Weigh In Motion Technology - Economics and Performance

Presented at NATMEC '98
Charlotte, North Carolina

Presented by Andrew J. Pratt

Written by:
Rob Bushman
Andrew J. Pratt

Weigh In Motion Technology - Economics and Performance

1. Introduction to WIM Technology and Accuracy

The number of WIM sensors and scales available has increased over the last few years as attempts are made to increase accuracy and performance and reduce costs. This discussion will focus on three traditional WIM technologies which are the most widely accepted and used in North America. The three technologies are Single Load Cell Scale, Bending Plate Scale, and in-road sensors (Piezoelectric).

For comparison of the performance of these technologies, there are many variables involved. The performance of any WIM system is dependent on road conditions, road geometry, and vehicle condition. Therefore the ASTM standards for accuracy will be used for comparison purposes. The actual performance of any WIM system will vary depending on specific conditions at the site. At a good site meeting the ASTM site requirements, an accuracy much higher than those listed here may be achieved. The relative difference in accuracy can still be expected to exist under these conditions.

Quantifying the accuracy of a WIM system is more difficult than assigning an accuracy to a static scale. With a static scale, the axle, axle group, or vehicle is placed on the scale. The force of that axle, axle group, or vehicle is constant while it is motionless on the scale. The only factor affecting the accuracy of the determined weight is the scale itself. With repeated testing and calibration, an accuracy level for every vehicle can be determined.

One of the purposes behind the development of WIM technology was the ability to measure the actual loads being applied to a roadway by a moving truck. It was felt that this would more accurately represent what the pavement is subjected to than a static weight. However, the calculated static weight is still the value used in evaluating accuracy and in recording traffic information. Although there is a definite relationship between static weights and applied loads, there are many other factors introduced.

The actual load applied by a vehicle includes much more than the weight of the vehicle. As a vehicle travels, the dynamic load applied to the road varies significantly due to the vehicle bouncing, acceleration or deceleration, and shifting of the load either physically or just in its distribution through the suspension system. The combination of all these loading factors is what is actually measured by a WIM system. In addition to the error in the measuring device which is also present in a static scale, there is a second error due to the dynamic effects of weighing a vehicle at high speeds. Figure 1 illustrates the difference between weighing statically and dynamically.

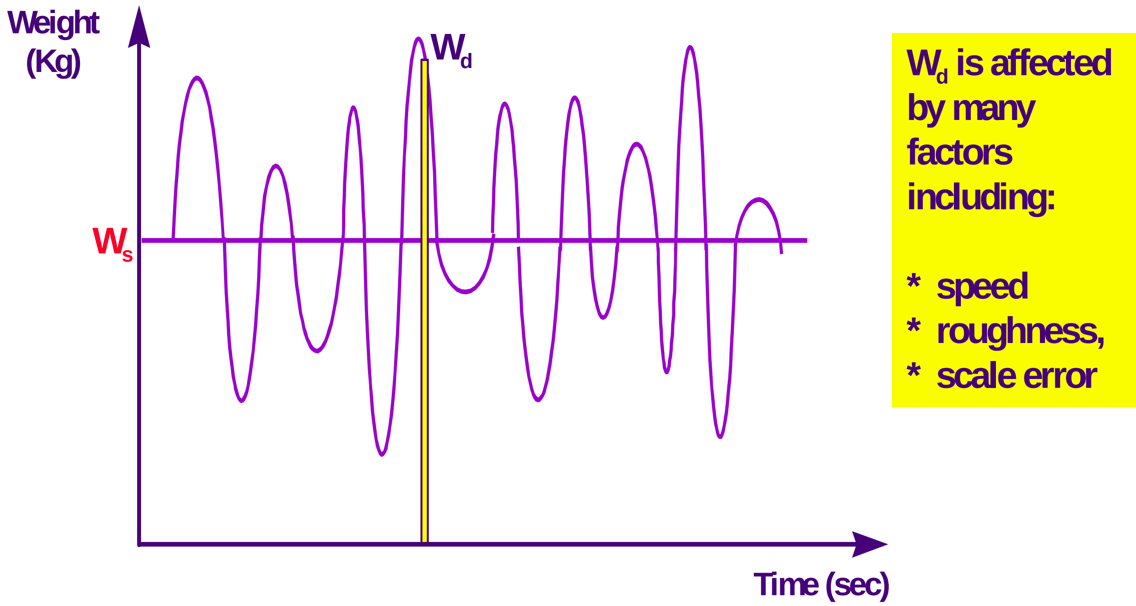

Figure 1 - Static and Dynamic Weighing

Various techniques are applied to the WIM weights being measured to minimize the effects of vehicle dynamics, but they can not be totally eliminated. One important factor is the number of measurements that can be taken to determine the weight. Very high sampling rates by the system electronics provide as much information as possible to provide more measurements and a better definition of the applied loads. In addition, the span over which the measurements are taken is also significant, and may be one factor for the relative accuracy of the various technologies. While the actual weighing element of a piezoelectric sensor is measured in fractions of an inch, a Single Load Cell scale is active over approximately three feet. Referring back to figure 1, the longer period of analysis will yield a greater section of the loading curve. Even if simple averaging were the only technique used, the greater the time of measurement would yield a more accurate result.

Because of the effects of vehicle dynamics, the accuracy level of any WIM system is lower than that for a static scale used for enforcement weighing. It is also not possible to quote an absolute accuracy for a WIM scale. Therefore, any WIM accuracy is always quoted as a percentage accuracy with a confidence level. The confidence level is typically set at either 68% or 95%. ASTM accuracy uses the 95 % level. This means that 95 % of measured WIM values will fall within the stated accuracy level.

Piezoelectric Sensors

The most common WIM sensor for data collection purposes is the Piezoelectric sensor. The basic construction of the typical sensor consists of a copper strand, surrounded by a piezoelectric material, which is covered by a copper sheath. When pressure is applied to the piezoelectric material an electrical charge is produced. The sensor is actually embedded in the pavement and the load is transferred through the pavement. The characteristics of the pavement will therefore affect the output signal. By measuring and analyzing the charge produced, the sensor can be used to measure the weight of a passing tire or axle group. There are a number of variations on the shape, size and packaging of the sensors produced to obtain better results, easier installation, and longer life. This discussion will treat piezoelectric sensors as a general group, rather than particular products.

For a complete data collection system, it is common to install two inductive loops and two piezoelectric sensors in each lane which is being monitored. Installation begins by making a relatively small cut in the road into which the sensor will be installed. The size of the cut varies depending on the sensor being installed, but is generally 1”-2” deep and 1” to 2” wide. The sensor is placed in the sawcut and secured in place by a fast curing grout. A complete lane installation consisting of two sensors and two loops can be accomplished in less than a full day, including curing time.

When properly installed and calibrated, a piezoelectric WIM system should be expected to provide gross vehicle weights that are within 15% of the actual vehicle weight for 95% of the trucks measured.

Bending Plate Scale

The bending plate scale uses a different approach to determine vehicle weight. The bending plate scale consists of two steel platforms which are each 2’ x 6’, placed adjacent to each other to cover a 12’ lane. The steel plate is instrumented with strain gages at critical points to measure the strain in the plate as a tire or axle passes over. The measured strain is analyzed to determine the axle load. The Bending Plate scale is typically installed in a lane with two inductive loops and an axle sensor to provide vehicle length and axle spacing information.

There are two basic installation methods for a Bending Plate scale. In concrete roadways of sufficient depth, a shallow excavation is made in the surface of the road. The scale frame is anchored into place using anchoring bars and epoxy. In asphalt roads or thin concrete roads, it is necessary to install a concrete foundation for support of the frame. The roadway is cut and excavated to form a pit of 30” deep by 4’10” wide by 13’10” long. The frame is positioned in place and then is cast into the concrete to form a secure and durable foundation for the scale.

Installing a complete lane of scales, loops and axle sensor can be accomplished in a day using the shallow excavation method and in 3 days using the concrete vault.

When properly installed and calibrated, Bending Plate WIM system should be expected to provide gross vehicle weights that are within 10% of the actual vehicle weight for 95% of the trucks measured.

Single Load Cell Scale

The Single Load Cell Scale consists of two weighing platforms with a surface size of 6’ by 3’2”, placed adjacent to each other to fully cover a normal 12’ traffic lane. A single hydraulic load cell is installed at the center of each platform to measure the force applied to the scale. The load measurements are recorded and analyzed by the system electronics to determine tire and axle loads.

The installation of a single load cell scale requires the use of a concrete vault, as explained earlier for the bending plate scale. The size of vault required is slightly larger, measuring 165” by 58” by 34”.

The Single Load Cell scale is typically installed in a lane with two inductive loops and an axle sensor to provide vehicle length and axle spacing information. Installing a complete lane of scales, loops and axle sensor can be accomplished in 3 days.

When properly installed and calibrated, Single Load Cell WIM system should be expected to provide gross vehicle weights that are within 6% of the actual vehicle weight for 95% of the trucks measured.

2. Comparison of WIM Technology Costs

The operation and expected performance of the various technologies has been explained. In order to evaluate which technology is most appropriate, the cost of each technology must also be considered. However, there are many factors to include in the cost of a WIM technology beyond the equipment cost or the installation cost. Other factors to consider include the expected life, maintenance cost, and replacement cost.

The three technologies will be evaluated based on a life cycle cost basis. For comparison, the equipment and installation costs will be for the in-road equipment only. The cost of the electronics, cabinet, power supply, telephone connection, and road preparation are assumed to be relatively constant, regardless of the technology used. The initial installation includes the equipment supply, installation by a local contractor, and installation supervision and calibration by a vendor representative.

In order for any WIM system to perform consistently and reliably it should be maintained. It is recommended that scheduled maintenance visits occur at least semi-annually, with calibration occurring at each visit. The cost of a calibration vehicle is not included, since all systems will require the use of a calibration vehicle. One of the maintenance visits can be a visual inspection and calibration check. The other visit should include an in depth on road inspection as well as a calibration check.

Other assumptions for the purposes of the comparison are noted for each technology. This comparison takes into account only direct costs for the work and equipment to provide the WIM data. Associated factors such as road deterioration and repair, traffic delay costs, and data reliability are not considered.

There are many variable which may affect the cost of installing and maintaining a system of this type including site conditions, site location, contractor installation costs, and traffic control requirements. The actual cost will vary for each specific application, so these numbers should be used for relative comparison of the technologies only.

Piezoelectric Sensors

The approximate cost to supply and install one lane of piezoelectric WIM is $9,000. Two Class 1 sensors, two inductive loops, and one temperature sensor are supplied for each lane of data collection. A vendor representative to supervise installation, a subcontractor to perform the installation work, and traffic control are also included.

After a successful installation, it is assumed that the entire system will have a life of 4 years, after which time the in road equipment will be replaced. During the 4 year life of the system, sensor failures are assumed as follows:

- 5% in year one
- 15% in year two
- 25% in year three
- Replacement in year four

The cost associated with sensor failure are calculated as a percentage of the original installation cost. Over the life of the system, the semi-annual maintenance and calibration visits also occur.

When all these costs are calculated over a 12 year cycle, using the Net Present Value of each cost, the cost per year of operation in present dollars is $4,750 per year per lane.

Bending Plate WIM

A Bending Plate WIM system consists of two weigh pads in an installation frame, two inductive loops, and an axle sensor. The installation can be either a concrete vault in an asphalt or concrete roadway or a shallow excavation in concrete. The shallow excavation is assumed for the installation cost of the system. A vendor representative to supervise installation, a subcontractor to perform the installation work, and traffic control are also included. The approximate cost for a fully installed lane of Bending Plate WIM is $21,500.

A Bending Plate WIM system is generally more durable than a piezoelectric installation, so a life of 6 years is assumed for the in road equipment. In addition to the scale itself being more durable, the installation is less dependent on the conditions of the roadway and less affected by deterioration.

Regular six month maintenance visits are assumed for the Bending Plate system. In addition to these maintenance visits a cost for sensor replacement or repair, based on the original installation cost, is included. The cost due to sensor failure or repair were estimated as follows:

- 4% in year one
- 6% in year two
- 8% in year three
- 10% in year four
- 15% in year five

Replacement in year six

When all these costs are calculated over a 12 year cycle, using the Net Present Value of each cost, the cost per year of operation for a Bending Plate Weigh In Motion data collection system, in present dollars, is $6,400 per year per lane.

Single Load Cell WIM

A Single Load Cell WIM system consists of two weigh pads in an installation frame, two inductive loops, and an axle sensor. The installation consists of casting the scale frame into a concrete vault in both asphalt and concrete roadways. A vendor representative to supervise installation, a subcontractor to perform the installation work, and traffic control are also included. The approximate cost for a fully installed lane of Single Load Cell WIM is $48,700.

A Single Load Cell scale is the most durable of the WIM technologies with an expected life of 12 years for the scale mechanism. A major overhaul of the scale after 6 years is included in the costing to provide high performance over the entire 12 year period. Since all single load cell scales are installed using a concrete vault installation, the integrity of the installation is not affected by the deterioration of the surrounding roadway.

Regular six month maintenance visits are assumed for the Single Load Cell system. In addition to these maintenance visits a cost for sensor and scale replacement or repair, based on the original installation cost, is included. The cost due to sensor failure or repair were estimated as follows:

4% of equipment cost per year over the life of the scale
A major overhaul in year six

When all these costs are calculated over a 12 year cycle, using the Net Present Value of each cost, the cost per year of operation for a Single Load Cell Weigh In Motion data collection system, in present dollars, is $8,300 per year per lane.

Conclusion

Three basic types of Weigh In Motion technology have been considered on the basis of accuracy and cost. The accuracy assumed according to ASTM standards for each technology are outlined below. In addition, some of the key figures regarding the cost of the system are also included. These costs are the direct costs of the inroad equipment only and do not include related conduit work, system electronics, time delays, etc.

	Piezoelectric	Bending Plate	Single Load Cell
Accuracy (95% confidence)	+/- 15 %	+/- 10 %	+/- 6 %
Expected Life	4 Years	6 Years	12 Years
Initial Installation Cost	$9,000	$21,500	$48,700
Annual Life Cycle Cost	$4,750	$6,400	$8,300

These are some of the factors that should be considered and planned for when installing a data collection system. There is no single system that is right for every application. A careful consideration of the accuracy required, the anticipated road usage, and the convenience of maintenance should be taken into consideration. In addition factors such as lane closure costs, pavement life, and traffic delay costs should also be considered.