Effectiveness of vehicle weight enforcement in a developing country using weigh-in-motion sorting system considering vehicle by-pass and enforcement capability

Mohamed Rehan Karima,⁎, Nik Ibtishamiah Ibrahim a, Ahmad Abdullah Saifizula, Hideo Yamanakab

a Center for Transportation Research, Faculty of Engineering, University of Malaya, Kuala Lumpur, Malaysia
b Department of Civil Engineering, University of Tokushima, 2-1 Minami Josan Jima Cho, 770-8500, Tokushima, Japan

A R T I C L E   I N F O
Article history:
Received 15 October 2012
Received in revised form 18 June 2013
Accepted 27 June 2013
Available online xxx

A B S T R A C T
Vehicle overloading has been identified as one of the major contributors to road pavement damage in Malaysia. In this study, the weigh-in-motion (WIM) system has been used to function as a vehicle weight sorting tool to complement the existing static weigh bridge enforcement station. Data collected from the developed system is used to explore the effectiveness of using WIM system in terms of generating more accurate data for enforcement purposes and at the same time improving safety and reducing the number of vehicle weight violations on the roads. This study specifically focus on the effect of vehicle by-pass and static weigh station enforcement capability on the overall effectiveness of vehicle weight enforcement system in a developing country. Results from this study suggest that the WIM system will significantly enhance the effectiveness and efficiency of the current vehicle weight enforcement, thus generating substantial revenue that would greatly offset the current road maintenance budget that comes from tax payers money. If there is substantial reduction in overloaded vehicles, the public will still gain through reduction in road maintenance budget, less accident risks involving heavy trucks, and lesser greenhouse gases (GHGs) emissions.

© 2013 International Association of Traffic and Safety Sciences. Production and hosting by Elsevier Ltd. All rights reserved.

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 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 offense and shall, upon conviction, be liable to a fine of not less than MYR1000 (USD330) but not more than MYR10,000 (USD3300) 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 [1]. The New Straits Times [2] reported that there were 19.3 million registered vehicles on Malaysia’s road and the government have spent MYR5 billion (USD1.6 billion) between 2001 and 2010 to sustain all the federal roads. 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 [3]. The ban applies to vehicles, except busses, weighing 10,000 kg 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 MYR1000 (USD300), jailed for three (3) months or both, as stipulated under Section 70(4) of the Road Transport Act 1987 [4]. 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 [5]. 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
fleets that are larger in terms of both loading and size. Besides gaining more profit through the increased sale 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 [6].

2. Problem of overloaded vehicles

Commercial vehicle safety has been an important focus of commercial vehicle enforcement agencies for some time [7]. Overloaded vehicles 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. Many researchers have shown that the important reason for road damage is the vehicle load [8]. A study by the International Road Dynamics Inc. found that 10% increase in weight can accelerate pavement damage by over 40% [9]. Furthermore, overload could cause the main part of the vehicle to be damaged and malfunction. According to Jacob and La Beaumelle [10] 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 height of 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 are 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.

According to Marshek et al. [11] 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 [12] 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 [13] 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. [14], 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.

Overloaded trucks may cause delays to other vehicular traffic and the experienced delay and the need to stay behind the slow-moving vehicle might increase frustration among the faster drivers and cause unsafe behavior [15]. As such, the presence of a significant number of overloaded trucks in a traffic stream may also create safety concern to other road users.

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. Objective

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 paper 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 paper, 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 (Fig. 1).

4. Methodology

Currently, enforcement officers will identify through visual assessment whether a truck is suspected to be overloaded and direct 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 in another earlier paper presented at the ITS World Congress in Busan, Korea in 2010 [16]. Data from the WIM system has also been analyzed in a previous study on differential speed limit for heavy vehicles [18].

5. Results

Overloaded trucks present a threat not only to road infrastructure but also to road safety. The results of the study (Table 2) showed that 21.5% of the total commercial vehicles exceed the permitted gross

---

Please cite this article as: M.R. Karim, et al., Effectiveness of vehicle weight enforcement in a developing country using weigh-in-motion sorting system considering vehicle by-pass..., IATSS Research (2013), http://dx.doi.org/10.1016/j.iatssr.2013.06.004

---

<table>
<thead>
<tr>
<th>Vehicle Class</th>
<th>2 axle</th>
<th>3 axle</th>
<th>4 axle</th>
<th>5 axle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross Vehicle Weight (GVW) in tons</td>
<td>16.8 tons</td>
<td>27.3 tons</td>
<td>33.6 tons</td>
<td>39.9 tons</td>
</tr>
</tbody>
</table>
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 USD200 million yearly) on fixing road damage in federal roads, whereas part of this money could have been used for new road infrastructure or channeled for other important development projects for the nation, if road damage from overloaded trucks could be minimized. 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 2). Heavy vehicle traffic vary between 900 veh/day and 1100 veh/day between Mondays and Saturdays and dropped to around 300 veh/day on Sundays (Fig. 2). GVW violations involving heavy vehicles correspondingly follow similar pattern as shown in Fig. 2.

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 Fig. 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.

Table 2

<table>
<thead>
<tr>
<th>Violate</th>
<th>Not Violate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day</td>
<td>21.5%</td>
</tr>
<tr>
<td>Night</td>
<td>6.2%</td>
</tr>
<tr>
<td>93.8%</td>
<td>78.5%</td>
</tr>
</tbody>
</table>

Fig. 1. (a) Layout of WIM system. (b) The CPU of the WIM system. (c) The WIM sensors in the road pavement.
The WIM system employed in this study also captures GVW violations according to heavy vehicle class (Fig. 4). Although the 2-axle trucks form the majority of trucks the GVW violations occur more from among 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.

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 paper also indicate that the daily pattern of vehicle overloading and number of violation cases is consistent throughout the month. Table 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 summon, 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).

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 6101 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). 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

![Fig. 2](image_url). Heavy vehicles GVW violations by day of the week.

![Fig. 3](image_url). GVW violation cases by hour of the day (Jan 2010, 1st week).

![Fig. 4](image_url). GVW violations according to heavy vehicle class.

### Table 3

Effectiveness analysis of WIM system (Jan 2010).

<table>
<thead>
<tr>
<th></th>
<th>WIM</th>
<th>Existing (static weigh station)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total number of commercial vehicles</td>
<td>28,359</td>
<td>No data</td>
</tr>
<tr>
<td>Total violation cases</td>
<td>6101</td>
<td>126</td>
</tr>
<tr>
<td>Revenue (USD) generated by penalty fine (USD100 per summon)</td>
<td>610,100</td>
<td>12,600</td>
</tr>
</tbody>
</table>

Note: 1USD = RM3.
alternative routes) as well as the limitation in enforcement capabili-
ties of the weigh station such as in terms of human resources and fa-
cilities 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 ca-
pability 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 vi-
olation cases, percentage of truck drivers bypassing 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 relationship among the calculated violation cases at static
weigh station, percentage of vehicle bypass the WIM system and per-
centage of enforcement capability are based on the assumption that a
linear relationship exists among them. These relationships can be de-
derived as follows:

\[ y_1 = -a_1 x_1 + b \]  

(1)

where, \( y_1 \) is the number of overloaded vehicles detected by WIM sys-
tem, \( x_1 \) is the percentage of vehicle bypass the WIM system, \( a_1 \) is a re-
gression coefficient, \( b \) is the total actual violation cases and

\[ y_2 = -a_2 (1-x_2) + y_1 \]  

(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 sta-
tion, \( a_2 \) is a regression coefficient.

Replacing Eq. (1) into Eq. (2), the simplified relationship is expressed
in Eq. (3).

\[ y_2 = -a_2 (1-x_2) -a_1 x_1 + b \]  

(3)

However, determination of regression coefficients for model in
Eq. (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 Eq. (3) is simplified as follows:

If it is assumed that, \( a_1 = b \) and \( a_2 = y_1 \), then Eq. (3) can be ex-
pressed as

\[ y_2 = (1-x_1)bx_2 \]  

(4)

Based on Eq. (4) and total actual violation cases at the selected site
in this study, the calculated violation cases at static weigh station con-
sidering vehicle bypass and enforcement capability factors are shown
in Table 4.

Based on existing static weigh station operations, only 126 vehi-
cles were summoned in the month of January 2010. By using WIM
sorting system, as shown in Table 4 above, the same number of viola-
tion cases would be achieved in the situation when almost 80% of
overloaded vehicles (i.e. 4881 vehicles) were to bypass the WIM sys-
tem 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

Table 4
Calculated violation cases according to percentage bypass and enforcement capability.

<table>
<thead>
<tr>
<th>Capability (%)</th>
<th>Bypass (%)</th>
<th>Violation cases</th>
<th>100</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>10</td>
<td>20</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td></td>
<td>50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>50</td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>70</td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>90</td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
<tr>
<td>100</td>
<td>0</td>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td></td>
<td>40</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>50</td>
</tr>
</tbody>
</table>

Please cite this article as: M.R. Karim et al., Effectiveness of vehicle weight enforcement in a developing country using weigh-in-motion sorting system considering vehicle by-pass... IATSS Research (2013), http://dx.doi.org/10.1016/j.iatssr.2013.06.004
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 to the truck operator 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 to the truck operator

7. Conclusion

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 among 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.

Acknowledgment

The authors would like to acknowledge the assistance from the flagship grant FL020-2012 awarded by the University of Malaya and PRGS grant PR005-2011A awarded by MOHE.

References

(unpublished thesis).


[7] M. Davis, Operational benefits of the long creek weigh-in-motion system, Senior 
Report II, Department of Civil Engineering, University of New Brunswick, 2003.  

[8] Shapu Yang, Shaohua Li, Yongjie Li, Investigation on dynamical interaction be-
tween a heavy vehicle and road pavement, Vehicle System Dynamics vol. 48 (8) 

Commercial Vehicle Weight Enforcement, International Road Dynamic Inc., Saskatoon, 
Saskatchewan, Canada, 2000.


pressure and axle load on flexible and rigid pavement performance, Transporta-


[13] S. Jarvis, 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-

[14] A. Ardani, S. Hussein, R. LaForce, Evaluation of premature PCC pavement longitudi-
dinal cracking in Colorado, Proceedings of the 2003 Mid-continent Transporta-

[15] A.M. Brewer, Road rage: what, who, when, were and how? Transport Reviews 20 

system for enhancing vehicle weight enforcement — a case study of Malaysian 
routes, 17th Intelligent Transport System (ITS) World Congress, Busan, Korea, 
2010.

and enforcement system, 17th Intelligent Transport System (ITS) World Congress, 
Busan, Korea, 2010.

and free flow speed and consideration on its relation with differential speed limit, 