Minimum Safe Time Gap (MSTG) as a new Safety Indicator incorporating Vehicle and Driver Factors

Mohamed Rehan KARIM[a], Ahmad SAIFIZUL[b], Hideo YAMANAKA[c], Airul SHARIZLI[d], Rahizar RAMLI[e]

[a, b, d, e] *Center for Transportation Research, Faculty of Engineering, University of Malaya, 50603 Kuala Lumpur, Malaysia*
[a] *Email: rehan@um.edu.my*
[b] *Email: saifizul@um.edu.my*
[d] *Email: airul7716@yahoo.com*
[e] *Email: rahizar @um.edu.my*
[c] *Department of Civil and Environmental Engineering, The University of Tokushima, Tokushima, 770-8506 Japan*
[c] *Email: yamanaka@ce.tokushima-u.ac.jp*

Abstract: Safety of traffic operations on roads is of utmost importance especially in developing countries like Malaysia where the rate of motorization is still increasing. Apart from the common approach of conducting safety analysis based on historical data, simulation-based traffic safety analysis is becoming more common. This paper aims to propose a new safety indicator called the minimum safe time gap (MSTG) which incorporates vehicle dynamics and gross vehicle weight (GVW). This simulation-based safety indicator is able to analyse the capability of a vehicle in a car-following situation to safely stop without hitting the vehicle in front when an emergency brake is applied by considering the braking time of the two consecutive vehicles and the perception-reaction time of the driver of the following vehicle. Results from this simulation study indicate that the MSTG is influenced by the vehicle type and GVW, hence providing a more comprehensive safety indicator for safety analysis.

Keywords: Road Safety, Braking Time, Safety Indicator, Close Following, Traffic Accidents, Perception-Reaction Time

1. INTRODUCTION

In a developing country like Malaysia, high traffic growth and an increasing level of motorization is something to be expected. The challenges that come with this phenomenon may take various forms including traffic congestion, road accidents and environmental degradation. Probably one of the most pertinent issues to be addressed currently is with regards to traffic accidents and fatalities. Malaysia is known to have a significantly high accident fatality rate in comparison to the developed countries. Accident fatality data has indicated that more than 25% of accident fatalities involve heavy vehicles. Although the number of registered heavy vehicles is hardly 5% of all vehicle registration, the composition of heavy vehicles in the traffic stream may reach 20% of all traffic on the road (depending on locations). Since the heavy vehicles vary in types and sizes, the gross vehicle weight (GVW) would vary considerably especially when loaded. The situation would be more serious when truck overloading exists on the roads.

For the purpose of developing accident countermeasures, traditional analyses are usually conducted based on accident data records and employing various statistical approaches. However, there are concerns that the conventional techniques may not be able to adequately consider driver behavior and a number of related variables which may influence the level of safety on the road (Ozbay et al., 2008). As such, simulation-based safety assessment studies have been conducted by many researchers over the years. Many of the microscopic simulation models associated with traffic safety involve car-following, gap acceptance and lane changing sub-models (Bevrani and Chung, 2011).

Car-following model has important applications in traffic and safety engineering. Bevrani and Chung (2011) have examined the capability of several microscopic simulation models from a safety perspective. They concluded that the main parameters in car-following models such as desired speed, headway, acceleration and deceleration time and also reaction time have direct effects on safety measures.

Ranjitkar et al. (2005) evaluated the performance of several car-following models based on how well they represent real driving behavior. They evaluated several car-following models based on test track experiment data using a GA based optimization method and found that a simple linear model could perform better than some sophisticated models. Chang and Chon (2005) introduced ‘perceptual threshold’ and reaction time distribution to improve sensitivity of non-linear car-following model. They found that the acceleration and deceleration rates are closer to real traffic condition and the model developed could perform closer to actual driver’s behaviour.

A comparison between ‘headway’ and ‘time to collision (TTC)’ with respect to their usefulness in determining the safety of different traffic situations was studied by Vogel (2003). He recommended using headway for enforcement purposes because small headways generate potentially dangerous situations while TTC should be used when a certain traffic environment is to be evaluated in terms of safety because it indicates the actual occurrences of dangerous situations. Many other studies have also provided empirical evidence to support the connection between short headway and rear-end collisions (Evans and Wasielewski, 1982; Postans and Wilson, 1983; Fairclough et. al., 1997).

One observation made regarding the parameters considered in most of the simulation models and safety indicators that have been proposed is that certain parameters which may have a direct impact on vehicle braking performance, hence the ability to safely stop in car-following situation, have not been explicitly considered. These parameters include the vehicle dynamic capability, namely the braking performance itself (which will vary according to type of vehicle) and the gross vehicle weight (GVW).

Although a few researches were working on stopping time, there was no detail investigation related to heavy vehicle (HV) gross vehicle weight (GVW) and number of axle. The characteristic of the vehicle dynamic such as GVW and deceleration capability is assumed to be same for all types of vehicle. The main reason is in the past it is difficult to obtain the weight, speed, acceleration and classification data simultaneously and continuously over the period of time without disrupting the natural way of traffic flow.

Vehicle weight is one of the essential parameters in vehicle design study that can affect vehicle driving, braking and handling performance characteristics (Bixel et. al., 1998) and most of the time vehicle dynamics influence driver behavior in controlling their vehicles (Wong, 1993). The study by Saifizul et. al. (2011a, 2011b) has shown that heavy vehicle GVW has direct influence on speed, whether the vehicle travel in a vehicle following situation or in free flow condition. Thus, it is important to extend the study on the influence of both heavy vehicle GVW and its class or size on stopping distance and stopping time in a vehicle following situation to further understand the subject not only from the driver visual input perspective but also from vehicle dynamics capability perspective.

At any given time, human, vehicular, and environmental influences and events conspire to affect crash risk. Crash causation studies consistently show, however, that vehicle and environmental factors are less significant than human factors. This is true for traffic crashes in general (Treat et al., 1979) and for large-truck crashes (Craft and Blower, 2004). Human factors involved in large-truck crashes can be subdivided in various ways. The most common critical errors made by drivers, whether they are truck drivers or other involved drivers, appear to be save time gap misjudgements, which is driver follow to closely and over confidence in their ability to stop the truck before crash. The consciousness of the minimum safe time gap is very crucial for heavy vehicle drivers to prevent collision with the vehicle in front. Therefore, some of the countries have imposed the rules and practices concerning the minimum time gap between two vehicles on roads to prevent front-end and rear-end collision. For instance, in Netherlands, fines can be imposed if the distance between the two vehicles is less than 1 second. In Norway, for vehicle weighing more than 3.5 tons, a distance of between 0.5 to 1 second leads to a suspension of the license for 3 to 6 months. In South Australia, the Driver's Handbook describes 2 second as reasonably safe distance (Hutchinson, 2008).

Braking time is the time it takes for a vehicle to stop from a specific speed without considering the driver reaction time. The ability of a vehicle to achieve short braking time under variable speed and loading is an essential aspect of heavy vehicle safety. Theoretically, higher travelling speed requires longer braking time. Heavy vehicles usually require larger braking time compared to other types of road users. Dey and Chandra (2009) also revealed the maximum desired time gap for tractors due to their characteristics of the HVs such as performance, braking and acceleration capability. Therefore, as mentioned by Sayer et al. (2000), depending on its size and weight, the existence of HVs in a traffic stream will definitely cause a significant difference in the vehicle-following behavior.

This paper attempts to propose a new safety indicator, named the minimum safe time gap (MSTG) which incorporates the vehicle dynamics and driver behavior factors.

2. THE PROPOSED MODEL

Keeping a safe following distance from the leading vehicle (LV) is critical for mitigating rear-end crashes in vehicle following situation since it allows the following vehicle (FV) sufficient time to stop, and to stop gradually. Thus, in this paper the concept of minimum safe time gap (MSTG) is introduced. The MSTG is defined as the minimum time required by the following vehicle to decelerate and safely stop without hitting the leading vehicle when both leading and following vehicles apply the emergency brakes due to unforeseen circumstances.

The value of MSTG (as illustrated in Figure 1) is obtained by considering the braking time of the following vehicle (BT_{FV}) and the leading car (BT_{LV}) as well as the perception-reaction time of the following vehicle driver.

Different compositions of leader-follower pairs, say for example in the case of truck-following-car, will affect the MSTG value due to different in braking performance and capability. Similarly, the following vehicle driver's physical and mental condition will affect the perception-reaction time hence affecting the MSTG.

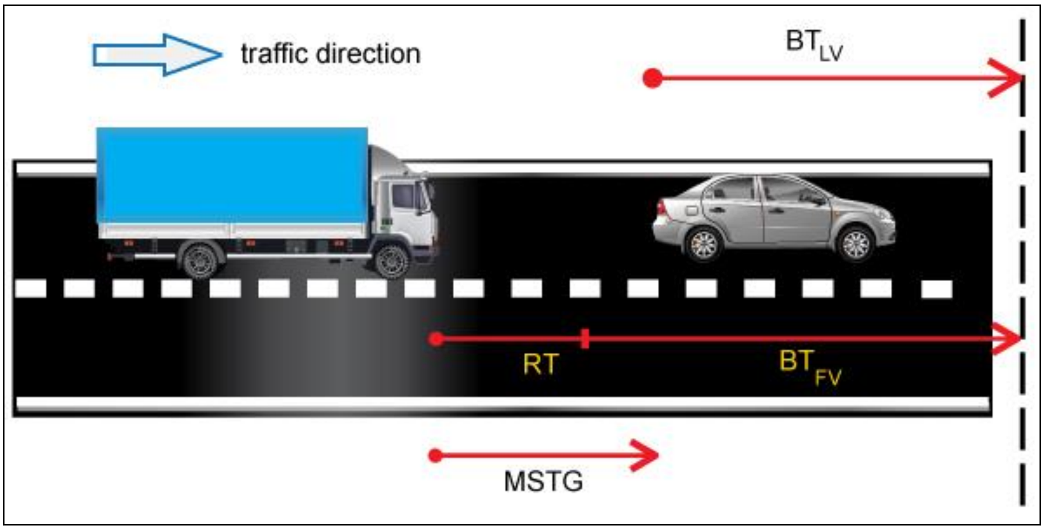

Figure 1. Concept of Mean Safe Time Gap (MSTG)

Figure 1 can be explained as follows:

"Suppose there are two vehicles in a following situation travelling at a small relative speed. The front of FV being t_g seconds behind the back of LV and t_g is defined as time gap. Further suppose that the LV commences emergency braking, and then, after some perception-reaction time, the FV also commences emergency braking. Then, the FV will or will not hit the LV depending upon whether t_g is smaller or greater than MSTG."

The general equation for MSTG incorporating braking time and perception-reaction time can be expressed as follows:

$$MSTG = BT_{FV} - BT_{LV} + RT \quad (1)$$

where, RT is driver's perception-reaction time,

BT_{FV} and BT_{LV} are braking time of following and leading vehicle, respectively.

Numerous factors influence BT and RT. According to Wong (1993) BT can be influenced directly by factors related to vehicle and road. Some of these factors are highlighted in Figure 2.

<u>Vehicle</u>

- Vehicle type
- Brake technology
- Speed
- GVW
- Tyre

<u>Road Condition</u>

- Pavement surface condition (coefficient of friction)
- Road geometry

Figure 2. Vehicle and road factors influencing braking time

The driver's perception-reaction time is often defined as the time interval between obstacle appearance and driver response initiation. According to TRI (1997) there are four elements that make up the perception-reaction process and usually referred as PIEV process (Perception-Intellection-Emotion-Volition). As given in TRI (1997), the 85th percentile time from four studies have shown 1.9 s as maximum perception-reaction time. The summary of the study is given in Table 1.

Table 1. Brake Reaction Times Studies

	85th Percentile
Gazis et al	1.48
Wortman et al	1.80
Chang et al	1.90
Sivak et al	1.78

Factors influencing the *RT* are generally associated with physical abilities and psychological influences (TRI, 1997). Some of these factors are listed in Figure 3.

Physical Abilities

- Age
- Gender
- Skill
- Profession
- Driving

Psychological

- Risk-taking propensity
- Stress
- Fatigue
- Hurry
- Distraction

Figure 3. Human factors influencing perception-reaction time

Thus, the determination of realistic MSTG requires the consideration of many factors associated to vehicle, driver and road elements.

3. SIMULATION RESULTS AND DISCUSSION

Most of the previous studies assuming the BT is always same when both FV and LV are traveling at the same speed regardless of vehicle braking capability. However, in this paper, in this section the effect of speed, GVW and vehicle type on BT will be discussed.

The brake performance of vehicles can be analyzed in several different ways. This can be through an actual experimental work or through vehicle dynamics simulation packages. Obviously, the process of building and instrumenting the prototype for actual experimental testing involves significant engineering time and expense. Furthermore, some actual testing is quite dangerous and difficult to implement such as determination of safe following gap time in a vehicle following situation.

As computers have gotten faster, and software user interfaces have improved, commercial simulation packages such as MSC ADAMS have become widely used in industry for rapidly evaluating hundreds of test conditions much faster than real time. In addition to testing, simulation provides substantial time and cost savings. MSC ADAMS software is a kind of virtual prototyping software for simulating vehicle dynamics and currently used by many major auto manufacturers.

To illustrate the concept of MSTG proposed in this paper, the simulation was done using MSC ADAMS. In this study, MSC ADAMS software has been used to generate braking time data for vehicles under various vehicle types, GVW (loading) and speed conditions. Since the aim of the study is to develop a model that can reflect an actual vehicle following situation, it is important to develop more realistic simulated following vehicle model. Thus, in this study, the vehicle model and its specification for passenger car (sedan), 2-axle, 3-axle, 4-axle and 5-axle single unit truck (SUT) has been developed in accordance to prevalent following vehicle type available on the road. Simulation was carried out under the assumption that the vehicle has reached a steady state condition and stay on the road at a constant speed before the brakes are applied at 285N. Furthermore, air drum brake and parabolic leaf spring suspension are used for truck category. For this study, the road profile is flat and straight road condition where differences in road materials and stiffness are not significant.

Simulation data on passenger car braking time as a function of speed is shown in Figure 4.

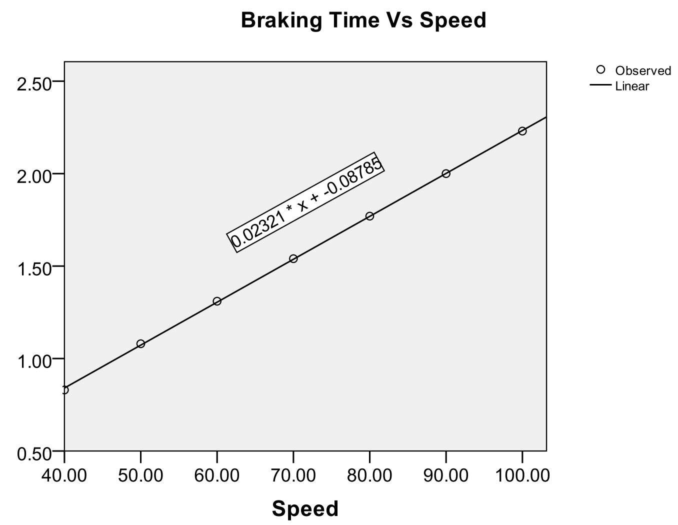

Figure 4. Effect of speed on braking time (BT) of passenger car

Based on Figure 4 plots, a braking time models for passenger car (sedan) with various travel speed can be expressed as follows:

$$BT_c = 0.02321v - 0.08785 \quad (2)$$

where, BT_c is a braking time for passenger car in second and v is vehicle speed.

The simulation results to indicate the effect of vehicle type/class, speed and GVW on braking time of 2-axle, 3-axle, 4-axle and 5-axle single unit truck (SUT) are shown in Figure 5(a),(b),(c).

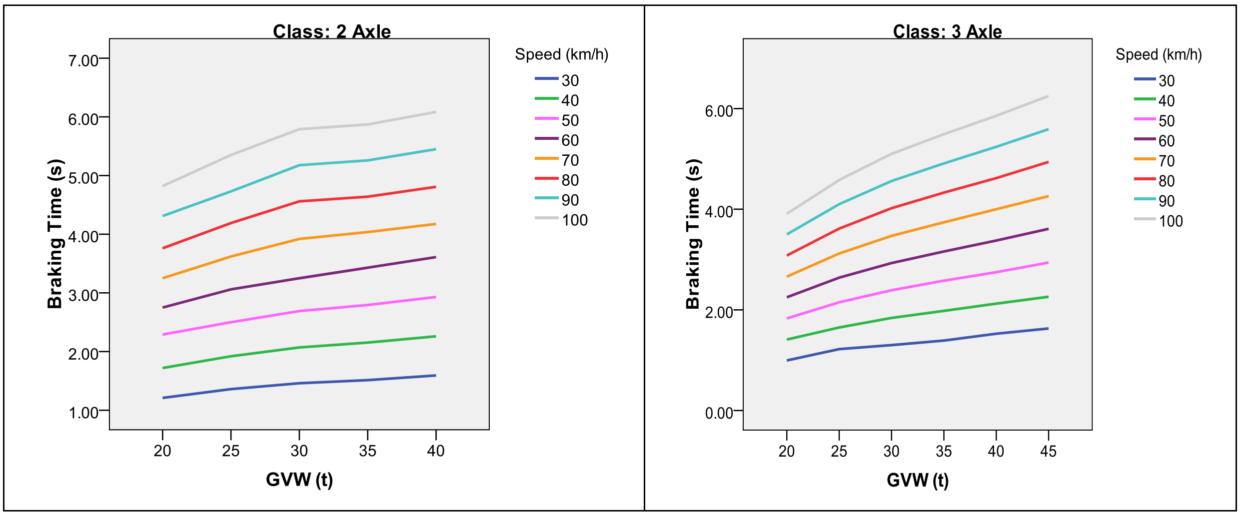

Figure 5(a). Effect of vehicle type/class (2-axle, 3-axle), speed and GVW on braking time (BT) of single unit truck (SUT)

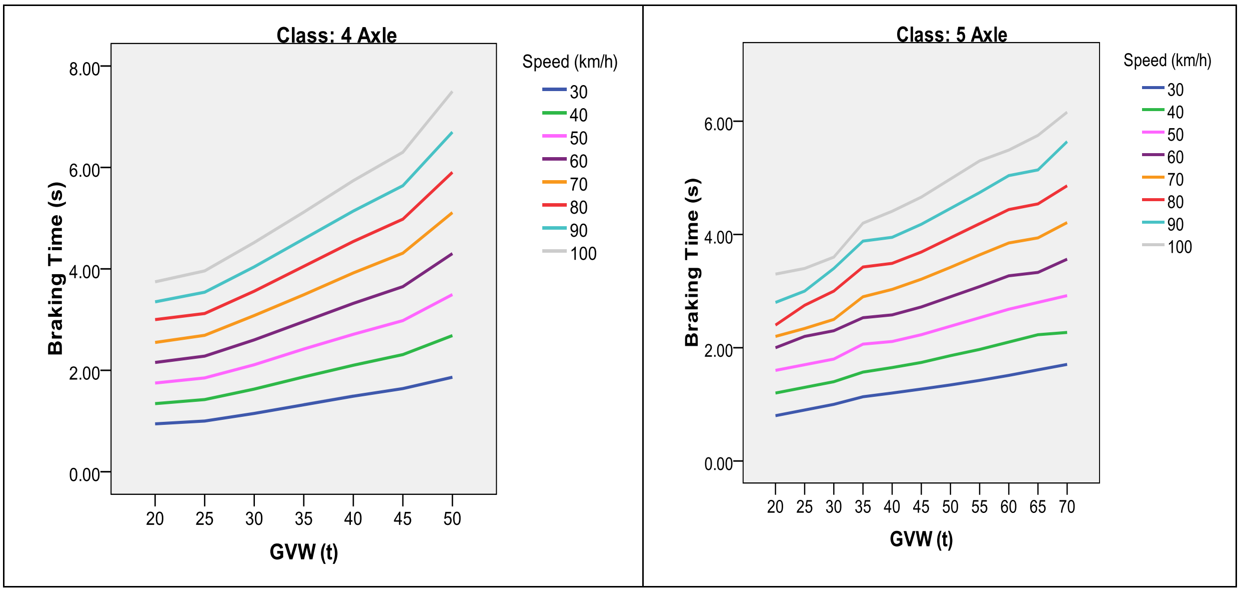

Figure 5(b). Effect of vehicle type/class (4-axle, 5-axle), speed and GVW on braking time (BT) of single unit truck (SUT)

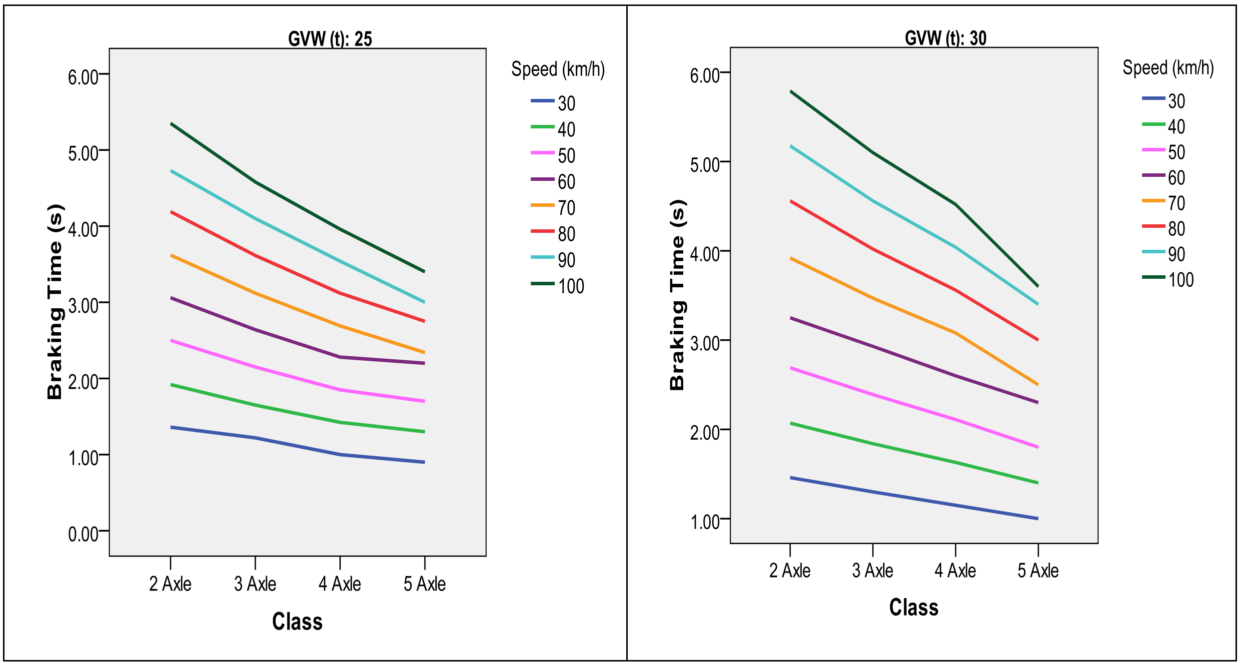

Figure 5(c). Effect of vehicle type/class (2-, 3-, 4-, 5-axle), speed and GVW (25t, 30t) on braking time (BT) of single unit truck (SUT)

Based on line graph plot in Figure 5(a),(b),(c), it can imply that heavy vehicle travel with minimum or low speed, the GVW has not much significant effect to braking time (BT). The BT only has significant effect when heavy vehicles travel with medium or high speed. From Figure 5(a),(b),(c) also, it can clearly be seen for the same GVW, speed has significant effect on braking time (BT). The BT is observed to increase when the heavy vehicle is moving at higher speed. BT is also dependent on vehicle class as shown in Figure 5(a),(b),(c). In this case, braking time will decrease with the increasing of heavy vehicle axle number since the different vehicle class/type has different dynamic capability.

Based on Figure 5(a),(b),(c) plots, a braking time model for each category of heavy vehicle is proposed. The proposed model incorporating GVW and travel speed of single unit truck (SUT) can be expressed as follows:

$$BT_t = aw + b \tag{3}$$

where $a = C_1 v + C_2$

$b = C_3 + C_4$

where BT_t is a braking time in second, w is GVW and v is speed. First regression was done to determine coefficients of the regression lines, a and b in Equation (3) for various speed. The values of these coefficients and coefficients of determination, R^2 for all cases are described as in Table 2.

Table 2: Regression coefficients with p-value of a and b

Vehicle type	Speed, *v*	*a*	p-value (*a*)	*b* (constant)	p-value (*b*)	R^2	N
2 axle	30	0.018	0.003	0.876	0.001	0.952	5
	40	0.026	0.002	1.237	0.001	0.970	
	50	0.031	0.001	1.697	<0.001	0.982	
	60	0.042	0.001	1.966	<0.001	0.985	
	70	0.045	0.006	2.441	0.001	0.941	
	80	0.051	0.009	2.865	0.002	0.922	
	90	0.056	0.008	3.300	0.001	0.930	
	100	0.061	0.010	3.753	0.001	0.918	
3 axle	30	0.024	<0.001	0.566	0.001	0.976	6
	40	0.033	<0.001	0.798	<0.001	0.986	
	50	0.043	<0.001	1.040	<0.001	0.985	
	60	0.053	<0.001	1.278	<0.001	0.987	
	70	0.062	<0.001	1.515	<0.001	0.985	
	80	0.072	<0.001	1.757	<0.001	0.985	
	90	0.081	<0.001	2.009	<0.001	0.985	
	100	0.091	<0.001	2.241	<0.001	0.985	
4 axle	30	0.031	<0.001	0.250	0.011	0.985	8
	40	0.045	<0.001	0.342	0.026	0.978	
	50	0.058	<0.001	0.450	0.033	0.974	
	60	0.071	<0.001	0.563	0.036	0.971	
	70	0.084	<0.001	0.653	0.045	0.969	
	80	0.096	<0.001	0.812	0.041	0.965	
	90	0.110	<0.001	0.878	0.042	0.968	
	100	0.123	<0.001	0.978	0.045	0.967	
5 axle	30	0.017	<0.001	0.476	<0.001	0.995	11
	40	0.022	<0.001	0.757	<0.001	0.996	
	50	0.027	<0.001	1.041	<0.001	0.995	
	60	0.030	<0.001	1.407	<0.001	0.994	
	70	0.041	<0.001	1.482	<0.001	0.993	
	80	0.047	<0.001	1.658	<0.001	0.989	
	90	0.054	<0.001	1.756	<0.001	0.988	
	100	0.058	<0.001	2.029	<0.001	0.991	

Another regression was done to determine the coefficients of the regression lines, C_i where i=1, 2, 3 and 4 in Equation (3) and coefficients of determination, R^2 for all cases are described as in Table 3.

Table 3: Regression coefficients with p-value for C_i

Vehicle type	C_1	C_2	C_3	C_4	$R^2(a)$	$R^2(b)$	N
2 AXLE	0.001	0.001	0.041	-0.398	0.986	0.986	8
(p-value)	<0.001	0.504	<0.001	<0.001			
3 AXLE	0.001	-0.005	0.024	-0.160	1.000	1.000	8
(p-value)	<0.001	<0.001	<0.001	<0.001			
4 AXLE	0.001	-0.008	0.011	-0.077	1.000	0.999	8
(p-value)	<0.001	<0.001	<0.001	0.006			
5 AXLE	0.001	-0.003	0.021	-0.051	0.986	0.967	8
(p-value)	<0.001	0.188	<0.001	0.657			

Regression coefficient in Table 4 indicate a positive-straight-line or linear relationship between braking distance and GVW. In this case, braking distance will increase as GVW increases for medium or high speed cases. The braking distance variation is small for low speed case. Table 4 also indicate that the estimate of the slope and intercept for Equation (3) is significantly different from zero and the model adequately describe the data (for each vehicle type, $p<0.001$ except for *a* and *b* intercept for 5-axle).

Using Equation (1), (2) and (3) with appropriate *RT* value, the respective values of MSTG can be determined for the different composition of follower-leader pair travelling at various speeds. As would be expected the MSTG varies for the different combinations of following vehicle type/class, following vehicle GVW and travel speed. In general, it is worth noting that for a particular following vehicle type/class, say the 4-axle following vehicle, travelling at a particular speed, say 80 km/h, the following vehicle braking time (BT_{FV}) will increase as the GVW increases. It means that as the GVW of the following vehicle increases it needs longer time to stop safely after the brakes are applied. Consequently, the MSTG also increases as the GVW increases implying that for a particular truck following a car, the minimum safe time gap will be longer than usual if the following vehicle is carrying higher payload than usual. The truck driver would need to understand this in order to avoid rear-end collision in emergency situation.

4. CONCLUSION

A new safety indicator, the minimum safe time gap (MSTG) is proposed for use in safety analysis in vehicle-following situation. The concept of MSTG introduced in this paper incorporates elements from vehicle (vehicle type, GVW, speed etc.), road (pavement surface condition, road geometry etc.) and driver (physical abilities, psychological factors etc). It has been established that vehicle braking performance is of utmost importance in relation to vehicle stopping time, hence it has to be incorporated into the safety indicator. Thus, the MSTG is determined by considering the vehicle braking time (for both leading and following vehicle in a vehicle-following situation) and driver perception-reaction time. The simulation data (for vehicle braking time) was generated using vehicle dynamics simulation software for the purpose of model development. In is envisaged that this safety indicator would provide a more realistic depiction of the real traffic situation for safety analysis.

REFERENCES

Bevrani, K., Chung, E. (2011) An examination of the microscopic simulation models to identify traffic safety indicators. *International Journal of Intelligent Transportation Systems Research*. http://dx.doi.org/10.1007/s13177-011-0042-0, pp. 1-15.

Bixel, R.A., Heydinger, G.J., Durisek, N. J., Guenther, D.A. (1998) Effect of loading on Vehicle Handling. SAE Paper 980228, SAE International Congress and Exposition

Chang, K., Chon, K. (2005) A car-following model applied reaction times distribution and perceptual threshold. *Journal of the Eastern Asia Society for Transportation Studies,* Vol. 6, pp. 1888-1903.

Craft, R., Blower, D. (2004) The Large Truck Crash Causation Study. Presented at FMCSA R&T Stakeholder Forum, Arlington, Va., November 2004.

Dey, P.P., Chandra, S. (2009) Desired Time Gap and Time Headway in Steady-State Car-Following on Two-Lane Roads. *Journal of Transportation Engineering*, 135(10), 687-693.

Evans, L., Wasielewski, P. (1982) Do accident-involved drivers exhibit riskier everyday driving behavior? *Accident Analysis and Prevention*, 14 (1), 57-64.

Fairclough, S. H., May, A. J., Carter, C. (1997) The effect of time headway feedback on following behaviour. *Accident Analysis and Prevention*, 29 (3), 387-397.

Ozbay, K., Yang, H., Bartin, B., Mudigonda, S. (2008) Derivation and validation of a new simulation-based surrogate safety measure. TRB 2008 Annual Meeting, pp. 1-19.

Postans, R. L., Wilson, W. T. (1983) Close-following on the motorway. *Ergonomics*, 26 (4), 317-327.

Ranjitkar, P., Nakatsuji, T., Kawamua, A. (2005) Car-following models: An experiment based benchmarking. *Journal of the Eastern Asia Society for Transportation Studies,* Vol. 6, pp. 1582 – 1596.

Saifizul, A.A., Yamanaka, H., Karim, M.R. (2011a) Empirical analysis of gross vehicle weight and free flow speed and consideration on its relation with differential speed limit. *Accident Analysis and Prevention*, 43, 1068-1073.

Saifizul, A.A., Yamanaka, H., Karim, M.R., Okushima, M. (2011b) Empirical analysis on the effect of gross vehicle weight and vehicle size on speed in car following situation. Proceedings of the Eastern Asia Society for Transportation Studies, Vol. 8, pp. 305-317.

Sayer, J.R., Mefford, M.L., Huang, R.W. (2000) The Effect of Lead-Vehicle Size on Driver Following Behavior (Report number UMTRI-2000-15). Ann Arbor, MI: The University of Michigan Transportation Research Institute.

Treat, J. R., Tumbas, N.S., McDonald, S.T., Shinar, D., Hume, R.D., Mayer, R.E, Stansifer, R.L., Catellan, N.J. (1979) Tri-Level Study of the Causes of Traffic Accidents: Final Report Volume I: Causal Factor Tabulations and Assessments, Institute for Research in Public Safety. DOT Publication No. DOT HS-805 085, Indiana University, 1979.

TRI (1997) Stopping sight distance and decision sight distance. Discussion Paper No. 8.A , Transportation Research Institute, Oregon State University, 1997.

Vogel, K. (2003) A comparison of headway and time to collision as safety indicators. *Accident Analysis and Prevention*, 35, 427-433.

Wong J. Y. (1993) *Theory of Ground Vehicle*. John Wiley & Sons Inc.