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Degree of Vehicle Overloading and its Implication on Road Safety in Developing Countries

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Abstract

The phenomenon of vehicle overloading is not new and has been discussed in relation to the adverse effects on road pavement damage, road safety and GHG emission. Although much has been said in the context of the more developed countries, there has not been much discussion on vehicle overloading in developing countries. In this study, the extent and degree of vehicle overloading in a developing country is established. Half of the 3-axle trucks were found to be overloaded and the degree of overloading is up to 101% of its legal weight limit! The effect of truck overloading on safety is discussed by establishing the relationship between truck stopping distance and gross vehicle weight for a certain travel speed. Comparison between actual overloading data for 2-axle, 3-axle and 4-axle trucks and the stopping distance illustrates the gravity of the situation which needs a comprehensive and effective strategy from the relevant agencies.

Keywords: Road Safety, Vehicle Overloading, Traffic Accidents, Weigh-in-Motion, Stopping Distance

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).

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 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 breaking 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).

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 is more likely to be involved in an accident, and have more severe consequences, than a legally loaded truck (Jacob and La Beaumelle, 2010). The heavier the vehicle, the higher its kinetic energy resulting in greater impact forces and damage – to other vehicles or to the infrastructure – in the event of a crash. An overloaded vehicle is less stable because of the increased height at the centre of gravity and more inertia of the vehicle bodies.

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).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.

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. 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., 2010). 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.

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 1. For the purpose of this study, focus will be given to the 2-axle, 3-axle and 4-axle trucks.

Table 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

A common sight on Malaysian roads is illustrated in Figure 1. Overloaded trucks such as those shown in Figure 1 have been of concerned to all road users especially the more vulnerable ones such as motorcyclists, bicyclists and pedestrians.

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 shows the number of GVW violations (based on maximum permissible GVW given in Table 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 1. Examples of overloaded trucks in Malaysia

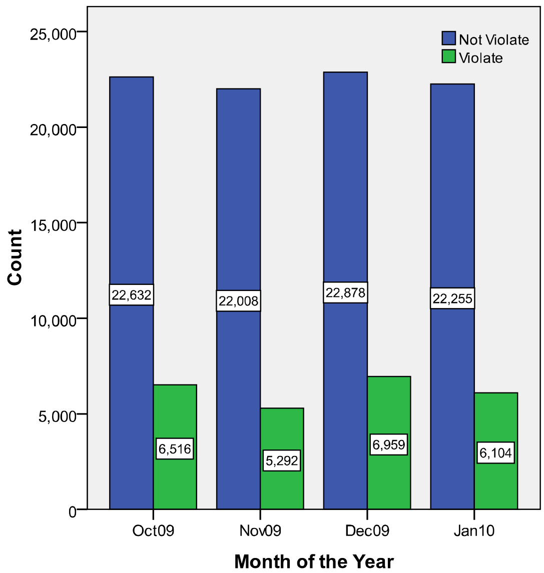

Figure 2. GVW violation cases by month of the year (Oct 2009 - Jan 2010)

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 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 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 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 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.

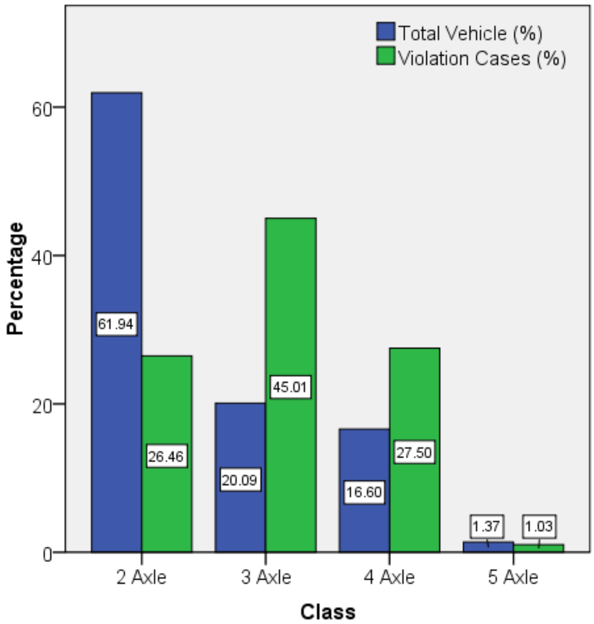

Figure 3. Heavy vehicle GVW violation cases by vehicle class (Jan 2010)

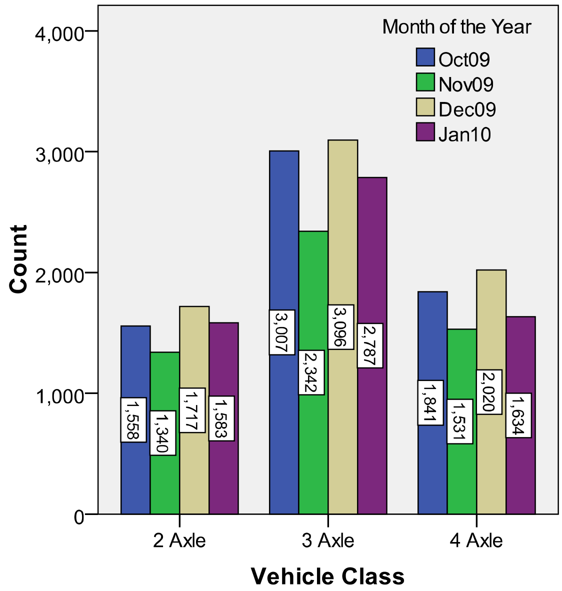

Figure 4. No. of overloaded trucks at study location

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).

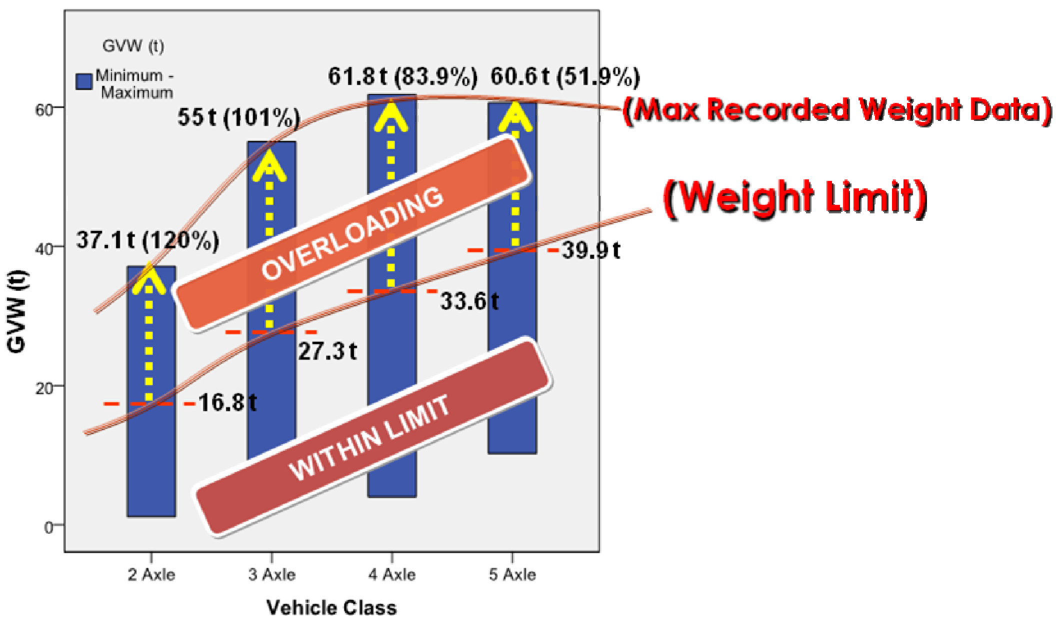

Figure 5. GVW variation by vehicle class (Jan 2010)

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 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 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 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.

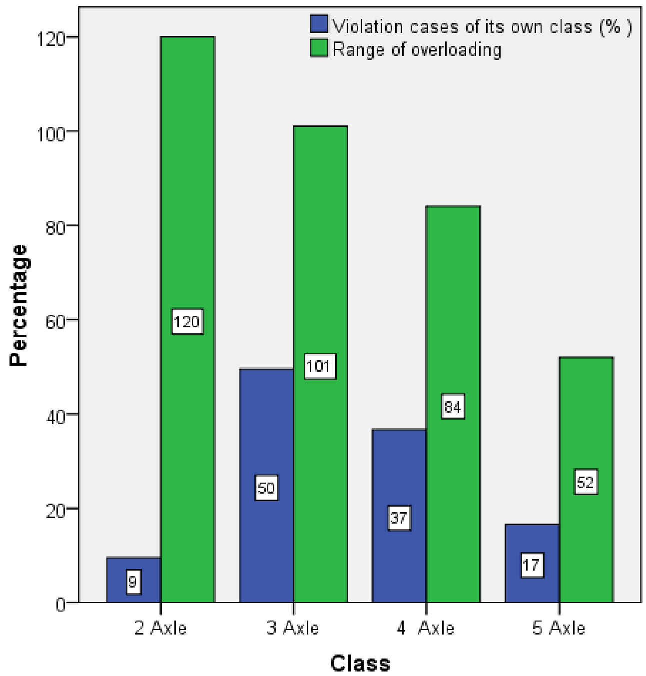

Figure 6. GVW violation of its own class

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.

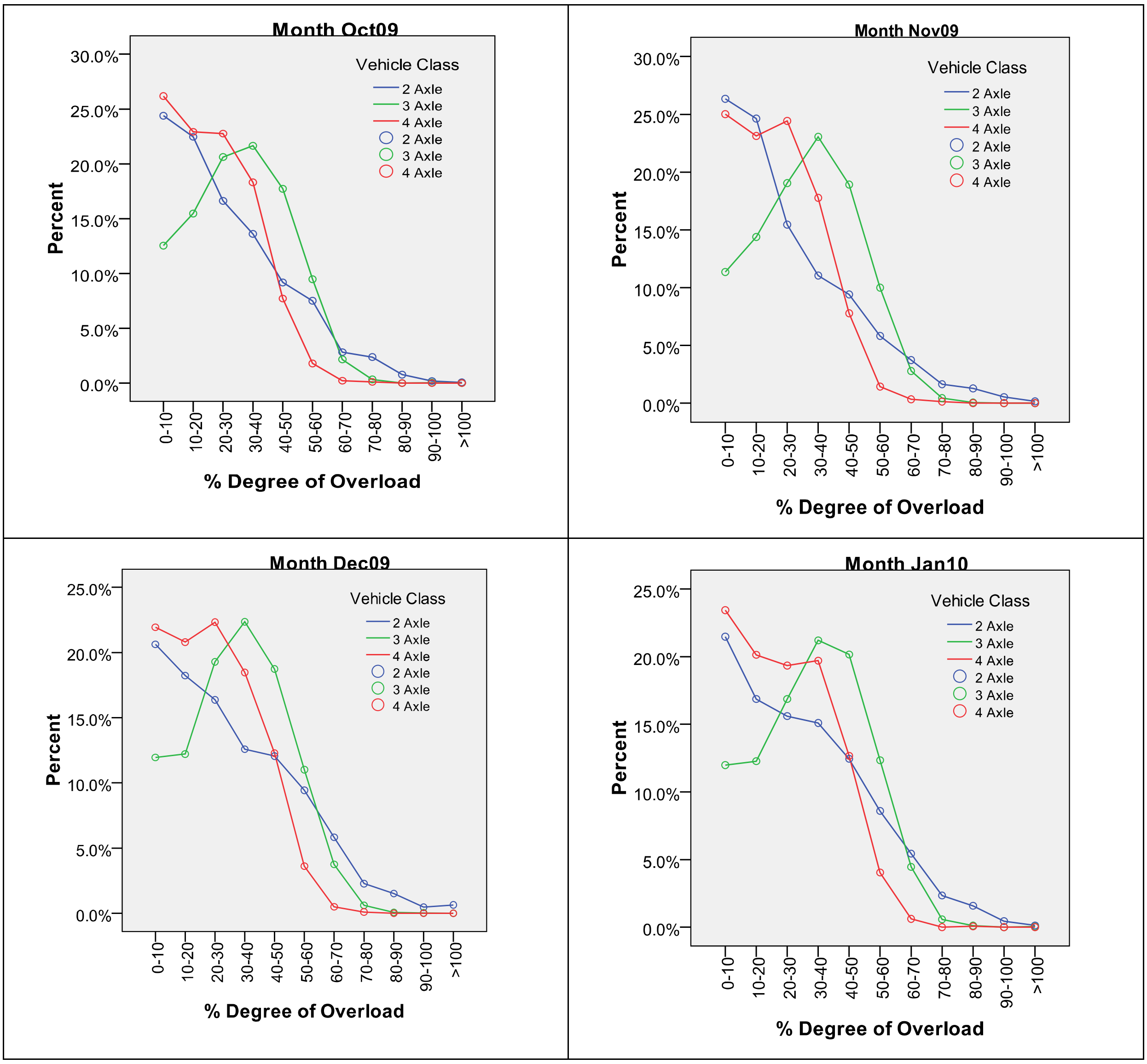

Figure 7. Distribution of Degree of Overloading

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 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.

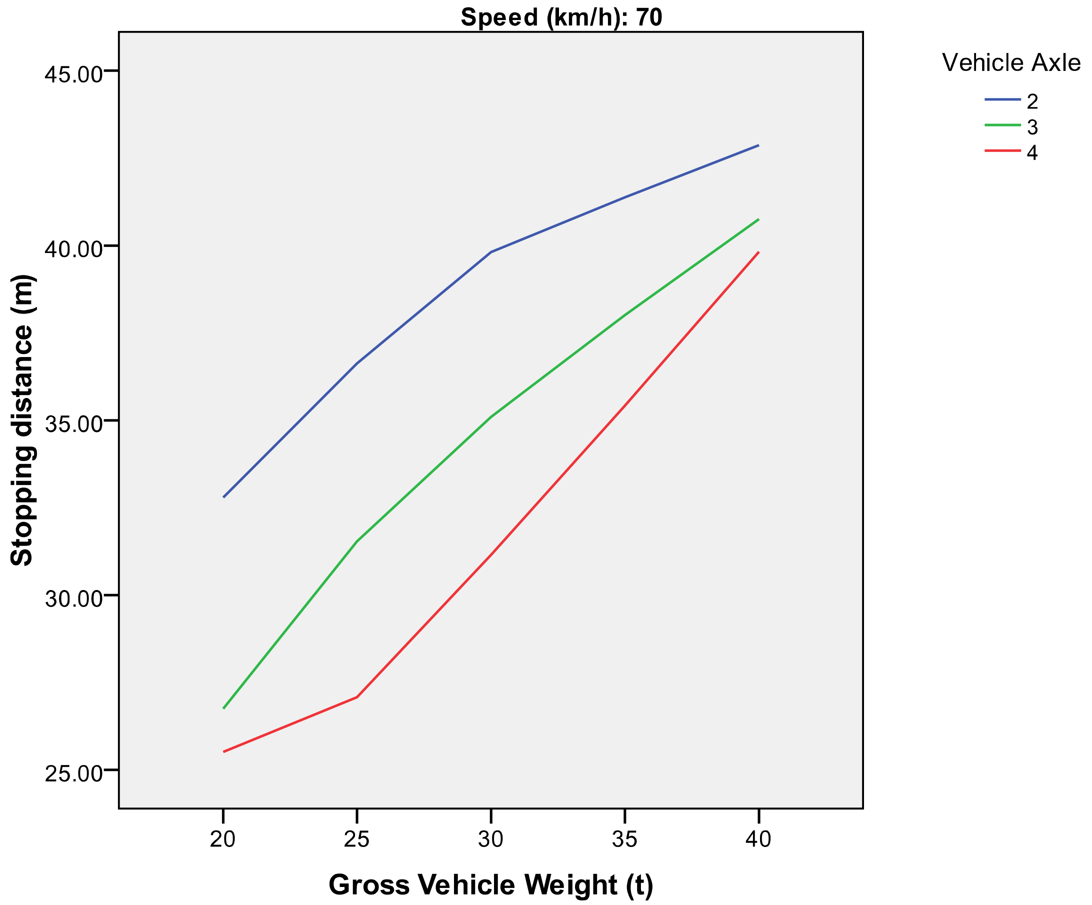

Figure 8. Effect of GVW on Stopping Distance for Different Truck Types

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 8 and Figure 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.

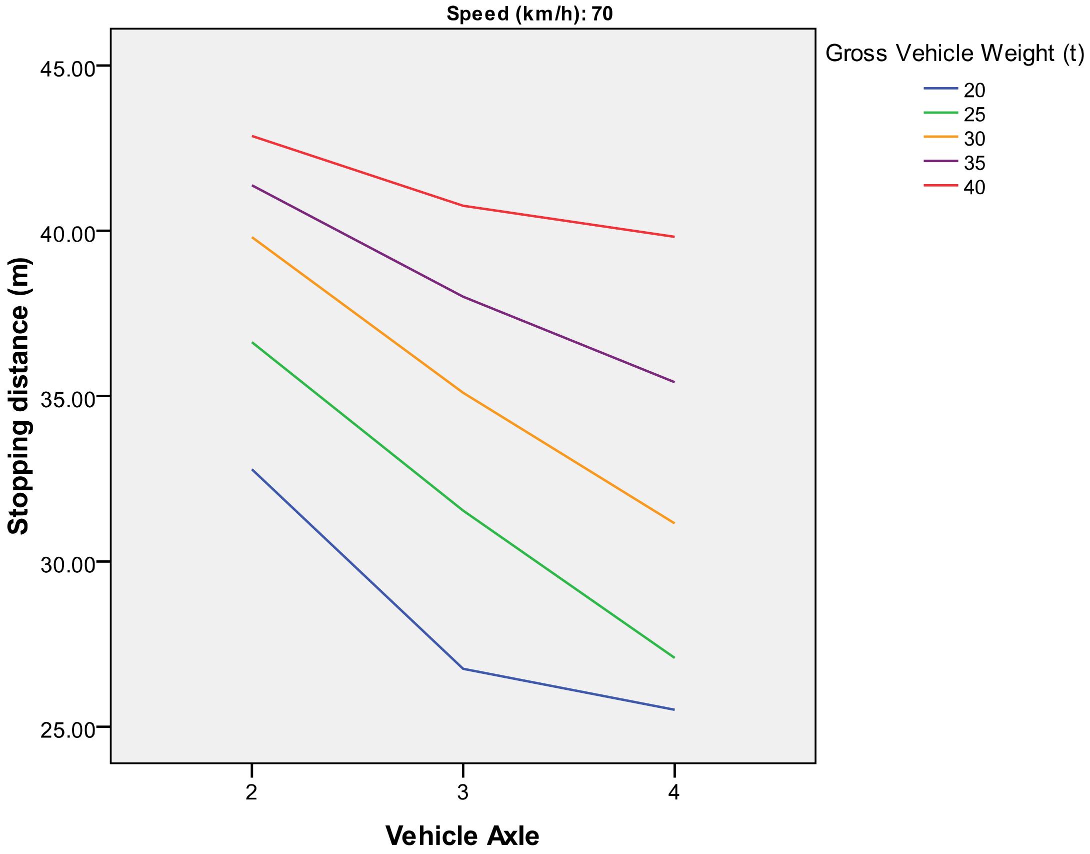

Figure 9. Effect of Axle Numbers on Stopping Distance

4. Conclusion

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 in this paper, 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/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 may be summarized as follows:

1. Significant GVW violation involving overweight commercial vehicles is observed.

2. The frequency and degree of overloading in heavy commercial vehicles is very significant and alarming.
3. Not only does overloading accelerate pavement damage (which in turn may contribute to accidents), overloaded heavy vehicles would be hazardous to other road users.
4. Monitoring and enhancing enforcement of weight limits of heavy vehicles may be a step in the right direction.
5. Comprehensive and continuous data is needed, especially at critical locations in the road network.

References

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

ARRB Transport Research, (1997). Assessment of truck/trailer Dynamics, Technical Working Paper No. 31, Contract Report, National Road Transport Commission, ISBN 0 7306 8436 9.

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.

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.

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.

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

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.

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

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

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.

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.

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.

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.

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.

Saifizul, A.A., Yamanaka, H., Karim, M.R., (2010). Development of integrated data collection and enforcement system, 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 Studies, 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.

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.

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.

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.

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.

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.