Safety Performance Assessment of Car Following Behavior using Integrated Weigh-In-Motion System

By

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A thesis submitted in accordance with the requirements for the degree of

Doctor of Engineering

The University of Tokushima

Japan

April 2014

The candidate confirms that the work submitted is his own and that appropriate credit has been given where reference has been made to the work of others

Acknowledgement

Abstract

This study attempts to propose a safety performance assessment using empirical-simulation technique. What is meant by empirical-simulation technique is empirical data will be compared with a safety indicator which is determined using simulated data. More specifically, empirical data such as time gap together with vehicle characteristics will be compared with a new proposed safety indicator named Minimum Safe Time Gap (MSTG) to investigate the behavior of drivers in a car following situation on a specific road segment.

The new safety indicator, MSTG incorporates vehicle and driver capabilities in calculating critical safe car following time gap for various leader-follower compositions. A critical safe following time gap is the time required by the following vehicle (FV) to safely stop without hitting the leading vehicle (LV) in an emergency stop situation. This new indicator is derived as a function of vehicle braking time and driver perception-reaction time. The braking time for vehicles for various gross vehicle weight, vehicle type and speed is determined using well-known and established vehicle dynamics simulation software.

The success of the proposed method is dependent not only on a realistic safety indicator, but also on the availability of the data-collection system to provide necessary traffic and vehicle data continuously and automatically in real-time.

As such, empirical data from an integrated weigh-in-motion (WIM) system is used in this study. The integrated WIM system is a comprehensive and continuous traffic data-collection system based on weigh-in-motion technology. This system is capable of simultaneously and continuously measuring large amount of all essential traffic data and vehicle parameters in real-time.

Through this empirical-simulation technique, the concept of safe vehicle-following behavior where actual time gap is more than MSTG, and unsafe vehicle-following behavior where actual time gap is less than MSTG can be explained through the sketch of the empirical-simulation plot. From this plot, the frequency of unsafe behavior and the degree of unsafe behavior referred to as "unsafe occurrence" and "unsafe deviation" indices on specific road segments can be assessed.

In summary, the close car following behavior at any particular road segment that need to be examined can be characterized through the proposed safety performance assessment and more importantly it may provide a realistic approach for various agencies to identify and mitigate problems related to rear-end crashes.

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CHAPTER 1

GENERAL INTRODUCTION

1. 1 Car-following Behavior and Road Safety

The number of road fatalities is growing every year around the world and the fatality rate is more pronounced in the developing countries. For example, the number of road fatalities in Malaysia is 6,872 in 2010 which gives an index of 23.8 deaths per 100,000 population and 3.4 deaths per 10,000 registered vehicles (MIROS, 2013). It is alarming and a cause for concern because despite having targets and various efforts to reduce road fatalities, the increasing trend still remains.

One of the main challenges in road transport planning, design and operations is to ensure that the safety of all road users is achieved. Although there are guidelines and standards with respect to the planning and design of safe road infrastructure, the management and operations of road traffic may be more challenging because it needs to deal with human behavior, in this particular case, the road user behavior. Safety on the roads will be compromised when factors that contribute to road crashes become dominant and fall in place. It has been well accepted that the accident causation factors may be grouped into human (road user) factor, vehicle factor and road and environment factor. It has also been established that human factor is involved in the majority of the accidents as compared to the other factors (Lewin, 1982; Marijonas Bogdevicius et al., 2004; Predrag Stanojevic et al., 2013; Guangnan Zhang et al., 2013).

Past researches suggest that the majority of drivers involved in incidents of rear-end crashes are associated with following too closely due to misjudgments and misbehavior. Knipling et al. (1993) stated that the main causal factors of rear-end collision are inattention and following too closely. Study by Michael et al. (2000) also stated that 28.3% of rear-end collisions in Tennesse in 1997 were because of close-following. There are many other studies that provide 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).

Drivers often misjudge their own capability as well as their vehicle capability to stop the vehicle before crash which include overconfidence with their reaction speed and their vehicle braking performance capability. Most people use their own perceptions in determining safe driving distance. No matter what type of vehicle they drive, the awareness and consciousness of the safe following distance is very crucial for drivers to prevent collision with the vehicle in front.

Thus, a proper study need to be conducted in order to have a thorough understanding of the car following behavior in a particular road segment so that adequate measures can be implemented to reduce incidents related to rear-end collisions. The findings from the study can be used by the related authorities from various agencies for various purposes such as awareness campaigns, establishing prior information on driving profile, provide effective enforcement measures towards close following driving behavior and many other applications. However, the success of the study very much depends on the quality of the measured traffic data and the method use for assessing the safety performance. In this study, both factors will be discussed in detail and a new assessment method will be proposed.

Car-following behavior may vary due to differences in the type of vehicle, the ability of the driver and the road environment. Among four main compositions of vehicle following pairs (car follows car, car follows truck, truck follows truck, and truck follows car), trucks following passenger car requires much more attention. This case requires higher level of concern since the car and truck have a huge difference in dynamics capability. The consequences from a collision would be more severe to the car in spite of which party is at fault.

Thus, it is important to extend the study on the influence of both heavy vehicle GVW and its class in a vehicle following situation to further understand the subject not only from the kinematic perspective but also from vehicle dynamics capability perspective.

1.2 Heavy Vehicle and Safety

Heavy vehicle not only present a threat to the road infrastructure but also to road safety. Out of the many forms of fatal road crashes, a major concern in Malaysia and possibly in other developing countries as well is those fatal crashes involving heavy commercial vehicles such as trucks and buses. Accident fatality data for Malaysia indicates that more than 25% of fatal accidents involve heavy vehicles (Karim and Saifizul, 2010). When the fatal accidents involving trucks for the year 2008 were analysed according to collision type, the majority of the fatal accidents (27.3%) involved rear-end collisions (Karim et al., 2014b). Rear-end collisions also occur in 22% of fatal accidents involving buses. It appears that the rear-end collision is also the most common pattern on expressways in other countries (Jianjun Zhang, 2013).

Heavy vehicle may cause delays to other vehicular traffic and the delay experienced and the need to stay behind the slow-moving vehicle might increase frustration among the faster drivers and cause unsafe behaviour (Brewer, 2000). As such, the presence of a significant number of heavy vehicles in a traffic stream may also create safety concern to other road users.

Without modifications of engines and drive trains, increased truck weights would lead to greater speed reductions on upgrades and greater difficulties for trucks to merge, weave and change lanes on freeways. Other things being equal, increased gross vehicle weights may also increase the probabilities of brake overheating on long, steep downhill runs. Any one of these situations can have adverse traffic (delays and congestion) and accident implications (Transportation Research Board, 1990). The braking system of any truck is designed for the maximum allowable weight indicated on the vehicle documents. The braking capacity not only depends on the brakes themselves, but also on the tire and suspension performances designed for the maximum allowable weight of the truck. Any weight in excess reduces the braking capacity of a truck, and may even damage the braking system (Jacob and La Beaumelle, 2010).

According to Jacob and La Beaumelle (2010) there were several adverse consequences that may occur when the heavy vehicles exceed the maximum permitted limit, i.e. (i) truck instability because of the increased of height at the center of gravity and more inertia of the vehicle bodies, (ii) braking default because besides the system itself, it depends on the tire

and suspension performance which is designed for the maximum allowable weight indicated on the vehicle documents, (iii) loss of motivity and maneuverability since the vehicles is under-powered, which resulted in lower speeds on up-hill slopes as well as the risk of congestion, inefficient engine braking and over speeding on down-hill slopes, (iv) overheating of tire and high risk of tire blowouts, and (v) accident or loss control of the vehicles will result in higher risk and severity of a fire, especially when transporting flammable goods.

An overloaded truck is more likely to be involved in an accident, and have more severe consequences, than a legally loaded truck. They produced higher kinetic energy, resulting in greater impact forces and damages to other vehicles or to the infrastructure, especially when met with an accident and are more likely to be fatal (Davis, 2003).

In situations when heavy vehicle drivers experience fatigue due to the factors mentioned above, the traffic safety level on the road may be compromised. It can only get worse if the heavy vehicles are overloaded because the safe handling of an overloaded truck will be more difficult as compared to a non-overloaded truck. Thus, truck overloading in combination with driver fatigue will jeopardize the safety of road users in a traffic stream.

Although the involvement of heavy vehicles in the accident have been extensively studied, very little works have been done to empirically investigate the behavior of heavy vehicle drivers in a car following situation by taking into consideration the influence of other factors such as the GVW and vehicle class.

1.3 Safety Performance Assessment

There has been progress made on deriving safety indicator to identify the potential conflicts in car following situation and for highway safety evaluation. There are several safety indicators for safety analysis reported in the literature. Generally, such kind of safety indicators can be classified into four groups, namely, time-based, distance-based, deceleration-based as well as other composite measures. One of the most frequently used time-based measures is Time-To-Collision (TTC), which is defined as the time that remains until a collision between two vehicles would have occurred. TTC has been one of the well-recognized safety indicators in transportation safety (Chin and Quek, 1997; Shariat-Mohaymany et al., 2011; Matsui et al., 2013). In addition, TET (Time Exposed Time-to-collision) and TIT (Time Integrated Time-to collision) extended from TTC were also introduced by Minderhoud and Bovy (2001). Deceleration to avoid crash, namely, DRAC could be a typical deceleration-based indicator. Crash potential (CP) proposed by Saccomanno and Cunto (2006) could also be an indirect use of such kind of measure.

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). Most previous studies have focused on passenger cars and there were no explanation on how to use the proposed safety indicators in investigating truck following car behavior incorporating GVW and class. The characteristic

of the vehicle dynamic such as GVW and deceleration capability is assumed to be same for all types of vehicles.

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.

Therefore, the determination of a realistic threshold for critical safe following distance incorporating GVW and class is a very fundamental and pivotal step in developing a realistic safety indicator which can then be used to assess accident potential more effectively.

1.4 Integrated Weigh-in-Motion (WIM) System

At present, various types of systems or devices used to collect data on traffic and vehicle work independently between one another. However, these devices may have limited measurement capabilities and unsuitable for this study, where the devices are incapable of simultaneously measuring all essential traffic and vehicle parameters such as speed, headway as well as weight in real-time. The use of these independent devices for this study will result in data inconsistency and incomprehensive measurable traffic parameters.

For this study, the gap time data along with vehicle characteristics data such as GVW, wheelbase and vehicle class must be obtained simultaneously and continuously in real-time. Thus, a comprehensive and continuous traffic data-collection system based on weigh-in-motion technology has been developed named as integrated weigh-in-motion system. The developed system is capable of simultaneously and continuously measuring large sample and all essential traffic and vehicle parameters in real-time (Saifizul et al., 2010). The unique capabilities of the integrated WIM system may be summarized as follows:

- Manage to capture various traffic and vehicular data for all types of vehicle using a single set of weigh-in-motion (WIM) quartz sensors for statistics and enforcement purposes.

- Manage to capture speeds of vehicles based on vehicle classification and vehicle weight in real time and compare these speeds to the legal speed limit for the respective vehicle class. This will allow for variable speed limit application to be implemented automatically and continuously in all weather conditions.

- Manage to capture vehicle weights while in motion within a wide range of speeds with a high level of accuracy. This will enhance the vehicle weight enforcement when used as a screening or sorting system for the existing static weigh stations.

- Data will be captured through the system in real time, automatically, continuously and in all weather conditions, and can be remotely accessed by a central monitoring facility.

Empirical data from the integrated WIM system is used in the empirical-simulation technique to assess the safety performance of car following behavior in the traffic stream.

1.5 Research Objective

There are two-fold objectives in this study. The first objective of this study is to propose a new safety indicator which incorporates elements from vehicle (vehicle type, GVW and speed) and driver (perception-reaction time) and can be used to evaluate actual traffic data for safety performance assessment.

The second objective is to propose a new technique that can quantify the frequency and degree of unsafe driving among the truck drivers in car following situation.

1.6 Research Approach

The safety performance assessment should go beyond the traditional/conventional methods which may sometimes lead to over simplification of the complexity of situation such as involving vehicle dynamics. Considering kinematics only is not enough to explain the actual situation in road safety involving heavy vehicles.

Hence, a new approach on safety performance assessment involving empirical-simulation technique will be suggested. This safety performance assessment technique requires both simulation data (as benchmark) and empirical data (as depicting the actual situation).

With advancement of computer technology and simulation techniques, more accurate simulation data can be easily achieved at much lower cost. More accurate and comprehensive data on vehicle characteristics and performance can be achieved through advanced simulation software which may be quite difficult to obtain using other means. Thus, in this study, vehicle dynamics simulation packages will be used to generate braking time data for vehicles under various vehicle types, GVW (loading) and speed conditions. These data will then be used to produce a safety indicator.

On the other hand, empirical time gap data for truck-following-car is obtained through integrated WIM on specific locations along a road network. Without accurate empirical data a proper assessment on safety performance could not be done even though accurate simulation data is available. The empirical time gap data for various following truck type, GVW and speed will statistically be analysed for the purpose of comparison with the proposed safety indicator to evaluate actual traffic data for safety performance assessment.

With respect to the research approach discussed above, four main areas of work have been focused as follows:

1. To establish the extent and degree of vehicle overloading in the commercial vehicles that plies our roads in Malaysia. This is an important issue because the focus in this study is car following behavior involving heavy vehicles and since in Malaysia there is a high possibility that heavy vehicles do overload for the truck operators' economic reasons, the extent and degree of vehicle overloading need to be established (Karim et al., 2013a). The overloading of trucks would affect the truck braking performance and its maneuverability, thus compromising the safety of road users. In this case, vehicle weight data is needed and was obtained from an integrated WIM system installed

along a Federal Route near an existing static weigh station belonging to the Ministry of Works, Malaysia.

2. In cases when the possibility of overloaded trucks by-passing the locations where WIM systems are installed is expected and where weight enforcement capability is lacking, a study was conducted to determine whether there is a significant reduction in the effectiveness of the WIM assisted weight enforcement system. Results from this study suggest that the WIM system will significantly enhance the effectiveness and efficiency of the current vehicle weight enforcement system, hence reducing the accident risks involving heavy vehicles (Karim et al., 2013b).

3. To formulate a new safety indicator that incorporates vehicle and driver factors for the assessment of the car following behavior, particularly involving heavy vehicles. A new concept called the Minimum Safe Time Gap (MSTG) is introduced which determines the minimum time gap between the following vehicle (FV) and a leading vehicle (LV) that would allow the FV to safely stop without hitting the LV in an emergency stop situation (Karim et al., 2014a). The braking time for vehicles (varying gross vehicle weight (GVW) and speed) is determined using established vehicle dynamics simulation software.

4. Finally, an investigation on safety performance assessment of close car following behavior of heavy vehicles using empirical-simulation technique was conducted. In this study, empirical data from the WIM system is analysed together with the MSTG and a procedure to assess the safety performance of the car following behavior was developed with the introduction of two new indicators, namely, occurrence of unsafe time gaps (UO) and UD, i.e. the deviation of the mean of the unsafe time gaps from MSTG (Karim et al., 2014b).

1.7 Thesis Layout

Following the introduction in Chapter One, Chapter Two presents the degree of vehicle overloading and its implications on road safety in developing countries. Chapter Three provides the results of a study on the effectiveness of vehicle weight enforcement in a developing country using weigh-in-motion sorting system considering vehicle by-pass and enforcement capability. Chapter Four presents and discuss the Minimum Safe Time Gap (MSTG) as a new safety indicator incorporating vehicle and driver factors while Chapter Five presents the results on an investigation on safety performance assessment of close following behavior of heavy vehicle using empirical-simulation technique. Finally, Chapter Six presents the conclusion and recommendations of the study.

CHAPTER 2

DEGREE OF VEHICLE OVERLOADING AND ITS IMPLICATION ON ROAD SAFETY IN DEVELOPING COUNTRIES

2.1 Introduction

It is important for those responsible for the maintenance and operation of highway infrastructures to monitor and prevent truck overloading. The additional weight carried by overloaded trucks accelerates the deterioration of the roadway, leading to rutting, fatigue cracking, and in certain cases structural failure (Sharma, 1995; CSIR, 1997; Bushman et al., 2003; Santero et al., 2005). In a 1990 report (Transportation Research Board, 1990), illegally loaded trucks were estimated to cost United States taxpayers $160 to $670 million per year on the highway system. Straus and Semmens (2006) conducted a study to quantify state highway damage on the basis of the impacts of overweight vehicles. Each year, millions of dollars of damage associated with life span, design, and maintenance of state highways and structures are attributed to vehicles that exceed state weight limits. They found that for every dollar invested in motor carrier enforcement efforts, there would be $4.50 in pavement damage avoided. It is possible to develop a system that would increase the proportion of noncompliant vehicles subjected to inspection relative to compliant vehicles (Titus, 1996). The fact vehicle overloading causes road pavement structural distress and decrease in service life has also been reported by Mulyono et al. (2010) and an analysis of lost cost of road pavement distress due to overloading freight transportation was also presented. Podborochynski et al. (2011) quantified incremental pavement damage caused by overweight trucks in Saskatchewan, Canada and reported that accelerated damage from truck overloading has decreased the expected performance life of many of the roads and also increased maintenance and rehabilitation requirements and costs.

Campbell et al. (1988) evaluated crash types and found that a there is moderate increase in accidents rates for higher gross weights. Francher et al. (1989) later reported that the number of fatal truck crashes related to rearward amplification per mile traveled significantly increased as rearward amplification increased. This implies that, other things being equal, significant increases in gross vehicle weight (GVW) would increase the probabilities of the vehicle being involved in a fatal rearward amplification crash. Fatal involvement rates in rollover and ramp-related crashes also increased with increased GVWs. For curve related crashes and crashes in which trucks rear-ended other vehicles, increased GVWs may increase fatal involvement rates, although the trend was not as conclusive as those for rollover and ramp-related accidents.

The effect of higher mass on the performance of general access truck/trailer combinations has been studied by ARRB Transport Research (1997). Three performance measures were used to assess and characterise vehicle performance, namely, dynamic stability, braking and handling gradient. Vehicle performance characteristics were obtained using ADAMS multi-body simulation software. Based on the lane encroachment information and dynamic stability tests for 3.7m wheelbase truck towing a 5 axle trailer with a 5.6m wheelbase both fitted with steel suspensions and coupled with a 3m drawbar, it was concluded that mass ratios up to 1:1.6 would compromise safety (ARRB Transport Research, 1997).

Arbitrary increases in gross weight should not be allowed because they would allow the overloading of existing vehicles and thereby promote a decrease in the intrinsic safety of the vehicles in the truck fleet (Fancher and Mathew, 1989). According to Winkler (2000), the rollover threshold of a commercial truck changes regularly as the load changes, so drivers may not have the chance to get used to the stability of their vehicle. Heavy trucks are more susceptible than light vehicles to rollover accidents caused directly by inadvertently operating the vehicle beyond the rollover threshold.

If vehicle dimensions, number of axles, and other aspects of the vehicle and component designs were unchanged, substantial increase in gross vehicle weight would lower rollover resistance in steady turns for all trucks, which may lead to more rollover accidents. For existing five-axle doubles, increased weight would also downgrade the rearward amplification behaviors, which may increase the probabilities of rear-trailer overturns during obstacle avoidance or sudden lane change maneuvers. In addition, increased gross weight would require brakes with a higher torque capacity, which, if not provided, would result in trucks that were deceleration limited by brake torque capacity rather than by tire friction levels and fore-aft brake balance (Transportation Research Board, 1990).

As mentioned by Bixel et al. (1998), vehicle weight is one of the essential parameters in vehicle design study that can affect vehicle driving, braking and handling performance characteristics. Furthermore, most of the time vehicle dynamics influence driver behavior in controlling their vehicles (Wong, 1993). The study by Saifizul et al. (2011a, 2011b) has also shown that heavy vehicle GVW has direct influence on speed, whether the vehicle travel in a vehicle following situation or in free flow condition.

An overloaded truck will experience loss of motility and maneuverability. The overloaded vehicle becomes under-powered resulting in lower speeds on up-hill slopes as well as the risk of congestion, inefficient engine braking and over speeding on down-hill slopes. Overtaking also takes longer, and thus incurs additional risks for the other road users (Jacob and La Beaumelle, 2010).

Heavy vehicle drivers are also prone to driver fatigue especially if it involves long working hours and long distance trips with limited recovery time (Friswell and Williamson, 2013; Morrow and Crum, 2004; McCartlett et al., 2000). The monotony of long distance driving task may also increase the effects of fatigue on the driving performance and safety of heavy vehicle drivers (Thiffault and Bergeron, 2003; Sallinen et al., 2004; Larue et al., 2011).

A study by Liu and Wu (2009) showed that fatigued drivers faced greater attention demand, were less alert, and tended to overestimate the distance to roadside traffic signs. Fatigue caused by driving in complex road environment had the greatest negative impact on driving behavior and visual distance estimation, and the fatigue transfer effect worsened significantly but differently on both driving behavior and performance of fatigued drivers when switching from a complex to a monotonous road environment and vice versa (Liu and Wu, 2009).

As such, the need to identify the occurrence and extent of vehicle overloading, particularly in a developing country has to be acknowledged. Based on a clear understanding of the situation on vehicle overloading, decision makers will be in a better position to formulate more comprehensive and effective policy measures to mitigate the problem.

2.2 Study Purpose and Methodology

The main purpose of this study is to understand and establish the extent to which vehicle overloading is happening in a developing country like Malaysia. There has been significant number of studies on vehicle overloading in developed countries and the use of weigh-in-motion (WIM) technology to monitor the occurrence of vehicle overloading for various purposes (Taylor et al., 2000; Wang and Wu, 2004; Conway and Walton, 2004; Turner et al., 2008; Jacob and La Beaumelle, 2010). However, there has not been much discussion on the extent and degree of vehicle overloading in developing countries. With the lack of advanced facilities such as the WIM system and the corresponding static weigh stations and weight enforcement mechanisms, the problem of vehicle overloading in developing countries may not have been fully realized to enable appropriate and effective mitigation measures to be employed.

In this study, traffic data has been collected for a four months period between October 2009 and January 2010 at a weigh station operated by the Malaysian Road Transport Department on Federal Route 54 in the province of Selangor in Malaysia. Continuous traffic and vehicular data including the gross vehicle weight (GVW) of all vehicle categories (as specified by the Malaysian Road Transport Department) were obtained from a WIM system customized and installed on site. To ensure the accuracy of weight data obtained from the WIM system, proper calibration of the WIM system and validation of the WIM data were conducted (Saifizul et al., 2010a). Thorough analysis of the vehicle weight data, namely the GVW was performed to determine the vehicle overloading characteristics at the study location.

In order to understand the implications of vehicle overloading on safety, simulation data on the stopping distance of different truck categories traveling at different speeds and GVW is generated using the MSC ADAMS software. Different truck category will have different performance characteristics related to vehicle dynamics and in particular the braking performance. The relation between the stopping distance of each truck category and its GVW is of fundamental importance in terms of safety especially when truck overloading is happening and the degree of overloading is significant. Depending on the type of relationship between the truck stopping distance and its GVW, the safety level on roads (especially those having significant truck composition in the traffic stream) in developing countries may be significantly compromised.

2.3 Data Analysis and Discussion

There are several regulations on the operation of commercial vehicles in Malaysia. The Road Transport Department (RTD) under the Ministry of Transport (MOT) is responsible for vehicle weight enforcement. The Automotive Engineering Division under the RTD is responsible for deciding the maximum permissible laden weight or gross vehicle weight (GVW) for each class of commercial vehicle. On the other hand, the government agency which is responsible to issue the permit is the Commercial Vehicle Licensing Board (CVLB). Under the regulation, all commercial vehicles must apply GVW permit through CVLB in order to be allowed to operate on the road so that severe road damage can be reduced and problems related to road safety can be minimized. Basically, the GVW permit is categorized based on vehicle class and the summary is shown in Table 2.1. For the purpose of this study, focus will be given to the 2-axle, 3-axle and 4-axle trucks.

A common sight on Malaysian roads is illustrated in Figure 2.1. Overloaded trucks such as those shown in Figure 2.1 have been of concerned to all road users especially the more vulnerable ones such as motorcyclists, bicyclists and pedestrians.

Table 2.1: Maximum permissible laden weight (GVW) by vehicle class

	Class			
	2 Axle	3 Axle	4 Axle	5 Axle
GVW (t)	16.8 t	27.3 t	33.6 t	39.9 t

In this study, a total of more than 100,000 commercial vehicle data obtained during four months (October 2009 to January 2010) from a weigh-in-motion (WIM) system was analyzed. Figure 2.2 shows the number of GVW violations (based on maximum permissible GVW given in Table 2.1) for each month from October 2009 to January 2010. On the whole, the rate of GVW violation is found to range between 24% and 29% of the total commercial vehicles for each month and it is expected that the violation rate will hover within this range every month if no drastic action such as regular enforcement exercise is undertaken.

Figure 2.1. Examples of overloaded trucks in Malaysia
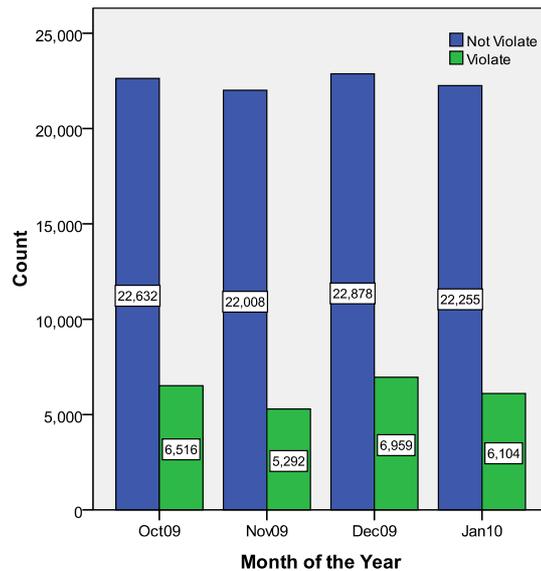
Figure 2.2. GVW violation cases by month of the year (Oct 2009 - Jan 2010)

The predominant types of heavy vehicles in Malaysia may be classified by the number of axles, namely from the 2-axle up to the 5-axle trucks. The 2-axle trucks make up almost 62% of the total heavy vehicle population (see Figure 2.3) followed by 3-axle trucks, 20% and 4-axle trucks, 16.6% while the 5-axle trucks forms only around 1.4%. For this reason, the focus in this study is on the 2-axle, 3-axle and 4-axle trucks because they form the majority of the truck population in a traffic stream.

It may be observed that although the 3-axle trucks forms around 20% of the total truck volume, almost half (45%) of the GVW violation comes from this truck category (Figure 2.3). On the other hand, although the 2-axle trucks forms 62% of the truck volume, only 26% of GVW violations come from this truck category. The occurrence of truck overloading for the 2-axle, 3-axle and 4-axle trucks for the four months period (October 2009 to January 2010) is illustrated in Figure 2.4. It is quite apparent that the pattern of overloading for each truck category is similar and consistent throughout the four months period with the 3-axle trucks recording the highest number of violations. This finding could assist the planning of weight enforcement program priorities.

Although the GVW violation rate may be considered rather high, what is more alarming is the range of GVW values and degree of overloading beyond the allowable limit for each category of heavy commercial vehicles (see Figure 2.5). It can be observed that there are cases that the actual GVW is almost double the permissible GVW allowed by law for the particular commercial vehicle category. This phenomenon is probably non-existent in the developed countries but in developing countries this could be quite common. The significantly high GVW beyond the permissible level for each commercial vehicle category would be a cause of major concern especially in terms of the capability of handling the extra heavy commercial vehicle in emergency situations. As such, the extra heavy commercial vehicle may be hazardous and could compromise the safety of other road users should such situations arise. In addition, the fuel consumption of the extra heavy commercial vehicle will increase significantly and the final carbon footprint attributed to this extra heavy commercial vehicle will be higher than what it should be if the permissible GVW was abided to.

The extra heavy commercial vehicle would also have significantly higher axle loads beyond the permissible axle load (which is usually used in pavement design) which would increase the pavement deterioration significantly and shorten the pavement life well below what it was designed for. This is because the damage factor of the pavement surface is to the fourth power of the axle load (Huang, 1993; AASHTO, 1993).
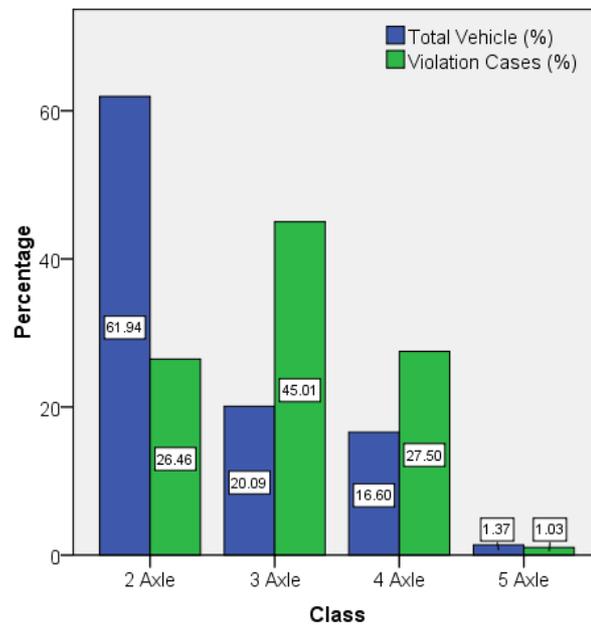
Figure 2.3. Heavy vehicle GVW violation cases by vehicle class (Jan 2010)
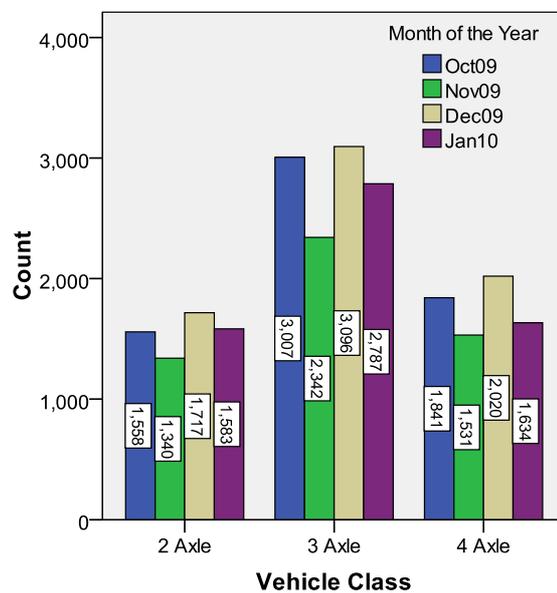
Figure 2.4. No. of overloaded trucks at study location
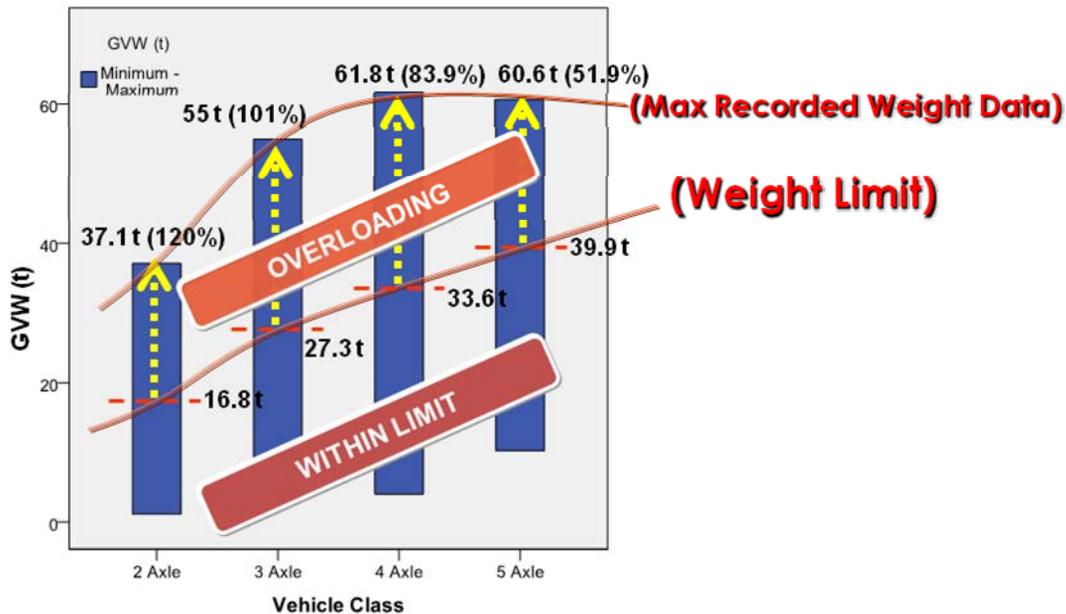
Figure 2.5. GVW variation by vehicle class (Jan 2010)

In terms of safety, the outcome of a crash between an overloaded truck and a smaller vehicle, say a passenger car could be more severe as compared to a crash between a non-overloaded truck with the smaller vehicle because of the larger impact mass ratio between the colliding vehicles.

Data on GVW violations amongst the different truck types revealed that 50% of the 3-axle trucks are overloaded and the degree of overloading reaches 101% (Figure 2.6). More than a third of the 4-axle trucks (37%) are also overloaded and degree of overloading reaches 84% of the legal weight limit. As such, the 3-axle and 4-axle trucks may be considered as the main contributors to truck overloading occurrences in Malaysia. Furthermore, even though only 9% of the 2-axle trucks are overloaded, however, the degree of overloading ranges up to 120%!

Further analysis of the truck overloading data reveals the distribution of the degree of overloading for the four months period (Figure 2.7) for each truck category. There is a distinct difference in the distribution of the degree of overloading for the 3-axle trucks as compared to the other truck categories. While the 2-axle and 4-axle trucks degree of overloading pattern follows a negative exponential curve distribution, the 3-axle trucks degree of overloading pattern is almost similar to a skewed normal distribution with a distinct maximum point. This means that contrary to the usual anticipated situation where more cases is expected for low degree of loading as compared to the higher degrees of overloading (as shown by 2-axle and 4-axle trucks in Figure 2.7), the majority of cases for 3-axle trucks occur at much higher degree of overloading. This pattern is consistent throughout the four months period. As such, greater monitoring and weight enforcement actions and measures should be directed towards this category of trucks in the case of Malaysia.
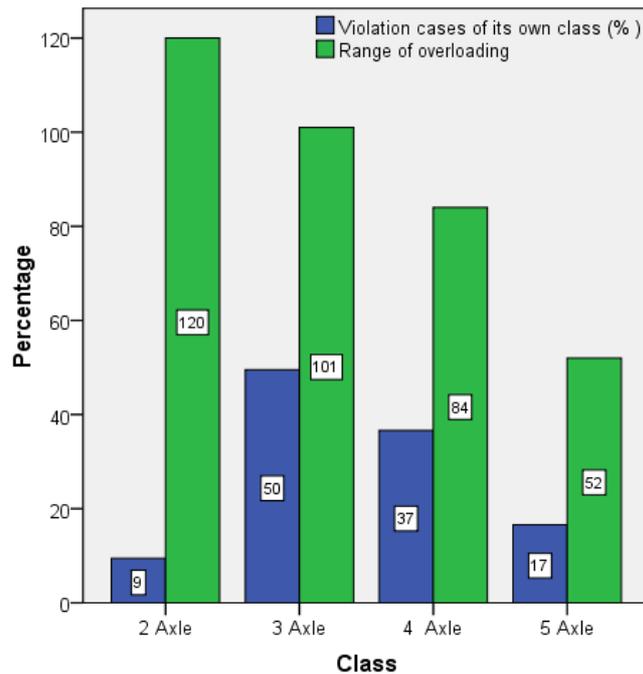
Figure 2.6. GVW violation of its own class

There are about 1.0 million registered commercial vehicles on the road in year 2008 throughout Malaysia. According to the results from this study, using four months data, it can be estimated that the average number of illegal overweight commercial vehicles was about 27% which will come out to 270,000 illegal overweight commercial vehicles. If each of these commercial vehicles makes one trip a day, there will already be that huge number of overweight commercial vehicles plying our roads daily.

One pertinent question to ask would be why is the overloading rate very high? There could be many reasons for this and probably the main reasons are as follows:

1. The payment scheme in road freight business in Malaysia is based on the number of trips. More trips to deliver goods would mean higher operating cost to truck operators. In order to reduce the number of trips, the truck operator would overload the truck so that the same amount of goods could be delivered in less number of trips. Thus, in this way the total operating cost to the truck operator would be reduced.

2. The limitations in enforcement capability (limitations from visual inspection and static weigh scale) make the intentional violators more likely to be habitual violators that overload their trucks frequently.
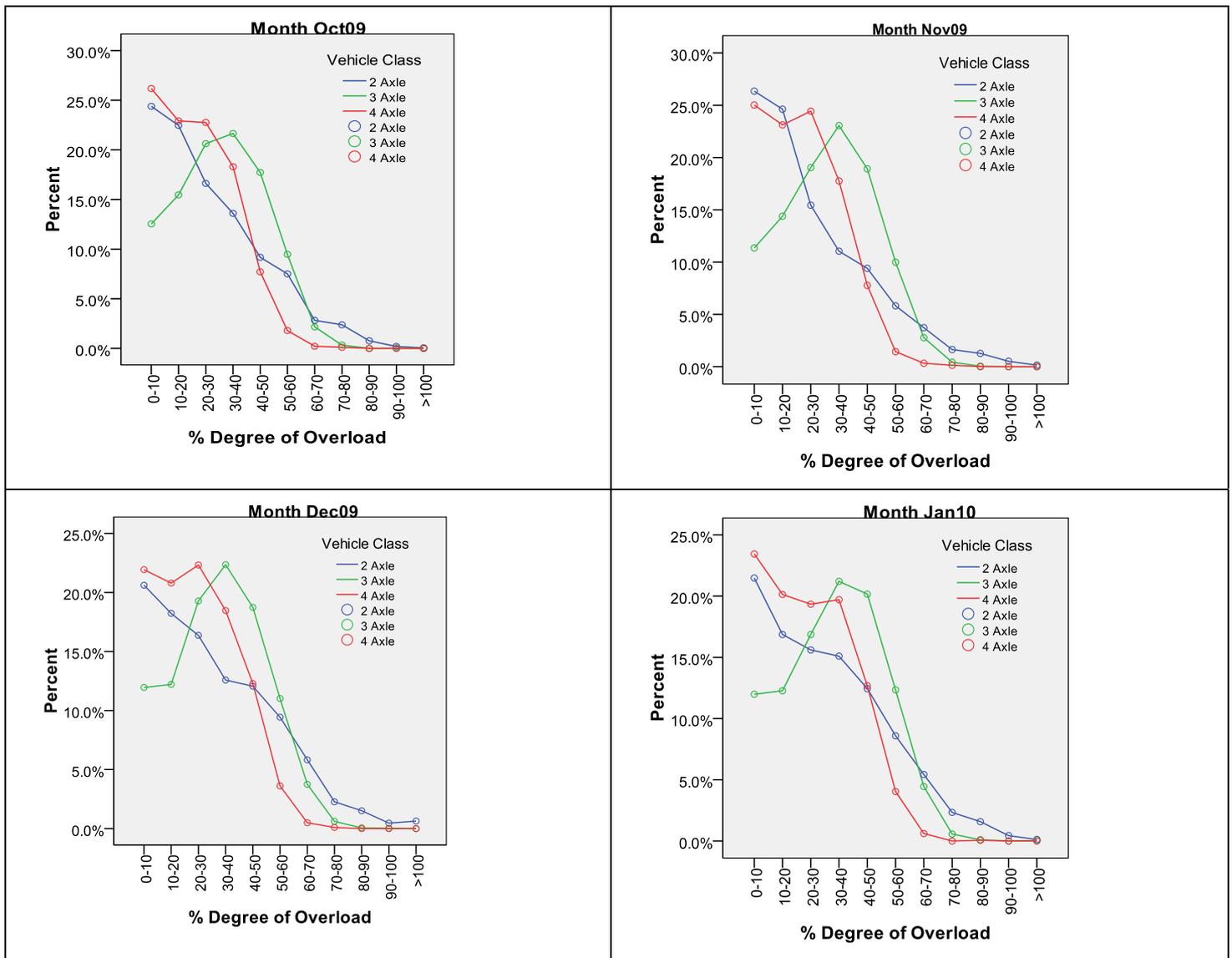
Figure 2.7. Distribution of Degree of Overloading

The Malaysian government has spent a large portion of the yearly infrastructure budget on road network and bridge maintenance. A significant amount of the total allocated budget for road maintenance could be saved if road damage caused by overweight vehicles can be avoided or at least minimized. The damage on road pavements would be accelerated as the volume of overweight vehicles increases.

In terms of safety, 25.1% of all fatal accidents in 2008 involve heavy vehicles and 45.1% of these fatal accidents occur between heavy vehicle and motorcycle. Obviously due to the large difference in impact mass ratio between the truck and motorcycle, the motorcyclist(s) will end up as fatality in the event of a crash.

The maximum stopping distance for 2-axle, 3-axle and 4-axle trucks at a certain speed (in this case 60 km/h) generated from the MSC ADAMS software is shown to vary with GVW (Figure 2.8). The higher the truck GVW the longer will be the maximum stopping distance of the trucks. Thus, in an emergency situation the overloaded truck will not be able to stop in the

same distance as a non-overloaded truck, no matter how hard the truck driver tries. On the contrary, the outcome of any crash would probably be more severe than otherwise.
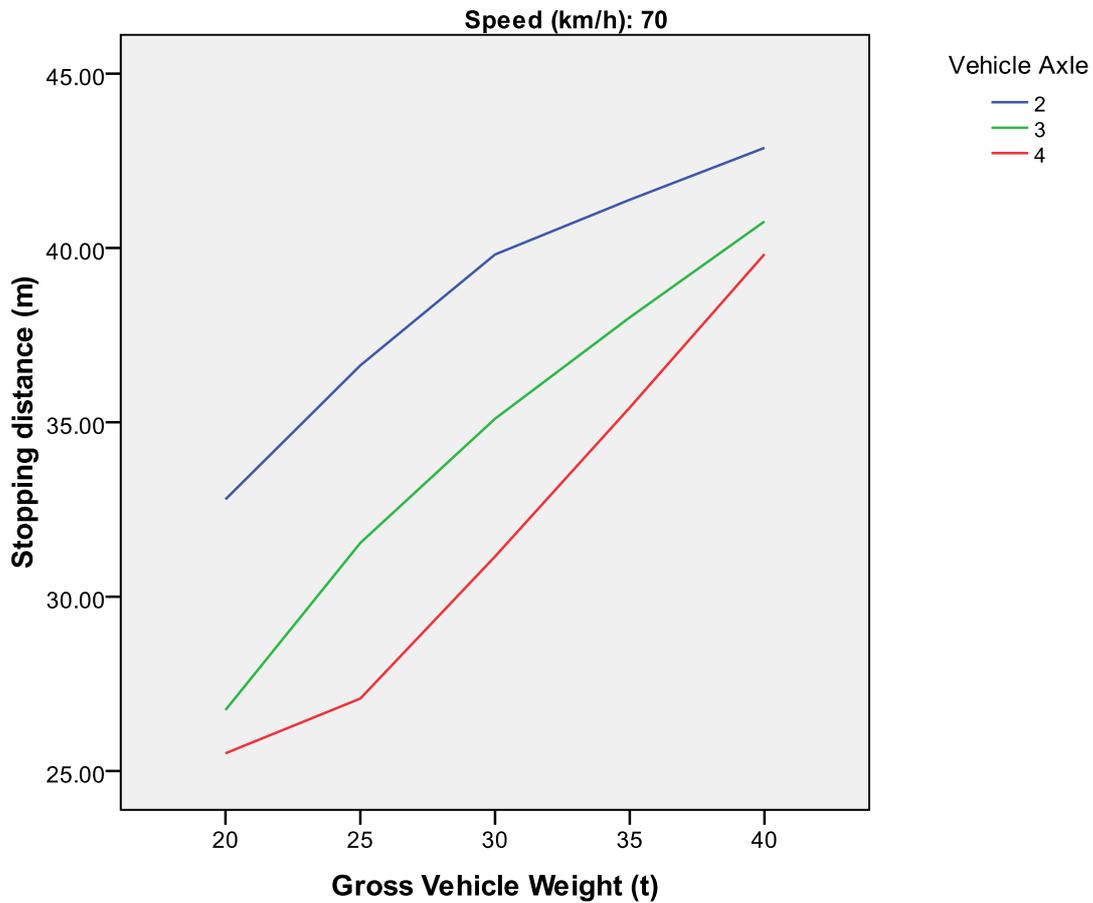
Figure 2.8. Effect of GVW on Stopping Distance for Different Truck Types

Due to the superior vehicle dynamics and braking performance characteristics of the 3-axle truck as compared to the 2-axle truck, and the 4-axle truck as compared to the 2-axle and 3-axle trucks, for any value of GVW the truck with higher number of axles will have a lower stopping distance and vice-versa. For example, a 2-axle truck overloaded with GVW of 25 tons will need around 27m to stop while a 3-axle truck with the same GVW (not overloaded) will only need around 23m to stop because of its superior vehicle dynamics and braking performance (Figure 2.8 and Figure 2.9). This clearly shows the safety implication of overloaded trucks and the higher the degree of overloading the longer will be the stopping distance. It should be mentioned that the simulation of the stopping distance is based on the ideal condition of the truck and road surface. If the truck condition is less than ideal (for e.g. poor brake condition, bad tires etc) and wet/slippery road surface, the outcome of an emergency situation may be fatal.
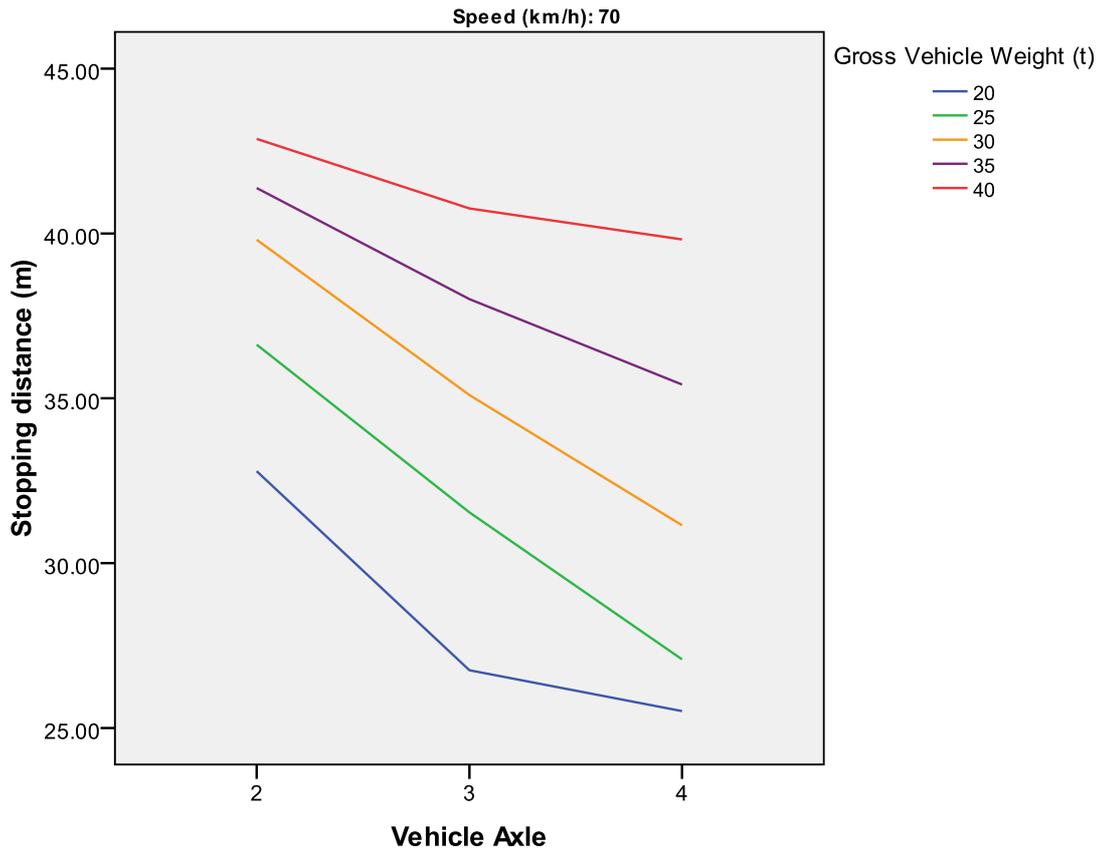
Figure 2.9. Effect of Axle Numbers on Stopping Distance

The outcome of this study has highlighted the magnitude of the problem of vehicle overloading in Malaysia. What is more worrying is the degree of overloading is extremely high, particularly for the 2-axle and 3-axle trucks. Half of the 3-axle trucks are found to be overloaded and the degree of overloading is up to 101% of its legal weight limit. Apart from the impact on pavement damage and carbon emission, vehicle overloading would lead to a more hazardous road environment because of the limitations in vehicle dynamics and braking performance of the trucks to cope with the higher demands from the excess payload. This is illustrated by studying the relationship between the maximum stopping time of each truck category (traveling at a certain speed) and the changes in GVW. As discussed earlier, vehicle overloading will lengthen the stopping distance beyond the usual case when the truck is not overloaded. If the truck driver is not aware (or unconcerned) with the need to adjust his/her driving habit, the driver may not be able to handle or maneuver the truck safely in an emergency situation. Furthermore, if the truck is not in good condition and/or the road surface is wet or slippery, the high degree of overloading may result in fatality in case of a crash.

CHAPTER 3

EFFECTIVENESS OF VEHICLE WEIGHT ENFORCEMENT IN A DEVELOPING COUNTRY USING WEIGH-IN-MOTION SORTING SYSTEM CONSIDERING VEHICLE BY-PASS AND ENFORCEMENT CAPABILITY

3.1 Introduction

Trucks or heavy vehicles are dominant in transporting goods or materials from manufacturer to wholesalers and retailers before distributing it to other small businesses and end users. Table 3.1 shows the maximum permissible laden weight for each axle class in Malaysia. The axle is an important component of a wheeled vehicle that maintains the position of the wheels relative to each other and to the vehicle body. Wheels and axles bear the weight of the vehicle including any cargo, as well as acceleration and braking forces. Section 19 (4) of the CVLB Act 1987 states that anyone who fails to comply with any condition stipulated under the CVLB license, which includes the maximum weight permissible for a lorry to carry, shall be guilty of an offence and shall, upon conviction, be liable to a fine of not less than MYR1,000 (USD 330) but not more than MYR10,000 (USD 3,300) or to imprisonment for a term not exceeding one year or both.

More than 51,045 km paved roads in Malaysia are well planned and maintained, and provide easy access throughout Malaysia (Ibtishamiah, 2007). The New Straits Times (The New Straits Times, June 22, 2010) reported that there were 19.3 million registered vehicles on Malaysia's road and the government have spent MYR5 billion (USD 1.6 billion) between 2001 to 2010 to sustain all the federal roads.

Table 3.1: Maximum Permissible Gross Vehicle Weight (GVW) by Vehicle Class

	Vehicle Class			
Gross Vehicle Weight (GVW) / tons	2 axle	3 axle	4 axle	5 axle
	16.8 tons	27.3 tons	33.6 tons	39.9 tons

Source: adapted from Saifizul et al. (2010a)

Following an attempt to reduce traffic congestion, all heavy vehicles were not permitted to enter several stretches on the North-South Expressway, starting from August 2, 2010 during morning peak hours (The Star, July 27, 2010). The ban applies to vehicles, except buses, weighing 10,000kg and above. Accordingly, those found flouting the law would be issued MYR300 (USD100) maximum fine and if offenders were to be charged in a court, they can be fined up to MYR1,000 (USD330), jailed for three (3) months or both, as stipulated under Section 70(4) of the Road Transport Act 1987 (The Malay Mail, July 26, 2010). However, such a move has very little impact since the heavy vehicles could use other alternative roads to get to their destination.

The Malaysia's manufacturing sales continued to gain positive double digit growth, an increase of 12.9% or MYR5.8 billion to reach MYR50.8 billion as compared with the same period in 2010 (Malaysia Industrial Development Authority, 2011). In order to stay

competitive and efficient in handling cargo and following the positive growth in the GDP as well as manufacturing sectors in Malaysia, many of the transport companies have adopted truck fleet that are larger in terms of both loading and size. Besides gaining more profit through the increasing sales volumes, the movements of the transport companies, especially the overloaded trucks can cause damage to the road surface such as reducing the pavement service life and overall service level of the pavement system (Zhang, 2007).

3.2 Problem of Overloaded Vehicles

Many researchers have shown that the important reason for road damage is the vehicle load (Shaopu Yang, 2010). A study by the International Road Dynamics Inc. found that 10 percent increase in weight can accelerate pavement damage by over 40 percent (Kishore and Klashinski, 2000). Furthermore, overload could cause the main part of the vehicle to be damaged and malfunction.

According to Marshek *et al.* (1986) the damages on the road pavements will not be increased by increasing the number of axles and tires per axles because the load will be distributed evenly among the axles. Another study carried out by Paul and David (1997) found that road damage is primarily caused by the heavier axle loads associated with large commercial vehicles but at the same time an increase in permitted GVW on commercial vehicles can save up to 5% in haulage cost**.** This statement was supported by Jarvis (2008) who reiterated that the increase of vehicles' GVW on highways while at the same time keeping individual axle limits at the current level, will increase productivity, fuel conservation, air quality, infrastructure conservation and public safety, and at the same time reducing the carbon emission and traffic congestion.

Another study by Ardani *et al.* (2003), found that the longitudinal cracking always occur at the middle between two tires and there are several primary cause for this situation, i.e. (i) improper construction practices, (ii) combination of heavy load repetition, and (iii) loss of foundation support due to heave caused by swelling soil.

The vehicles/trucks that violate the weight limits in Malaysia are currently determined by static weighing at designated weigh stations. Currently, there are 52 static weigh stations in operation along the country's road network. Vehicles/trucks that appear to be overloaded are first identified through manual observations by the Road Transport Department officials on patrol along public roads and these vehicles/trucks are asked to go to the specified static weigh station for the actual vehicle weight (Gross Vehicle Weight, GVW) to be determined. If the vehicle is found to be overloaded, the driver will be given a summons.

3.3 Objective of Study

The aim of this study is to identify the effectiveness of using WIM sorting system in enhancing the operations of the current static weigh station in enforcing vehicle weight limit regulations. Specifically, this study attempts to quantify the effect of overloaded vehicle bypassing the static weigh station facility as well as the enforcement capability of the weigh station system and facilities to enforce the weight limit regulations. In this study, bypass is defined as the situation when the violating trucks do not pass through the stretch of road that

has the static weigh station and WIM sorting system while enforcement capability is defined as the capability of the static weigh station system and facilities to enforce the weight limit regulations.

3.4 Methodology

Currently, enforcement officers will identify through visual assessment whether a truck is suspected to be overloaded and directed the truck to come into the static weighing facility to be confirmed whether it is overloaded or otherwise. The enforcement officers could not make all trucks to come in for weight inspection because the number of trucks is just too large. More often than not, a truck may be found to be within the legal weight limit, and the long waiting time in the long queue during inspection procedure may end up to be a waste of time and resources.

A weigh-in-motion system would be an ideal solution to this predicament. The prospect of using the WIM system has been deliberated by Saifizul et al. (2010a). Data from the WIM system has also been analysed in a previous study on differential speed limit for heavy vehicles (Saifizul et al., 2011). The WIM system was installed on a rural single carriage-way two-lane road with straight and flat road geometry, named Federal Route 54, to capture all traffic data in the westward direction (see Figure 3.1(a,b,c)). The development of this system has been customised to suit the vehicle enforcement regulation in Malaysia. Furthermore, all sensors and hardware installed have been critically chosen to be reliable in Malaysian climate and environment, especially on temperatures and lightning conditions. The data obtained for this study is for January 2010 (1 month period).
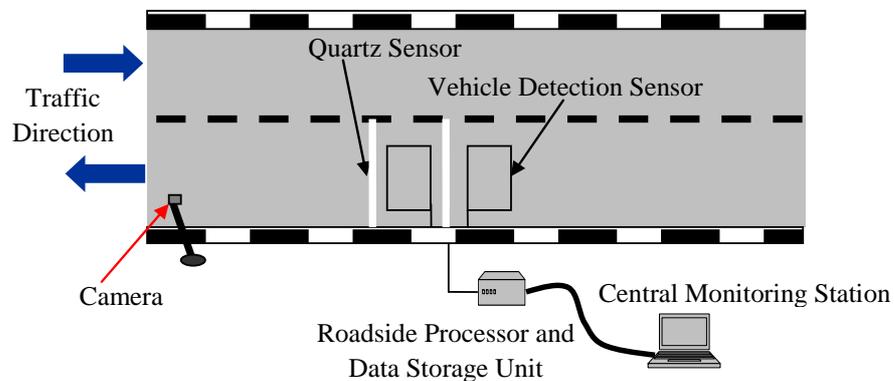
Figure 3.1(a) Layout of WIM system

Figure 3.1(b) The CPU of the WIM system

Figure 3.1(c) The WIM sensors in the road pavement

The validation exercise and accuracy of the WIM system has been proven by Saifizul et al. (2010b) in a paper presented at the ITS World Congress in Busan, Korea in 2010. In the validation exercise, comparison was made between GVW measurements made by the static weigh scale and that of the WIM system. Since the accuracy of the WIM system developed and installed at the study location is within +/-10% of the static weight, only those GVW data +10% above the legal weight limit were considered in this study.

An effectiveness study in using a WIM system as a weight screening or weight sorting facility was conducted for a period of one month in January 2010 at the static weighing station in Ijok on Federal Route 54 in Malaysia. The calibrated and validated WIM system was utilised for the purpose of identifying gross vehicle weight (GVW) violations for all categories of trucks in the traffic stream during that month.

3.5 Results

The results of the study (Table 3.2) showed that 21.5% of the total commercial vehicles exceed the permitted gross vehicle weight (GVW) limits. Since the actual volume of trucks is large and is increasing over time, the implication of this GVW limits violation in terms of pavement damage, road safety and GHG emission is expected to be huge. The government have been using public funds for road maintenance (about USD 200 million yearly) on fixing road damage in federal roads, whereas part of this money could have been used for new road infrastructure or channelled for other important development projects for the nation, if road damage from overloaded trucks could be minimised. The daily transportation activities for

heavy vehicles occur mostly during the day and up to 93.8% of GVW violation was found to occur during the day (Table 3.2). Heavy vehicle traffic vary between 900 veh/day and 1100 veh/day between Mondays to Saturdays and dropped to around 300 veh/day on Sundays (Figure 3.2). GVW violations involving heavy vehicles correspondingly follows similar pattern as shown in Figure 3.2.

Table 3.2: Gross Vehicle Weight limit violations by Heavy Vehicles

Violate		Not Violate
21.5%		
Day	Night	78.5%
93.8%	6.2%	
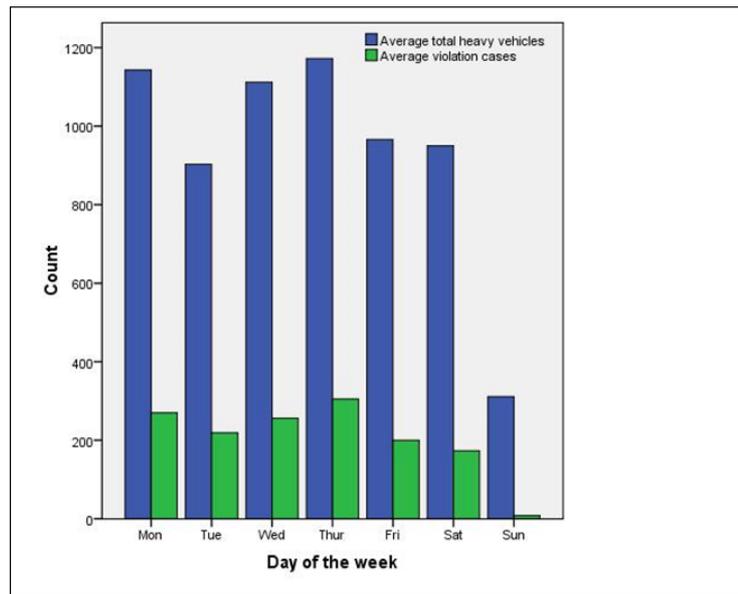
Figure 3.2: Heavy vehicles GVW violations by day of the week
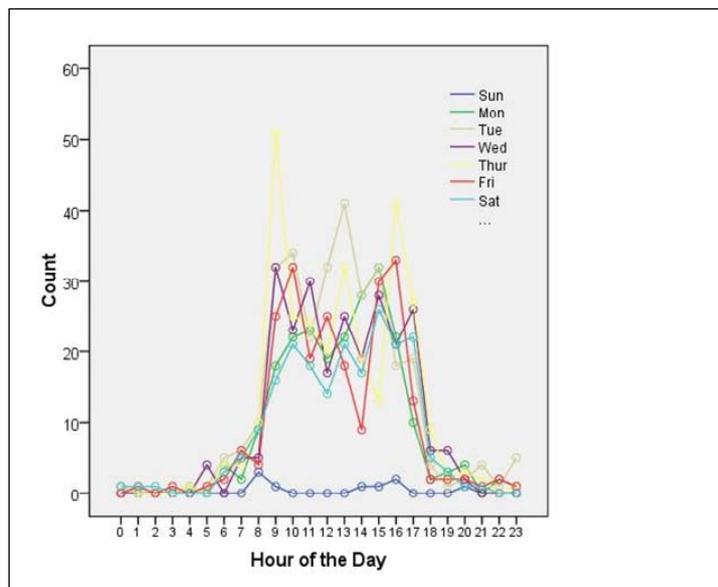
Figure 3.3: GVW violation cases by hour of the day (Jan 2010, 1st week)

Distribution of GVW violations involving heavy vehicles according to the hour of the day in each day of the week is also obtained during the study as shown in Figure 3.3. The GVW violation cases increased significantly after 8 am and remain in the range of 15-30 GVW violations per hour till 5 pm in the afternoon for each day of the week except Sundays. This information may be useful in planning for effective manual GVW enforcement activities.
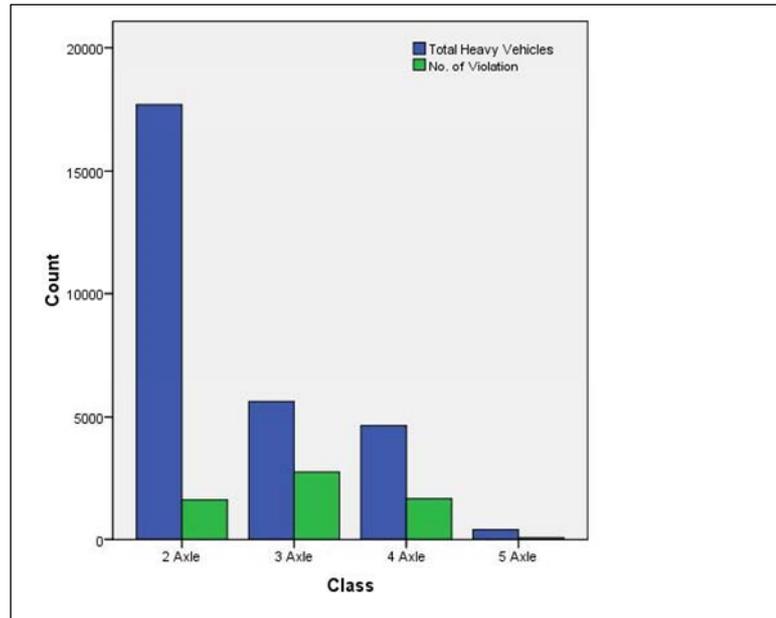
Figure 3.4: GVW violations according to Heavy Vehicle class

The WIM system employed in this study also captures GVW violations according to heavy vehicle class (Figure 3.4). Although the 2-axle trucks form the majority of trucks the GVW violations occur more from amongst the 3-axle and 4-axle trucks. As such more emphasis on GVW enforcement may be directed towards the 3-axle and 4-axle trucks as compared to 2-axle trucks.

3.6 Discussion

All aforementioned figures are examples on how a WIM system may assist enforcement efforts through an automated weight screening process. This automated screening process can provide preliminary dynamic weight data which can be used to automatically screen and sort overloaded vehicles. The overloaded vehicles will be directed to a nearby static enforcement station for enforcement purposes. The results in this study also indicate that the daily pattern of vehicle overloading and number of violation cases is consistent throughout the month.

Table 3.3 shows the effectiveness analysis of WIM based weight sorting as compared to existing system by assuming that all overloaded vehicles detected by WIM system are directed to static weigh station and summoned. The existing system employs enforcement officers who move on special vehicles and visually identify heavy vehicles which looked overloaded and direct those drivers into the static weighing facility to weigh the vehicles. If

the vehicles are found to be overloaded the driver will be issued a summons, otherwise the vehicle will be allowed to leave. This mechanism of manual enforcement have not been very effective since more than 50% of the time the heavy vehicle was found to be within the legal GVW limit. The limitations of manpower and time have also limit the number of GVW violations recorded per month to only around 126 cases (Table 3.3).

Table 3.3: Effectiveness analysis of WIM system (Jan 2010)

	WIM	Existing (Static Weigh Station)
Total number of commercial vehicles	28,359	No Data
Total violation cases	6,101	126
Revenue (USD) generated by penalty fine (USD 100 per summon)	**610,100**	**12,600**

Note: 1USD = RM 3

The study found that with the use of the WIM system as a weight sorting device, the GVW violations for the same period increased to 6,101 cases (compared to 126 cases) after correcting for percentage error of the WIM system. The effectiveness of using a WIM system for sorting vehicle GVW prior to a static weigh station is certainly very obvious from this finding. The revenue generated from penalty with the WIM sorting system in place would be far greater than existing (see Table 3.3). This new source of revenue may be used for road maintenance purposes (which currently comes from taxpayers money) or for other purposes such as infrastructure development, education, health, housing or other necessary development for the nation.

This study also explore the effect of truck drivers bypassing the static weigh station which has the WIM sorting system (because of alternative routes) as well as the limitation in enforcement capabilities of the weigh station such as in terms of human resources and facilities to enforce all violated vehicles identified by the WIM system. Vehicle bypassing the static weigh station can happen if there will be alternative routes for the driver to avoid being summoned. The limitations in existing static weigh station enforcement capability; on the other hand, can be caused by the limited number of static weigh scale, lack of parking space, lack of enforcement officers and some other technical reasons. Enforcement capability refers to the capability of the static weigh station system and facilities to enforce the weight limit regulations. As such, a 100% enforcement capability would mean that all trucks with weight violations will be given the summons while a 20% enforcement capability would mean that only 20% of the violating trucks will be given the summons. This situation is investigated in this study by considering the relationship among violation cases, percentage of truck drivers bypassing the WIM system and percentage of static weigh station enforcement capabilities.

The relationship among the calculated violation cases at static weigh station, percentage of vehicle bypass the WIM system and percentage of enforcement capability are based on the assumption that a linear relationship exists among them. These relationships can be derived as follows:

$$y_1 = -a_1 x_1 + b \qquad (3.1)$$

where,

y_1 is the number of overloaded vehicles detected by WIM system,

x_1 is the percentage of vehicle bypass the WIM system,

a_1 is a regression coefficient,

b is the total actual violation cases

and

$$y_2 = -a_2(1 - x_2) + y_1 \quad (3.2)$$

where,

y_2 is the total calculated violation cases at static weigh station,

x_2 is the enforcement capability (in percentage) at static weigh station,

a_2 is a regression coefficient

Replacing Equation (3.1) into Equation (3.2), the simplified relationship is expressed in Equation (3.3).

$$y_2 = -a_2(1 - x_2) - a_1 x_1 + b \quad (3.3)$$

However, determination of regression coefficients for model in Equation (3.3) cannot be derived in this study due to limited empirical data of y_2, x_1 and x_2. Hence, based on percentage reduction method, the model in Equation (3.3) is simplified as follows:

If it is assumed that, $a_1 = b$ and $a_2 = y_1$, then Equation (3.3) can be expressed as

$$y_2 = (1 - x_1)bx_2 \quad (3.4)$$

Based on Equation (3.4) and total actual violation cases at the selected site in this study, the calculated violation cases at static weigh station considering vehicle bypass and enforcement capability factors are shown in Table 3.4.

Table 3.4: Calculated violation cases according to percentage bypass and enforcement capability

Capability (%)						100					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	6101	5491	4881	4271	3661	3051	2440	1830	1220	610	0
Capability (%)						90					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	5491	4942	4393	3844	3295	2745	2196	1647	1098	549	0
Capability (%)						80					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	4881	4393	3905	3417	2928	2440	1952	1464	976	488	0

Capability (%)						70					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	4271	3844	3417	2989	2562	2135	1708	1281	854	427	0
Capability (%)						60					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	3661	3295	2928	2562	2196	1830	1464	1098	732	366	0
Capability (%)						50					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	3051	2745	2440	2135	1830	1525	1220	915	610	305	0
Capability (%)						40					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	2440	2196	1952	1708	1464	1220	976	732	488	244	0
Capability (%)						30					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	1830	1647	4881	4271	3661	3051	2440	1830	1220	610	0
Capability (%)						20					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	1220	1098	976	854	732	610	488	366	244	122	0
Capability (%)						10					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	610	549	488	427	366	305	244	183	122	61	0
Capability (%)						0					
Bypass (%)	0	10	20	30	40	50	60	70	80	90	100
Violation cases	0	0	0	0	0	0	0	0	0	0	0

Based on existing static weigh station operations, only 126 vehicles were summoned in the month of January 2010. By using WIM sorting system, as shown in Table 3.4 above, the same number of violation cases would be achieved in the situation when almost 80% of overloaded vehicles (i.e. 4881 vehicles) were to bypass the WIM system and only 10% of the remaining (i.e. 10% out of 1220 vehicles) will be directed to the existing static weigh station due to limitations in enforcement capability. What this means is that with the use of the WIM sorting system, the static weigh station can afford to function at 10% enforcement capability and allow 80% of the overloaded trucks to by-pass the static weigh station (which include the WIM system) and yet able to achieve almost the same number of overloaded trucks to be summoned as what they are currently getting.

The payment scheme in road freight business in Malaysia is based on the number of trips. The more trips to deliver goods means the higher operating cost to truck operators will be. In order to reduce the number of trips, the truck operator would overload the truck so that the same amount of goods could be delivered in less number of trips. Thus, by doing this the total operating cost to the truck operator can be reduced. So if the purpose of overloading is to

save the total operating cost by reducing the number of trips, many of them would prefer to pay the penalty rather than taking the longer and hassle-prone alternative routes. Other factors such as road category, location and traffic direction need to be considered so that a more generic and robust analysis on the relationship can be achieved. The relationship from the model is very useful for enforcement agencies to make prediction and to come out with a proper enforcement strategy.

CHAPTER 4

MINIMUM SAFE TIME GAP (MSTG) AS A NEW SAFETY INDICATOR INCORPORATING VEHICLE AND DRIVER FACTORS

4.1 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

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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).

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

4.2 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 4.1) 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.
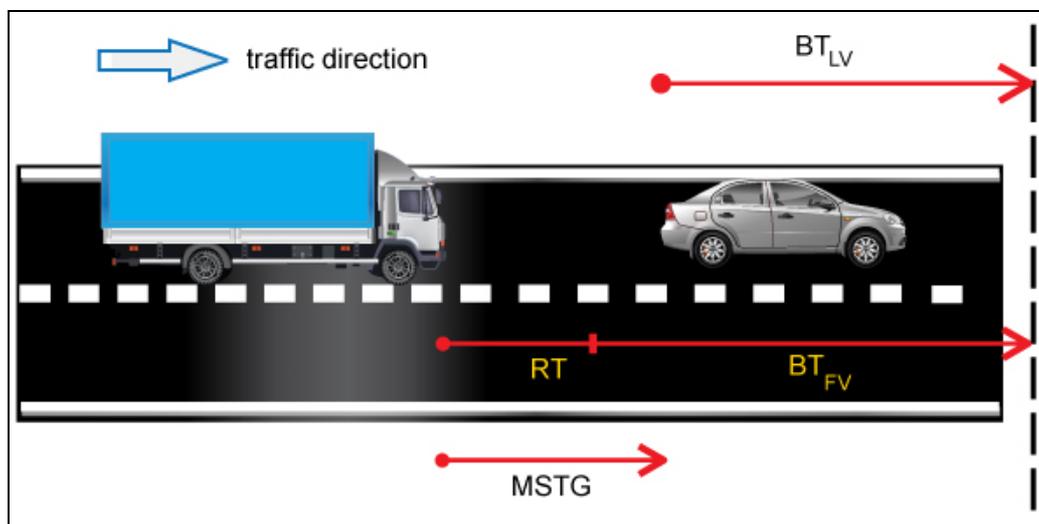
Figure 4.1. Concept of Mean Safe Time Gap (MSTG)

Figure 4.1 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:

$$MSTG = BT_{FV} - BT_{LV} + RT \qquad (4.1)$$

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 4.2.

<table>
<tr><td align="center">Vehicle</td><td align="center">Road Condition</td></tr>
<tr><td>

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

</td><td>

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

</td></tr>
</table>

Figure 4.2. 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 4.1.

Table 4.1. 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 4.3.

<table>
<tr><td align="center">Physical Abilities</td><td align="center">Psychological</td></tr>
<tr><td>

- Age
- Gender
- Skill
- Profession
- Driving experience

</td><td>

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

</td></tr>
</table>

Figure 4.3. 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.

4.3 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 4.4.
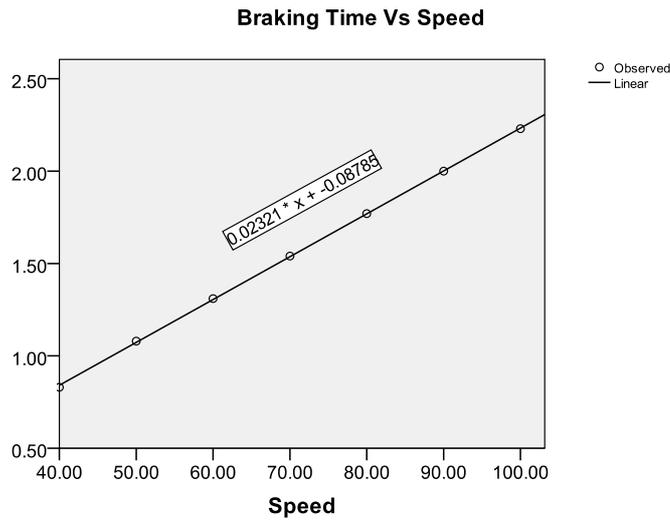
Figure 4.4. Effect of speed on braking time (BT) of passenger car

Based on Figure 4.4 plots, a braking time models for passenger car (sedan) with various travel speed can be expressed as follows:

$$BT_c = 0.02321v - 0.08785 \tag{4.2}$$

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 4.5(a),(b),(c).
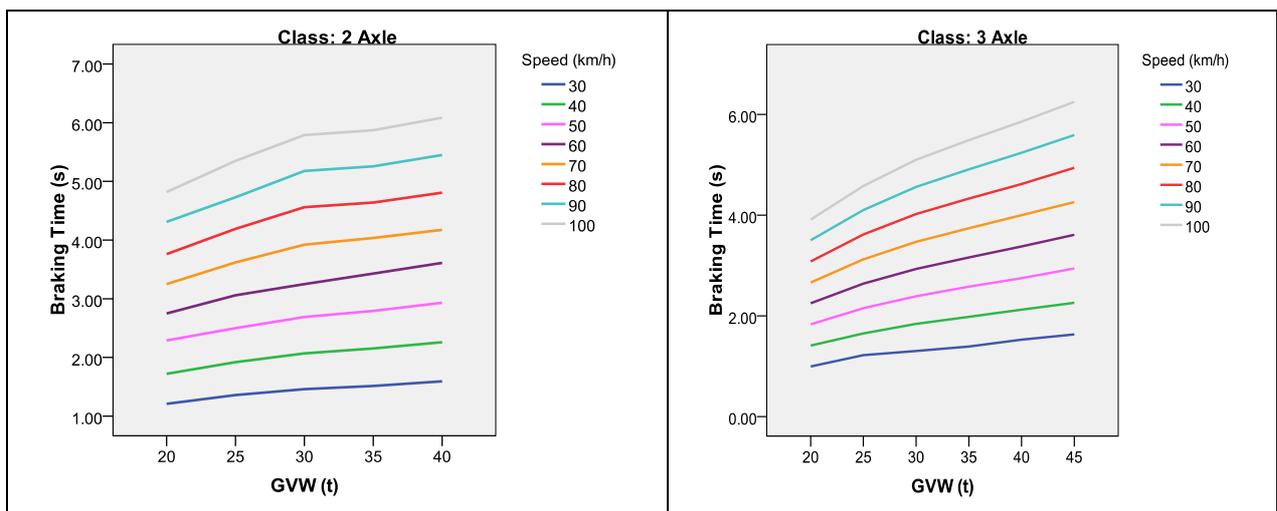
Figure 4.5(a). Effect of vehicle type/class (2-axle, 3-axle), speed and GVW on braking time (BT) of single unit truck (SUT)
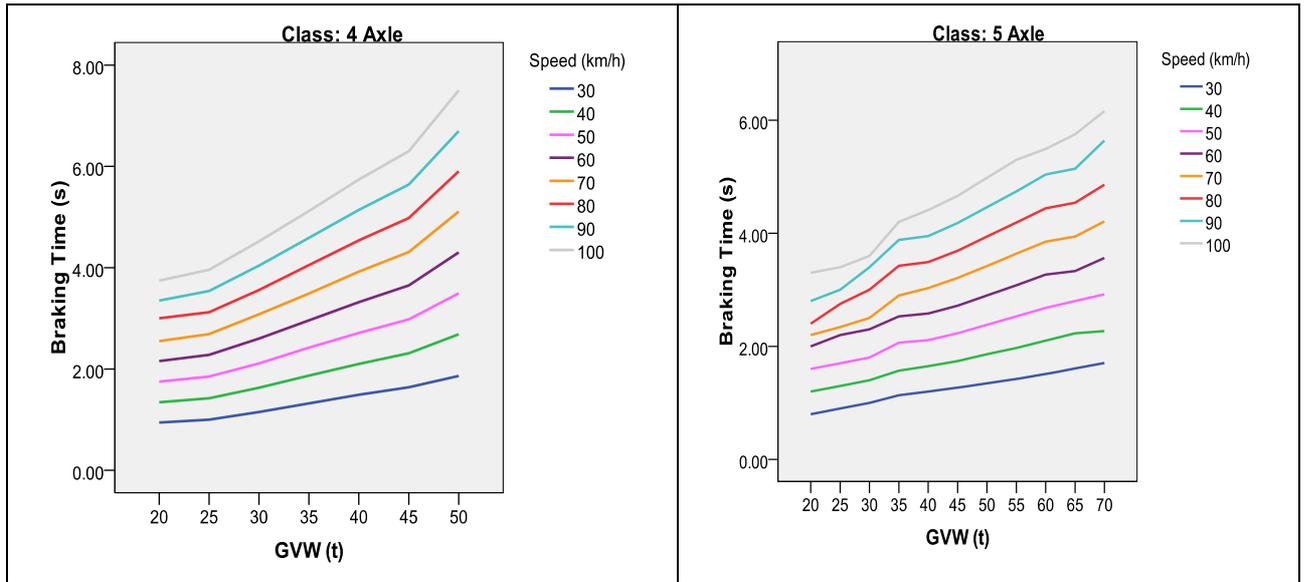
Figure 4.5(b). Effect of vehicle type/class (4-axle, 5-axle), speed and GVW on braking time (BT) of single unit truck (SUT)
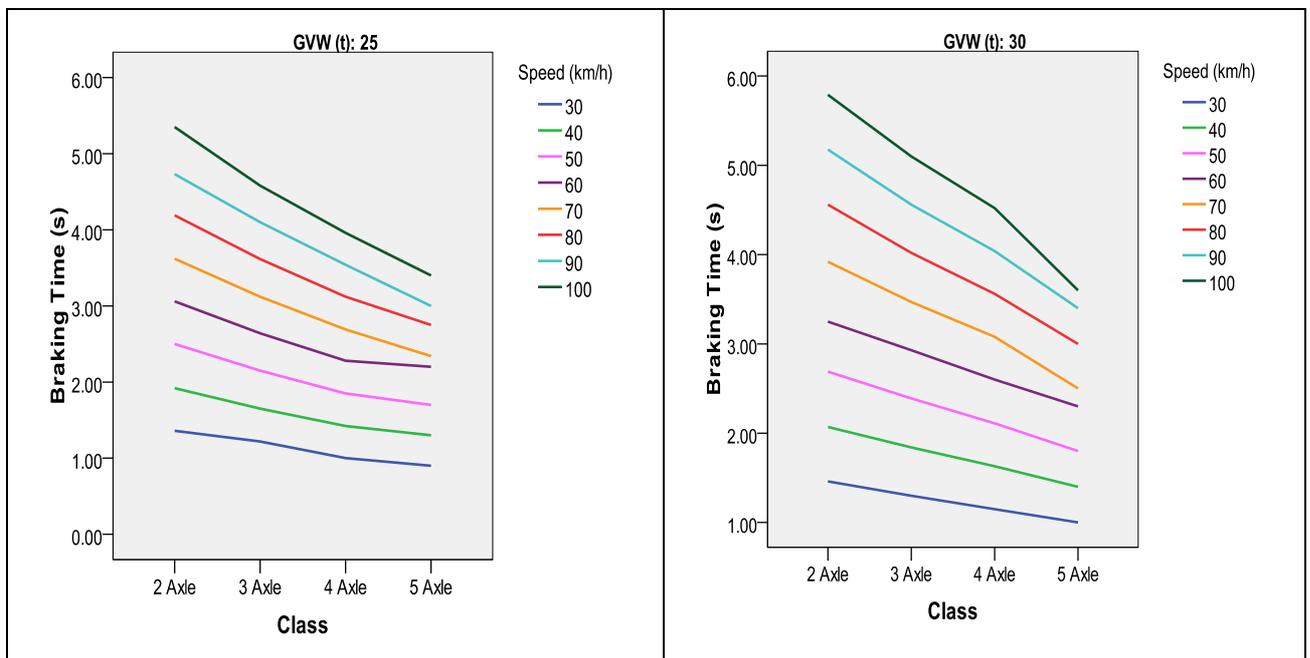
Figure 4.5(c). Effect of vehicle type/class (2-, 3-, 4-, 5-axle), speed and GVW (25t, 30t) on braking time (BT) of single unit truck (SUT)

Based on line graph plot in Figure 4.5(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 4.5(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 4.5(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 4.5(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:

$$BT_t = aw + b \qquad\qquad (4.3)$$

where $\quad a = C_1v + C_2$
$\qquad\quad b = C_3 + C_4$

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 (4.3) for various speed. The values of these coefficients and coefficients of determination, R^2 for all cases are described as in Table 4.2.

Table 4.2: 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
	30	0.017	<0.001	0.476	<0.001	0.995
	40	0.022	<0.001	0.757	<0.001	0.996
	50	0.027	<0.001	1.041	<0.001	0.995
5 axle	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

(N = 11 for 5 axle)

Another regression was done to determine the coefficients of the regression lines, C_i where $i = 1, 2, 3$ and 4 in Equation (4.3) and coefficients of determination, R^2 for all cases are described as in Table 4.3.

Table 4.3: 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 4.3 indicate a positive-straight-line or linear relationship between braking time and GVW. In this case, braking time will increase as GVW increases for medium or high speed cases. The braking time variation is small for low speed case. Table 4.3 also indicate that the estimate of the slope and intercept for Equation (4.3) is significantly different from zero and the model adequately describe the data (for each vehicle type, $p < 0.001$ except for intercept of equation *a* (for 2-axle and 5-axle) and intercept for equation *b* (for 5-axle).

Using Equation (4.1), (4.2) and (4.3) 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.

CHAPTER 5

AN INVESTIGATION ON SAFETY PERFORMANCE ASSESSMENT OF CLOSE-FOLLOWING BEHAVIOR OF HEAVY VEHICLE USING EMPIRICAL-SIMULATION TECHNIQUE

5.1 Introduction

It is very crucial for drivers to keep a safe following time gap in order to prevent a rear-end collision with the vehicle in front. The time gap should be sufficient for the reaction time and stopping time.

With the increase of in-vehicle electronic gadget for information and entertainment, the risk of rear-end collisions may increase in the near future. Young and Salmon (2012) stated that driver distraction may contribute to errors through a range of means: by affecting cognitive processes such as perception, planning, decision making, and situation awareness, as well as by interfering with vehicle control tasks. Therefore, distractions such as glance to the other side, making phone calls, playing with electronic gadgets and searching for directions should be avoided as it may cause delay in response time and increase the risk of a collision. In addition, a case study found that there is also the effect of behaviour compensation: drivers start to take more risks (e.g. higher speeds, shorter distance headways, etc.) because they feel safer in a car with certain safety features (SWOV, 2010). As a result, the advanced safety features may not necessarily be able to protect drivers from involving in crashes.

Theoretically, higher travelling speed requires longer time gap. Piao and McDonald (2003) revealed more variability of distance gap between vehicles in high speed situations than in low speed situations. However, heavy vehicles (HVs) usually require larger time gap compared to other types of road users. According to Manitoba Public Insurance (2008), the stopping time for trucks using air brake systems consists of one additional variable which is brake lag. Brake lag refers to the time air takes to travel through a properly maintained air brake system, approximately 4/10 of a second. Dey and Chandra (2009) also revealed the maximum desired time gap for tractors in relation to the 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.

Close-following behavior in a traffic stream may be of serious concern when heavy vehicles are involved. Accident data has shown that a significant proportion of fatal accidents involving trucks and buses in Malaysia are the rear-end collision type (see Figures 5.1 & 5.2). As such, the objective of this study is to investigate the safety performance of truck-following-car under various truck type, GVW and travel speed. The study focuses on two aspects, namely, the frequency of unsafe behavior and the degree of the unsafe behavior of the truck-following-car situation on specific road segments. This can be achieved by comparing the empirical time gap data to the minimum safe time gap (MSTG) required for a truck of a certain GVW travelling at a particular speed in a truck-following-car situation. The concept of MSTG will be further explained in the next section. Based on this approach, a possible safety performance assessment technique is proposed.
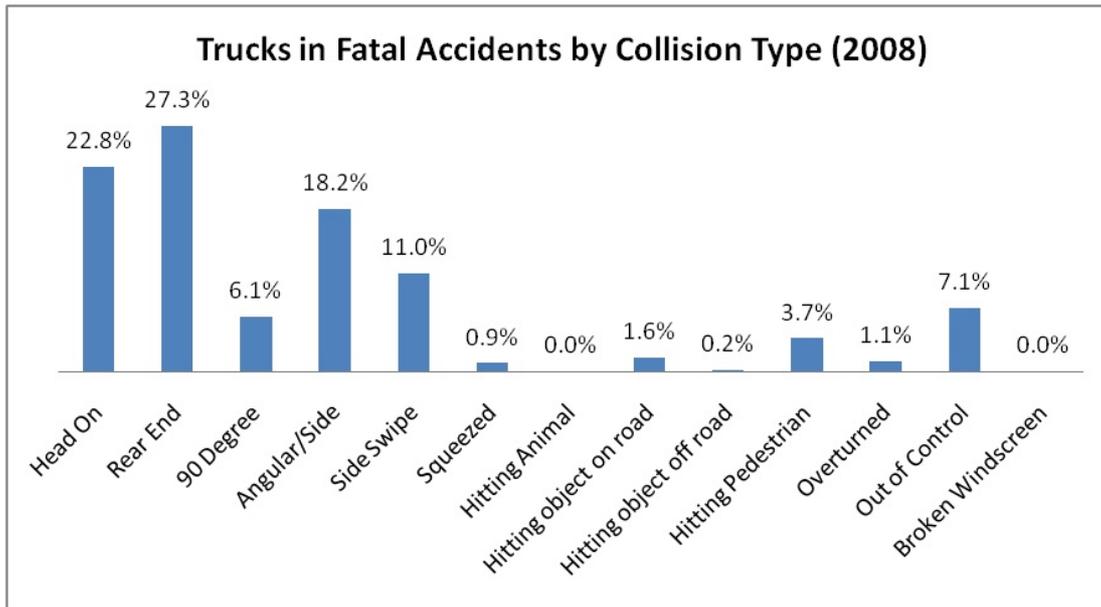
Figure 5.1. Trucks in fatal accidents by collision type (2008)
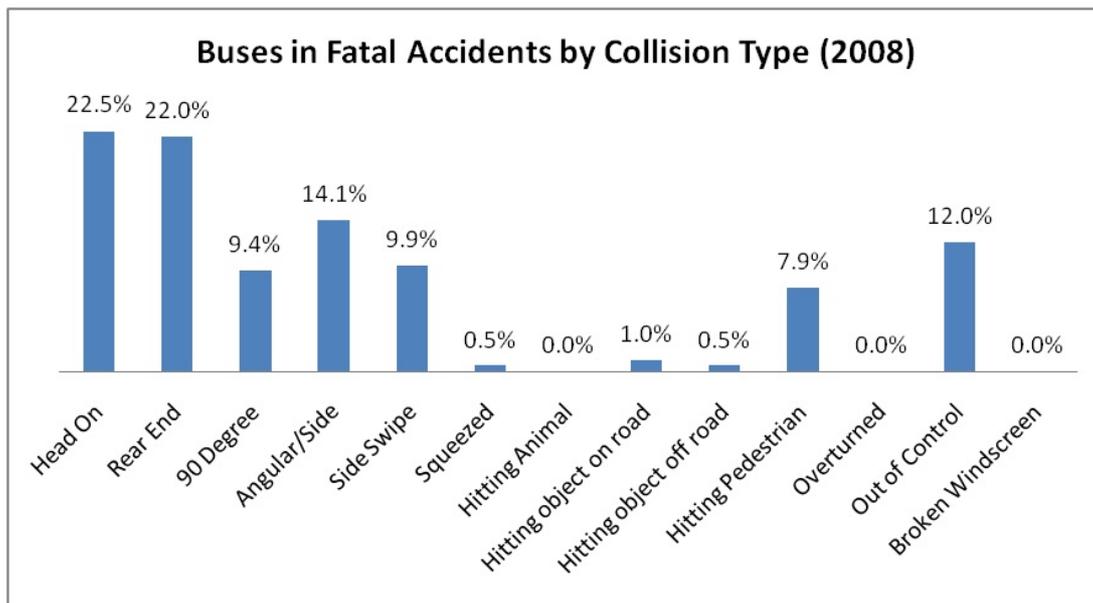
Figure 5.2. Buses in fatal accidents by collision type (2008)

5.2 Proposed Empirical-Simulation Safety Performance Assessment Technique

The proposed safety performance assessment technique is introduced to investigate the safety performance in vehicle following situation. The main vehicle parameters which have not been explicitly considered in previous safety indices, namely the gross vehicle weight (GVW) and vehicle braking performance will be included in the analysis and development of the safety performance assessment technique.

Keeping a safe following distance from the front vehicle is critical for mitigating rear-end crashes in truck-following-car situation since it allows the truck 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 5.3) is obtained by considering the braking time of the following truck (BT_{FV}) and the leading car (BT_{LV}) as well as the perception-reaction time of the truck driver (RT). Both the braking time of the following truck and leading car are generated from simulation using the MSC ADAMS software which incorporates vehicle characteristics including vehicle type and braking performance. As such, the MSTG considers both the truck drivers characteristics as well as the truck characteristics (such as truck type, braking performance, GVW and speed). Changes in truck characteristics, say for example the truck GVW, will affect the truck braking performance and its ability to safely stop in an emergency situation, hence affecting the BT_{FV} and MSTG. Similarly, the truck driver's physical and mental condition will affect the perception-reaction time (RT), hence affecting the MSTG.
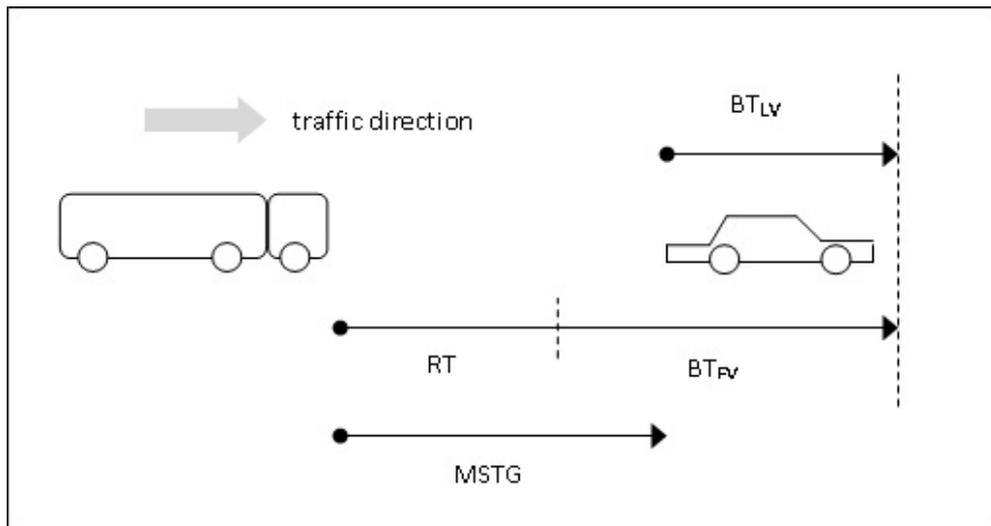
Figure 5.3. Concept of Mean Safe Time Gap (MSTG)

The MSTG incorporating GVW and travel speed of trucks following passenger car can be expressed as follows:

$$MSTG = BT_{FV} - BT_{LV} + RT \qquad (5.1)$$

where,

  RT is truck driver's reaction time (1.5 seconds will be adopted),
  BT_{FV} and BT_{LV} are braking time of following truck and leading car, respectively

Actual time gap data for truck-following-car is obtained through empirical study on specific locations along a road network. The empirical time gap data for various following truck type, GVW and speed will be analysed for the purpose of comparison with the respective *MSTG* data.

In the interest of measuring safety performance related to close following behavior in a selected traffic stream, the concept of safe vehicle-following behavior (actual time gap is more than *MSTG*) and unsafe vehicle-behavior (actual time gap is less than *MSTG*) may be explained through the sketch of the empirical-simulation plot shown in Figure 5.4.

The frequency of unsafe behavior in truck-following-car situation is based on the comparison between the numbers of cases where the actual time gap is less than the *MSTG*. The degree of unsafe behavior in truck-following-car situation is based on the comparison of the deviation of mean time gap from the *MSTG* for each cluster of vehicle class, speed and truck GVW. The frequency of unsafe behavior referred to as "unsafe occurrence" (*UO*) and the degree of the unsafe behavior referred to as "unsafe deviation" (*UD*) on specific road segments may be assessed.
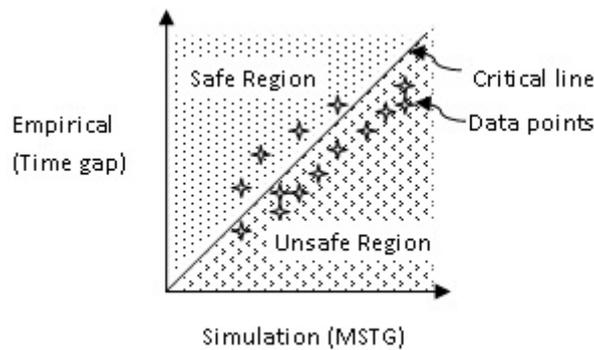
Figure 5.4. Sketch of empirical-simulation plot for time gap and MSTG

Based on Figure 5.4, the unsafe occurrence (*UO*) may be calculated by dividing number of points in the unsafe region by total data points as given in Equation (5.2).

$$UO = \frac{No. \, of \, Data \, Points \, in \, Unsafe \, Region}{Total \, Data \, Points} \times 100 \qquad (5.2)$$

The value of *UD* is calculated as follows:

$$UD = MSTG - MUTG \qquad (5.3)$$

where,
    UO is in percentage and *UD* is in seconds,
    MUTG is the mean unsafe time gap in seconds.

5.3 An Illustrative Example

To illustrate the application of the proposed safety performance assessment technique, a case study was conducted on a rural two-lane highway in the state of Selangor in Malaysia. The empirical data is collected for a four months period using a weigh-in-motion system and the simulation data is obtained using the MSC ADAMS software.

5.4 Simulation Data and Analysis

Close following has been identified as one of the most important contributors to rear-end collisions. Most of the time vehicle dynamics influence driver behavior in controlling their vehicles. Thus, braking performance parameters such as stopping time, stopping distance and deceleration are essential parameters in close-following study. In a truck-following-car situation, there are significant dissimilarities in terms of braking performance characteristics.

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.

In this study, MSC ADAMS software has been used to generate stopping time data for passenger cars and trucks under various loading and speed condition. Since the aim of the study is to investigate the safety performance of truck drivers in an actual truck-following-car situation, it is important to develop more realistic simulated truck model. Thus, in this study, the truck model and its specification for 2-axle, 3-axle and 4-axle truck has been developed in accordance to prevalent truck 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, the trucks with air drum brake and parabolic leaf spring suspension have adequate braking force. The road profile is flat and straight road condition where differences in road materials and stiffness are not significant.

Simulation data on leading car braking time (BT_{LV}) is shown in Table 5.1 while the following truck braking time (BT_{FV}) for 2-axle, 3-axle and 4-axle trucks are shown in Table 5.2, Table 5.3 and Table 5.4 respectively.

Table 5.1. Braking Time of Passenger Car (Sedan)

	Speed (km/h)		
	50	60	70
Braking time, BT_{LV} (s)	1.08	1.31	1.54

Table 5.2. BT_{FV} and MSTG for 2-Axle Trucks

Axle	Speed (km/h)	GVW (t)	BT_{FV} (s)	MSTG (s)
2	50	20	2.29	2.71
		25	2.50	2.92
		30	2.69	3.11
	60	20	2.75	2.94
		25	3.06	3.25
		30	3.25	3.44
	70	20	3.25	3.21

Table 5.3. BT_{FV} and MSTG for 3-Axle Trucks

Axle	Speed (km/h)	GVW (t)	BT_{FV} (s)	MSTG (s)
3	50	20	1.83	2.25
		25	2.15	2.57
		30	2.39	2.81
		35	2.58	3.00
		40	2.75	3.17
	60	20	2.25	2.44
		25	2.64	2.83
		30	2.93	3.12
		35	3.16	3.35
		40	3.38	3.57
	70	20	2.66	2.62
		25	3.12	3.08
		30	3.47	3.43
		35	3.74	3.70
		40	4.00	3.96

Table 5.4. BT_{FV} and MSTG for 4-Axle Trucks

Axle	Speed (km/h)	GVW (t)	BT_{FV} (s)	MSTG (s)
4	50	20	1.75	2.17
		25	1.85	2.27
		30	2.11	2.53

	35	2.42	2.84
	40	2.71	3.13
	20	2.16	2.35
	25	2.28	2.47
60	30	2.60	2.79
	35	2.96	3.15
	40	3.32	3.51
	20	2.55	2.51
	25	2.69	2.65
70	30	3.08	3.04
	35	3.49	3.45
	40	3.92	3.88

Using equation (5.1) the respective values of MSTG are determined for the different truck types travelling at three different speeds with different GVWs. As would be expected the MSTG varies for the different combinations of truck type, truck GVW and travel speed. In general, it is worth noting that for a particular truck type, say the 3-axle truck, travelling at a particular speed, say 60 km/h, the truck braking time (BT_{FV}) will increase as the GVW increases. It means that as the GVW of the truck 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 truck is carrying higher payload than usual. The truck driver would need to understand this in order to avoid rear-end collision in emergency situation.

5.5 Empirical Data Collection and Analysis

Time gap data together with all other traffic and vehicular data such as GVW, wheelbase and vehicle class were obtained from a weigh-in-motion (WIM) system installed on Route 54 in the state of Selangor in Malaysia. The WIM system was installed next to a static weight station operated by the Road Transport Department of Malaysia. The road type is rural single carriageway with standard width and layout and having a straight geometry in a flat terrain as shown in Figure 5.**5**. Further elaboration of the WIM system is presented in Saifizul et al. (2010b)

Figure 5.5. The data collection site with WIM system installation

In this study, data was collected for four months from the system. In order to remove the influence of the surroundings and focus on the driver behavior and vehicle performance capability in a vehicle following situation, data were filtered based on the following conditions:-

- Dry weather condition
- Daytime from 7am (after sunrise) and before 7 pm (before sunset)
- No change in the infrastructure and surrounding at the site
- Time headway less than 4 s [16]

By limiting the number of samples consisting of small relative speed between leading and following vehicle, the time gap data for 2-axle, 3-axle and 4-axle trucks that passed the filtering stage of this study consisted of 3,743 observations. The time gap data are then grouped according to leader-follower pair composition, GVW and vehicle class (the heavy vehicle is classified based on their number of axles). In this study, only truck following passenger car pairs will be investigated. The analysis of results is presented based on the assumption that all the vehicles travel in one lane without overtaking.

For the case of 2-axle trucks following cars, the occurrence and frequency of unsafe time gap (UO) are shown in Table 5.5 while cases involving 3-axle trucks and 4-axle trucks following cars are shown in Table 5.6 and Table 5.7 respectively. As explained earlier, the UO is obtained by comparing the actual time gap and the MSTG for each vehicle class (truck type), speed range and GVW range, and all actual time gaps which are less than the MSTG will be considered unsafe time gap (UO). The mean of the unsafe time gaps (MUTG) for each truck type, speed range and GVW range are also given in Tables 5.5, 5.6 and 5.7.

Table 5.5. Unsafe Occurrence (UO) and Mean Time Gap of UO Cases for 2-Axle Trucks

Class	Speed	GVW	Total Cases	UO (cases)	UO (%)	MUTG (s)
2	45-55	17.5-22.5	151	88	58.3	1.78
		22.5-27.5	95	61	64.2	1.86
		27.5-32.5	24	18	75.0	2.13
	55-65	17.5-22.5	168	99	58.9	1.93
		22.5-27.5	128	93	72.7	2.04
		27.5-32.5	28	20	71.4	2.16
	65-75	17.5-22.5	17	10	58.8	2.02

Table 5.6. Unsafe Occurrence (UO) and Mean Time Gap of UO Cases for 3-Axle Trucks

Class	Speed	GVW	Total Cases	UO (cases)	UO (%)	MUTG (s)
		17.5-22.5	34	15	44.1	1.53
		22.5-27.5	86	53	61.6	1.67
	45-55	27.5-32.5	116	71	61.2	1.80
		32.5-37.5	212	141	66.5	1.95
		37.5-42.5	152	115	75.7	2.00
		17.5-22.5	84	44	52.4	1.70
		22.5-27.5	152	89	58.6	1.91
3	55-65	27.5-32.5	195	139	71.3	2.01
		32.5-37.5	384	300	78.1	2.16
		37.5-42.5	276	233	84.4	2.43
		17.5-22.5	22	12	54.5	1.75
		22.5-27.5	33	20	60.6	2.28
	65-75	27.5-32.5	43	30	69.8	2.36
		32.5-37.5	55	44	80.0	2.40
		37.5-42.5	27	26	96.3	2.71

From the observed data it is quite apparent that for each truck type and speed range, both the UO percentage and MUTG increases as the truck GVW increases. This means that there are relatively more occurrences of unsafe time gaps as the truck GVW increases. This implies that the truck driver is generally insensitive to the need to adjust his/her driving behavior (in this case, truck following car behavior) as the truck GVW increases. It may also imply that the truck drivers are over confident in their ability to handle the truck even though they are carrying higher payloads than usual. The MUTG will be compared with the respective MSTG to determine the degree of deviation of MUTG from the MSTG and this will be discussed in the next section.

Table 5.7. Unsafe Occurrence (UO) and Mean Time Gap of UO Cases for 4-Axle Trucks

Class	Speed	GVW	Total Cases	UO (cases)	UO (%)	MUTG (s)
		17.5-22.5	50	27	54.0	1.61
		22.5-27.5	37	17	45.9	1.70
	45-55	27.5-32.5	34	15	44.1	1.84
		32.5-37.5	62	40	64.5	2.05
		37.5-42.5	88	58	65.9	2.22
		17.5-22.5	221	122	55.2	1.61
		22.5-27.5	81	40	49.4	1.56
4	55-65	27.5-32.5	78	34	43.6	1.97
		32.5-37.5	153	98	64.1	2.29
		37.5-42.5	154	115	74.7	2.33
		17.5-22.5	206	130	63.1	1.71
		22.5-27.5	26	16	61.5	1.79
	65-75	27.5-32.5	12	7	58.3	2.10
		32.5-37.5	26	20	76.9	2.29
		37.5-42.5	37	34	91.9	2.47

5.6 Discussion

The frequency of occurrence of unsafe time gap (UO) and degree of unsafe time gap (UD) for 2-axle trucks following cars is given in Table 5.8. The UO varies between 58.3% and 75.0% for mean speeds of 50km/h to 70 km/h and mean GVW of 20 tons to 30 tons. The mean UO of 65.6% indicates that a significant proportion of the trucks are following cars at time gaps below the minimum safe time gap (MSTG) and the trucks will not be able to avoid hitting the leading car in an emergency situation. The degree of unsafe time gap (UD) indicates that the deviation of the mean unsafe time gap is 1.09 seconds below the MSTG. The mean unsafe time gap is 35.4% below the MSTG. In the case of an emergency situation, not only does the truck hit the leading car, it may end up as a fatal accident.

A similar characteristic is observed for the case of 3-axle trucks following cars wherein the mean UO is 67.7%, mean UD is 1.02 seconds and deviation of the mean UD below the MSTG is 33.2% (Table 5.9). Although the occurrence of unsafe time gap is slightly higher as compared to the 2-axle trucks following cars, the degree of unsafe time gap is slightly lower for the case of 3-axle trucks following cars. The case of UO and UD for 4-axle trucks is given in Table 5.10.

Table 5.8. Unsafe Occurrence (UO) and Unsafe Deviation (UD) Cases for 2-Axle Trucks

Class	Mean Speed	Mean GVW	UO (%)	UD (s)	UD (%)
		20	58.3	0.93	34.3
	50	25	64.2	1.06	36.3
		30	75.0	0.98	31.5
2		20	58.9	1.01	34.4
	60	25	72.7	1.21	37.2
		30	71.4	1.28	37.2
	70	20	58.8	1.19	37.1
		Mean	65.6	1.09	35.4

Table 5.9. Unsafe Occurrence (UO) and Unsafe Deviation (UD) Cases for 3-Axle Trucks

Class	Mean Speed	Mean GVW	UO (%)	UD (s)	UD (%)
		20	44.1	0.72	32.0
		25	61.6	0.9	35.0
	50	30	61.2	1.01	35.9
		35	66.5	1.05	35.0
		40	75.7	1.17	36.9
		20	52.4	0.74	30.3
		25	58.6	0.92	32.5
3	60	30	71.3	1.11	35.6
		35	78.1	1.19	35.5
		40	84.4	1.14	31.9
		20	54.5	0.87	33.2
		25	60.6	0.8	26.0
	70	30	69.8	1.07	31.2
		35	80.0	1.3	35.1
		40	96.3	1.25	31.6
		Mean	67.7	1.02	33.2

The proposed safety performance assessment technique allows the investigation on vehicle following considering vehicle type, speed and GVW. In this study, the technique is illustrated for the case of truck following car situation. The value of UO indicates the high frequency of unsafe driving among the truck drivers in car-following situation. Results of UD indicate that significant proportion of truck drivers follow the leading car well below the minimum safe time gap. The results also indicate that on the whole an assessment of the safety level on any stretch of road should consider vehicle type, GVW and speed. It is proposed that UO and UD

may be used as indicators on the potential of rear-end collisions along a specific stretch of road.

Table 5.10. Unsafe Occurrence (UO) and Unsafe Deviation (UD) Cases for 4-Axle Trucks

Class	Mean Speed	Mean GVW	UO (%)	UD (s)	UD (%)
		20	54.0	0.56	25.8
		25	45.9	0.57	25.1
	50	30	44.1	0.69	27.3
		35	64.5	0.79	27.8
		40	65.9	0.91	29.1
		20	55.2	0.74	31.5
		25	49.4	0.91	36.8
4	60	30	43.6	0.82	29.4
		35	64.1	0.86	27.3
		40	74.7	1.18	33.6
		20	63.1	0.8	31.9
		25	61.5	0.86	32.5
	70	30	58.3	0.94	30.9
		35	76.9	1.16	33.6
		40	91.9	1.41	36.3
		Mean	60.9	0.88	30.6

For this case study, the mean UO is found to be 64.5% while mean UD is 0.98 sec. Hence, this means that 64.5% of all truck drivers are following cars at 0.98 seconds less than the minimum safe time gap! This could probably explain why rear-end fatal accidents involving heavy vehicles are alarming in Malaysia, i.e. resulting in 27% of all fatal accidents involving trucks in Malaysia (see Figures 5.1 and 5.2 earlier).

Nomenclature

WIM	-	weigh-in-motion
GVW	-	gross vehicle weight
MSTG	-	minimum safe time gap
MUTG	-	mean of the unsafe time gaps
UO	-	occurrence of unsafe time gaps
UD	-	deviation of MUTG from MSTG
ST_{FV}	-	stopping time of following vehicle
ST_{LV}	-	stopping time of leading vehicle

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CHAPTER 6

CONCLUSION

6.1 Degree of Vehicle Overloading

The outcome of this study has highlighted the magnitude of the problem of vehicle overloading in Malaysia. What is more worrying is the degree of overloading is extremely high, particularly for the 2-axle and 3-axle trucks. Half of the 3-axle trucks are found to be overloaded and the degree of overloading is up to 101% of its legal weight limit. Apart from the impact on pavement damage and carbon emission, vehicle overloading would lead to a more hazardous road environment because of the limitations in vehicle dynamics and braking performance of the trucks to cope with the higher demands from the excess payload. This is illustrated by studying the relationship between the maximum stopping time of each truck category (traveling at a certain speed) and the changes in GVW. As discussed earlier, vehicle overloading will lengthen the stopping distance beyond the usual case when the truck is not overloaded. If the truck driver is not aware (or unconcerned) with the need to adjust his/her driving habit, the driver may not be able to handle or maneuver the truck safely in an emergency situation. Furthermore, if the truck is not in good condition and/or the road surface is wet or slippery, the high degree of overloading may result in fatality in case of a crash.

Being a developing country, efforts to reduce fatalities from traffic accidents have to be intensified. Since at least a quarter of accident fatalities in Malaysia involve heavy vehicle crashes, continuous and proper monitoring of the heavy vehicle traffic and truck overloading need to be seriously considered. Occasional manual weight enforcement actions have proven to be insufficient to curb the vehicle overloading problem. A more comprehensive strategy which includes real-time monitoring using appropriate technology (such as the WIM system) and more efficient weight enforcement program has to be formulated by the relevant agencies. The occurrence of a high degree of vehicle overloading in a developing country like Malaysia, a phenomenon which may not be found in the more developed countries, has to be dealt with in order to prevent unnecessary economic loss to the nation.

The results of this study on the extent and degree of vehicle overloading may be summarized as follows:

i. Significant GVW violation involving overweight commercial vehicles is observed.
ii. The frequency and degree of overloading in heavy commercial vehicles is very significant and alarming.
iii. Not only does overloading accelerate pavement damage (which in turn may contribute to accidents), overloaded heavy vehicles would be hazardous to other road users.
iv. Monitoring and enhancing enforcement of weight limits of heavy vehicles may be a step in the right direction.
v. Comprehensive and continuous data is needed, especially at critical locations in the road network.

6.2 Effectiveness of WIM System as an Aid in Vehicle Weight Enforcement

Based on the findings from the study, the effectiveness of using WIM system to enhance weight limit enforcement will definitely benefit not only the road authorities but also the motorist at large. The results of this study may be summarized as follows:

   i. Significant percentage of violation involving overloaded commercial vehicles is observed in a developing country such as Malaysia.
  ii. The effectiveness of existing static weigh station is rather low as compared to the actual number of GVW violation cases amongst the commercial vehicles measured using the WIM system.
 iii. A simple linear model that relates static weigh station capability and percentage truck bypass with GVW violation cases may be a useful tool that can be used by the weigh station operators to develop the appropriate enforcement strategies.
  iv. The WIM system is an appropriate tool in assisting the enforcement agencies in helping to preserve road infrastructure from premature deterioration and enhance safety of other road users.
   v. Excess revenue generated from the enhanced GVW enforcement system (static weighing plus WIM sorting system) may be directed towards better road maintenance program and expenditures on other infrastructures.

With the use of a weigh-in-motion system as a sorting device to enhance the current static weighing mechanism, the number of violating trucks that need to be handled at the weigh stations will increase and may lead to traffic obstructions on the road itself. In order to avoid this problem, it is proposed that the physical size of the current area around the station be increased to accommodate the increased number of violating trucks to be given the summons. If the number of violating trucks is too large, the weigh-in-motion system may be used to only identify the more serious weight violators during a certain time period so as to reduce the number violating trucks at the weigh station areas.

Nonetheless, the successful implementation of this system would likely require proper legislative effort, close co-operation among related organizations and also require a new level of trust and cooperation among truck companies and authorities.

Apart from the issue of weight enforcement, data pertaining to vehicle weight will be utilized in the safety performance assessment of car following behavior especially involving heavy vehicles and overloaded trucks.

6.3 Minimum Safe Time Gap (MSTG) as a New Safety Indicator

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 and speed) and driver (perception-reaction time). 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.

The proposed safety indicator, MSTG, requires data from simulation and it is influenced by the factors associated with the driver (perception-reaction time) and vehicle (vehicle type, GVW and speed). In future works on MSTG it is suggested that other factors such as road (e.g. wet/dry, pavement type etc.) and the surrounding conditions (e.g. rain, day/night, fog etc.) as shown in Figure 6.1 may also be considered.
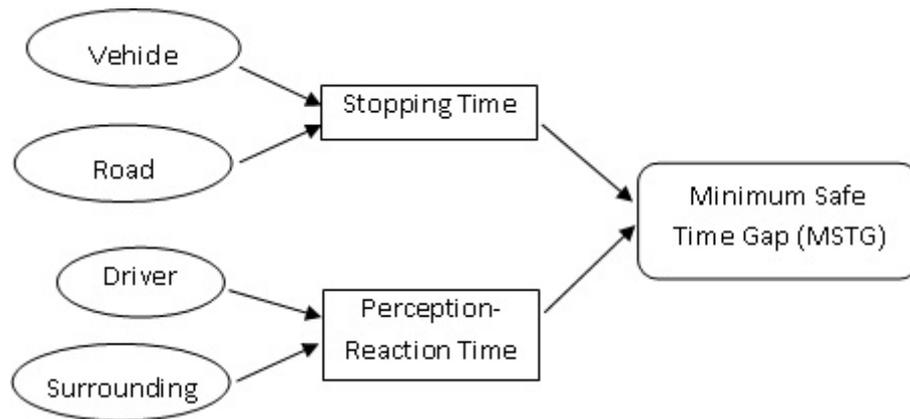

Figure 6.1. Significant factors influencing MSTG

6.4 Safety Performance Assessment using Empirical-Simulation Technique

The final aim of this study is to investigate safety implications of driver behavior in truck-following-car situation considering truck type, time gap, gross vehicle weight and speed. A new approach on safety performance assessment involving empirical-simulation technique is suggested. The minimum safe time gap (MSTG) is proposed as an indicator to be employed in the safety performance assessment technique. The frequency of occurrence of unsafe time gap (UO) and degree of unsafe time gap as measured by the deviation of the mean unsafe time gap from the MSTG (UD) are suggested as indicators for safety performance in truck-following-car situation. This is illustrated in Figure 6.2.

To illustrate the application of this technique, empirical data was obtained under near optimal driving conditions characterized by dry weather, daytime, no changes in surrounding, and small relative speed using the developed weigh-in-motion based transport data-collection system, which has been installed on one of the federal roads in Malaysia. The findings of this research highlight the importance of considering the truck type, truck GVW and speed in a truck-following-car situation. Based on this safety performance assessment technique, hazardous vehicle-following behavior of truck drivers may be established for any road segment.
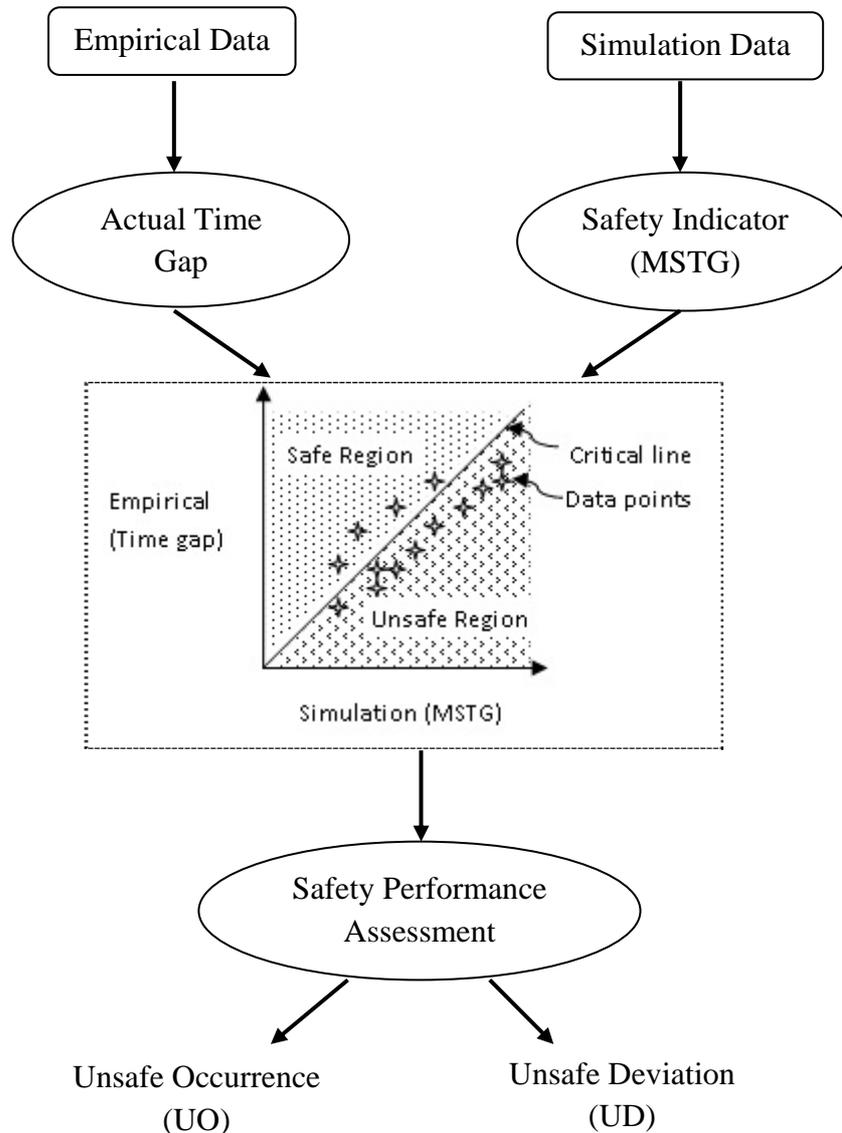
Figure 6.2 Safety Performance Assessment using Empirical Simulation Technique

With advancement of computer technology and simulation techniques, more accurate simulation data can be easily achieved at much lower cost. More accurate and comprehensive data on vehicle characteristics and performance can be achieved through advanced simulation software which may be quite difficult to obtain using other means.

Nevertheless, without accurate empirical data a proper assessment on safety performance could not be done even though accurate simulation data is available. This safety performance assessment technique requires both simulation data (as benchmark) and empirical data (as depicting the actual situation).

The safety performance assessment should go beyond the traditional/conventional methods which may sometimes lead to over simplification of the complexity of situation such as involving vehicle dynamics. Considering kinematics only is not enough to explain the actual situation in road safety involving heavy vehicles.

A major outcome of this study indicates that truck overloading would be a problem in truck-following-car situation when emergency situation arises, and this is rather common in developing countries like Malaysia. Proper monitoring and weight control enforcement strategies maybe a step forward in addressing this issue. Use of weigh-in-motion systems for road safety studies need to be considered and enhanced as it has proven to be beneficial. Proper and adequate education of the truck drivers may also be necessary to increase their knowledge and awareness on the need to adjust their driving habits and time gaps when they carry higher payloads than usual, especially when the leading vehicle has superior dynamic performance capability.

CHAPTER 7

FUTURE WORK

7.1   The concept of MSTG has incorporated certain vehicle parameters (GVW, speed, vehicle type) and driver characteristic (perception-reaction time). For future work it is suggested that MSTG may be expanded to incorporate other factors such as road characteristics, for example, dry/wet road surface and road gradient. From the driver's characteristics, the perception-reaction time may be developed into a function (instead of a constant) which incorporates parameters such as gender, age and driving experience.

7.2   Studies may be embarked to establish correlations between the proposed safety index and accident data at accident prone locations and non-accident prone locations. Through this exercise, the numerical values of safety indices UO and UD may be grouped into bandwidths in terms of accident potential.

7.3   Since there may be a tendency for logistics operators to overload in order to economise their operations, a study may be conducted on the possibility and mechanism to have a permit system for those who prefer to pay for the extra load for them to carry.

7.4   Studies may be embarked on establishing correlations between the proposed safety index and geometric features of the road as well as the basic traffic flow variables. Findings from this study may be useful to evaluate options in geometric design options for the new roads and road improvement schemes.

7.5   Environmental conditions such as day/night, dawn/twilight, rain/sunny etc may also be included in the study so as to understand the changes in the safety index (significant or otherwise) with respect to the different situations.

REFERENCES

AASHTO, (1993). *AASHTO Guide for Design of Pavement Structure*, American Association of State and Highway Transportation Officials, Washington, DC, 1993.

Ardani, A., Hussein, S. And LaForce, R. (2003). Evaluation of Premature PCC Pavement Longitudinal Cracking in Colorado. Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa.

ARRB Transport Research, (1997). Assessment of truck/trailer Dynamics, Technical Working Paper No. 31, Contract Report, National Road Transport Commission, ISBN 07306 84369.

Banks, J.H. (2003). Average time gaps in congested freeway flow. *Transportation Research Part A: Policy and Practice*, 37(6), 2003, pp. 539-554.

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.

Brewer, A. M. (2000) Road rage: what, who, when, were and how? *Transport Reviews,* 20, pp. 49–64.

Bushman, R., Berthelot, C., Taylor, B., (2003). Commercial Vehicle Loading in an Urban Environment, Paper presented at the Emerging Technologies in Traffic Operations Session of the 2003 Annual Conference of the Transportation Association of Canada St. John's, Newfoundland and Labrador.

Campbell, K.L., Blower, D.F., Gattis, R.G., Wolfe, A.C., (1988). Analysis of Accident Rates of heavy Duty vehicles, Final Report, Univ. of Michigan Transportation Research Institute.

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.

Conway A., Walton C. M., (2004). Potential application of ITS technologies to improve commercial vehicle operations, enforcement, and monitoring, Research Report SWUTC/04/473700-00069-1, The University of Texas at Austin, Texas.

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

CSIR, (1997). The damaging effects of overloaded heavy vehicles on roads, *CSIR Roads and Transport Technology*, 4th Edition, ISBN: 1-86844-285-3.

Davis, M. (2003). Operational Benefits of the Long Creek Weigh-In-Motion System. Senior Report II, Department of Civil Engineering, University of New Brunswick.

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.

Fancher, P., Mathew, A., Campbell, K., Blower, D., Winkler, C., (1989). Turner Truck handling and Stability Properties Affecting Safety: Final Report. Univ. of Michigan Transportation Research Institute.

Fancher, P.S., Mathew, A., (1989). Safety implications of various truck configurations, Vol. III, FHWA-RD-89-085, The Univ. of Michigan Transportation Research Institute.

Friswell R., Ann Williamson, A., (2013). Comparison of the fatigue experiences of short haul light and long distance heavy vehicle drivers. *Safety Science* 57 (2013) 203–213.

Guangnan Zhang, Kelvin K.W. Yau, Guanghan Chen (2013) Risk factors associated with traffic violations and accident severity in China. *Accident Analysis and Prevention* 59 (2013) 18– 25

Huang, Y.H., (1993). *Pavement Analysis and Design*, Prentice-Hall, Englewood Cliffs, NJ.

Ibtishamiah N.I (2007), A Study on Bus Passenger Demand Satisfaction in Malacca (unpublished thesis).

Jacob, B., La Beaumelle, V.F., (2010). Improving truck safety: Potential of weigh-in-motion technology, *IATSS Research* 34 (2010) 9–15.

Jarvis, S. (2008). Increase Truck Weight Limits for Agricultural Transportation from 80,000 to 97,000 Pounds. Retrieved from Agricultural Transportation Efficiency Coalition website on August 12, 2011 at http://ag-haul.org/resources/multimedia/PDF/AgTEC-GVWstatement.pdf.

Jianjun Zhang (2013) Existing Traffic Safety Problems of Expressways in China. *Procedia - Social and Behavioral Sciences* 96 (2013) 130 – 135.

Karim M.R. and Saifizul A. (2010) Vehicle overloading on Malaysian roads and its implications on safety. Presentation at the International symposium on safe mobility and international cooperation, March 9-10, 2010, Kuala Lumpur.

Karim M.R., Saifizul A., Yamanaka H., Sharizli A., Ramli R. (2013a) Degree of vehicle overloading and its implications on road safety in Developing countries. *Journal of Civil and Environmental Research*, Vol. 3, No. 12, 2013, 20-31.

Karim M.R., Ibrahim N.I., Saifizul A.A., Yamanaka H. (2013b) Effectiveness of vehicle weight enforcement in a developing country using weigh-in-motion sorting system considering vehicle by-pass and enforcement capability. *IATSS Research* 2013, http://dx.doi.org/10.1016/j.iatssr.2013.06.004.

Karim M.R., Saifizul A., Yamanaka H., Sharizli A., Ramli R. (2014a) Minimum Safe Time Gap (MSTG) as a new safety indicator incorporating vehicle and driver factors. *Journal of Eastern Asia Society for Transportation Studies,* Vol.10, pp.2069-2079, 2013.

Karim M.R., Saifizul A., Yamanaka H., Sharizli A., Ramli R. (2014b) An investigation on safety performance of close-following behavior of heavy vehicle using empirical-simulation technique. *Journal of Transportation Technologies,* Vol. 4 No. 1, 2014, pp. 22-30. 2014.

Kishore, A. and Klashinski, R. (2000). Prevention of Highway Infrastructure Damage Through Commercial Vehicle Weight Enforcement. International Road Dynamic Inc., Saskatoon, Saskatchewan, Canada.

Knipling, R.R, Wang, J.S., Yin, H.M. (1993). Rear-end Crashes: Problem size assessment and statistical description. NHTSA Tech. Report DOT HS 807 994, 1993.

Larue, G.S., Rakotonirainy, A., Pettitt, A.N., (2011). Driving performance impairments due to hypovigilance on monotonous roads. *Accident Analysis and Prevention* 43, 2037– 2046.

Lewin, I. (1982) Driver training: a perceptual-motor skill approach. *Ergonomics* 25, 917–924.

Liu, Y.C., Wu, T.J, (2009). Fatigued driver's driving behavior and cognitive task performance: Effects of road environments and road environment changes. *Safety Science* 47 (2009) 1083–1089.

Malaysia Industrial Development Authority (MIDA), (2011). Retrieved on 16 August 2011 from www.mida.gov.my

Manitoba Public Insurance (2008). Air Brake Manual. http://www.mpi.mb.ca/PDFs/Air BrakeManual/ AirBrakeManualComplete.pdf, 2008.

Marijonas Bogdevicius, Olegas Prentkovskis, Oleg Vladimirov (2004) Engineering solutions of traffic safety problems of road transport. *TRANSPORT*, Vol. XIX, No.1, 43-50.

Marshek K.M., Chen H.H., Connell R.B. and Saraf C.L. (1986). The Effect of Truck Tire Inflation Pressure and Axle Load on Flexible and Rigid Pavement Performance. *Transportation Research Record* N1070, TRB, Washington DC

McCartt, A.T., Rohrbaugh, J.W., Hammer, M.C., Fuller, S.Z., (2000). Factors associated with falling asleep at the wheel among long-distance truck drivers. *Accident Analysis and Prevention* 32, 493–504.

Michael, P.G., Leeming, F.C., Dwyer, W.O. (2000). Headway on urban streets: observational data and an intervention to decrease tailgating. *Transport Res. Part F* 3 (2), 2000, 55–64.

MIROS (2013) Road Facts. Malaysian Institute of Road Safety Research. http://www.miros.gov.my/web/guest/road.

Morrow, P.C., Crum, M.R., (2004). Antecedents of fatigue, close calls and crashes among commercial motor-vehicle drivers. *Journal of Safety Research* 35, 59–69.

Mulyono, A.T., Parikesit, D., Antameng, M., Rahim, R., (2010). Analysis of Loss Cost of Road Pavement Distress due to Overloading Freight Transportation, *J. Eastern Asia Soc. for Transp. Stud.,* Vol.8, 706-721.

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.

Paul C. and David C. (1997). The Design and Performance of Road Pavements (3rd revised ed.). New York: McGraw-Hill 1997.

Piao J., McDonald M. (2003). Low speed car following behaviour from floating vehicle data. Proc. of Intelligent Vehicles Symposium 2003. IEEE Intelligent Vehicles Symposium 2003 ,IEEE, 462-467.

Podborochynski, D., Berthelot, C., Anthony, A., Marjerison, B., Litzenberger, R., Kealy, T., (2011). Quantifying Incremental Pavement Damage Caused by Overweight Trucks, Paper prepared for presentation at the Effects of Increased Loading on Pavement Session of the 2011 Annual Conference of the Transportation Association of Canada, Edmonton, Alberta.

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

Predrag Stanojevic, Dragan Jovanovic, Timo Lajunen (2013) Influence of traffic enforcement on the attitudes and behavior of drivers. *Accident Analysis and Prevention* 52 (2013) 29– 38.

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., (2010a). Development of integrated data collection and enforcement system, Proceedings of the 17th ITS World Congress, October 25–29, BEXCO Busan, Korea.

Saifizul A.A., Karim M.R. and Yamanaka H. (2010b), Prospect of Using Weigh-In-Motion Based System for Enhancing Vehicle Weight Enforcement – A Case Study of Malaysian

Roads. Proceedings of the 17th ITS World Congress, October 25–29, BEXCO Busan, Korea.

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. *Proc. of the Eastern Asia Society for Transportation S*tudies, Vol. 8, pp. 305-317.

Sallinen, M., Härmä, M., Akila, R., Holm, A., Luukkonen, R., Mikola, H., Müller, K., Virkkala, J., (2004). The effects of sleep debt and monotonous work on sleepiness and performance during a 12-h dayshift. *Journal of Sleep Research* 13, 285–294.

Santero, N. J., Nokes, W., Harvey, J.T., (2005). Virtual Weigh Stations: The Business Case. Institute of Transportation Studies, University of California, Davis, Research Report UCPRC-TM-2005-03.

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.

Shaopu Yang, Shaohua Li and Yongjie Lu (2010). Investigation on dynamical interaction between a heavy vehicle and road pavement. *Vehicle System Dynamics*, Vol. 48, No. 8, August 2010, 923–944

Sharma, B.M, Sitaramanjaneyuiu, K., Kanchan, P.K., (1995). Effect of Vehicle Axle Loads on Pavement Performance, Road Transport Technology-4, University of Michigan Transportation Research Institute.

Straus, S.H., Semmens, J., (2006). Estimating the Cost of Overweight Vehicle Travel on Arizona Highways, Arizona Department of Transportation, Final Report 528.

SWOV (2010). Fact sheet: Intelligent Transport Systems (ITS) and Road Safety. http://www.swov.nl/ rapport/Factsheets/UK/FS_ITS_UK.pdf, 2010.

Taylor, B., Bergan, A., Lindgren, N., Berthelot, C., (2000). The importance of commercial vehicle weight enforcement in safety and road asset management, Traffic Tech International 2000, Annual Review pp. 234-237.

The New Straits Times, June 22, 2010. Fewer Potholes with New Type of Asphalt, pp. 14

The Star, July 27, 2010. Heavy Vehicle Banned. Pp. 12

The Malay Mail, July 26, 2010. Retrieved on August 10, 2011 from http://www.mmail.com.my /content/44350-heavyduty-vehicles-banned-highways-aug-2

Thiffault, P., Bergeron, J., (2003). Monotony of road environment and driver fatigue: a simulator study. *Accident Analysis and Prevention* 35, 381–391.

Titus, M.J., (1996). Benefits of Electronic Clearance for Enforcement of Motor Carrier Regulations, *Transportation Research Record*, TRB, Vol. 1522, pp64-68.

Transportation Research Board, (1990). Truck weight limits: Issues and options – Special Report 225.

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.

Turner, D., Nicholson, L.A., Agent, K., (2008). Oversize/overweight commercial vehicle safety, Paper presented at the HVTT10 International Conference on Heavy Vehicles, Paris, 19-22 May 2008.

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

Wang J., Wu M., (2004). An overview of research on weigh-in-motion system, Proc. of 5th World Congress on Intelligent Control and Automation, China.

Winkler, C.B., (2000). Rollover of Heavy Commercial Vehicles, UMTRI Research Review, Vol. 31, No.4, ISSN 0739 7100.

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

Young, K.L., Salmon, P.M. (2012). Examining the relationship between driver distraction and driving errors: A discussion of theory, studies and methods. *Safety Science*, 50(2), 2012, 165-174.

Zhang, L. (2007). An Evaluation of the Technical and Economic Performance of Weigh-in-Motion Sensing Technology. (unpublished thesis).

LIST OF PUBLICATIONS

Refereed Journals (1ˢᵗ. Author):

1. Karim M.R., Saifizul A., Yamanaka H., Sharizli A., Ramli R. (2013) Degree of Vehicle Overloading and its Implication on Road Safety in Developing Countries. *Journal of Civil and Environmental Research*, Vol.3, No.12, 2013 pp. 20-31.

2. Karim M.R., Ibrahim N.I., Saifizul A.A., Yamanaka H. (2013) Effectiveness of Vehicle Weight Enforcement in a Developing Country using Weigh-In-Motion Sorting System considering Vehicle By-Pass and Enforcement Capability. *IATSS Research* (2013), http://dx.doi.org/10.1016/j.iatssr.2013.06.004.

3. Karim M.R., Saifizul A., Yamanaka H., Sharizli A., Ramli R. (2013) Minimum Safe Time Gap (MSTG) as a new Safety Indicator incorporating Vehicle and Driver Factors. *Journal of Eastern Asia Society for Transportation Studies,* Vol.10, pp.2069-2079, 2013.

4. Karim M.R., Saifizul A., Yamanaka H., Sharizli A., Ramli R. (2014) An Investigation on Safety Performance Assessment of Close-Following Behavior of Heavy Vehicle using Empirical-Simulation Technique. *Journal of Transportation Technologies,* Vol. 4 No. 1, 2014, pp. 22-30. 2014.

Co-Author (Journals and Proceedings):

1. Saifizul, A.A., Yamanaka, H., Karim, M.R. (2011) 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.

2. Karim M.R., Saifizul A., Yamanaka H., Sharizli A., Ramli R. (2013) Minimum Safe Time Gap (MSTG) as a new Safety Indicator incorporating Vehicle and Driver Factors. *Proc. Eastern Asia Society for Transportation Studies*, Vol.9, 2013, p407. (http://easts.info/on-line/proceedings/vol9/index.html).

3. Saifizul A.A., Yamanaka H., Karim, M.R., Okushima M. (2013) Empirical analysis on the effect of gross vehicle weight and vehicle size on speed in car following situation. Asian Transport Studies, Vol.2, Issue 4, pp. 351-362, http://dx.doi.org/10.11175/eastsats.2.351.

4. Karim M.R., Saifizul A.A., Yamanaka H. (2013) Overloading of Malaysian Road Pavements. *THE INGENIEUR*, Vol. 55, June 2013, pp. 55-60.