Investigating the Effects of High Productivity Vehicles on Road Infrastructure Using Weigh-in-Motion Technology

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***Abstract*—Growing levels of freight demand are contributing to rising levels of congestion in many cities. Increasing freight demand from imports as well as exports is particularly significant in cities near ports, intermodal terminals and distribution centres. Larger trucks provide an opportunity for reducing road congestion as well as increasing productivity. However, road infrastructure managers are often concerned about the effects of larger trucks on the health and maintenance of road infrastructure such as bridges and road pavements. Weigh-in-Motion (WIM) technologies allow the weight of individual vehicles and axles of trucks operating on roads to be accurately measured without interfering with the flow of traffic. This paper illustrates how WIM data can be used to investigate the effects of high productivity vehicles on road infrastructure. A comparison of the impacts of B-Doubles with conventional trucks such as semi-trailers on pavements operating in Melbourne is presented. The results indicate that in terms of pavements, B-Doubles provide a substantial increase in efficiency.**

***Index Terms*—Weigh-in-Motion, high productivity vehicles, pavement damage, road infrastructure management**

I. Introduction

Information of the weight of vehicles using roads is important for the management of road infrastructure such as pavement and bridges. Traditionally, information relating to the gross vehicle weight and axle loads of trucks were collected from static weigh stations. However, such weigh stations have limited capacity and disrupt the flow of vehicles. On high volume roads only a sample of trucks are generally inspected and that can lead to bias. To overcome these limitations, Weigh-in-Motion (WIM) systems have been developed that measure the static axle weight of moving vehicles [1]. This paper provides an overview of WIM systems as well as an application of WIM data to investigate the impacts of larger trucks on pavement damage.

II. Weight-in-Motion (WIM) Systems

WIM systems use sensing technologies embedded in or bonded to pavements to collect a variety of traffic data such as axle weights, axle spacing, gross vehicle weights, average daily truck traffic and speeds. Signals are produced as vehicles pass over sensors which record various characteristics of vehicles. WIM systems generally consist of mass sensors, vehicle classification and/or identification sensors, a processor and data storage unit as well as a user-communication unit [1].

Data from WIM systems can be used for many applications, such as pavement design, transportation operation and management, truck overload enforcement and highway bridge design and maintenance. When compared to stationary weighing, WIM systems provide a continuous, safe and fast method of collecting vehicle mass data [2]. WIM systems can be categorised as either pavement or bridge based. Bridge based WIM systems not only provide the same traffic data as pavement WIM systems, but also measure a number of parameters that can be used for assessing structural performance of existing bridges [3]. Based on functionality and accuracy purposes, WIM systems can be divided into two groups, low speed (less than or equal to 15 km/h), and high speed (greater than 15 km/h) [1].

Several WIM systems were developed in Australia in the 1980s, including the Axway system [4] and the Culway system [5]. Culway involves truck travelling on highway at certain speed across the culvert triggering tape switches and strain sensors. Sensors generate information on the axle spacing, speed, classification, gross vehicle mass, mass of axle groups and time of arrival for each vehicle. Recently, there are 18 WIM system types currently used throughout Australia [1]. The Culway system has proved to be a comprehensive and reliable WIM system that is now installed on many intercity routes, urban freeways, rural and urban arterial roads around Australia [6].

Data acquisition units are typically used to record detailed information of vehicles passing WIM sites. In general, the raw data recorded from vehicles consists of location identification, lane, vehicle identification number, date, time when leading axle passes sensors, speed, number of axles (number of axle groups and vehicle patterns), category (vehicle class, Equivalent Standard Axles (ESA)), Gross Vehicle Weight (GVW) including tare, freight and legal limit weights as well as codes such as gross weight class violation, individual axle loads, the

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sum of which is the GVW and axle spacings. Vehicle information is stored in a data acquisition unit that can be retrieved for off-site analysis.

WIM systems provide information can assist in managing road infrastructure more effectively. Large quantities of data can be collected quickly and continuously at low cost for analysing the loads applied to pavements and bridges [7]. This can be used for developing improved maintenance procedures and freight networks as well as enforcement strategies.

III. High Productivity Vehicles

High productivity vehicles have been estimated to provide substantial economic, environmental and safety benefits [8]–[13].

Although B-doubles were initially trialled in Australia in the early 1980s it is only recently that they have been permitted to operate on most rural highways and urban arterial roads [14]. B-Doubles have now overtaken semi-trailers in terms of the total road freight task and the share of freight to be carrying by them is predicted to grow.

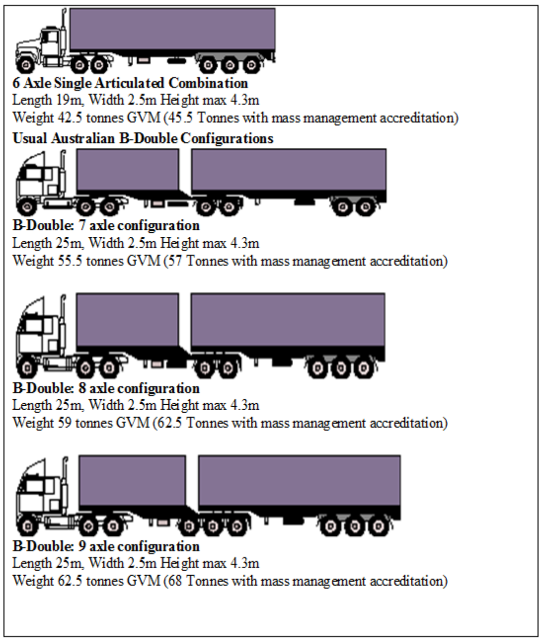

Figure 1. Standard B-Doubles and the common 6 axle articulated truck (Semi-trailer)

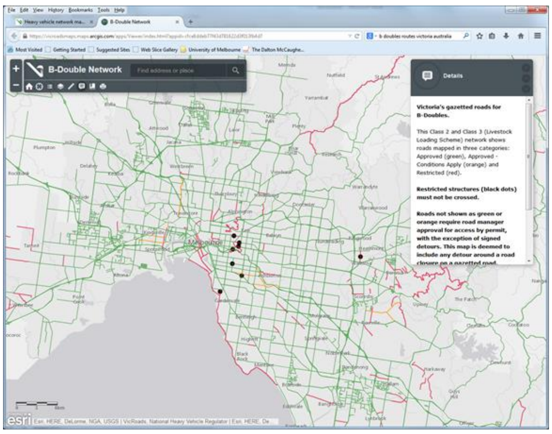

Figure 2. B-Double road network in Melbourne (source: [15])

Both 6 axle articulated trucks and B-Doubles have a variety of axles and axle groupings, including, Single Axle with Single Tyres (SAST), Tandem Axle with Dual Tyres (TADT) and Triaxle with Dual Tyres (TRDT) (Fig. 1).

Currently in Melbourne, B-Doubles are permitted to operate on over 90% of arterial roads (Fig. 2). It is important to estimate the effects of High Productivity vehicles such as B-Doubles on the performance of road pavements and bridges.

IV. Data Collection

WIM data was provided by Vicroads (the State Road Authority of Victoria) for traffic travelling on each of the 4 lanes of the south bound carriageway on the Western Ring Road (M80) between Boundary Rd and Deer Park By-Pass from 1st April 2013 to 30th April 2013. This road is a divided freeway located approximately 10 kilometres west of the central city area of Melbourne.

The WIM data was collected using the VIPERWIM system, a high speed weigh-in-motion system that uses piezo electric sensors and inductive loops [16]. Within each lane of the carriageway two piezo sensors are installed before and after an inductive loop. Piezo sensors installed below the pavement surface are used to determine the loading and spacing of axles. Cables imbedded within the pavement are used to connect the sensors to data storage and control equipment housed within a roadside cabinet.

The data files used to analyse the truck data were produced by WIMNet a software module designed to manage WIM data [17]. WIMNet allows WIM data to be validated and calibrated across time periods for a variety of detection equipment.

WIMNet provides a range of data for individual vehicles. As well as the location (including site & lane), the time, speed, configuration (number of axles and axle groups, pattern of axle groups - axles in each axle group) and class (Austroads Classification) of each vehicle is provided. A range of weights are also estimated including, Gross Vehicle Mass (GVM), Tare (Unladen) and Freight (Load) as well as the equivalent Standard Axles (ESA), based on axle group loadings, standard loads and the 4th power law. The weight and spacing of all axles as well as the weight and type of the axle groups are estimated. The vehicles length as well as whether it is deemed legal (satisfying regulations) is also provided.

V. Data Analysis

The vehicle class (Austroads classification), number of axle groups and the number of axles per group were used to extract both semi-trailers and B-Doubles to undertake the analysis. Semi-trailers - six axle articulated trucks (Class 9 vehicles) with 3 axle groups and axle pattern 1-2-3 depicting trucks with a leading single (steer axle) followed by a dual axle group and then a tri axle group were the most common recorded Class 9 vehicle. A total of 14,563 readings corresponding to this vehicle type were recorded as not to exceeding the legal weight limits during the 30 day period.

B-Doubles (Class 10 vehicles) with 9 axles and 4 axle groups with an axle pattern 1-2-3-3 depicting trucks with a single steer axle followed by dual axle group then two tri axles groups were also extracted. For this vehicle configuration, a total of 388 vehicles were recorded as complying with the legal weight limits during the 30 day period.

The distribution of the Gross Vehicle Mass (GVM) for both the semi-trailer and B-Double configurations defined above are shown in Fig. 3 and Fig. 4. It can be seen that the distribution of GVMs is bi-modal, reflecting the prevalence of both unloaded and loaded vehicles. The distribution of GVMs for B-Doubles has 3 distinct clusters, unloaded, fully loaded as well as moderate proportion of vehicles only partially utilising their weight capacity, suggesting that these vehicles maybe constrained by volume not weight.

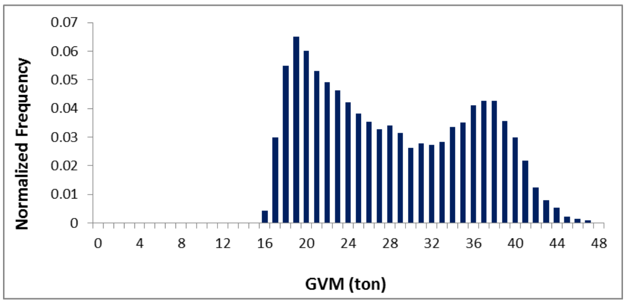

Figure 3. Distribution of GVM for semi-trailers

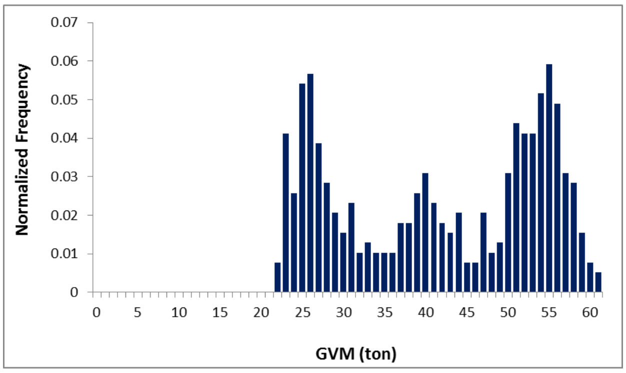

Figure 4. Distribution of GVM for B-Doubles

The Pavement Wear Damage Factor (PWDF) also termed the number of Equivalent Standard Axles (ESA) was estimated by WIMNet for each vehicle using the recorded weights and standard loads for axle groups based on the 4th power law developed in the United States in the 1950's. Dual tyres are assumed to be present on all but the first axle. To estimate the PWDF for each vehicle the recorded weights for each axle group are divided by the standard axle loads for each axle group [18] and raised by the power of 4 and then summed for all axle groups.

The WIM data was used to estimate the average PWDF per vehicle for both semi-trailer and B-Double configurations defined above. Although the average PWDF for semi-trailers was estimated to be significantly lower than B-Doubles, the freight capacity of B-Doubles in terms of weight is substantially higher (Table I).

TABLE I. ATTRIBUTES OF SEMI-TRAILERS AND B-DOUBLES

	Semi-Trailers	B-Doubles	% Difference
Tare (t)	15.7	21.4	36.3
Max. Freight (t)	32.05	48.35	50.9
Gross Legal Limit (t)	47.75	69.75	46.1
Average PWDF per vehicle	1.83	2.27	24.2

The WIM data allowed a comparison of the performance of pavement for transporting a large amount of freight in terms of load. The maximum loads recorded for both semi-trailers and B-Doubles was used to estimate the number of vehicles required for transporting 1 Million tonnes of freight (Table II). The PWDFs of the maximum loaded vehicles recorded were also used to estimate the total PWDFs. Since considerably fewer B-Double vehicles are required for transporting the equivalent loads as well as the lower PWDF for B-Doubles, the overall effect on pavements for B-Doubles compared with semi-trailers is substantially less, 38.3%.

TABLE II. PERFORMANCE FOR TRANSPORTING 1 MILLION TONNES OF FREIGHT

	Semi-Trailers	B-Doubles	% Change
Maximum Load (t)	31.9	38.7	21.3
Number of Trucks	31,348	25,840	-17.6
PDWF per vehicle	7.08	5.30	-25.1
Total PDWF	221,974.9	137,002.6	-38.3

The WIM data also allowed the efficiency in terms of the freight and pavement performance for both semi-trailers and B-Doubles to be compared. Here, efficiency was defined as the total freight carried divided by the total PWDF (Table III). It was estimated that B-Doubles have significantly higher efficiency than semi-trailers, an improvement of 33.4%.

TABLE III. EFFICIENCY OF VEHICLES

	Total Freight Carried (t)	Total PWDF	Efficiency
Semi-Trailers	175,127.457	26,637.3	6.6
B-Doubles	7,676.978	881.7	8.7

VI. CONCLUSIONS

In Australia, larger trucks are becoming prevalent providing opportunities for increasing productivity and reducing congestion. However, there is a need to determine the effects of larger vehicles on pavements and bridges. WIM systems provide an effective means of recording the weights of vehicles operating on roads. Details of the class of vehicle and axle weights allow the effects of specific vehicles class on the road infrastructure to be determined.

This paper has illustrated how WIM data can be used to investigate the effects of B-Doubles on road pavements. It was shown that on average, larger vehicles have a higher impact on pavements per vehicle compared with smaller conventional vehicles. However, when maximum loaded vehicles are analyzed, B-Doubles have less impact on pavements than semi-trailers per vehicle. Also, since fewer of these vehicles are required for transporting the equivalent amount of freight the overall effect on pavements for B-Doubles is considerably less. Significant improvements in the efficiency of pavements for B-Doubles were also estimated.

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