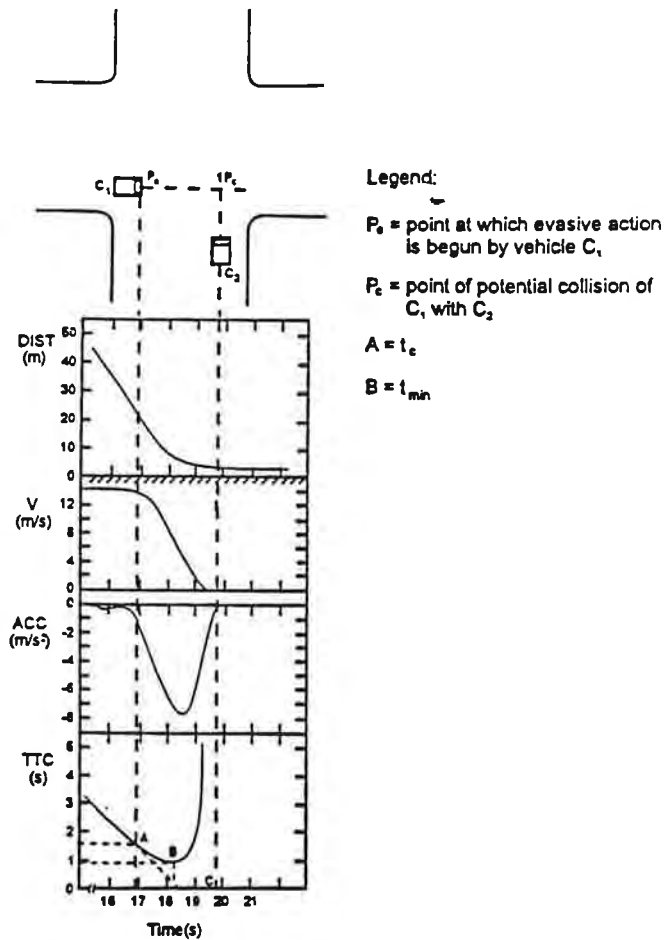


Figure 1. Concept of Traffic Conflict, Showing Time-to-collision (TTC), Critical Event (t_c) and Minimum Time-to-collision (t_{min}).

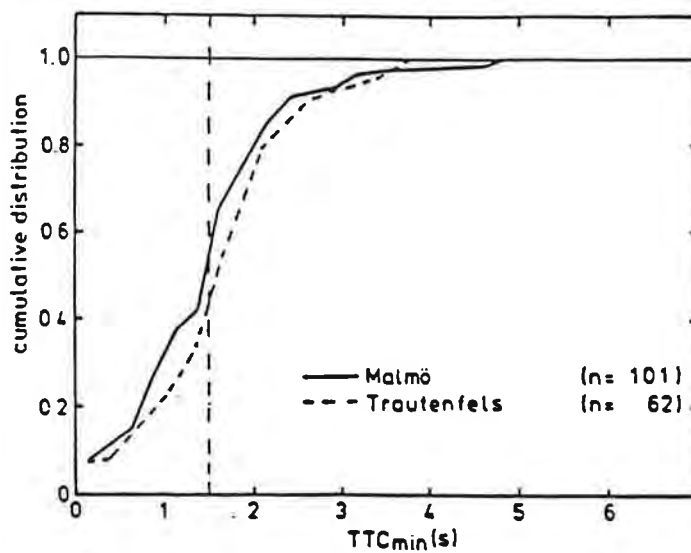


Figure 2. TTC_{min} Distributions of Conflicts from the Malmö and the Trautenfels Calibration Studies.

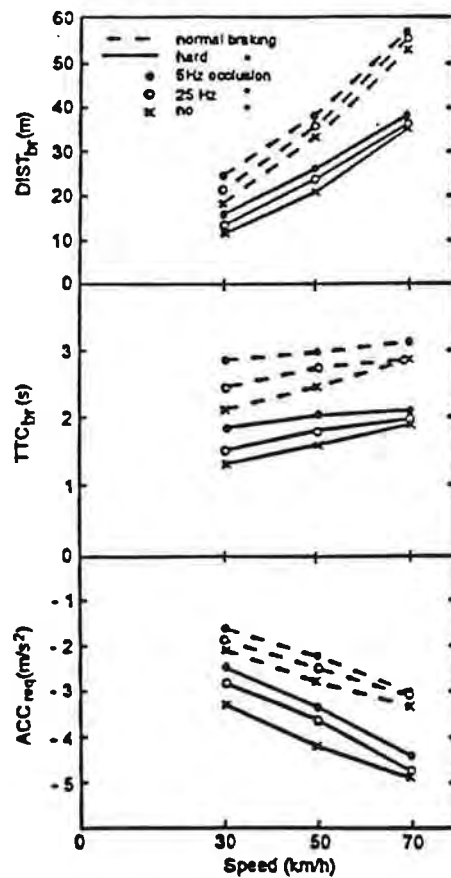


Figure 3. Braking Strategy for 12 Male Subjects in Closed Course Experimental Conditions (Source: van der Horst and Brown, 1989).

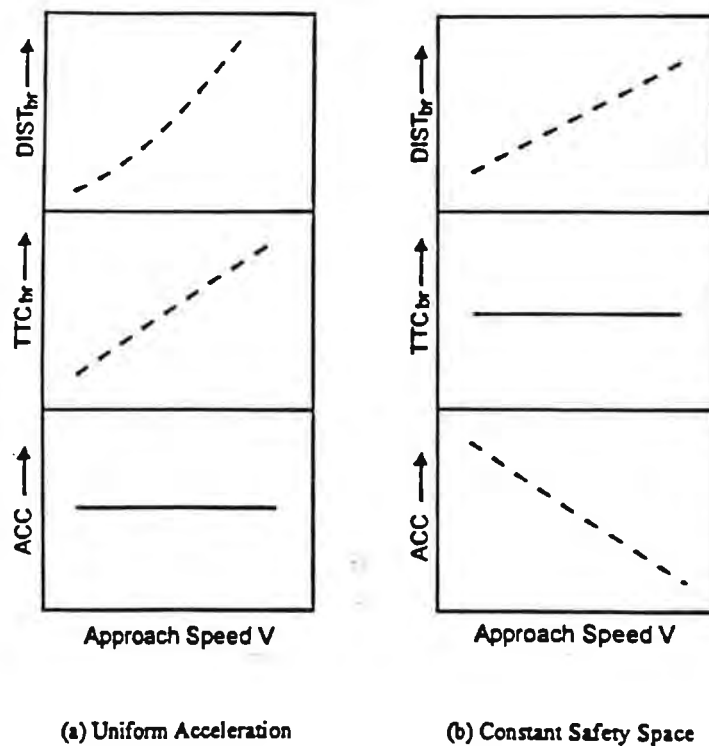


Figure 4. Two Hypotheses of Driver Braking Strategy (Source: van der Horst and Brown, 1989).