A NON-INTRUSIVE METHOD FOR PERIODICALLY RECORDING THE LOCATION AND MASS OF AN IN-SERVICE HEAVY VEHICLE USING ON-BOARD SYSTEMS

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ABSTRACT

A non-intrusive method for periodically recording the location and mass of an in-service heavy vehicle using on-board systems was devised, tested and improved. The method was deployed on commercially operating buses in Victoria, Australia, for a period of 12 months. The purpose was to gain insight into the typical ranges of in-service front and rear axle loads as they varied throughout the day, and to test the appropriateness of existing legal axle load limits relative to actual daily loading. While traditional infrastructure-based Weigh-In-Motion systems collect vehicle weight data for many different anonymous vehicles at a fixed point on a transport network, for this purpose it was desirable to collect vehicle weight data for a small number of specific vehicles at any time during their travel, wherever they may have gone on the transport network. This necessitated the use of a vehicle-based system. A bus is an interesting subject for this method of data collection because its mass can change frequently during a journey and is often unknown. On-board electronic weighing systems are designed to accurately indicate static weight only under controlled conditions. Application of such a system to a commercially operating vehicle at any time during travel presented measurement accuracy challenges that were overcome during this project through the use of basic data processing algorithms to remove unwanted variations and spikes in the data. The end result was a procedure of sufficient accuracy to enable a policy decision to be made about the regulation of bus mass in Victoria.

INTRODUCTION

The Roads Corporation of Victoria ('VicRoads') wished to conduct a field survey of the static laden weight of two-axle buses while in service. One of the objectives of the survey was to determine if instances of high mass occurred—and if so, where, when, how high and for how long—for each bus involved in the survey. This required weight to be determined at frequent intervals, because the number of passengers on a bus often varies during a journey and sometimes a bus may be at a high load for only a short period of time.

The survey was to use suspension airbag pressure transducer-based on-board Electronic Weighing Systems (EWS) and Global Positioning Systems (GPS) to achieve this objective, as this was the most cost-effective way of taking measurements at frequent intervals and identifiable locations over an extended period of time without disruption to bus services. VicRoads engaged a heavy vehicle tracking company (Transtech Driven) to equip the vehicles with the required EWS, GPS, data logging and communications equipment and to supply the logged data to VicRoads. VicRoads engaged Advantia Transport Consulting to conduct data processing and analysis and to report back to VicRoads.

Manufacturers of airbag pressure transducer-based on-board EWS claim reasonably accurate measurement of static laden weight (to within 250 kg) only when the vehicle is stationary on a flat and level surface (such as in a warehouse) with the brakes released. Without such conditions the EWS may be adversely affected by abnormal airbag pressures due to the vehicle dynamics, the attitude of the vehicle and the effects of braking on suspension reaction forces. In order to overcome these problems for the survey, EWS measurements were averaged in the hardware as described later. This, however, did not remove all of the measurement errors. This paper describes a post-processing method that was developed to obtain results that were sufficiently accurate for the purpose of the project, which was to enable a policy decision to be made about how bus mass should be regulated in Victoria. Passenger-level measurement accuracy was not required.

ON-BOARD ELECTRONIC WEIGHING SYSTEMS

Calibration and use

An on-board EWS used on a heavy vehicle with air suspensions determines the static load on an axle from measurement of the air pressure in that axle's suspension airbags. The relationship between airbag pressure and static axle load must be determined first using a calibration process. The typical calibration process involves recording the axle load and airbag pressure for two separate static load conditions—usually empty and fully laden. Later, when the vehicle is laden to some other unknown weight, the sensed airbag pressure can be converted to a static axle load by linear interpolation or extrapolation (Figure 1). This method relies on the airbags having a linear load-pressure relationship (which is typically the case), and the calibration points being sufficiently far apart to minimise error in the gradient of the straight line passing through them.

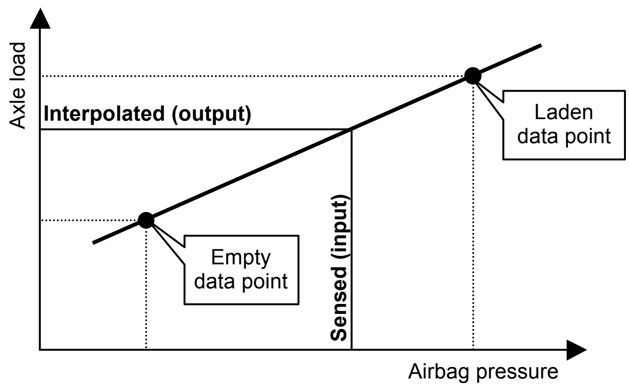

FIGURE 1 Linear Interpolation of Sensed Airbag Pressure to Obtain Static Axle Load.

Static measurement versus dynamic measurement

On-board EWS are designed to be effective in determining static axle load when a vehicle is stationary on a flat and level surface with the brakes released. When the system pressure is stable, it correlates well with static axle load. During travel, however, when the pressure in the airbags varies dynamically, pressure measurements do not correlate well with dynamic axle load. Averaged dynamic pressure data, converted into load, has been reported as being effective in estimating with reasonable accuracy the static axle load during travel (Transport Certification Australia 2009), however in this study it was found that certain travel conditions can upset readings to the degree that even averaging is not sufficient, and additional post-processing was required.

Air pressure was sampled at 2 Hertz, and at 30-second intervals the average of the previous 30 seconds of measurements (i.e. the average of the previous 60 samples) was recorded. This provided a degree of filtering that removed higher-frequency variations in the data. The necessary additional post-processing of the data is described later.

FIELD SURVEY INITIATION

Equipment setup

Each bus was fitted with an EWS and a communications system that included GPS tracking capability. The EWS was calibrated so that it would report front and rear axle loads individually, in kilograms, to the communication equipment at a frequency of 2 Hertz, which in turn calculated the average weight every 30 seconds and then stored the averaged weight along with the GPS location and some other fields of information in a database. The database was transferred automatically by a wireless system from the bus to a back-office at regular intervals. Data could then be extracted from the back-office database for processing and analysis.

Checking Dynamic Weight Measurement Accuracy

Checking the accuracy of dynamic weight measurements during service is difficult, because the payload of most buses varies constantly throughout the day. In the case of a freight vehicle, it may be possible to obtain documents through a mass management system or from weighbridges at loading depots, and then it is understood that the vehicle will have a constant mass until its next stop. In the case of a bus, passengers may board and alight every minute or so as it travels along a route service. There is no way of knowing what the bus actually weighs at any point in time unless it is stopped mid-service (with paying passengers on-board) to have its mass checked by portable scales or by a weighbridge that is probably off the route. These methods take time and would be unacceptable to passengers and the bus company.

Data accuracy was checked by riding on a bus for a period of time and keeping a running total of the number of passengers on-board, with notes to link the passenger numbers to geographic locations and time. This could later be correlated with the mass readings, which were also linked to geographic locations and time. The empty weight of the bus plus the number of passengers at any time multiplied by an assumed average passenger mass provided an estimated laden weight. Figure 2 shows an example of the weight measured by a system (blue), the weight expected from the number of passengers (green), and the number of passengers (magenta) versus time, for a trip of duration 55 minutes. It can be seen that there is poor agreement between the measured (blue) and expected (green) values of mass. The amount of error possibly introduced into the expected value of mass, by the assumption of what one passenger weighs, is very small in comparison with the differences between the two traces.

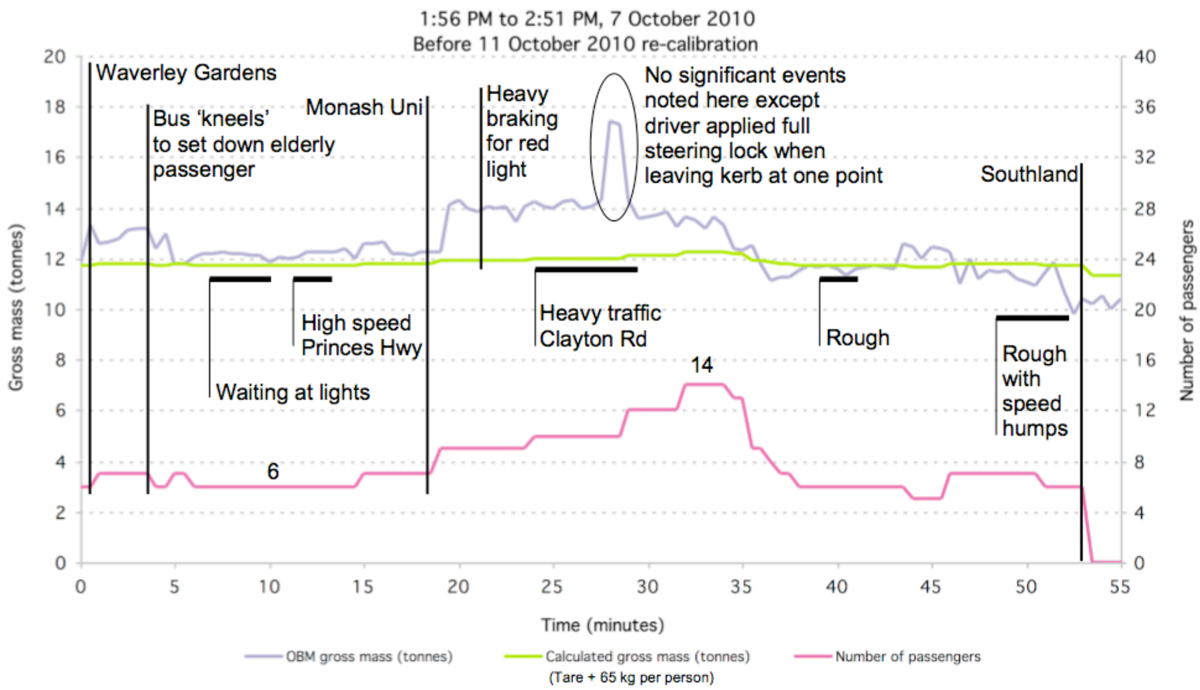

FIGURE 2 First Check of Dynamic Weight Measurement Accuracy.

It was discovered that some of the initial calibrations were not performed to a suitable standard, so calibrations were repeated.

Re-calibration of System

After re-calibration, the journey depicted by the chart in Figure 2 was repeated and another chart was produced (Figure 3). Here it can be seen that the output from the weighing system is acceptable almost all of the time, and that the times where output departs from expected values can generally be isolated as short periods (typically one or two weight records, or 30 to 60 seconds) when the bus has stopped to take on or drop off a large number of passengers. During such times the weight of the bus and the distribution of that weight can change considerably, depending on how the passengers board and alight. There are also some other periods where discrepancies cannot be explained by passenger changes (e.g. around the 50-minute mark, where the vehicle was travelling slowly and traversing speed humps). The magnitude of these errors was not acceptable for the purposes of the project.

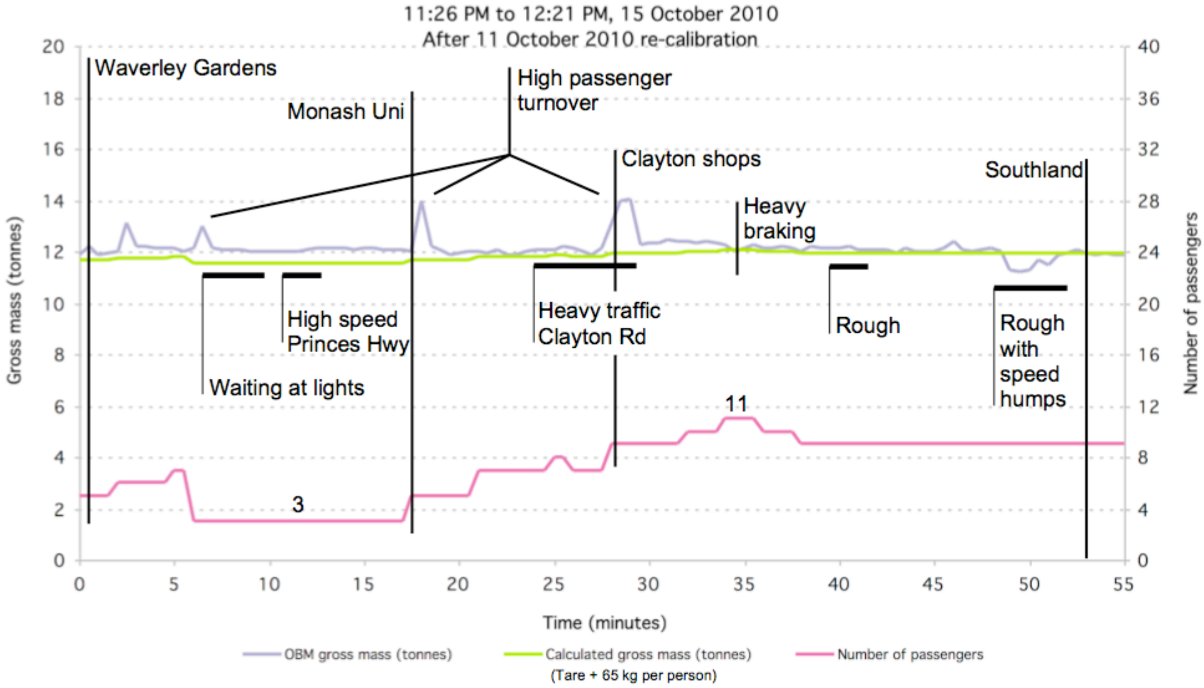

FIGURE 3 Second Check of Dynamic Weight Measurement Accuracy.

Post-processing

In consultation with Transport Certification Australia, it was determined that two further levels of filtering were required.

Neglect all records for which speed is less than 20 km/h

This is because when a bus is travelling at low speed it is usually starting or stopping, experiencing relatively heavy acceleration or braking, making tight turns, traversing speed humps, and it may even be stopped with its brakes engaged, all of which can upset the weighing system readings. Longitudinal and lateral loads on air suspensions can induce compression and extension of the airbags that cause pressures to differ from what they would be if the vehicle was under suitable weighing conditions (i.e. stationary on a flat and level surface with the brakes released). This filter typically neglected about half of all records.

Neglect all records for which weight is more than 500 kilograms higher (or lower) than the records immediately preceding and following (i.e. weight 'spikes')

It was considered highly unlikely that a bus would in fact vary in mass by more than 500 kilograms in one 30-second interval and then go back by more than 500 kilograms in the following 30-second interval, and that if such a variation occurred it must have been caused by some other measurement error. This filter removed a small proportion of records.

Figure 4 shows how this post-processed filter affected the data previously shown in Figure 3. It was found that removing the data for travel less than 20 km/h removed the large deviations in mass. In this particular data set, there were in fact no '500 kg weight spikes' left after the speed filter, so in effect only the speed filter was required.

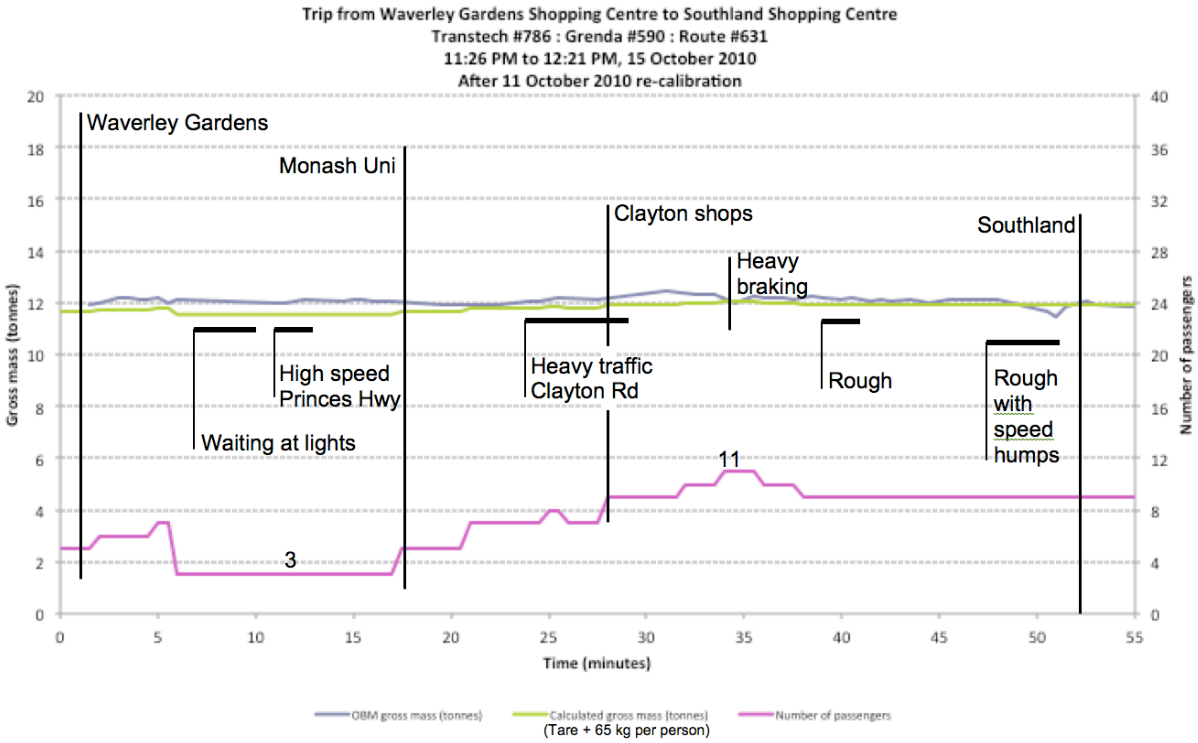

FIGURE 4 Application of Filter Through Post-Processing.

Figure 5 shows the effect of progressive application of the two additional filters to some data that was collected from one bus over a period of about four weeks.

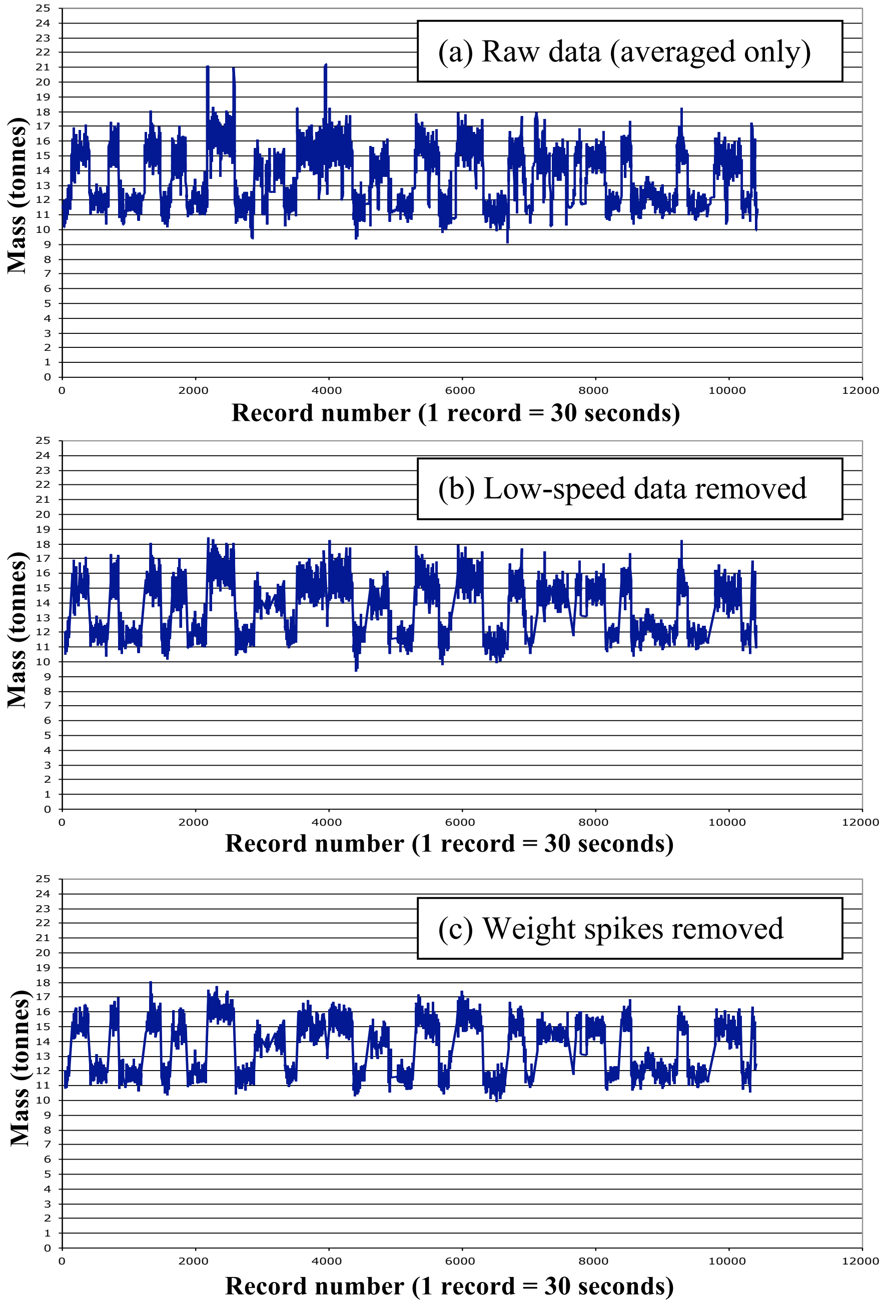

FIGURE 5 Progressive Filtering of Data.

DISCUSSION

From Figure 5 it can be seen that both of the filters removed a considerable amount of variation from the data. In fact, some portions of the raw data in Figure 5(a) that appeared to be 'spikes' were removed by the speed filter in Figure 5(b) before the spike filter was applied. It follows that some weight spikes (the most prominent ones in this data) occurred during low-speed operation, but some spikes also occurred at higher speeds.

The described filtering process is simple enough that it can be performed either in real-time (by not recording any data that is captured by either of the two filters) or during post-processing (by applying a simple algorithm to remove unwanted records). For this study, all data was collected and then post-processed using Microsoft Excel.

CONCLUSION

On-board Electronic Weighing Systems (EWS) are designed to provide an accurate indication of vehicle static weight when the vehicle is stationary on a flat and level surface with the brakes released. Weight readings taken at intervals during vehicle travel indicate neither the static load nor the dynamic load, although to a certain extent, taking an average of such weight readings provides an indication of the static load. Under certain circumstances this too can be erroneous.

The method presented is suitable for obtaining an indication of static weight for size and weight policy purposes.

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Transport Certification Australia (2009) *On-board Mass Monitoring Test Report (Final)*, Publication No. TCA-A43, Transport Certification Australia, Melbourne.