METHODS OF MONITORING THE OVERLOADING OF GOODS VEHICLES

by W H Newton

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ABSTRACT

This report examines three methods of monitoring overloading of goods vehicles: (i) using data from enforcement statistics; (ii) weigh-in-motion systems which measure the weight of each axle of vehicles travelling at normal highway speeds; and (iii) random surveys of goods vehicle weights. The potential sources of error in weighing vehicles are examined as are the effects of these errors on the apparent overloading rate. Other factors affecting the choice of method, such as knowledge of the maximum permitted weights, sample composition and time coverage are also examined. The report concludes that enforcement statistics indicate the efficiency of selecting vehicles to weigh rather than the rate of overloading, that random surveys can provide useful information on overloading but are expensive and cover limited time periods, and that the accuracy of weigh-in-motion systems needs to be substantially improved before they can serve as a useful method for monitoring overloading.

1 INTRODUCTION

Overloading of goods vehicles increases road wear and bridge loading unnecessarily, is detrimental to safety, and results in unfair competition between companies. For example, it was estimated from surveys conducted by TRRL (Shane and Newton, 1988), that about 6 per cent of all road wear by goods vehicles is attributable to overloading. It has been estimated that the cost of abnormal road wear attributable to overloading could be £50 million a year (National Audit Office, 1987). At present, information on overloading is available from enforcement statistics and from random roadside surveys.

Recently new methods of gathering vehicle weight information have been developed. These are weigh-in-motion (WIM) systems using piezo-electric or other types of sensor to measure axle weights continually at normal highway speeds. Automatic monitoring of the level of overloading should aid the efficient deployment of enforcement resources. For example, the rates of overloading at different times of the day or different days of the week could be examined so that enforcement officers could be deployed at the times when overloading is most serious.

This report outlines the three methods of monitoring overloading (Section 2) and their accuracy when weighing vehicles (Section 3). The effect of weighing errors on the indicated overloading is examined in Section 4 by superimposing different hypothetical errors onto data from 9 random surveys of goods vehicle weights. Other factors which should be considered when selecting a method for monitoring overloading are examined in Section 5.

In this report, particular reference is made to the roadside survey of randomly selected heavy goods vehicles (HGVs) conducted at Doxey on the M6 in 1985 (JMP Consultants Ltd, 1986).

2 METHODS OF MONITORING OVERLOADING

In this section, three different methods of monitoring overloading are described. A vehicle is overloaded if its gross weight or any axle weight exceeds the maximum permitted weights. Since road wear is related to axle weight and structural loads on bridges tend to be related to gross weight, it is important that both the gross weight and individual axle weights are controlled.

The rules defining maximum weights are defined in the Construction and Use regulations (Secretary of State for Transport, 1986). The values for a particular vehicle or trailer are specified on a plate which is attached to it, and these weights are known as 'plated' weights.

2.1 ENFORCEMENT STATISTICS

The most commonly quoted figures for overloading are those derived from enforcement statistics. These are compiled by enforcement officers (Department of Transport traffic examiners, local authority trading standards officers or police officers) as part of their enforcement work. Typically, the traffic examiners find about 20 per cent of vehicles weighed to be overloaded with respect to either the gross weight limits or the axle weight limits (National Audit Office, 1987).

In practice, these figures are not a measure of overloading (ie: overloaded vehicles as a proportion of all vehicles). Instead they are a measure of the efficiency of selection of vehicles to weigh (ie: overloaded vehicles as a proportion of vehicles stopped because they are believed to be heavily laden). If enforcement officers had perfect knowledge, they would only weigh vehicles which were overloaded. In this case the 'overloading rate' figures compiled by enforcement officers would be 100 per cent.
Enforcement officers normally use either whole-vehicle (static) weighbridges or slow speed ‘dynamic’ axle weighers (Prudhoe, 1988) to weigh vehicles. In the latter case, each axle is weighed separately and in turn as the vehicle is driven at a slow and steady speed (less than 4 km/h) over a weighbeam set in a precision-laid concrete apron. The vehicle’s gross weight is then calculated by summing the axle weights.

2.2 RANDOM SURVEYS
In random surveys, vehicles are stopped and weighed at random. Between 1980 and 1986, TRRL conducted 10 such surveys (Shane and Newton, 1988) and a total of about 12,500 vehicles were weighed. (In 9 of the 10 surveys, vehicles were weighed using slow speed ‘dynamic’ axle weighers.) In addition to the weights, information about vehicle dimensions, journeys, commodities carried, etc was gathered for each vehicle. Over all 10 surveys, it is estimated that 8.0 per cent of the vehicles were overloaded with respect to the gross weight limits (1.8 per cent by a margin of more than 5 per cent) and a further 5.4 per cent were within the gross weight limits but had overloaded axles, bogies, tractors or trailers (3.9 per cent by a margin of more than 5 per cent). The proportion of vehicles found to be overloaded (gross weight and/or axle weight overloads) varied from 7.6 per cent for the survey at Lichfield to 24.5 per cent for the survey at Barham. (For 5 of the 10 surveys, between 10 and 14 per cent of vehicles were found to be overloaded.) Similar surveys have been conducted by other organisations (for example, Urquhart and Rhodes, 1987).

2.3 WEIGH-IN-MOTION (WIM)
For a number of years, equipment has been available to weigh vehicles as they travel along highways at normal speeds (Moore, Hodge and Spindlow, 1988). Until recently this equipment, using plates mounted in the highway, has been complicated and expensive to install. More recently cheaper equipment, generally using piezo-electric cables mounted in narrow grooves cut in the road, has been developed (Stewart, 1987). As a vehicle passes over a piezo-electric cable, the load on the cable changes and an electric charge is produced. This is measured and used to indicate the weight of the axle passing over the cable. Whilst weigh-in-motion equipment is most commonly used to monitor the loads imposed on roads (Robinson, 1988), it has also been used to select vehicles for enforcement weighing and to monitor overloading (Siffert, 1988).

3 ACCURACY OF WEIGHING VEHICLES
In this section, the accuracy of the weight information obtained from weighing equipment is examined. Weighing errors can be caused either by inaccuracies in the weighing equipment or because the loads applied to the road at any instant are not the same as the static axle weights because the vehicles bounce on their suspensions. For enforcement weighing in the United Kingdom, only static or slow speed weighing equipment may be used.

3.1 ACCURACY OF WEIGHING EQUIPMENT
The accuracy of weighing equipment depends on:
- its initial calibration;
- variation of output depending on the position of the load on the weighing device (the sensitivity of some systems varies along their length);
- stability of the output with time, changes in temperature, ageing of the equipment, etc;
- the procedure (usually electronic in modern systems) for processing the signals from weight sensing transducers to give the weight reading.

The equipment used for enforcement weighing (and random surveys) consists of weighing platforms which can be calibrated and whose accuracy can be tested using known loads traceable to National Standards. For example, for the initial test the weight indicated by slow-speed ‘dynamic’ axle weighers has to be within 10 kg of the true (static) load at 1 tonne increments up to full capacity (Department of Transport, 1981).

The latest generation of weigh-in-motion systems use piezo-electric cables. Currently available piezo-electric cables respond to the change in load rather than to the load itself. This means that they have to be calibrated using moving vehicles. Usually this involves passing a small group of vehicles (with known axle weights) several times over the sensors. A more representative method would be to base the calibration on the axle weights of a random selection of vehicles which have been weighed using both the WIM sensor and an enforcement quality axle weigher (during a type of random survey). Also, the output from these cables may vary by up to 5 per cent along their length (thus the indicated weight may depend on the position of the vehicle across the road) and their calibration may vary over time.

3.2 VEHICLE BOUNCE
At speed, all vehicles bounce on their tyres and suspension. Because of this the instantaneous axle loads vary cyclically, at typically 2 to 4 times each second (see Figure 1). For a vehicle travelling along a main road with a smooth pavement surface at 40 mph (64 km/h), the standard deviation of the instantaneous load is typically 10 to 20 per cent of the static load (Mitchell, 1987). An axle may be at any point in its bounce cycle when it passes over a sensor mounted in the road.
3.3 LOAD TRANSFER BETWEEN PARTS OF A VEHICLE

The load on individual axles of many mechanically linked compensating bogies depends on the relative heights of the axles. This effect is quasi-static—it does not involve any inertia forces and occurs at any vehicle speed or with the vehicle at rest. Test with a slow speed ‘dynamic’ axle weigher (Prudhoe, 1988) have shown that load transfers of up to 100 kg can occur for each millimetre of height difference between linked axles. Thus, if weighing equipment is installed in a slightly raised position relative to the surrounding road, the measured weight of each bogie axle is likely to be greater than if the weighing equipment is installed flush with the road surface. This effect is likely to be reduced if only part of the wheels/axle is raised.

Weight transfers between axles can also occur when vehicles are weighed on sloping ground. On a 2 per cent longitudinal slope weight transfer between axles of 1.2 to 4.2 per cent have been measured (Eastman, 1988). Also, when a vehicle is travelling at speed aerodynamic drag and drag from the non-driven axles can cause load transfers between axles. Similarly, load transfers can occur if the vehicle is accelerating or braking during weighing.

Whilst these load transfers will not necessarily affect the indicated gross weight, they will affect indicated axle weights (and are therefore likely to affect the gross weight if it is obtained from the sum of individual axle weights).

3.4 INCOMPLETE WEIGHING

Some WIM systems are arranged to weigh only one end of each axle (normally the nearside) with the assumption that half the axle weight is borne by each end of the axle. During tests of portable weighpads (Eastman, 1988), 5 different evenly-loaded vehicles (listed in Table 1) were weighed both on level ground and on a section of road with a 2.5 per cent crossfall (a typical value for a highway). When weighed on the crossfall, the loads on the offside wheels of the vehicles (the road sloped down the offside) were on average 6.3 per cent heavier than they were when the vehicles were weighed on level ground. Thus, if only the nearside wheels of these vehicles were weighed on a typical crossfall (sloping down to the nearside) the indicated wheel loads should be multiplied by 1.88 (2.0 divided by 1.063) rather than 2.0 to obtain a proper estimate of the axle weights. In addition, other errors may be introduced if vehicles are unevenly loaded. Also, parts of the vehicle may not be properly weighed. For example, even when a WIM system is arranged to weigh complete axles only half the true weights will be recorded when vehicles straddle lanes. Most of these effects can be overcome by careful system design and calibration.

3.5 TYPICAL ACCURACY WHEN WEIGHING VEHICLES

For enforcement weighbridges, the errors listed above are either small or do not apply. Whole-vehicle weighbridges measure the gross weight of the complete vehicle while it is stationary with an
TABLE 1
Comparison of axle weights measured statically and at slow speed

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Axle</th>
<th>Slow-speed (&lt; 2.5 mph)</th>
<th>Static (Weighpads)</th>
<th>Difference/number of axles</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-axle rigid</td>
<td>1</td>
<td>5.89</td>
<td>5.89</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>10.36</td>
<td>10.42</td>
<td>-0.06</td>
</tr>
<tr>
<td>4-axle rigid</td>
<td>1</td>
<td>5.73</td>
<td>5.67</td>
<td>+0.06</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>6.23</td>
<td>6.22</td>
<td>+0.01</td>
</tr>
<tr>
<td></td>
<td>3+4</td>
<td>18.45</td>
<td>18.49</td>
<td>-0.02</td>
</tr>
<tr>
<td>5-axle artic (3 + 2)</td>
<td>1</td>
<td>4.47</td>
<td>4.50</td>
<td>-0.03</td>
</tr>
<tr>
<td></td>
<td>2+3</td>
<td>10.75</td>
<td>10.67</td>
<td>+0.04</td>
</tr>
<tr>
<td></td>
<td>4+5</td>
<td>15.11</td>
<td>14.83</td>
<td>+0.14</td>
</tr>
<tr>
<td>5-axle artic (2 + 3)</td>
<td>1</td>
<td>5.96</td>
<td>6.02</td>
<td>-0.06</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>8.57</td>
<td>8.45</td>
<td>+0.12</td>
</tr>
<tr>
<td></td>
<td>3+4+5</td>
<td>19.44</td>
<td>19.47</td>
<td>-0.01</td>
</tr>
<tr>
<td>6-axle artic (3 + 3)</td>
<td>1</td>
<td>4.27</td>
<td>4.38</td>
<td>-0.11</td>
</tr>
<tr>
<td></td>
<td>2+3</td>
<td>11.68</td>
<td>11.53</td>
<td>+0.08</td>
</tr>
<tr>
<td></td>
<td>4+5+6</td>
<td>19.36</td>
<td>19.19</td>
<td>+0.06</td>
</tr>
</tbody>
</table>

Notes: Results from project to evaluate portable weighpads (Eastman, 1988), slow-speed results are the averages of 8 passes over a slow-speed 'dynamic' axle weigher and the weighpad results are the average of 16 weighings (10 for 2-axle rigid) using weighpads (types 'X' and 'Z' as defined in Eastman, 1988) on level ground.

accuracy of 1 part in 2000 or better. Multiple-plate weighbridges, which are almost as accurate, are also available. These consist of two or more weighbridges set in line so that different parts of a vehicle can be weighed simultaneously (Glover, 1989). For example, to weigh an articulated vehicle, one weighbridge would be used to weigh the tractive-unit and a second to weigh the semi-trailer bogie. The accuracies of whole-vehicle and multi-plate weighbridges are checked regularly using weights traceable to National Standards.

Slow-speed 'dynamic' axle weighers are also used for enforcement weighing. They measure individual axle weights as a vehicle moves slowly along a precision-laid concrete apron which is flat and level to within ± 3 mm and are designed to minimise any potential errors. Their accuracy is checked every six months. During these checks, three different goods vehicles (a 2-axle rigid, a 4-axle rigid and a 4 or 5-axle artic) are each weighed nine times. During each pass, the gross vehicle weight determined using the slow-speed axle weigher (sum of the axle weights) has to be within 100 kg times the number of axles of the true gross weight (measured using a whole-vehicle weighbridge).

The average axle and bogie weights of 5 vehicles measured using a slow-speed axle weigher have been compared with the corresponding weights measured when the vehicles were stationary (using portable weighpads) (Eastman, 1988). Table 1 shows that the difference between these weights was always less than 150 kg per axle (the weights of individual axles of compensating bogies being summed). Furthermore, this difference was less than 100 kg per axle for all except three of the axles or bogies. This is within the tolerance for slow-speed axle weighers when used for enforcement weighing (150 kg per axle) and some of the differences are due to small errors in weighing axles using weighpads (up to 150 kg per axle). These results indicate that any systematic weight transfers between axles due to a vehicle moving slowly are small.

The errors in weigh-in-motion systems are much greater than those in enforcement weighing equipment. Not only are the weighing devices inherently less accurate (and therefore less easy to calibrate) but also large 'errors' (due to axles/vehicles bouncing) are introduced as the vehicle passes over them at speed. Results from limited trials (using three different goods vehicles) with WIM systems at TRRL (TRRL, 1987) indicated that the error in measuring gross weights had a coefficient of variation (standard deviation divided by the mean value) of between 6 and 16 per cent. The coefficients of variation when measuring the axle weight were between 12 and 28 per cent. It is possible that these coefficients of variation would have been greater if a larger variety of vehicles had been used.

Errors from WIM systems could be reduced if more than one sensor were used. From statistical theory, the standard deviation of the mean value from several sensors is the standard deviation for a single
sensor divided by the square root of the number of sensors, if the measurements are independent. For example, the standard deviation of the mean value from 9 sensors would be one third (square root of 9) of the standard deviation of the weight using one sensor, and coefficients of variations for gross weights of 2 to 5 per cent might be expected. Moreover, since it appears that vehicles’ axes bounce in a systematic way relative to the profile of the road, these errors may be further reduced by proper choice of sensor spacing and data processing.

4 EFFECT OF WEIGHING ERRORS ON INDICATED OVERLOADING RATES

The errors described in Section 3 affect both the axle and the gross weights recorded by the weighing systems. These errors cause the systems to exaggerate the proportion of vehicles that are measured as being overloaded. This is because the distribution of vehicle weights over a typical population of vehicles includes a large number of vehicles whose weights are just below their maximum permitted gross weights. For example, for the two surveys shown in Figure 2, about 20 per cent of the vehicles were loaded to between 90 and 100 per cent of their maximum permitted gross weights. In this section, the results of the TRRL random surveys are used to show the effect of systematic and random weighing errors on the proportion of vehicles appearing to exceed the maximum permitted gross weight limits (the gross weight overloading rate).

4.1 SYSTEMATIC ERRORS IN THE CALIBRATION FACTOR

Weighing systems are calibrated to ensure maximum accuracy. The effect of systematic errors in this calibration on the perceived overloading rate for the Doxey (1985) survey are shown in Figure 3. Similar figures for 9 surveys are shown in Figure 4. The calibration factor is defined as:

\[
\text{indicated weight} \div \text{true weight}
\]

These figures show that even small errors in the calibration can lead to large changes in the recorded overloading rate. This is because many vehicles operate close to the maximum permitted limits. For example, for the Doxey (1985) survey, calibration factors of 0.95 and 1.05 would have led to overloading rates of 0.9 and 15.1 per cent respectively compared with the actual figure of 4.1 per cent.

If the magnitude of the calibration error is known, it can be compensated for fairly easily. However, if it is unknown or changing, the resulting overloading figures are unlikely to be reliable. It is likely that the accuracy of weigh-in-motion systems will have to be checked regularly. It may be possible to do this automatically by taking moving averages of certain axle weights (for example, the first axle of 5-axle artic) and comparing them with predetermined values (this average remains fairly stable across a changing sample of vehicles, providing that the sample is sufficiently large for the average value to be unaffected by the random variation due to vehicle bounce).

4.2 RANDOM ERRORS

Even if there are no systematic errors in the calibration of a weighing system, random errors affecting individual weight readings occur. Random errors have a ‘blurring’ effect on the distribution of vehicle weights. For example, Figure 5 shows the effect on a weight distribution of random errors in the weighing process with a coefficient of variation (standard deviation divided by the mean) of 10 per cent. (The values were calculated by superimposing a Normal or Gaussian distribution onto the gross weight data.) In Figure 6, the ability of an error of this magnitude to cause the mis-classification of vehicles in two important parts of the distribution of vehicle weights is shown. These parts are, those vehicles nearly fully laden (85 to 100 per cent of the Plated Gross Weights, marked \(P_{(85-100)}\)) and those overloaded with respect to the Plated Gross Weight (marked \(P_{(OL)}\)). With a 10 per cent random error, 39 per cent of the vehicles that are actually overloaded would be counted as legally loaded and 24 per cent of the nearly fully laden vehicles would be counted as overloaded. Since there were many more vehicles nearly fully laden than there were vehicles overloaded, the overall effect would be to increase the indicated overloading.

The effect of different sizes of error on the recorded gross weight overloading at Doxey (1985) is shown in Figure 7 and comparable figures for 9 surveys are shown in Figure 8. The rate of overloading at Doxey (1985) would be increased from its true value of 4.1 per cent to 7.1 per cent if the error had a coefficient of variation of 5 per cent and to 9.2 per cent if the coefficient of variation was 10 per cent. The effect on the indicated rate of serious overloading (by more than 10 per cent) is even greater. For the Doxey (1985) data, this would be increased from its true value of 0.4 per cent to 2.6 per cent (a six-fold increase) if the coefficient of variation was 10 per cent.

As Figure 8 shows, similar relationships exist for the other surveys, though the effect of increased measurement error would be especially marked on the 1985 Doxey sample because it had a relatively small proportion of overloaded vehicles, and a large proportion close to the limits. This dependence of the misestimation on the difference between the proportion of vehicles loaded to between 85 and 100 per cent of the limit, and the proportion overloaded, ie \(P_{(85-100)}\) minus \(P_{(OL)}\), has been investigated.
Notes: PGW = Plated Gross Weight (maximum permitted gross weight)
GVW = Gross Vehicle Weight (actual gross weight when weighed)

Fig. 2 Distribution of vehicle weights for two random surveys
Fig. 3 Effect of systematic error in the calibration factor on the gross weight overloading rate

Note: Calibration factor = indicated weight/true weight
Fig. 4 Effect of systematic error in the calibration factor on the gross weight overloading rate for nine random surveys
Fig. 5 Effect of random error on distribution of vehicle weights

(a) Original distribution (random error is negligibly small)

(b) Distribution with superimposed random (Normal) error with a coefficient of variation of 10 per cent

Note: Gaussian or normal distribution assumed. Data for all vehicles in 1985 Doxey survey.
Doxey (1985) Survey

Notes: $P_{(85-100)}$ = Proportion of vehicles between 85 and 100 per cent of their Plated Gross Weights

$P_{(OL)}$ = Proportion of vehicles overloaded with respect to their Plated Gross Weights

Fig.6 Effect of random error on two groups of vehicles
Fig. 7 Effect of random error on the gross weight overloading rate
Fig. 8 Effect of random error on the gross weight overloading rate for nine random surveys

Note: Gaussian or Normal distribution assumed
Fig. 9 Relationship between the gradients of random error lines in Fig. 8 and distribution of vehicle weights.

Notes: 
- $P(85-100)$ = Proportion of vehicles between 85 and 100 per cent of their Plated Gross Weights (per cent)
- $P(OL)$ = Proportion of vehicles overloaded with respect to their Plated Gross Weights (per cent)

The relationship between the gradients of random error lines in Fig. 8 and distribution of vehicle weights is given by:

$$G = 0.018 \times (P(85-100) - P(OL)) + 0.063$$

with $r^2 = 0.987$. 

The graph shows data points from various locations with the following years:
- Lichfield (1981)
- Lutterworth (1982)
- Towcester (1986)
- Boughton (1984)
- Barham (1981)
- Cramond (1983)
Notes: Gaussian or Normal distribution assumed, Simple plated axle weights assumed
(1st axle 6.5 tonnes, other 10.17 tonnes except 2nd and 3rd axles of 5 or 6-axle
vehicles at 10.5 tonnes)

Fig.10 Effect of random error on axle overloading rate for nine random surveys
Although the relationships between error and misestimation of overloading (as shown in Figures 7 and 8) are not linear, to simplify the analysis they have been approximated by straight lines (using linear regression analysis). The gradients of these lines (ie: the change in the indicated overloading rate per unit change in the coefficient of variation) varied between 0.18 and 0.41 (average value of 0.31) but for 5 of the 9 surveys they were between 0.33 and 0.37. In Figure 9 the gradients are plotted against the difference between $P_{\text{ax}-100}$ and $P_{\text{olu}}$, showing a clear linear relationship between the gradients and this difference.

Figure 10 shows the effect of random errors on the indicated proportion of vehicles with one or more overloaded axles. Since weigh-in-motion systems have to use estimated plated axle weights, estimated values are used in this figure (details of estimated plated axle weights are given in Section 5.1.2). Straight lines were also fitted to these curves. The gradients of these lines were steeper (between 0.54 and 0.87 with an average of 0.70) than those for the gross weight overloading regression lines. This shows that random errors have a greater effect on the indicated axle overloading than on the indicated gross weight overloading. In addition, the coefficient of variation for the measurement of axle weights is normally larger than that for gross weights.

Two methods of correcting for the effect of random weighing errors on the indicated gross weight overloading rate (using the equation shown in Figure 9) are examined in Appendix A. It should be noted that it has been assumed that the random errors are Normally distributed, that there is no systematic calibration error and that both the coefficients of variation and the shapes of the distribution of vehicle weights can be determined and are constant over the period between calibrations. There is evidence to support some of these assumptions. For example, measurements of axle load variations on an instrumented vehicle (Dickerson and Mace, 1981) indicate that the assumption of a Normal distribution is realistic. Also, the similarity of the lines in Figure 8 for the 1982 and 1983 Doxey surveys are consistent with the hypothesis that the distribution of vehicle weight remains relatively constant over time. Further work is required to fully test these assumptions and to verify that the methods work in practice.

However, it should be noted that, even if these types of overall correction can be used to improve the estimate of the overloading rate, because of the errors from WIM devices the vehicles indicated as overloaded are not necessarily the same as those actually overloaded. The use of multiple weigh-in-motion sensors (see Section 3.5) should reduce the coefficient of variation for the measurement of both axle and gross weights. This would improve the estimate of the proportion of vehicles that are overloaded and would more accurately identify the individual vehicles that are overloaded.

5 OTHER FACTORS INFLUENCING THE CHOICE OF METHOD

In addition to the accuracy of weighing axles and vehicles, a number of other factors need to be considered when evaluating a method for monitoring overloading.

5.1 KNOWLEDGE OF THE MAXIMUM PERMITTED WEIGHTS

To assess whether a vehicle is overloaded, the relevant maximum permitted weights (plated weights) have to be known. If the vehicle has been stopped (for enforcement check-weighing or for a random survey) this is simple since the necessary details can be read from plates attached to the vehicle. For vehicles in motion (weighed using WIM systems), the weight limits have to be assessed from observable characteristics of the vehicles. In this section the effects of assuming different limits are assessed.

The weight limits referred to are those in force in September 1985. Since then some limits have been raised.

5.1.1 Gross weights

The simplest assumed plated gross weights (PGWs) are either the maximum value for a vehicle with the given number of axles or the maximum value for the type of vehicle (rigid, artic or draw-bar) and number of axles. Table 2 shows the perceived levels of gross weight overloading at Doxey (1985) given that:

- only the number of axles on each vehicle is known;
- both the number of axles and type of vehicle (rigid, artic or drawbar) are known;
- the actual limits are known (read from the vehicles plates).

The simplifications reduced the perceived gross weight overloading at Doxey (1985) from 4.1 per cent to between 2.3 and 2.5 per cent. For example, with the assumption that only the number of axles on each vehicle is known, no 4-axle rigs were counted as overloaded compared with an actual figure of 7.4 per cent.

In the Doxey survey, 67 vehicles were found to exceed their gross weight limits. Only 41 of these (61 per cent) would have been detected if only the type of vehicle (rigid, artic or drawbar) and the number of axles were known. Of those with undetected overloads (26 vehicles), 73 per cent (19 vehicles) would have been 2-axle rigs with plated gross weights less than 16.26 tonnes (see Table 3). About half (9) of these 19 vehicles had plated gross weights (PGWs) of 7.49/7.50 tonnes. It might be possible to differentiate between 7.5 tonne PGW and 16.26 tonne PGW 2-axle vehicles if the length of their wheelbases is known (see Appendix B).
### TABLE 2

Effect of differing assumed gross weight limits on gross weight overloading rates at Doxey (1985)

<table>
<thead>
<tr>
<th>Type of vehicle</th>
<th>Number of vehicles</th>
<th>Maximum limit for number of axles (A)</th>
<th>Maximum limit for type of vehicle (B)</th>
<th>Actual limits (C)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Weight limit (tonnes)</td>
<td>% with max. gross weight at this limit</td>
<td>overloaded at this limit (%)</td>
</tr>
<tr>
<td>2-axle rigid</td>
<td>663</td>
<td>16.26</td>
<td>46</td>
<td>1.5</td>
</tr>
<tr>
<td>3-axle rigid</td>
<td>61</td>
<td>24.39</td>
<td>98</td>
<td>1.6</td>
</tr>
<tr>
<td>4-axle rigid</td>
<td>54</td>
<td>32.52</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>3-axle artic</td>
<td>65</td>
<td>24.39</td>
<td>55</td>
<td>0.0</td>
</tr>
<tr>
<td>4-axle artic</td>
<td>527</td>
<td>32.52</td>
<td>88</td>
<td>3.0</td>
</tr>
<tr>
<td>5/6-axle artic</td>
<td>229</td>
<td>38.00</td>
<td>89</td>
<td>4.4</td>
</tr>
<tr>
<td>4-axle drawbar</td>
<td>39</td>
<td>32.52</td>
<td>38</td>
<td>0.0</td>
</tr>
<tr>
<td>5-axle drawbar</td>
<td>6</td>
<td>38.00</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>All vehicles</td>
<td>1644</td>
<td></td>
<td>65</td>
<td>2.3</td>
</tr>
</tbody>
</table>
### TABLE 3
Gross weight overloading of 2-axle rigid vehicles

<table>
<thead>
<tr>
<th>Maximum permitted gross weight (tonnes)</th>
<th>Number of vehicles</th>
<th>Proportion of vehicles (percent)</th>
<th>Number overloaded</th>
<th>Per cent overloaded</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.49-7.48</td>
<td>71</td>
<td>10.7</td>
<td>7</td>
<td>9.9</td>
</tr>
<tr>
<td>7.49-7.50</td>
<td>131</td>
<td>19.8</td>
<td>9</td>
<td>6.9</td>
</tr>
<tr>
<td>7.51-16.24</td>
<td>159</td>
<td>24.0</td>
<td>3</td>
<td>1.9</td>
</tr>
<tr>
<td>16.25-16.26</td>
<td>302</td>
<td>45.6</td>
<td>10</td>
<td>3.3</td>
</tr>
<tr>
<td>3.49-16.26</td>
<td>663</td>
<td>100.0</td>
<td>29</td>
<td>4.4</td>
</tr>
</tbody>
</table>

Whilst information about the type of vehicle improves the accuracy of the perceived overloading rates for some types of vehicle (for example, 4-axle rigid vehicles), automatic systems to distinguish between vehicle types are more costly than those that simply count the number of axles.

#### 5.1.2 Axle weights

Determining the plated axle weights of vehicles remote from the observer is even more difficult. Plated axle weights were recorded for 1389 (85 per cent) of the vehicles sampled during the 1985 Doxey survey. In Table 4 the most common and the maximum plated weights for axles and bogies on these vehicles are listed. For some types of vehicle, less than half of the vehicles had the most common plated axle weight. For example, only 46 per cent of 2-axle rigid vehicles had the most common second axle weight (10.17 tonnes).

The effect on the perceived level of axle and bogie overloading of using three different sets of assumed plated limits for axle, bogie and gross weights have been examined using the data from the 1985 survey at Doxey (see Table 5). These are:

- the simplest assumption: 1st axle 6.5 tonnes, others 10.17 tonnes except 2nd and 3rd axles of 5 and 6-axle artics at 10.5 tonnes;
- the maximum values observed in the 1985 Doxey survey (see the last column of Table 4);
- the actual limits.

The assumed plated gross weights were as used in Section 5.1.1. Using the simplified plated axle weights reduced the indicated level of vehicles overloaded only on axles from 8.6 per cent to about 4 per cent. The overall rate of overloading (gross and/or axle) was halved (from 12.2 per cent to 6 per cent).

#### 5.2 SAMPLE COMPOSITION AND SIZE

Although time-consuming, random stop-and-weigh surveys provide a convenient method of establishing overloading rates and for calibrating equipment. However, care must be taken to ensure that there is no bias in the sampling since this would affect the indicated overloading rate. For example, police officers normally select laden vehicles for weighing and may inadvertently bias the sample towards such vehicles. This would lead to an overestimate of the overloading rate since insufficient numbers of lightly loaded vehicles would be included. To check for bias in the TRRL random surveys, the proportions of certain types of vehicle in the sample were compared with the proportions in the traffic flow (Shane and Newton, 1988). Generally, the correspondence was good for the two main classes of vehicle (2-axle rigid and 4-axle artic). This does not directly show that there is no bias towards the more heavily laden vehicles but, since 4 and 5-axle vehicles tend to be more heavily laden than 2-axle vehicles as a proportion of their carrying capacity (Newton, 1985), this test does indicate that it is unlikely.

In addition, it is likely that the presence of the surveys quickly became known at some distance through Citizens Band radios and headlamp flashing. Fear of prosecution for overloading (even though no action was taken against overloaded vehicles in the surveys) may have led some drivers to take diversionary routes. This could have led to under-estimation of the true overloading rates. To counter this possibility, drivers were asked to let other drivers know that no action was being taken against drivers of overloaded vehicles unless the vehicles were clearly dangerous. Since there is a time delay between the start of a survey and the time when the first vehicles take diversions, the earliest results from a survey are likely to be the most reliable.

The size of the sample is also important since the greater the sample size, the greater the precision of the estimated overloading figures. For the surveys where over 1000 vehicles were weighed, the overall overloading rates were estimated to within ± 2 percentage points (95 per cent confidence limits). Further details are given in the report on the surveys conducted on trunk roads and motorways between 1980 and 1986 (Shane and Newton, 1988).
### TABLE 4
Most common maximum permitted axle or bogie weights for 1985 Doxey survey

<table>
<thead>
<tr>
<th>Vehicle type</th>
<th>Number of vehicles</th>
<th>Axle(s)</th>
<th>Most common plated axle or bogie weights (tonnes)</th>
<th>Axles plated at this limit (per cent)</th>
<th>Axles at greater than this limit (per cent)</th>
<th>Maximum value in survey (tonnes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-axle rigid</td>
<td>610</td>
<td>1</td>
<td>6.10</td>
<td>46</td>
<td>1</td>
<td>6.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>10.17</td>
<td>46</td>
<td>---</td>
<td>10.17</td>
</tr>
<tr>
<td>3-axle rigid</td>
<td>56</td>
<td>1</td>
<td>6.10</td>
<td>82</td>
<td>18</td>
<td>6.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2+3</td>
<td>18.80</td>
<td>52</td>
<td>4</td>
<td>19.32</td>
</tr>
<tr>
<td>4-axle rigid</td>
<td>52</td>
<td>1</td>
<td>6.10</td>
<td>87</td>
<td>8</td>
<td>6.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>6.10</td>
<td>87</td>
<td>8</td>
<td>6.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3+4</td>
<td>19.32</td>
<td>75</td>
<td>---</td>
<td>19.32</td>
</tr>
<tr>
<td>3-axle artic</td>
<td>63</td>
<td>1</td>
<td>6.10</td>
<td>49</td>
<td>8</td>
<td>7.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>10.17</td>
<td>70</td>
<td>---</td>
<td>10.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>10.17</td>
<td>30</td>
<td>---</td>
<td>10.17</td>
</tr>
<tr>
<td>4-axle artic</td>
<td>426</td>
<td>1</td>
<td>6.10</td>
<td>74</td>
<td>20</td>
<td>7.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>10.17</td>
<td>92</td>
<td>---</td>
<td>10.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3+4</td>
<td>18.80</td>
<td>59</td>
<td>9</td>
<td>20.34</td>
</tr>
<tr>
<td>5-axle artic (2+3)</td>
<td>98</td>
<td>1</td>
<td>6.10</td>
<td>46</td>
<td>53</td>
<td>7.12</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>10.50</td>
<td>74</td>
<td>---</td>
<td>10.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3+4+5</td>
<td>22.50</td>
<td>97</td>
<td>---</td>
<td>22.50</td>
</tr>
<tr>
<td>5-axle artic (3+2)</td>
<td>42</td>
<td>1</td>
<td>6.50</td>
<td>48</td>
<td>14</td>
<td>6.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>6.10</td>
<td>33</td>
<td>36</td>
<td>10.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>10.17</td>
<td>31</td>
<td>24</td>
<td>10.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4+5</td>
<td>18.80</td>
<td>57</td>
<td>19</td>
<td>20.34</td>
</tr>
<tr>
<td>6-axle artic</td>
<td>21</td>
<td>1</td>
<td>6.50</td>
<td>52</td>
<td>10</td>
<td>6.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>8.89</td>
<td>29</td>
<td>43</td>
<td>10.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>6.61</td>
<td>29</td>
<td>33</td>
<td>10.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4+5+6</td>
<td>22.50</td>
<td>100</td>
<td>---</td>
<td>22.50</td>
</tr>
<tr>
<td>4-axle draw-bar</td>
<td>28</td>
<td>1</td>
<td>6.10</td>
<td>68</td>
<td>21</td>
<td>6.61</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>10.17</td>
<td>86</td>
<td>---</td>
<td>10.17</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>6.86*</td>
<td>14</td>
<td>61</td>
<td>9.40</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>8.13</td>
<td>18</td>
<td>29</td>
<td>10.17</td>
</tr>
</tbody>
</table>

Note: * equal number of axles plated at 6.10, 6.86 and 8.13 tonnes. Three 5-axle draw-bar vehicles have been excluded from this table, all three had different plated axle weights.

Sample composition and size should not affect the results from WIM systems since they should weigh every axle/vehicle. WIM systems also have the advantage that they are not affected by bias due to driver avoidance.

### 5.3 TIME COVERAGE
A major limitation in the use of sample surveys is that their results are based on samples taken over fairly short timespans. The TRRL surveys were conducted for a total of 39 days over a 7 year period and, in most cases, between 7 am and 7 pm. In addition, it is possible that survey results could be affected by short-lived phenomena on a particular road (for example roadworks or seasonal traffic).

Thus, the surveys provided no information about overloading at night. There are indications that the rate of overloading may be higher at night than during the day. For example, results from WIM experiments on an Interstate Highway in Arizona indicated that 35 per cent of vehicles were overloaded during the day compared with 65 per cent at night (Davies, Sommerville and Schmitt, 1988). However, traffic flows at night in the United Kingdom are generally much lower than during the day.
### TABLE 5
Axle and gross weight overloading given various assumed plated weights

| Vehicle type       | Number of vehicles | Proportion of vehicles with overloaded axles, gross weight or both (per cent) given three different sets of assumed axle and gross weights (A, B and C) |  |  |  |  |  |  |  |  |
|--------------------|--------------------|---------------------------------------------------------------------------------------------------------------------------------|---|---|---|---|---|---|---|
|                    |                    | Only axle overloads                                                                                                                | (A) | (B) | (C) | (A) | (B) | (C) | (A) | (B) | (C) | (A) | (B) | (C) |
| 2-axle rigid       | 610                | 3.0 2.8 6.6 0.5 0.5 0.7 1.0 1.0 3.0                                                                                                   | 4.4 | 4.3 | 10.2 |
| 3-axle rigid       | 56                 | 3.6 3.6 17.9 0.0 0.0 0.0 1.8 1.8 1.8                                                                                                   | 5.4 | 5.4 | 18.6 |
| 4-axle rigid       | 52                 | 1.9 13.5 19.2 0.0 1.9 1.9 0.0 5.8 5.8                                                                                                   | 1.9 | 21.2 | 26.9 |
| 3-axle artic      | 63                 | 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0                                                                                                   | 0.0 | 0.0 | 0.0 |
| 4-axle artic      | 426                | 4.0 2.1 6.1 0.7 0.9 0.7 1.2 0.9 1.4                                                                                                   | 5.9 | 4.0 | 8.2 |
| 5-axle artic (2+3)| 98                 | 10.2 14.3 23.5 1.0 1.0 1.0 1.0 1.0 4.1                                                                                                   | 12.2 | 16.3 | 28.6 |
| 5-axle artic (3+2)| 42                 | 14.3 2.4 16.7 2.4 7.1 2.4 7.1 2.4 9.5                                                                                                   | 23.8 | 11.9 | 28.6 |
| 6-axle artic      | 21                 | 9.5 0.0 4.8 14.3 14.3 14.3 0.0 0.0 0.0                                                                                                   | 23.8 | 14.3 | 19.0 |
| 4-axle drawbar     | 28                 | 10.7 10.7 10.7 0.0 0.0 0.0 0.0 0.0 0.0                                                                                                   | 10.7 | 10.7 | 10.7 |
| 5-axle drawbar (3+2)| 3               | 0.0 0.0 33.3 0.0 0.0 0.0 0.0 0.0 0.0                                                                                                   | 0.0 | 0.0 | 33.3 |
| All               | 1399              | 4.2 3.8 8.6 0.8 1.1 0.9 1.1 1.1 2.6                                                                                                    | 6.1 | 6.0 | 12.2 |

Notes: Assumed limits:
- **A**: 1st axle = 6.5 tonnes, others 10.17 tonnes except 2nd and 3rd of 5 or 6-axle vehicles at 10.5 tonnes; Gross weights = maximum for number of axles (A in Table 2).
- **B**: Axles = maximum values given in Table 4; Gross weights = maximum for type of vehicle and number of axles (B in Table 2).
- **C**: Actual limits from plates on the vehicles.

This table is based on those vehicles in the Doxey, 1986 survey for which full plated axle weight information was available.
The weight limits used were based on those applicable in 1985.
Bogie overloads are counted with axle overloads (axles of bogies are summed in assumptions B and C).
5.4 DISTURBANCE TO TRAFFIC
During the roadside surveys, vehicles were stopped by police officers and directed to the survey site. In general, this resulted in delays to vehicles of about 10 minutes. Whilst drivers were only diverted if they were willing to cooperate with the surveys (very few refused), the surveys still added to the time taken for their journeys.

5.5 COST
The costs involved in gathering information on overloading are an important constraint on the amount of information that can be gathered.

Random surveys generally use either existing enforcement weighing equipment or portable weighing equipment. In each case, the equipment cost is normally relatively low. The running costs of random weight checks are similar to those for enforcement weight checks. The TRRL random surveys were more costly because extra staff were required to interview the drivers, conduct classified traffic counts and photograph the vehicles (the dimensions of vehicles were determined from measurements taken from side-view photographs).

The costs of weigh-in-motion information include those of the purchase and installation of the equipment. At present, a single sensor site using piezo-electric cable is expected to cost about £12,000 when batch produced. Once installed, the running costs include recovering the data, analysis, maintenance and checking the calibration.

6 SUMMARY AND CONCLUSIONS
Cheap and reliable information about the overloading of goods vehicles would aid the efficient deployment of enforcement resources and serve as a continuous check on the effectiveness of enforcement procedures. (Such information could also be used as an input to automatic systems which protect weak bridges.) This report has outlined three sources of information about overloading. In particular, the limitations of each method have been examined.

6.1 ENFORCEMENT STATISTICS
Enforcement statistics are commonly quoted as an indication of the rate of overloading of goods vehicles. In practice, since the vehicles that are weighed are not chosen at random, these figures cannot be an accurate measure of overloading. Instead they are a measure of the efficiency with which enforcement officers choose vehicles to weigh. If they had perfect knowledge of vehicle weights, they would only stop and weigh overloaded vehicles and thus the 'overloading rate' would be 100 per cent. Their knowledge could be improved if weigh-in-motion systems are used to indicate the weights of vehicles approaching check points. The proportion of vehicles confirmed as overloaded will increase with the accuracy of pre-selection WIM systems.

Enforcement statistics only indicate the true level of overloading if all vehicles are stopped or if vehicles are stopped at random (this would mean that even some obviously unladen vehicles would be stopped).

6.2 RANDOM SURVEYS
The procedures used in random surveys and enforcement sessions are similar except that during the surveys vehicles are chosen at random and no prosecutions are made. Their main limitations are their cost and time coverage. The surveys conducted by TRRL have gathered data for over 12,000 vehicles which were stopped and weighed but still only give information on traffic at a limited number of sites. The results do not cover overloading at night, at other times of the year or on other roads. The use of surveys as a principal method of monitoring overloading, covering the nation intensively, as would be required to monitor the effect of changes in enforcement procedures on overloading in an area, is likely to be prohibitively expensive. Nevertheless, some random surveys are essential in order to check the other monitoring procedures.

Care is needed to ensure that drivers of heavily laden vehicles do not avoid the survey sites. This can be largely achieved by siting the survey where there are no easy alternative routes and by asking the drivers who are stopped to let other drivers know that the vehicles are being weighed for statistical purposes. It is also important to ensure that the sample is representative of the traffic on the road. This requires careful briefing of the police officers and comparison of the mix of vehicle types in the sample with the mix in the main traffic stream.

6.3 WEIGH-IN-MOTION
Weigh-in-motion systems have the potential to give continuous information on the loading and overloading of all vehicles passing over the sensors. However, at present their accuracy in determining static axle and gross weights is poor. This is because vehicles bounce on their suspensions as they move at normal highway speeds. For a single weigh-in-motion sensor, gross weight errors with coefficients of variation of between 6 and 16 per cent have been found. (The equivalent errors in determining individual axle weights were between 12 and 28 per cent.) Even small random errors can have a large effect on the indicated overloading rate. For example, a random error with a coefficient of variation of 5 per cent would have increased the indicated gross weight overloading at Doxey by 73 per cent (from 4.1 per cent to 7.1 per cent). It should be possible to reduce these errors by using multiple weigh-in-motion sensors at a single site.
If the accuracy of weigh-in-motion systems cannot be substantially improved at reasonable cost, it may be possible to develop methods to compensate for the effect of weighing error on the indicated overloading rate provided that the magnitude of the weighing error is known. This can only be established using a random survey. A random survey is also required to calibrate the equipment, so the cost of gathering the extra information would be small. The first method given in Appendix A could be used to calculate and correct for the effect of the random error on the indicated gross weight overloading rate. These calculations depend on several major assumptions; in particular that the proportion of vehicles between 85 and 100 per cent of their Plated Gross Weight ($P_{(85-100)}$), the proportion of vehicles overloaded with respect to the gross weight limits ($P_{oul}$) and the coefficient of variation of the random errors are constant over time. Any large changes in the distribution of vehicle weights would invalidate this method. (The iterative method in Appendix A should be unaffected by changes in the distribution of vehicle weights but is generally less accurate.) Similar calculations could be made to compensate for the effect of random weighing errors on the indicated rate of axle overloading. It is also important that there are no uncompensated systematic errors in the calibration factor. For example, a hypothetical increase in the calibration factor for the 1985 Doxey survey from 1.00 to 1.05 increases the indicated gross weight overloading rate from 4.1 per cent to 15.1 per cent.

If these problems can be resolved, weigh-in-motion systems could be used to aid the efficient deployment of enforcement resources. For example, the rates of overloading at different times of the day or different days of the week could be examined. This would mean that enforcement officers could be deployed when the overloading is most serious. Also, the effect of different levels or patterns of enforcement effort on overloading could be examined and used to design efficient strategies.

6.4 CONCLUSIONS
In summary, the following conclusions can be drawn:

1. Statistics on overloading collected by enforcement officers during routine weight checks indicate the efficiency with which the officers select heavily-loaded vehicles to weigh, rather than the proportion of all vehicles on the road that are overloaded;

2. Random surveys can provide reliable information on overloading but are relatively costly and are therefore normally limited to a few days at selected sites and to between 7 am and 7 pm. Care has to be taken to ensure that drivers of overloaded vehicles do not avoid the survey site and that vehicles are chosen randomly;

3. Unattended weigh-in-motion systems have the potential to provide relatively cheap continuous information about overloading. However, the accuracy of such systems is at present poor. These inaccuracies cause the systems to exaggerate the proportion of vehicles that are overloaded. There are also problems in determining the plated weights of moving vehicles, calibrating the equipment and dealing with vehicles which straddle lanes. Improvements in the design and technology of WIM systems, and the use of several sensors to provide average measurements, may be able to overcome some of these problems.

7 ACKNOWLEDGEMENTS
The work described in this report was carried out in the Vehicles and Environment Division of the Vehicles Group of TRRL.

8 REFERENCES


**APPENDIX A:**

**CALCULATING CORRECTION FACTORS TO ALLOW FOR THE EFFECT OF RANDOM WEIGHING ERRORS ON THE INDICATED OVERLOADING RATE**

Two methods of calculating correction factors to allow for the effect of random weighing errors on the indicated gross weight overloading rate are given in this section. The first method (Section A.1) assumes that data is available from random surveys to establish the distribution of vehicle weights. The second method (Section A.2) applies if these accurate data are not available, so that the distribution has to be extracted from the WIM data itself. These two methods are compared in Section A.3 and their sensitivity to various assumptions is examined in Section A.4.

**A.1 METHOD IF DISTRIBUTION OF VEHICLE WEIGHTS IS KNOWN**

In Section 4.2, a method of compensating for the effect of random weighing errors on the indicated proportion of vehicles overloaded with respect to their Plated Gross Weights has been outlined. This assumes that the ‘true’ distribution of vehicle weights has been determined using a random survey. In this section, a worked example, based on the 1985 Doxey survey data, is given.

The following data is required:

\[
P_{(85-100)} = \text{the proportion of vehicles between 85 and 100 per cent of their Plated Gross Weights;}
\]

\[
P_{(101)} = \text{the proportion of vehicles overloaded with respect to their Plated Gross Weights.}
\]
These two items are determined from survey work and it is assumed that they remain constant over time. (It is also assumed that there are no random errors associated with the survey data.)

Survey data is also used to determine the coefficient of variation of the random weighing errors (CoV). The calculations below are for a CoV of 10 per cent and an indicated overloading rate from weigh-in-motion equipment (with this CoV) of 9.2 per cent.

The gradient of the relationship between the coefficient of variation and the indicated rate of overloading (G) is determined as follows:

\[ G = 0.018 \times (P_{(85-100)} - P_{(OL)}) + 0.063 \]

Thus, for the 1985 Doxey survey where \( P_{(85-100)} \) was 23.9 and \( P_{(OL)} \) was 4.1:

\[ G = 0.018 \times (23.9 - 4.1) + 0.063 = 0.42 \]

The correction to the overloading rate (\( C_{(OL)} \)) for a CoV of 10 per cent is:

\[ C_{(OL)} = CoV \times G = 10 \times 0.42 = 4.2 \]

This is then subtracted from the indicated overloading rate with a 10 per cent CoV (9.2 per cent—from Figure 7) to give an estimated true overloading rate of 5.0 per cent. (The actual value was 4.1 per cent.)

### A.2 ITERATIVE METHOD IF DISTRIBUTION OF VEHICLE WEIGHTS IS NOT KNOWN

In this section, a possible, but rather less satisfactory, method is shown which might be used if it is not possible to conduct a random survey. In these circumstances the 'true' distribution of vehicle weights would not be known. (It is likely that the coefficient of variation would also be unknown and have to be estimated from experience from similar equipment.) This method uses values of \( P_{(OL)} \) and \( P_{(85-100)} \) characterised by random errors.

In Figure A1 the relationship between the indicated value of \( P_{(85-100)} \) and the coefficient of variation of the random error is shown. In order to simplify the analysis, straight lines were fitted to these curves. In Figure A2 the gradients of these lines are plotted against the 'true' value of \( P_{(85-100)} \). From Figure A2:

\[ G_1 = 0.174 - 0.031 \times (P_{(85-100)}) \]

where \( G_1 \) is the gradient of the relationship between the coefficient of variation and the indicated \( P_{(85-100)} \). The equivalent gradient (G) for the relationship between the coefficient of variation and the indicated overloading (\( P_{(OL)} \))—from Figure 9—is:

\[ G = 0.018 \times (P_{(85-100)} - P_{(OL)}) + 0.063 \]

These equations are based on the results of the 9 surveys. This justifies the working assumption that they will be characteristic of future surveys. The iterative method described below (see flow chart in Figure A3) uses these two equations with estimated values of \( P_{(85-100)} \) and \( P_{(OL)} \) pertaining to the site in question but which are affected by random errors. For example, if a random error with a coefficient of variation of 10 per cent is superimposed on the 1985 Doxey data, the value of \( P_{(85-100)} \) becomes 16.7 and the value of \( P_{(OL)} \) becomes 9.2. If these values are used in the equations above, the values of G and G1 are:

\[ G = 0.018 \times (16.7 - 9.2) + 0.063 = 0.198 \]

\[ G_1 = 0.174 - 0.031 \times 16.7 = -0.344 \]

The correction to \( P_{(OL)} \) is:

\[ CoV \times 0.198 = 10 \times 0.198 = 1.98 \]

The correction to \( P_{(85-100)} \) is:

\[ CoV \times (-0.344) = -3.44 \]

Thus the corrected values are:

\[ P_{(OL)} = 9.2 - 1.98 = 7.22 \]

\[ P_{(85-100)} = 16.7 + 3.44 = 20.14 \]

These values are then inserted into the original equations to obtain revised values of G and G1. Since improved estimates of G and G1 are used, the assumed value for the coefficient of variation (CoV) is halved (to 5 per cent). The new values of G, G1 and CoV are then used to calculate new corrections. This iteration is continued (with the assumed coefficient of variation halved at each stage) until the assumed coefficient of variation is small.

Using this method, the gross weight overloading rate was calculated to be 3.8 per cent. (The actual value was 4.1 per cent.)

### A.3 COMPARISON OF THE TWO METHODS

In Table A1, gross weight overloading rates estimated using each method are shown for each of the 9 surveys. For the first method (see Section A.1) the estimated overloading rate for each survey was within one percentage point of the actual rate. The comparable figure for the iterative method was 2.9 percentage points (see Table A1). The average size of the difference (in percentage points) was 0.6 for the first method and 1.4 for the iterative method.
Fig. A1 Effect of random error on $P_{(85-100)}$ for nine random surveys

Note: Gaussian or Normal distribution assumed
Fig. A2 Relationship between the gradients of random error lines in Fig. A1 and distribution of vehicle weights

Data with random error (eg: from WIM system)

Estimated $P_{(85-100)}$

Estimated $P_{(OL)}$

Data from random survey

Coefficient of variation of random error (CoV)

CALCULATING GRADIENTS:

$$G_1 = 0.174 - 0.031 \times P_{(85-100)}$$

$$G = 0.018 \times (P_{(85-100)} - P_{(OL)}) + 0.063$$

CALCULATING REVISED VALUES:

revised $P_{(OL)} = $ previous $P_{(OL)} - (G \times CoV)$

revised $P_{(85-100)} = $ previous $P_{(85-100)} - (G_1 \times CoV)$

revised CoV = previous CoV divided by 2

Fig. A3 Flow chart of iterative method of calculating correction factors

Note: $P_{(85-100)} = $ Proportion of vehicles between 85 and 100 per cent of their Plated Gross Weights (per cent)
### TABLE A1
Comparison of the two methods of calculating correction factors

<table>
<thead>
<tr>
<th>Survey</th>
<th>Actual gross weight overloading rate (per cent)</th>
<th>Estimated overloading rate (per cent) (difference between estimate and actual in brackets)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Method with known weight distributions</td>
</tr>
<tr>
<td>Lichfield (1981)</td>
<td>3.9</td>
<td>4.9 (+1.0)</td>
</tr>
<tr>
<td>Barham (1981)</td>
<td>16.9</td>
<td>16.0 (−0.9)</td>
</tr>
<tr>
<td>Lutterworth (1982)</td>
<td>12.2</td>
<td>12.0 (−0.2)</td>
</tr>
<tr>
<td>Doxey (1982)</td>
<td>7.6</td>
<td>8.2 (+0.6)</td>
</tr>
<tr>
<td>Crummond (1983)</td>
<td>7.4</td>
<td>7.4 (−)</td>
</tr>
<tr>
<td>Doxey (1983)</td>
<td>6.8</td>
<td>7.5 (+0.7)</td>
</tr>
<tr>
<td>Boughton (1984)</td>
<td>9.3</td>
<td>8.4 (−0.9)</td>
</tr>
<tr>
<td>Doxey (1985)</td>
<td>4.1</td>
<td>5.0 (+0.9)</td>
</tr>
<tr>
<td>Towcester (1986)</td>
<td>9.0</td>
<td>9.0 (−)</td>
</tr>
</tbody>
</table>

### TABLE A2
Sensitivity of estimated overloading rates (1985 Doxey survey) to assumed values

<table>
<thead>
<tr>
<th>Variable</th>
<th>Standard value</th>
<th>Alternative value</th>
<th>Estimated overloading using alternative values (error* in brackets)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Method with known weight distributions</td>
</tr>
<tr>
<td>$P_{0.85-100}$ from survey</td>
<td>23.90</td>
<td>22.70 (−5%)</td>
<td>5.24 (+4.2%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>25.10 (+5%)</td>
<td>4.81 (−4.4%)</td>
</tr>
<tr>
<td>$P_{0.05}$ from survey</td>
<td>4.10</td>
<td>3.90 (−5%)</td>
<td>4.99 (−0.8%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4.30 (+5%)</td>
<td>5.06 (+0.6%)</td>
</tr>
<tr>
<td>$P_{0.85-100}$ with random error</td>
<td>16.72</td>
<td>15.88 (−5%)</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17.56 (+5%)</td>
<td>—</td>
</tr>
<tr>
<td>$P_{0.05}$ with random error</td>
<td>9.22</td>
<td>8.76 (−5%)</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9.68 (+5%)</td>
<td>—</td>
</tr>
<tr>
<td>Coefficient of variation</td>
<td>10.00</td>
<td>9.50 (−5%)</td>
<td>4.80 (−4.6%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.50 (+5%)</td>
<td>5.19 (+3.2%)</td>
</tr>
<tr>
<td>Calibration factor (see Section 4.1)</td>
<td>1.00</td>
<td>0.95 (−5%)</td>
<td>0.87 (−82.7%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.05 (+5%)</td>
<td>0.88 (−9.4%)</td>
</tr>
<tr>
<td>Standard values</td>
<td>—</td>
<td>—</td>
<td>5.03</td>
</tr>
</tbody>
</table>

Note: *error is defined as:

\[
\text{error} = \left( \frac{\text{overloading using alternative value} - \text{overloading using standard value}}{\text{overloading using standard value}} \right) \times 100
\]
A.4 SENSITIVITY TO ASSUMPTIONS

The accuracy of the estimated overloading rates depends on the accuracy of the values used in the equations. In Table A2, the effect of increasing or decreasing each value in turn by 5 per cent is shown for the 1985 Doxey survey. This shows the effect of inaccuracies in determining the variables used to calculate the correction factors. For example, if the true coefficient of variation was 10.5 per cent but the calculations were made assuming that it was 10.0 per cent, the iterative method would have estimated the gross weight overloading as 4.2 per cent rather than the 3.8 per cent figure derived above.

For each of the variables shown in Table A2, the iterative method was more sensitive than the first method to inaccuracies in the variables. The effect of inaccurate values of the calibration factor (as defined in Section 4.1) is much greater than that of inaccurate values of any other variable. For example, if the calibration factor was 1.05 but was assumed to be 1.00, the estimated overloading using the first method would be increased by 96 per cent and the estimate using the iterative method by 183 per cent.

APPENDIX B:

POTENTIAL METHOD OF DIFFERENTIATING BETWEEN 7.5 TONNE PGW AND 16.26 TONNE PGW 2-AXLE VEHICLES

It might be possible to use the wheelbase lengths of 2-axle vehicles to differentiate between 7.5 tonne PGW and 16.26 tonne PGW vehicles and so enable automatic systems to detect overloaded 7.5 tonne PGW vehicles. Generally, the wheelbases of 7.5 tonne PGW vehicles at Doxey in 1985 were shorter than the wheelbases of 16.26 tonne PGW vehicles (see Figure B1). Using this length to differentiate between the two types of vehicle could improve detection of overloaded vehicles, but it may also mean that some vehicles are spuriously counted as overloaded. For example, if the critical length is set at 4.0 metres, a 16.26 tonne PGW vehicle with a 3.9 metre wheelbase and loaded to 15.0 tonnes gross weight would be counted as overloaded even though it was legally loaded. Thus, the critical length which separates the two types of vehicle has to be chosen to balance the number of such spurious overloads against the number of real overloads that are missed (see Figure B2). If vehicles with wheelbases of up to 4.0 metres were assumed to have a plated gross weight of 7.5 tonnes and longer vehicles 16.26 tonnes, a further 9 vehicles at Doxey (1985) would have been counted as overloaded compared with assumptions A or B. It should be noted that this length depends on the mix of vehicles at the survey site. As alternatives to this method, it might be possible to use the magnetic signature from an inductive loop detector, wheel size and/or width to distinguish between the different sizes of 2-axle vehicle. Further work, possibly using a combination of methods, will be required to determine an effective method of detecting overloaded 7.5 tonne PGW vehicles.
Fig. B1 Distribution of wheelbase lengths for two types of 2-axle rigid vehicles
(Source: 1985, Doxey survey)
Number of spurious overloads (ie: vehicles with PGW > 7.5 tonnes which were legally-loaded but were counted as overloaded because their wheelbases were shorter than the given limit and therefore their PGW's were assumed to be 7.5 tonnes)

Real overloads missed (ie: vehicles with PGW ≤ 7.5 tonnes which were overloaded but were counted as legally-loaded because their wheelbases were greater than the given limit and therefore their PGW's were assumed to be 16.26 tonnes)

Fig B2 Effect of differing lengths of wheelbase used to differentiate between 7.5 tonne PGW (shorter) and 16.26 tonne PGW (longer) 2-axle rigid vehicles
(Source: 1985, Doxey survey)