High-speed weigh-in-motion systems and applications

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In the last three years many weigh-in-motion systems have been installed in the UK, Europe and USA. This paper assesses the various WIM systems and highlights typical installations. A practical approach to installation and calibration is described.

INTRODUCTION

1. Weigh-in-Motion (WIM) systems have been available for over thirty years. The earlier systems developed in North America and Europe produced reasonable results but were relatively expensive and at that time, vehicles were required to travel at low speed due to the limitations of the data processing. In the last ten years, as the demand for better management of our roads and highways has been realised, there have been considerable technical developments to produce systems with increased performance and wider application. Bridge systems using strain gauge and load cell technology improved the performance and reliability level and with the advent of high speed microprocessors the capacity to measure vehicles travelling at normal highway speeds became a reality. With the increased requirement for truck weight data came the demand for lower cost systems for both portable and permanent application.

ADVANCES IN TECHNOLOGY

2. There are many forms of WIM monitoring systems including the Bridge and Bending Plate methods for permanent installations. The capacitive weight pad was extensively used in many countries as a portable solution whereby the sensor could be re-laid after short surveys in order that a data bank of heavy goods vehicle information could be obtained. Whilst successful, this remained a relatively expensive solution. More recently, narrow strip sensors using either piezo or capacitive technologies have been developed. This technology required a different approach to vehicle weighing because only a small part of the wheel load is acting on the sensor at any one instant in time. By integrating the sensor output with respect to distance along the tyre footprint the instantaneous axle weight can be measured. These sensors are considerably cheaper and easier to install and can be used in a multi lane application to provide extensive real time data even in high flow traffic. These sensors cause less disturbance to the road profile and lane closure timescales are reduced.

WIM APPLICATIONS

3. There are now many applications of WIM technology:

Enforcement screening systems designed to improve the efficiency of weigh stations.

Bridge Protection systems to ensure that vehicles above a pre-scribed weight do not travel across an unsound structure. WIM equipment is often used with camera systems.

Weight Restricted Highway systems where heavy vehicles can cause further erosion of property foundations or where HGV access is impaired.

Truck Weight Studies are undertaken by authorities as part of the planning, truck routing, and maintenance tasking. One national example is the LTPP study in the US which is a twenty year program forming part of the SHRP activity.

Quarry and Mining systems used to monitor material movement at entry or departure points.

Most Toll systems use vehicle class as the basis of tariff structures. With the recognition that heavy vehicles cause the most damage (generally accepted to be proportional to the 4th power of the axle weight ie. doubling the axle weight causes a 16 fold increase in damage), there is a growing demand to use WIM technology as a method and basis of toll collection.

4. There are other applications using strip sensors. For instance as a research tool, to better understand the dynamic effects of heavy vehicles on pavements and how vehicle suspension design can be improved to reduce the damage factors. Golden River Traffic in conjunction with engineers from Cambridge University and TRL have developed a Mat measuring system containing 100 capacitive sensors encapsulated in rigid polyurethane tiles. Each tile has three WimStrip sensors mounted transverse to the wheel path at a spacing of 400mm between the sensors. Each WimStrip sensor records the instantaneous weight of the vehicle axle travelling over the Mat section. Following successful experiments in the US and at TRL the Mat section has recently been installed on a public highway. Up to 10,000 random heavy goods vehicles were recorded and a considerable amount of data obtained.

FACTORS AFFECTING PERFORMANCE

5. There are numerous factors affecting the performance and reliability of WIM

systems. The aim is to measure the static axle weights and gross vehicle weights of heavy goods vehicles travelling at normal highway speeds without interruption to the traffic flow. The performance of the data processing instrument is important but the performance of the sensing technology is critical to the long term reliability of the system.

6. A WIM sensor measures the instantaneous dynamic force exerted by each measured axle as a heavy vehicle 'bounces' along the road. This force is normally significantly different to the static axle load that would be measured on a conventional weighbridge. (in the order of 10% to 30%)

7. Among the more important factors which affect the dynamic forces are:

Pavement profile and condition

Vehicle suspension type and design

Vehicle class and vehicle speed

8. These factors interact to cause a series of oscillations (in the order of 4 Hz) to the truck as it proceeds along the road.

9. In addition, individual vehicle suspension characteristics contribute to the dynamic weight factor. Therefore, the accuracy of a high speed 'single sensor' system is limited according to the measurement point on the dynamic curve of the vehicle. Further factors which can influence accuracy include changes in ambient and pavement temperature and the possibility of sensor wear and drift over time.

WIM - A COMPLEX PROBLEM

10. Assessing the performance and reliability of the available sensor technologies together with the material and installation cost requires an appreciation of the aforementioned factors. It is relatively easy to fine tune a system to repeatedly measure one type or model of truck. Achieving an acceptable level of accuracy for a wide variety of vehicles travelling at a variety of speeds under many varying conditions without significant drift over time is more difficult.

11. Manufacturers are at the forefront of the sensor technology evolution. Continuous development of WIM systems progressively increases our knowledge base leading to increased performance and greater long term reliability. However, it should be recognised that we are dealing with a very complex set of parameters requiring extensive testing and evaluation procedures.

A REVIEW OF HIGH SPEED WIM SYSTEMS

12. Looking at the available high speed WIM systems the following provides a review of their performance capabilities for temporary and permanent application .

Bridge Systems (load cell or strain gauge)

Temporary Application
Not Available

Permanent Application
Typical cost £25K for single lane.
Installation time 3 Days
Axle weight accuracy 10%
Major disruption to highway during installation.
Heavy lifting equipment required.
Generally installed on a single lane only.

Bending Plate Weightpads

Temporary Application
Not Available

Permanent Application
Typical cost £20K for single lane using two weightpads. Installation time 3 days.
Gross weight accuracy 6%
Moderate disruption to highway during installation
Lifting equipment required at site
Single and Multi lane application.

Capacitive Pad System

Temporary Application.
Typical Cost £9K.for single lane
Installation time 1 hour.
Gross weight accuracy 10%. Axle weight accuracy 18%
Care needed to ensure sensor durability, application and handling.
Single lane only

Permanent Application
Not Available

Piezo Cable System

Temporary Application
Not Available

Permanent Application.
Typical Cost £7K. for single lane
Installation time 1 day.
Gross weight accuracy 12% Axle weight accuracy 18%
Risk of Sensor drift and performance variation with temperature change.
Single lane or multi lane application.

Capacitive Strip System

Permanent Application
Typical Cost £8K.for single lane.
Installation time 1 day.
Gross weight accuracy 8% Axle weight accuracy 10%
No systematic temperature or drift.
Digital signal to max feeder length.
Can measure static weights. Single or multi lane application.

Temporary Application
Typical Cost £5K for single lane.
Installation time 1 hour.
Gross weight accuracy 17%.
Check installation frequently, up to 3 weeks with inspection.
Single or Multi lane application.

TYPICAL INSTALLATION PROCEDURES

13. The availability of lower cost strip sensors, such as the WimStrip, provides the opportunity of using two or more sensors installed in each traffic lane. This helps reduce the impact of the vehicle dynamic forces and allows the integration of several sensor inputs. Considerable work has been carried out to determine the optimum number of sensors to provide a cost effective system.

14. The installation procedures vary according to the application but follow similar rules. A typical installation sequence is described using WimStrip sensors.

SITE SELECTION

15. A key factor in the performance of a high speed WIM system is the site selection. The dynamic effects referred to earlier can be minimised if the site is selected with care and in accordance with the following criteria.

The approach to the site should be smooth and level, at least 300 metres prior to the site and 150 metres after the site. Roads with pronounced camber should be avoided.

Traffic should be free flowing with good lane discipline.

Absolute vehicle speeds are generally not critical but sectors of significant acceleration and deceleration, gear changing, should be avoided.

16. As standard practice, we recommend that a video is made of the possible sites to be considered. This enables the above factors to be recalled and studied under more controlled office conditions and the vehicle bounce factors for each site to be assessed.

17. Following the site selection, the site is marked out positioning the sensor and inductive loops in accordance with the prepared dimensions. Normally two pairs of WimStrip and two inductive loops are used for each lane and a configuration known as Loop-Weight-Loop-Weight sensor array would be selected. The system measures left and right hand wheels independently so two pairs of sensors are used. This represents the most cost effective approach giving acceptable results for an enforcement screening application. However, it has been shown that arrays with 3 pairs of evenly spaced sensors are more robust to speed variations and this array may be specified where higher accuracy results and increased cost can be justified. Sensors are generally spaced 4 metres apart (precise spacing is dependant upon vehicle speeds and number of sensors used) and are located just under the road surface where they detect the downward vertical force as the vehicle wheels pass through the weigh site.

18. Loop cutting and sensor slot cutting is commenced. The sensor slots are 35mm by 20mm deep. After correct height positing of the WimStrips using the levelling screws in the slot, a hard resin base material is used on which the sensor is located. Finally, when the base resin has cured a softer resin is poured into the slot to fill in the sides of the sensor slot and to complete a smooth finish.

SYSTEM CALIBRATION

19. Feeder cables from the WimStrips and Loops are connected to the data logger,in this case a Marksman 600. The data logger is programmed and calibration of the site started. This is achieved using a 2 axle known weight truck approximately 15 tonnes gross weight. The truck makes several passes over the site at various speeds and a series calibration factors is calculated by the Marksman 600. After several runs the calibration calculation is completed and entered into the M600.

20. The correct calibration of each site is crucial to the performance and check calibrations are recommended every six months to ensure the quality of data achieved. The site should be regularly inspected to ensure no damage has occurred to the sensors or loops and that the site is safe and secure.

AUTOMATIC CALIBRATION

21. Considerable work has been undertaken to introduce various techniques to automatically calibrate WIM systems. As the leading axle of Class 9 vehicles is generally measured within a close weight tolerance some manufactures have attempted to use this value to provide a means of auto calibration whenever Class 9 vehicles are detected.This concept has been more favoured in the USA and trials in Europe have shown that the success of this technique to be very site dependant and inconclusive. Generally therefore, this technique has not been accepted as beneficial and systems which offer more constant outputs over time have been selected.

AN EXAMPLE OF WIM SYSTEM RESULTS

22. During the Autumn of 1991 a series of acceptance tests were carried out at Ross on Wye under the supervision of the Department of Transport. The high speed WIM site is located downstream from a static weighbridge where Trading Standards Officers conduct enforcement weighing sessions. Vehicle axle and gross weight readings were recorded at the WIM site and compared to the weighbridge certificates. The results are illustrated on the graph and show a standard deviation of 6% and an Average Impact Factor of -4% for the gross weights for the random goods vehicles whilst the results for the known weight test vehicle resulted in a 4% standard deviation.

PORTABLE AND TEMPORARY SYSTEMS

23. With the increasing demand for better portable systems the WimStrip sensor can be mounted in an extruded sleeve and used in a temporary mode. The sensor is placed between two inductive road loops in the configuration shown and is capable of operating in very heavy traffic conditions. This application represents a very economical approach to monitoring truck traffic for 7 day periods but longer periods of operation are possible with inspection and correction of any sensor movement. Although not as accurate as permanent sensors the temporary set up produces accuracy results in the order of 17% to 20%. Because the sensor is reusable this technology offers a very low cost solution to the collection of weight data at temporary sites.

CONCLUSION

24. The use of WIM technology as part of the pavement design and management process has led to significant insights into the pattern of truck loadings and damage factors caused by various vehicle suspension designs. In the UK the maximum gross weight of 38 tonnes is to be increased to 40 tonnes and 44 tonnes for articulated European vehicles possibly entering from the Channel Tunnel. A conditional increase in axle loading will also be permitted. With a predicted rise in the HGV population of 15% a year it becomes even more critical to effectively measure and manage the truck traffic on our roads. There are many programs and studies continuing around the world into this important sector of highway management and we look forward to participating in the technology.

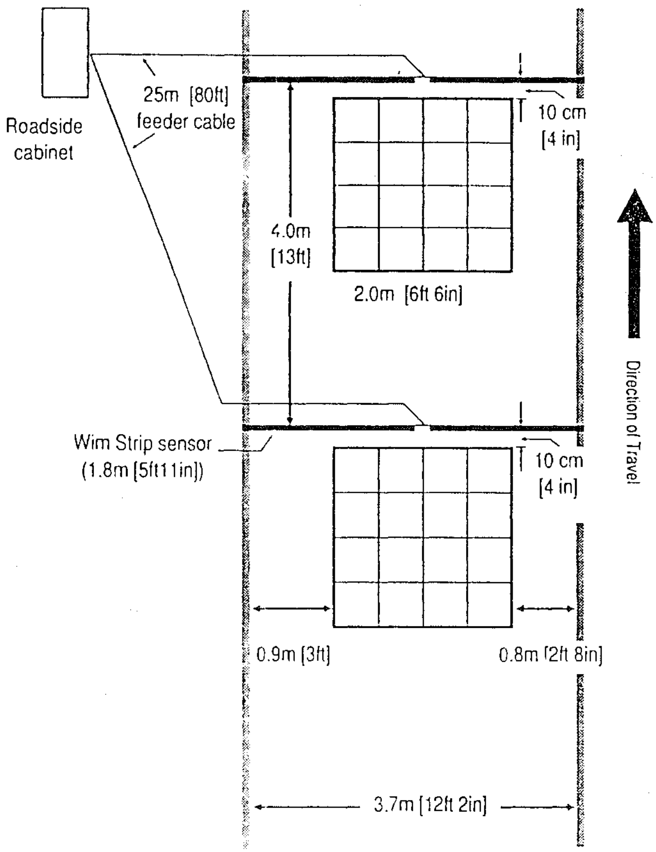

Figure 1. Typical sensor array layout for one traffic lane