A Study on the Classification of Danger from Traffic Conflict Caused by Aggressive Driving Behavior

Ja-Zen Kau [a] ,Chun-Zin Yang [b]

[a] *PH.D. student, PH. D Program in Civil and Hydraulic Engineering, Feng Chia University, 100 Wenhwa Rd. Seatwen, Taichung 40724, Taiwan, Republic of China (ROC), E-mail: kaojam@ms10.hinet.net*
[b] *Associate Professor, Department of Transportation Technology and Management, Feng Chia University, 100 Wenhwa Rd. Seatwen, Taichung 40724, Taiwan, Republic of China (ROC), E-mail: czyang@fcu.edu.tw*

Abstract: The conflicts caused by aggressive driving behaviors were explored in this study. By deducting, simplifying, and summarizing the patterns of aggressive driving behaviors and driving directions, this study obtained the four types of traffic conflicts, which are crossing conflict, same-direction merging conflict, same-direction tailgating conflict, and opposing passing conflict. Furthermore, the danger models and levels of driver and offended driver were established by the Traffic Conflict Technique. The cross conflict utilized PET (Post-Encroachment Time), TTC (Time to Collision), and TA/CS (Time to Accident and Conflicting Speed). The same-direction-merging conflict and the same-direction-tailing conflict applied PICUD (Potential Index for Collision with Urgent Deceleration). Opposing-passing conflict used TTC and TA/CS. The models took perception-response time, deceleration-rate, and velocity of a driver as the decision rules for danger levels, determined quantitative definitions and classifications of the dangers, and further provided reliable statistics to drivers, in order to enhance driving safety.

Keywords: Aggressive Driving Behaviors, Traffic Conflict, Time to Accident and Conflicting Speed, Time to Collision, Potential Index for Collision with Urgent Deceleration, Post-Encroachment Time

1.INTRODUCTION

According to the reported statistics of the National Police Agency, Ministry of the Interior, ROC (2013), with regard to the causes of car accidents, the cause of most serious accidents is inattention or distraction of drivers, which represents more than 95 percent of traffic accidents. Further analysis of the ten causes of traffic accidents found about 74 percent are related to aggressive driving.

Aggressive driving is a traffic offense and include a variety of dangerous driving maneuvers, such as: speeding: exceeding the posted limit or driving too fast for conditions; excessive lane changing: changing lanes without reasonable cause; improper passing: failing to signal intent, using an emergency lane to pass, passing on the shoulder, and cutting into another car's path; tailgating: driving too close to the back of another's car; violating traffic signs: running stop signs/lights, failing to yield the right of way, and unpredictable movement directions. The A1 accident rate of speeding, excessive lane changing, improper passing, tailgating and violating traffic signs are respectively 20.53%, 1.61%, 8.20%, 17.83% and 15.22% during the previous 3 years (2009- 2011).

The definition of aggressive driving behavior has different statements in different research areas. The National Highway Traffic Safety Administration (NHTSA, 2007) defines objective as, “when individuals commit a combination of moving traffic offenses so as to endanger other persons or property.” The AAA Foundation for Traffic Safety (2007) explained that driving during this process endangers the safety of others. Leon and Diane (2000) defined: It is driving under the influence of impaired emotions, resulting in behavior that imposes one's own preferred level of risk on others. Thus, this research will conduct a subject regarding a person whose driving behavior having an intention to affect the safety and damage property of another driver, and it tries to use the technique of traffic conflict to define and classify the danger from aggressive driving. Therefore, the main purpose is to provide drivers a reliable data in order to improve the driving behavior and can develop methods to further prevent accidents.

First of all, the data of car accidents are analyzed in terms of the heading directions of involved cars, then the aggressive car is selected for showing its trajectory and possible conflict with another car, and the conflict patterns are summarized as well, which ends up with four types such as crossing conflict, same-direction merging conflict, same-direction tailgating conflict, and opposing passing conflict. Further employed are techniques such as PET, TA/CS, TTC and PICUD in order to build hazard models and generate severity levels.

Hopefully, this study can be used to warn the aggressive drivers. While with the produced quantitative data, what is danger and danger level can be described in order to build the safe index for driving behaviors under different heading directions. Finally, it is hoped that driving risks into accidents can be reduced, and the conclusion can be applied as a reference to the promotion of the education on national traffic safety in the future.

2. METHOD

2.1 Traffic Conflict Technique

In 1968, the traffic conflict theory was originated at the U.S. General Motors Corporation Laboratory, by Perkins and Harris, who published their finding on "Traffic Conflict Technique (TCT)." Hydén (1977) and Gettman and Head (2003), defined it as "An observable situation in which two or more road users approach each other in time and space for such an extent that there is risk of collision if their movements remain unchanged."

Traditionally, road accident statistics are used to assess the level of road safety and evaluate road safety programs (Chin and Quek, 1997). In some cases, the lack of good and reliable accident records have hampered proper analyses. A promising approach that overcomes this problem is the traffic conflict technique, which relies on observations of critical traffic situations for safety analysis, as summarized in table 1.

Table 1. Traffic conflict indicators

TCT indicators	Definition
TIME TO ACCIDENT (TA) AND CONFLICTING SPEED (CS)	Almqvist and Hydén (1994) measured the degree of seriousness of conflicts on the basis of two variables, Time to Accident (TA) and Conflicting Speed (CS). TA refers to the time between one of the road users starting an evasive action, until a collision would have occurred if the two involved road users had continued with unchanged speed and direction. CS is the speed of the relevant road user just prior to an evasive maneuver, which requires further safety analysis for serious conflicts, and helps provide reasonable explanations of the risk of injury accidents in serious conflicts.
TIME TO COLLISION (TTC)	Hayward (1972) defined TTC as: "The time required for two vehicles to collide if they continue at their present speed and on the same path". TTC at the onset of braking, TTCbr, represents the available manoeuvring space at the moment the evasive action starts. The minimum TTC as reached during the approach of two vehicles on a collision course (TTCmin) is taken as an indicator for the severity of an encounter. In principle, the lower the TTCmin, the higher the risk of a collision has been.
POTENTIAL INDEX FOR COLLISION WITH URGENT DECELERATION (PICUD)	Uno *et al.* (2002), and Bin, Uno and Iida (2003) explored the typical situations of lane changing with it. It is an indicator for assessing two vehicles, where one follows the other in the same lane. It is the time from emergent braking of the leader until the braking of the follower, thus, it is defined as the time difference of two cars coming to a complete stop, as based on the distance between the two cars.
POST-ENCROACHMENT TIME (PET)	The method, which Archer (2005) applied to measure the two road users in the course of a collision, represents the difference in time

	between the passages of the “offended” and “conflicted” road users over a common conflict zone (i.e. area of potential collision), especially applicable to road users of a crossing or intersection, meaning the time for one of them to encroach into the common conflict zone, and after the encroachment, and the two cars involved safety-critical starting and ending time. In theory it comprises: Gap Time (GT) and Encroachment Time (ET).

2.2 Establishment Types of Traffic Conflict of Aggressive Driving

Gregersen, Nyberg and Berg (2003) analyzed conflict types based on the classification of accidents listed in the accident database. The following 10 conflict classifications were used: 1) no conflict; 2) oncoming vehicle; 3) overtaking or lane change; 4) rear-end collision; 5) turning at intersection; 6) vehicles on intersecting course; 7) reversing or turning around; 8) parking; 9) vehicle-animal; 10) unknown.

A basic set of conflict definitions for intersections were developed by Parker and Zegeer (1989), which correspond to the different types of maneuvers and related accident patterns. The primary types of intersection conflicts are as: 1) same-direction conflict: left-turn, right-turn, slow-vehicle, lane-change; 2) opposing left-turn conflict; 3) cross-traffic conflict from the right or the left cross street approach; 4) right-turn-on-red-from-right conflict; 5) pedestrian conflicts: pedestrian far-side conflict, near-side conflict; 6) secondary conflicts. Making inferences by aggressive driving behaviors and traffic conflict patterns, then simplifying and summarizing the same types of traffic conflicts, according to their definitions, result in the identification of four types: 1) cross traffic conflict, 2) same-direction merging traffic conflict, 3) same-direction tailgating traffic conflict, and 4) opposing passing conflict, for aggressive traffic conflict model analysis.

2.3 Perception-Response Time

Stopping (sight) distance is the sum of two components distance of perception-response time and braking. However, based on Green’s (2000) analysis, perception-response time is presented as a series of values for expected, unexpected, and surprise situations that appear in order to generalize a variety of different driver tasks and traffic situations without sufficient concern for urgency or the critical nature of the situations.

Regarding human perception-response time, when fully aware of the expected time for the brake signal, drivers can detect a signal and move their foot from the accelerator to the brake pedal in about 0.70 to 0.75 seconds (Green, 2000; Roberts, 2004). Response to unexpected, such as the lead car brake lights, and surprise events, such as an object suddenly moving into the driver's path, were respectively about 1.25 seconds and 1.5 seconds by Green (2000), below 1.0 seconds and about 4.0 seconds by Summala (2000). Fambro et al. (2007) suggested about 1.0 seconds for an unexpected object scenario.

The formula of stopping distance by AASHTO has new version specifications for brake deceleration, which uses an alternative longitudinal friction coefficient to calculate.

$$d = V_0 \times t_{pr} + \frac{{V_0}^2}{2a} \quad (1)$$

where

d = vehicle stopping distance (m)

V_0 = vehicle velocity (m/s)

t_{pr} = driver perception-response time (s)

a = vehicle deceleration rate (m/s^2)

2.4 Braking Deceleration Rates

ISO 15623 refers to the evaluation of the braking deceleration rates of cars and trucks, where the emergent braking performances of the vehicles are conducted on dry, flat roads. Their braking deceleration rate ranges between 3.6 m/s^2 and 7.9 m/s^2. The average braking deceleration rate is 7 m/s^2 for buses, and 5.3 m/s^2 for commercial trucks. This testing measurement is widely applied, and differs according to vehicle type, loading conditions, and driver reaction characteristics. FHWA use the value vehicle deceleration rate of 17.71 ft/sec^2 for their Publications. The Ministry of Transportation and Communication, ROC, published the "automotive braking distance, traffic speed, and road friction coefficient table", which contains provisions suggesting a braking deceleration between 6.9 and 8.3 m/s^2 for dry asphalt pavement and 6.9 to 8.8 m/s^2 for dry concrete pavement.

2.5 Danger Severity Classification

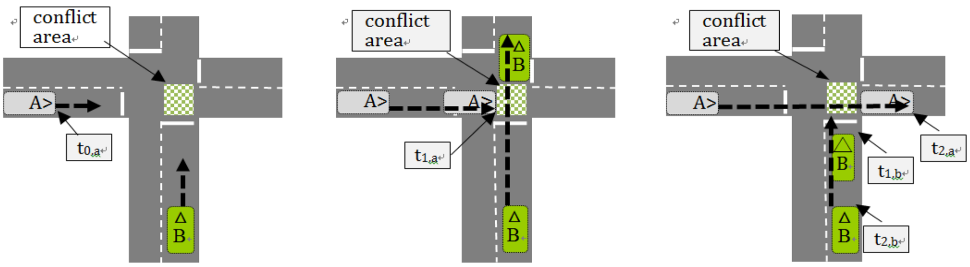
Traffic conflict caused by aggressive driving behaviors, for the drivers, involve primary factors and secondary factors. The primary factors include velocity, gap, and driver's perception-response time, in particular, the driver's perception-response ability determines the main danger level. The secondary factors are comprised of driver's perception-response ability, vehicle situations, road conditions, and evasive space, which can aggravate or alleviate the danger level. The focus of this study is the primary factors and aims to simplify the complex situations of actual road conflicts in order to quantitatively classify the danger.

The critical perception-response time of 0.7 seconds is a critical value, as the danger decreases one level for the increase of every 0.1 seconds. There are 6 levels from 0.7 seconds to 1.2 seconds. The deceleration rate of 7 m/s^2 is another critical value, as danger decreases one level for deceleration of every 0.5 m/s^2. There are 6 levels from 7 m/s^2 to 4.5 m/s^2. By the relative differences of velocity, 6 levels range from 5 kilometers to 30 kilometers, and the danger decreases one level for every increase of 5 kilometers.

3. RESULT

3.1 Model Analysis and Danger Classification of Cross Traffic Conflict

The model employs the concept of PET, uses the TA/CS method, and combines TTC simulated situations for analysis. Two vehicles are driving straight, from cross directions toward an intersection. When vehicle A, coming from the cross direction and speeding or violating traffic signs, forces through the common conflict area, after reaching, but before completely leaving the conflict area, vehicle B, which is driving straight, must brake to a stop. The safety indicator is the time difference between the car from cross direction leaving the common conflict area, and the car driving in the straight direction reaching the common conflict area. The danger level is determined on this basis, where the smaller the time difference, the more dangerous it is; and vice versa.



Initial cross situation Case 1 not cross situation Case 2 cross situation

Figure 1. Situation of Cross traffic conflict

1s and 1.5s are used as the simulated model situations for vehicle A from the cross direction, with three time points (Fig. 1). The first time point is $t_{0,a}$, the second time point is $t_{1,a}$ of vehicle A reaching the common conflict area, and the third time point is $t_{3,a}$ when vehicle A passes through and leaves the common conflict area. Analysis is conducted by different velocities, ranging from 20km to 60km at intervals of 10km. With different TTC and velocities, for vehicle B driving straight toward vehicle A, the minimum distance and velocity for deceleration at $t_{1,b}$ (equal to $t_{1,a}$) and $t_{2,b}$ (equal to $t_{2,a}$) is sufficient for vehicle B to brake to a stop. The time point $t_{2,b}$ is regarded as the reference point of the danger level, and in order to achieve a safe level, for every increase of 0.1s, the velocity of vehicle B should decrease according to this rule, as shown in Table 2, columns 10-15. The model uses TA/CS velocity and time as the measurements. At the fixed time point, a lower velocity and shorter braking stop distance and time means there might be time remaining before reaching the common conflict area. Before time point $t_{1,b}$, the vehicle can accelerate to pass, and after time point $t_{2,b}$, the vehicle should decelerate. The closer it approaches to this point, the larger the deceleration rate should be, with the related formula, as follows:

$$t_{1,a} = TTC \quad (2)$$

$$t_{2,a} = t_{1,a} + (w+l_a)/(v_a/3.6) \quad (3)$$

$$d_{t1,a} = v_a /3.6 \times TTC \quad (4)$$

$$v_{t1,b} = (t_{1,b} - t_{pr,b}) \times a_b \times 3.6 \quad (5)$$

$$d_{t1,b} = v_b /3.6 \times t_{pr,b} + (v_{t1,b} /3.6)^2 /2a_b \quad (6)$$

$$v_{t2,b} = (t_{2,b} - t_{pr,b}) \times a_b \times 3.6 \quad (7)$$

$$d_{t2,b} = v_b /3.6 \times t_{pr,b} + (v_{t2,b} /3.6)^2 /2a_b \quad (8)$$

$$v_{Li} = (t_{2,b} - t_{pr,b} - t_{intrvl}) \times a_b \times 3.6 \quad (9)$$

where

$t_{1,a}$ = TTC of vehicle A reaching the common conflict area (seconds)

$t_{2,a}$ = the time of vehicle A crossing and leaving the common conflict area (seconds)

l_a = the length of vehicle A (meters)

v_a = the velocity of vehicle A (kilometers/hour)

w = the width of common conflict area (meters)

$d_{t1,a}$ = the distance of vehicle A reaching the common conflict area at TTC (meters)

$v_{t1,b}$ = at time point $t_{1,a}$, when vehicle A reaches the common conflict area, the critical velocity of vehicle B percepts and brake stops at the same time $t_{1,b}$ before the common conflict area (kilometers/hour)

$t_{pr,b}$ = the perception-response time of vehicle b (seconds)

$d_{t1,b}$ = at time point $t_{1,a}$ when vehicle A reaches the common conflict area, the critical distance of vehicle B percepts and brake stops at the same time $t_{1,b}$ before the common conflict area (meters)

$v_{t2,b}$ = at time point $t_{2,a}$ when vehicle A has passed and is leaving the common conflict area, the critical velocity of vehicle B percepts and brake stops at the same time $t_{2,b}$ before the common conflict area (kilometer/hour)

$d_{t2,b}$ = at time point $t_{2,a}$ when vehicle A reaches the common conflict area, the critical distance of vehicle B percepts and brake stops at the same time $t_{2,b}$ before the common conflict area (meters)

a_b = the braking deceleration of vehicle b (m/s^2)

v_{Li} = the velocity at conflict danger level i (kilometers/hour), i={6,5,4,3,2,1}

t_{intrvl} = time interval of conflict danger level (seconds)), t_{intrvl} ={0,0.1,0.2,0.3,0.4,0.5}

The model uses the assumed conditions of the minimum value of 0.7s for vehicle B perception response time, and the maximum value of $7m/s^2$ of the deceleration rate. In Table 2, the TTC column is the dangerous situation of TTC 1-1.5 second. Where $v_{t1,b}$ and $d_{t1,b}$ are the critical velocity and distance of vehicle B braking stop from the conflict area at time point $t_{1,b}$, and $v_{t2,b}$ and $d_{t2,b}$ are the critical velocity and distance of vehicle B braking stop from the conflict area at time point $t_{2,b}$, and v_{Li} is the velocity of dangerous level Li. Where v_{Li} decreases with the increased vehicle A velocity, and is a dangerous level.

Table 2. Minimum velocity and danger level of Cross traffic conflict

vehicle A situation					vehicle B situation									
TTC	v_a	$t_{1,a}$	$t_{2,a}$	$d_{t1,a}$	$v_{t1,b}$	$d_{t1,b}$	$v_{t2,b}$	$d_{t2,b}$	v_{L6}	v_{L5}	v_{L4}	v_{L3}	v_{L2}	v_{L1}
1	20	1	2.26	5.56	7.56	1.79	39.31	16.16	39.31	36.79	34.27	31.75	29.23	26.71
	30	1	1.84	8.33			28.73	10.13	28.73	26.21	23.69	21.17	18.65	16.13
	40	1	1.63	11.11			23.44	7.58	23.44	20.92	18.40	15.88	13.36	10.84
	50	1	1.50	13.89			20.26	6.20	20.26	17.74	15.22	12.70	10.18	7.66
	60	1	1.42	16.67			18.14	5.34	18.14	15.62	13.10	10.58	8.06	5.54
1.5	20	1.5	2.34	8.33	20.16	6.16	41.33	17.45	41.33	38.81	36.29	33.77	31.25	28.73
	30	1.5	2.06	12.50			34.27	13.14	34.27	31.75	29.23	26.71	24.19	21.67
	40	1.5	1.92	16.67			30.74	11.19	30.74	28.22	25.70	23.18	20.66	18.14
	50	1.5	1.84	20.83			28.63	10.08	28.63	26.11	23.59	21.07	18.55	16.03
	60	1.5	1.78	25.00			27.22	9.37	27.22	24.70	22.18	19.66	17.14	14.62

Parameters: w=2m; l_a=5m; $t_{pr,b}$=0.7s; a_b =7m/s^2

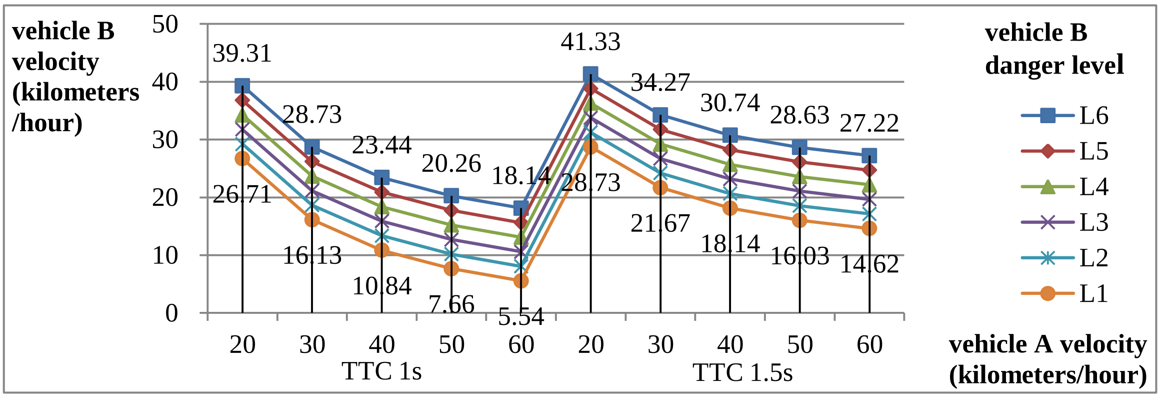


Figure 2. Minimum velocity and danger level of cross traffic conflict

Fig. 2 shows there are two simulated situations at TTC 1s and TTC 1.5s. With different velocities of vehicle A, the more dangerous vehicle B becomes, as the danger level curve (L6) is at a relatively high point; for simulated situations, the higher the number, the more dangerous the level curve (L6). For example, at TTC 1s, when the velocity of vehicle A is 20 km/hour and the danger level of vehicle B is level 6, at time point $t_{2,b}$, the velocity decreases to 39.31 km/hour, which reduces to 26.71 km/hour at danger level 1. At TTC 1.5s, when the velocity of vehicle A is 40 km/hour and the danger level of vehicle B is level 6, at time point $t_{2,b}$, velocity decreases to 30.74 km/hour, and reduces to 18.14 km/hour at danger level 1. The curves extend from the upper left side to lower right side, which means that with an increase in the velocity of vehicle A, when vehicle B reaches time point $t_{2,b}$, the velocity decreases. The difference of the simulated situation at TTC is due to the difference in time $t_{2,b}$, as its function lies only in the early awareness of conflicts and preparation for urgently stops.

3.2 Model Analysis and Danger Classification of Same-direction Merging Conflict

The same-direction merging traffic conflict is the situation of a car in an adjacent lane changing lanes, suddenly cutting into the target lane, thus, the follower must quickly decelerate or stop. The Potential Index for PICUD is used as an indicator, and deceleration rate is regarded as the criterion for calculation and measurement. Fig. 3 presents a situation where the aggressive vehicle fails to turn on its turn signal, changes lanes at a lower speed, and cutting into another car's path, resulting in the unprepared state of the following vehicle or even a collision accident. The key points of model analysis to prevent the follower from colliding with the leader are, as follows, how far between cars is a safe distance, and at what time point should the leader change lanes.

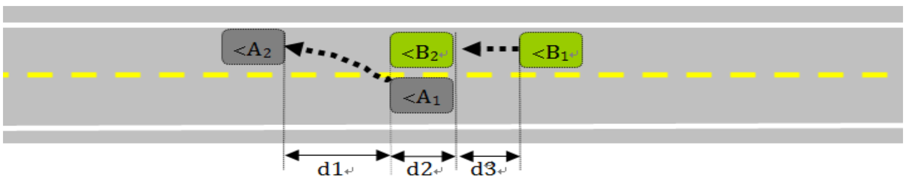


Figure 3. Situation of same-direction merging traffic conflict

In Fig. 3, vehicle A should change its lane at the minimum safe distance (d) from vehicle B, which is the total of d_2 and d_3. Where d_2 is vehicle A length, or the buffering distance of vehicle B when vehicle A cuts into the lane of vehicle B, and d_3 is the minimum approach distance of vehicle B, which is the stopping distance difference of the follower minus the braking distance of the leader. If the leader drives at a higher speed than the follower, the distance of the perception-response time must be maintained, as calculated by the following formula:

$$d_3 = \max[d_{stp,b} - d_{brk,a},\ d_{pr,b}] \quad (10)$$

$$d_{stp,b} = d_{pr,b} + d_{brk,b} \quad (11)$$

$$d_{pr,b} = v_b/3.6 \times t_{pr,b} \quad (12)$$

$$d_{brk,i} = (v_i/3.6)^2/2a_i \quad (13)$$

where

d = the gap distance between vehicle A (leader) and vehicle B (follower) (meters)

l_a = the length of vehicle A (meters)
v_i = the velocity of vehicle i (kilometer/hour), i = {a, b}
$d_{stp,b}$ = the stopping distance of vehicle b (meters)
$d_{pr,b}$ = the distance of perception-response time for vehicle b (meters)
$d_{brk,i}$ = the braking distance for vehicle i (meters), i = {a, b}
$t_{pr,b}$ = the perception-response time of the driver in vehicle b (seconds)
a_i = the braking deceleration rate of vehicle i (m/s^2), i = {a, b}

With respect to model construction, assume that the two vehicles are passenger car, vehicle A length is 5m, and vehicle B perception-response time and deceleration rate are 1.0s, and $7m/s^2$, respectively. In Table 3, the threshold value of the minimum safe distance is established for vehicle A and vehicle B at different velocities ranging from 40-110km (formula 10-13). The sum of vehicle B distance at perception-response time and vehicle A length is the minimum distance. For example, when the velocity of vehicle A is 60km, the minimum approach distance of vehicle B, ranging between 40-110km, are 16.11, 18.89, 21.67, 31.61, 42.65, 54.80, 68.05, and 82.40m, respectively. Among them, 16.11, 18.89, and 21.67m are the distance of perception response time for vehicle B at 40, 50, and 60km, respectively, plus vehicle A length. Table 4, time model, is converted from Table 3, distance model. In Table 4 when vehicle B is at 90km, it's TTC time, such as 2.63, 2.43, 2.19, 1.91, 1.57, and 1.20s, is gradually decreasing at 40-90km of vehicle A, and if over 90km of vehicle A, it is a constant value of TTC, thus, only 1.2s is required.

Table 3. Merging traffic conflict with different velocities (distance model)

vehicle A velocity(v_a) kilometers/hour	vehicle B minimum approach distance (d, meters)								
	(v_b)	40	50	60	70	80	90	100	110
40		16.11*	23.85	32.69	42.63	53.68	65.82	79.07	93.43
50		**	18.89*	27.73	37.67	48.72	60.86	74.11	88.47
60		**	**	21.67*	31.61	42.65	54.80	68.05	82.40
70		**	**	**	24.44*	35.49	47.64	60.89	75.24
80		**	**	**	**	27.22*	39.37	52.62	66.97
90		**	**	**	**	**	30.00*	43.25	57.60
100		**	**	**	**	**	**	32.78*	47.13
110		**	**	**	**	**	**	**	35.56*

Parameters: la=5m; $t_{pr,b}$=1.00s; a_a=7.00 $m/s^{2;}$ a_b=7.00 m/s^2
*: leader car's velocity not lower than follower's; **: ditto

Danger levels are established on the basis of PICUD, with the deceleration rate as the rule. From $7m/s^2$ to $4.5m/s^2$, the danger decreases one level every 0.5 m/s^2, and there are 6 levels. When vehicle B is at a velocity of 80km, the danger levels to vehicle A at different velocities are as presented in Table 5. The total of all distance also uses TTC time to express a clearly dangerous situation, as embodied in Table 5. The danger level 6 (L6) is the most serious danger. As the danger level drops, the minimum safety distance and the TTC time become larger. At one of levels when vehicle A is at different velocities from 40km to 70km, the minimum safety distance and the TTC time of vehicle B decreases, and velocities over 80km of vehicle A, the minimum safety distance of vehicle B will be constantly at 27.22m, which is vehicle B distance at the perception-response time and vehicle A length.

Table 4. Merging traffic conflict with different velocities (time model)

vehicle A velocity(v_a)	vehicle B TTC time (second)								
kilometers/hour	(v_b)	40	50	60	70	80	90	100	110
40		1.45*	1.72	1.96	2.19	2.42	2.63	2.85	3.06
50		**	1.36*	1.66	1.94	2.19	2.43	2.67	2.90
60		**	**	1.30*	1.63	1.92	2.19	2.45	2.70
70		**	**	**	1.26*	1.60	1.91	2.19	2.46
80		**	**	**	**	1.23*	1.57	1.89	2.19
90		**	**	**	**	**	1.20*	1.56	1.89
100		**	**	**	**	**	**	1.18*	1.54
110		**	**	**	**	**	**	**	1.16*

Parameters: la=5m; $t_{pr,b}$=1.00s; a_a=7.00 m/s^2; a_b=7.00 m/s^2

*: leader car's velocity not lower than follower's; **: ditto

Table 5. 80km danger level of merging traffic conflict

vehicle A	vehicle B approach distance (d, meters)							vehicle B TTC time (seconds)					
velocity	Lvl	L6	L5	L4	L3	L2	L1	L6	L5	L4	L3	L2	L1
(v_b) k/h	Dcl	7.00	6.50	6.00	5.50	5.00	4.50	7.00	6.50	6.00	5.50	5.00	4.50
40		53.68	55.71	58.09	60.89	64.26	68.37	2.13	2.27	2.43	2.62	2.85	3.13
50		48.72	50.37	52.30	54.58	57.31	60.66	1.93	2.07	2.23	2.42	2.65	2.93
60		42.65	43.84	45.23	46.86	48.83	51.23	1.69	1.83	1.99	2.18	2.41	2.68
70		35.49	36.13	36.87	37.74	38.80	40.08	1.41	1.54	1.70	1.89	2.12	2.40
80-110		27.22*	27.22*	27.22*	27.22*	27.22*	27.22*	1.07*	1.21*	1.37*	1.56*	1.79*	2.07*

Parameters: la=5m; $t_{pr,b}$=1.00s; a_a=7.00 m/s^2; a_b=7.00 m/s^2

Lvl: danger level; Dcl : deceleration rate; *: leader car's velocity not lower than follower's

3.3 Model Analysis and Danger Classification of Same-Direction Tailing Conflict

The same-direction tailgating traffic conflict utilizes PICUD as the indicator, and the deceleration rate as the criterion for calculation and measurement. In reality, it most often occurs when an aggressive car closely follows another car, or fails to maintain a safe distance. In Fig. 4, the leader (vehicle B) stops abruptly, resulting in an unprepared state of the following car (vehicle A), speeding and tailing, or even a collision accident. In order to prevent the follower from colliding with the leader, how far is the minimum safe distance is the key point.

Calculated by the threshold value, the distance of vehicle A perception's of the sudden stop of vehicle B, and its braking stop, equals the vehicle B braking stop distance. If the leader drives faster than the follower, vehicle A should at least maintain the distance of perception-response time, as obtained by the following calculation formula:

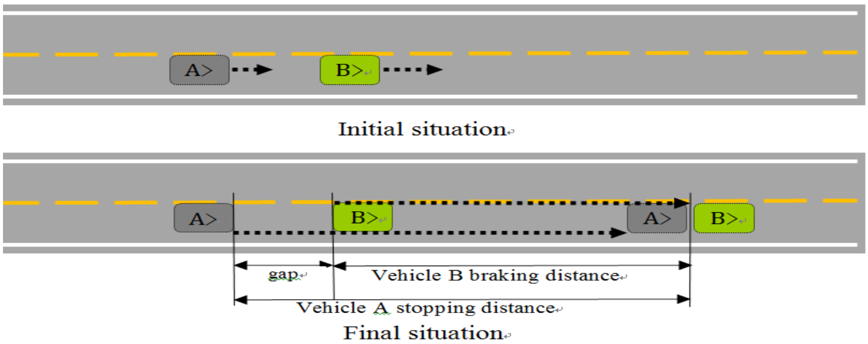


Figure 4. Same-direction tailing traffic conflict

$$d = \max[\,d_{stp,a} - d_{brk,b}, d_{pr,a}] \quad (14)$$

$$d_{stp,a} = d_{pr,a} + d_{brk,a} \quad (15)$$

$$d_{brk,i} = (v_i/3.6)^2 \,/\, 2a_i \quad (16)$$

$$d_{pr,a} = v_a/3.6 \times t_{pr,a} \quad (17)$$

where

d = the minimum approach distance between leader and follower (meters)

$d_{stp,a}$ = the stopping distance of vehicle a (meters)

$d_{brk,i}$ = the braking distance for vehicle i (meters), i = {a, b}

$d_{pr,a}$ = the distance of perception-response time for vehicle a (meters)

$t_{pr,a}$ = the perception-response time of the driver in vehicle b (seconds)

v_i = the velocity of vehicle i (kilometers/hour), i = {a, b}

a_i = the braking deceleration rate of vehicle i (m/s^2), i = {a, b}

When constructing the tailing model, assume that the velocities, perception-response time, and deceleration rates of vehicles A and B are, respectively, 40-100km, 0.7s, and $7m/s^2$. In Table 6, the threshold value of the minimum approach distance is established for vehicles A and B at different velocities. When vehicle A is slower than vehicle B , it only needs to maintain the distance of the perception-response time, as those marked with "*" in the table. For example, when the velocity of vehicle B is 60km, the minimum approach distance of vehicle A ranging between 40-110km are 7.78, 9.72, 11.67, 20.78, 30.99, 42.3, 54.72, and 68.24m, respectively. Among them, 7.78, 9.72, and 11.67m are, respectively, the distance of the vehicle A perception response time at 40, 50, and 60km, plus vehicle A length.

Table 6. Tailgating traffic conflict with different velocities (distance model)

vehicle B velocity (v_b)	vehicle A minimum approach distance (d, meters)								
kilometers/hour	(v_a)	40	50	60	70	80	90	100	110
40		7.78*	14.68	22.69	31.8	42.01	53.32	65.74	79.26
50		**	9.72*	17.73	26.84	37.05	48.36	60.78	74.3
60		**	**	11.67*	20.78	30.99	42.3	54.72	68.24
70		**	**	**	13.61*	23.82	35.14	47.55	61.07
80		**	**	**	**	15.56*	26.87	39.29	52.8
90		**	**	**	**	**	17.50*	29.92	43.43
100		**	**	**	**	**	**	19.44*	32.96
110		**	**	**	**	**	**	**	21.39*

Parameters: $t_{PR,a}$=0.70s; a_a =7.00m/s^2; a_b =7.00m/s^2

*: leader car's velocity not lower than follower's; **: ditto

Table 7. Tailgating traffic conflict with different velocities (time model)

vehicle B velocity (v_b)	vehicle A TTC time (second)								
kilometers/hour	(v_a)	40	50	60	70	80	90	100	110
40		0.70*	1.06	1.36	1.64	1.89	2.13	2.37	2.59
50		**	0.70*	1.06	1.38	1.67	1.93	2.19	2.43
60		**	**	0.70*	1.07	1.39	1.69	1.97	2.23
70		**	**	**	0.70*	1.07	1.41	1.71	2.00
80		**	**	**	**	0.70*	1.07	1.41	1.73
90		**	**	**	**	**	0.70*	1.08	1.42
100		**	**	**	**	**	**	0.70*	1.08
110		**	**	**	**	**	**	**	0.70*

Parameters: $t_{PR,a}$=0.70s; a_a =7.00m/s^2; a_b =7.00m/s^2

*: leader car's velocity not lower than follower's; **: ditto

Table 7, time model, is converted from Table 6, distance model. In Table 7 when vehicle A is at 90km, it's TTC time, such as 2.13, 1.93, 1.69, 1.41, 1.07, and 0.7s, is gradually decreasing at 40-90km of vehicle B, and if over 90km of vehicle B, it is a constant value of TTC, thus, only 0.7s is required.

Danger levels are established on the basis of PICUD, with the deceleration rate as the rule. From 7m/s^2 to 4.5m/s^2, the danger decreases one level for every 0.5 m/s^2, and there are 6 levels. A simulation of vehicle A on a highway; when vehicle A is at the velocity of 90km, the danger levels to vehicle B at different velocities are as presented in Table 8. The total of all distance also uses TTC time to express a clearly dangerous situation, as embodied in Table 8. The danger level 6 (L6) is the most serious danger. As the danger level drops, the minimum safety distance and the TTC time gradually increases. At one of levels when vehicle B is at different velocities from 40km to 110km, the minimum safety distance and the TTC time of vehicle A gradually also decreases, and "*" and "**" is presented vehicle A distance at the perception-response time.

Table 8. 90km danger level of tailgating traffic conflict

vehicle B	vehicle A approach distance (d, meters)							vehicle A TTC time (seconds)					
velocity	Lvl	L6	L5	L4	L3	L2	L1	L6	L5	L4	L3	L2	L1
(v_b) k/h	Dcl	7.00	6.50	6.00	5.50	5.00	4.50	7.00	6.50	6.00	5.50	5.00	4.50
40		53.32	56.76	60.76	65.50	71.18	78.13	2.13	2.27	2.43	2.62	2.85	3.13
50		48.36	51.80	55.80	60.54	66.22	73.17	1.93	2.07	2.23	2.42	2.65	2.93
60		42.30	45.74	49.74	54.48	60.16	67.10	1.69	1.83	1.99	2.18	2.41	2.68
70		35.14	38.57	42.58	47.31	52.99	59.94	1.41	1.54	1.70	1.89	2.12	2.40
80		26.87	30.30	34.31	39.04	44.73	51.67	1.07	1.21	1.37	1.56	1.79	2.07
90		17.50*	20.93	24.94	29.68	35.36	42.30	0.70*	0.84	1.00	1.19	1.41	1.69
100		**	17.50*	17.50*	19.20	24.89	31.83	**	0.70*	0.70*	0.77	1.00	1.27
110		**	**	**	17.50*	17.50*	20.26	**	**	**	0.70*	0.70*	0.81

Parameters: $t_{PR,a}$=0.70s; a_a =7.00m/s^2; a_b =7.00m/s^2

Lvl: danger level; Dcl : deceleration rate; *: leader car's velocity not lower than follower's; **: ditto

3.4 Model Analysis and Danger Classification of Opposing Passing Traffic Conflict

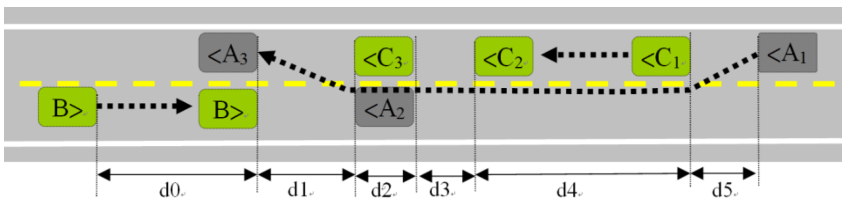


Figure 5. Opposing passing traffic conflict

The model employs TA/CS and TTC as the indicators, and the relative velocity difference and remaining time as the criteria for calculation and measurement. In reality, it most often the overtaking car cuts into another car's lane and passes. In Fig. 5, the aggressive vehicle A overtakes and passes vehicle C and collides with vehicle B. In the model, vehicles A and C have an overtaking conflict relationship, which influences the opposing conflict of vehicles A and B. Considering the safety of vehicle C, if vehicle A runs more slowly (large distance) back to the original lane after overtaking, it is safer. For vehicle B, the shorter the time and distance for vehicle A to occupy the overtaking lane, the safer it is, and after passing vehicle A should drive back to the original lane as quickly as possible (small distance). In theory, whether the severity of conflict between vehicles A and B can be effectively alleviated depends on whether vehicle C decelerates and gives way. The shorter the time that vehicle A occupies the opposing lane, the safer vehicle B is.

The model aims at vehicles B and C driving 40-100km at different design velocities, and conducts analysis at intervals of 5km when the velocity of vehicle A, when overtaking vehicle C, is greater than 5km to 30km. This research finds that vehicle A occupies the opposing lane for a long duration when the relative velocity difference of vehicles A and C is small. In Table 9, with vehicle C at the velocity of 60km, vehicle A overtakes it at the velocity of 70km, which requires a distance of 260.27m for overtaking. If vehicle A overtakes at 80km, 160.67m is required. If it overtakes at 90km, only 143.42m suffices for overtaking. However, if vehicle A drives too fast, other risks may be brought about, such as loss of control, and even a serious accident. The danger level of this model is based on the relative velocity difference between vehicles A and C, from 5km to 30km, it increases by one level every 5km, and there are 6 levels in total, with relevant calculation formula, as follows:

$$\mathrm{d_{all}} = \mathrm{d_1} + \mathrm{d_2} + \mathrm{d_3} + \mathrm{d_4} + \mathrm{d_5} \tag{18}$$

$$\mathrm{d_0} = \mathrm{d_{pr,b}} + d_{brk,b} \tag{19}$$

$$\mathrm{d_1} = \mathrm{w}_r / \sin(\theta \times \pi/180) \tag{20}$$

$$\mathrm{d_2} = \mathrm{l_a} \tag{21}$$

$$\mathrm{d_3} = \mathrm{d_{pr,c}} \tag{22}$$

$$\mathrm{d_4} = \mathrm{v_c}/3.6 \times \mathrm{t_c} + \mathrm{l}_c \tag{23}$$

$$\mathrm{d_5} = \sqrt{d_{\mathrm{gap},a}{}^2 + \mathrm{w_r}^2} \tag{24}$$

$$\mathrm{d_{gap,a}} = \max(\mathrm{d_{pr,a}} + d_{brk,a} - d_{brk,c}, \mathrm{d_{pr,a}}) \tag{25}$$

$$\mathrm{d_{pr,i}} = \mathrm{v_i}/3.6 \times \mathrm{t_{pr,i}} \tag{26}$$

$$\mathrm{d_{brk,i}} = (\mathrm{v_i}/3.6)^2 / 2a_\mathrm{i} \tag{27}$$

$$\mathrm{t_c} = (\mathrm{d_2} + \mathrm{d_3} + \mathrm{d_5} + \mathrm{l}_c) / ((\mathrm{v_a} - \mathrm{v}_c)/3.6) \tag{28}$$

$$\mathrm{t_0} = \mathrm{t_{pr,b}} + (\mathrm{v_b}/3.6)/a_\mathrm{b} \tag{29}$$

$$\mathrm{t_{all}} = (\mathrm{d_1} + \mathrm{d_2} + \mathrm{d_3} + \mathrm{d_4} + \mathrm{d_5}) / (\mathrm{v_a}/3.6) \tag{30}$$

where

d_{all} = the distance of vehicle A passing vehicle C (meters)

d_0 =the distance of vehicle B braking stop (meters)

d_1 = the distance of vehicle A cutting into original lane (meters)
d_2 = the length of vehicle A (meters)
d_3 = the distance of perception-response time for vehicle C (meters)
d_4 = the distance of vehicle A passing vehicle C (meters)
d_5 = the distance of vehicle A cutting into opposing lane (meters)
$d_{gap,a}$ = the gap distance between leader vehicle C and follower vehicle A (meters)
θ = the lane-changing angle, the study set this value as 20° (Lv *et al.*, 2013)
v_i = the velocity of vehicle i (kilometers/hour), i= {a, b, c}
$t_{pr,i}$ = the perception-response time of the driver in vehicle i (seconds), i= {a, b, c}
a_i = the braking deceleration of vehicle i (m/s^2), i= {a, b, c}
w_r = the width of road (meters)
l_i = the length of vehicle i (meters) , i= {a, c}
t_c = the travel time of vehicle C (seconds)
t_0 = the braking stop time of vehicle B (seconds)
t_{all} = the time for vehicle A to pass vehicle C (seconds)

Table 9. Passing minimum approach distance/time and danger level

Passed-car velocity(v_c) (kilometers/hour)	Passing-car traveling distance(d_{all}, meters)						Passing-car traveling time(t_{all}, seconds)					
	L6	L5	L4	L3	L2	L1	L6	L5	L4	L3	L2	L1
	v_{+5}	v_{+10}	v_{+15}	v_{+20}	v_{+25}	v_{+30}	v_{+5}	v_{+10}	v_{+15}	v_{+20}	v_{+25}	v_{+30}
40	255.05	150.78	116.67	106.48	104.86	105.95	20.40	10.86	7.64	6.39	5.81	5.45
50	350.95	201.65	152.52	128.45	124.49	125.58	22.97	12.10	8.45	6.61	5.98	5.65
60	462.39	260.27	193.55	160.67	141.80	143.42	25.61	13.39	9.29	7.23	6.01	5.74
70	589.36	326.67	239.76	196.79	171.40	158.41	28.29	14.70	10.15	7.87	6.49	5.70
80	731.88	400.85	291.15	236.79	204.56	183.40	31.00	16.03	11.03	8.52	7.01	6.00
90	889.95	482.80	347.73	280.68	240.84	214.61	33.72	17.38	11.92	9.19	7.54	6.44
100	1063.57	572.53	409.49	328.46	280.23	248.40	36.47	18.74	12.82	9.85	8.07	6.88

Parameters: $t_{PR,a}$=0.70s; $t_{PR,c}$=0.70s; a_a=7.00 m/s^2; a_c =3.50 m/s^2; la=5m; lc=5m; w_r=3.5m
lane changing (cutting in) angel=20° ;d_1=10.23m

The model adopts the assumed conditions of the minimum value of 0.7s for the perception-response time, the maximum value of $7m/s^2$ for the deceleration rate, and car length of 5m for vehicle A, together with the deceleration rate of 3.5 m/s^2 for vehicle C. Table 9 mainly presents the driving distance required for the aggressive car (vehicle A) to overtake and occupy the opposing lane. Fig. 5 shows that the model has 5 stages: d_5 is the approach distance of vehicle A from vehicle C, d_4 is the distance of vehicle A passing vehicle C, d_3 is the distance of the vehicle C perception-response time, d_2 is vehicle A length, which provides a buffering distance for vehicle C when vehicle A cuts into the original lane, and finally, d_1 is the distance of vehicle A cutting into the original lane. The total of all distance uses time to express a clearly dangerous situation, as embodied in Table 9. The larger the relative velocity difference, the less time vehicle A occupies the opposing lane. The most dangerous level is level 6. When relative velocity increases, the danger level decreases. The higher the velocity of the overtaken car, the longer the overtaking distance required; as the relative velocity increases, the danger level falls; however, attention should be focused on whether the increased velocity may incur other dangers.

When vehicle B encounters vehicle A during overtaking, the danger level assumes the minimum braking stop distance and time as the most dangerous indicator of L6 which is the critical perception-response time of 0.7s. For an increase of 0.1s gap time, the danger level also decreases from 0.7s to 1.2s, as presented in Table 10, with formula 19 and 29.

Table 10. Danger level of meeting passing-vehicle

	Opposing vehicle B velocity 60km					
Danger level	L6	L5	L4	L3	L2	L1
Increasing perception-response time(s)	0	0.10	0.20	0.30	0.40	0.50
Braking Stop distance (d_0)(meters)	36.51	38.17	39.84	41.51	43.17	44.84
Braking Stop time (t_0)(seconds)	3.38	3.48	3.58	3.68	3.78	3.88
Parameters: $t_{pr,b}$ =1.00s; a_b=7.00 m/s^2						

4. CONCLUSIONS

This research deduced, simplified, and summarized the patterns of aggressive driving behaviors and traffic conflict types, and obtained four types: 1) cross traffic conflict; 2) same-direction merging traffic conflict; 3) same-direction tailgating traffic conflict; and 4) opposing passing conflict, for analysis of the aggressive traffic conflict model. The model supposes that a driver with aggressive driving behaviors, and the offended driver, remain aware and alert and can respond in real-time to the dangers of traffic.

For the establishment of the danger level, the driver's velocity, gap, and perception-response ability in the face of conflict are the primary factors, and based on these factors, the danger level is decided; the secondary factors include the driver's status other than the perception-response ability, the braking performance, road conditions, evasive space, etc., are considered as influential factors for increased/decreased danger levels.

Cross traffic conflict conducts model analysis by PET, TA/CS, and TTC. The offended vehicle should decelerate to the braking stop velocity at the same time points of the aggressive vehicle passing through the common conflict area, which is the rule for dividing the danger level. The danger level decreases with the increase of every 0.1s.

The same-direction merging traffic conflict and same-direction tailgating traffic conflict conduct model analysis by PICUD, and divides the danger level according to the deceleration rate of the follower's vehicles. The deceleration rate of $7m/s^2$ is another critical value, as danger decreases one level for deceleration of every 0.5 m/s^2. There are 6 levels from $7m/s^2$ to $4.5m/s^2$. In theory the minimum safety distance or time is the distance or time the leader brakes and the follower percepts and decelerates. If the velocity of the leader is larger than the follower, the follower only requires the distance of the perception-response time; however, same-direction merging traffic conflict also consider car length.

TA/CS and TTC are utilized for opposing passing conflict model analysis. The model reveals that, the shorter the time and distance for overtaking a car occupying an opposing lane, the safer it is, which also determines the danger level. By the relative differences of velocity, 6 levels range from 5km to 30km, and the danger decreases one level for every increase of 5km. Although higher relative velocity may shorten the overtaking time, such high speed driving may cause other more serious problems. Besides, the danger level of opposing passing conflict is based on TTC. The critical perception-response time is 0.7s. The danger level from 0.7s to 1.2s decreases one level for every increase of 0.1s. Hence, in this model, the relative velocity of both the overtaking and overtaken cars should ideally adopt an intermediate value.

Finally, for effectively reducing the occurrences of accidents and traffic conflicts must become the focus. The danger level of aggressive traffic conflict types may be offered as reference for Taiwan's traffic safety education and propagation, and correct the mistakes of drivers.

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