




## APPLICATION OF WEIGH-IN-MOTION (WIM) TECHNOLOGIES IN OVERWEIGHT VEHICLE ENFORCEMENT

		
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### ABSTRACT

A variety of Intelligent Transportation Systems (ITS) have been tested and proven to be practical solutions for commercial vehicle safety enforcement. Many systems have already been deployed in the USA and abroad. Many other systems are being tested and refined for future deployment. A system that has been in use for many years is weigh-in-motion (WIM). While the practice of weighing heavy trucks at highway speeds has been in use for several years, the systems continue to be refined in order to achieve optimal performance. This paper examines the feasibility and applications of weigh-in-motion systems in overweight vehicle enforcement in today's 24-hour per day environment.

**Keywords: ITS, Safety, Enforcement, 24-hour.**

### RESUMEN

Una variedad de Sistemas de Transporte Inteligentes (ITS) se puso a prueba y resultó ser una solución práctica para la seguridad de los vehículos comerciales. Muchos sistemas ya se han puesto en uso en los Estados Unidos así como en el extranjero. Muchos otros sistemas se están examinando y refinando para su uso en el futuro. Un sistema que se ha usado por muchos años es el peso en movimiento (WIM). Mientras la práctica de pesar los camiones pesados a velocidades de carretera se ha usado por varios años, se continúa refinando los sistemas para lograr un funcionamiento óptimo. Este ensayo examina la viabilidad y las aplicaciones de los sistemas de peso en movimiento en cumplimiento forzoso de los vehículos sobre pasados de peso en el ambiente actual las 24 horas al día.

**Palabras clave: Sistemas de Transporte Inteligentes (ITS), seguridad, las 24 horas al día,**

### RÉSUMÉ

Une variété de Systèmes de Transport Intelligents (STI) a été testée et reconnue comme étant des solutions pratiques pour le renforcement de la sécurité des véhicules commerciaux. Plusieurs systèmes sont déjà en cours d'utilisation aux Etats-Unis et à l'étranger. Beaucoup d'autres systèmes sont actuellement examinés et perfectionnés pour leur usage dans le futur. Un système qui a été en utilisation depuis plusieurs années est le pesage-en-marche (WIM). Alors que la pratique du pesage des poids-lourds sur les autoroutes est en usage depuis plusieurs années, ces systèmes sont perfectionnés continuellement dans le but d'obtenir la performance optimale. Cet essai examine la faisabilité et les mises en application des systèmes du pesage-en-marche (WIM) dans le cadre d'un

contrôle continu, 24 heures sur 24, dans l'environnement actuel, des véhicules qui sont en excès du poids réglementaire.

**Mots-cles: Systèmes de Transport Intelligents (STI), renforcement, sécurité,**

## **1. Introduction**

The current system of weighing trucks at roadside weigh stations is expensive, inefficient, labor intensive, and time consuming for both legal trucks and enforcement officers. This paper presents the concept of allowing safe and legal trucks to move freely throughout the United States. The concept is called electronic screening employed on a 24-hour-7-day-a-week (24/7) basis and is supported by weigh-in-motion (WIM) and automatic vehicle identification (AVI) technologies. WIM calibration is accomplished using a “feedback loop” between the WIM system and the static scales at the weigh station. Further, current laws will require modification to accommodate 24/7 operating practices in an unmanned environment.

Why are we concerned with overweight trucks? Estimates vary greatly, but according to one study completed by the Texas Transportation Institute, overweight trucks cost the state of Texas between \$6 million and \$48 million each year in road damage (Texas Transportation Institute 1999), and those costs are expected to rise with the increasing number of trucks needed to deliver increasing amounts of freight.

Increasing truck traffic creates the need to improve weight enforcement methods. For example, truck traffic in Iowa has increased over 300% in the past 30 years. At the same time the Iowa DOT has only approximately 120 motor vehicle enforcement officers to cover 10,500 miles of highway. Vehicle-miles traveled by truck in Iowa are expected to increase to 41 billion miles by 2020, equating approximately one officer for every 34 million-miles traveled by truck. For the enforcement officer to be effective in this environment, creative solutions are required. Using automated electronic screening, a system can be developed that will enable automated unmanned 24/7 roadside enforcement activity.

This paper presents the concept of applying electronic screening to enforce overweight, safety and credentials regulations on a 24/7 basis. Furthermore, the paper discusses the legal issues involved when implementing automated electronic screening and suggests an approach to implementing 24/7 enforcement activity.

## **2. Electronic Screening**

Electronic screening is a process that allows commercial vehicles, whether operating intrastate or interstate, to pass a check point (e.g., weigh station) at mainline speeds without stopping to be checked for proper credentials, weight, and safety status. Checking vehicle weight at mainline speed is accomplished using AVI and WIM. Credential and safety checks are supported by roadside databases. Figure 1, Typical Electronic Screening Configuration, illustrates the relationship between subsystems.

The vehicle identity is communicated to the roadside processor using AVI. The roadside processor correlates the vehicle identity with the WIM data, safety data, and credentials data. Legal vehicles are given an in cab green signal to proceed past the weigh station, and potentially illegal vehicles are given a red light to pull into the weigh station for further observation.

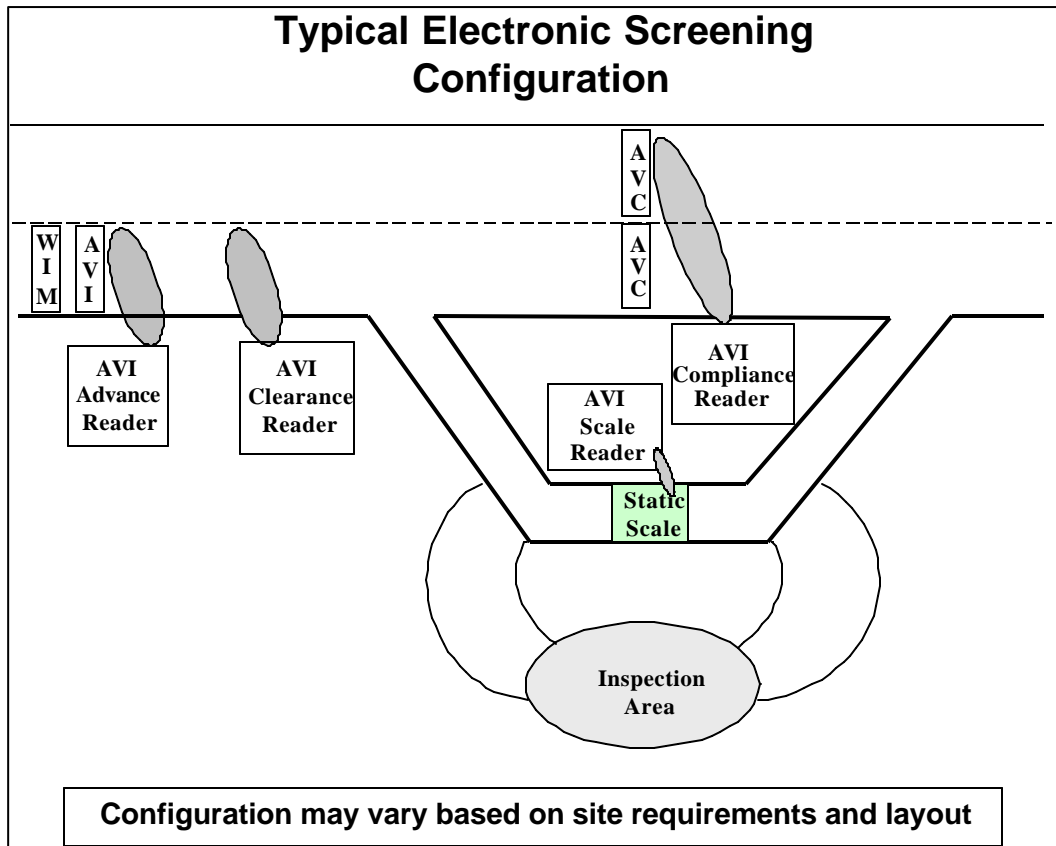


Figure 1-Typical Electronic Screening Configuration

## 2.1 Automatic Vehicle Identification

An AVI system consists of transponder, antennas, and readers. The reader transmits Radio Frequency (RF) energy over an adjustable area called the read zone or reader footprint. The transponder on the vehicle responds to the reader interrogation by sending the vehicle ID to the reader receiver. This process is called dedicated short-range communication (DSRC).

## 2.2 Weigh-In-Motion

Weigh-in-motion (WIM) is the process of measuring the dynamic tire forces of a moving vehicle and estimating the corresponding tire loads of the static vehicle. Gross-vehicle weight of a highway vehicle is due only to the local force of gravity acting upon the composite mass of all connected vehicle components and is distributed among the tires of the vehicle through connectors such as springs, motion dampers, and hinges. Highway WIM systems are capable of estimating the static gross weight of a vehicle as well as the portion of this weight carried by the tires of each wheel assembly, axle, and axle group on the vehicle. The static weight is estimated using the measured dynamic force and calibration parameters. The calibration parameters account for the influences that factors, such as vehicle speed, pavement condition, and suspension dynamics, have on estimating the static weight. WIM calibration is necessary to ensure that the static weight estimates are accurate within an acceptable tolerance. Estimating the static weight of the vehicle within an acceptable tolerance is key to providing an automated 24/7 roadside enforcement operation.

Generally, there are three types of weigh-in-motion (WIM) systems: bending plate, piezoelectric sensors, and load cell. The Bending Plate WIM systems utilize plates with strain gauges bonded to the underside. As a vehicle passes over the bending plate, the system records the strain measured by the strain gauge and calculates the dynamic load. Piezoelectric WIM systems utilize piezo sensors to detect a change in voltage caused by pressure exerted on the sensor by an axle and measures the axle's weight. Load Cell WIM systems utilize a single load cell with two scales to detect an axle and weigh both the right and left side of the axle simultaneously. (McCall and Vodrazka 1997) Typical bending plate and load cell technologies and recommended installation procedures can be used in mainline electronic screening applications. This paper introduces a technique called "feedback loop" to provide continued calibration of the WIM site based on static scale weights.

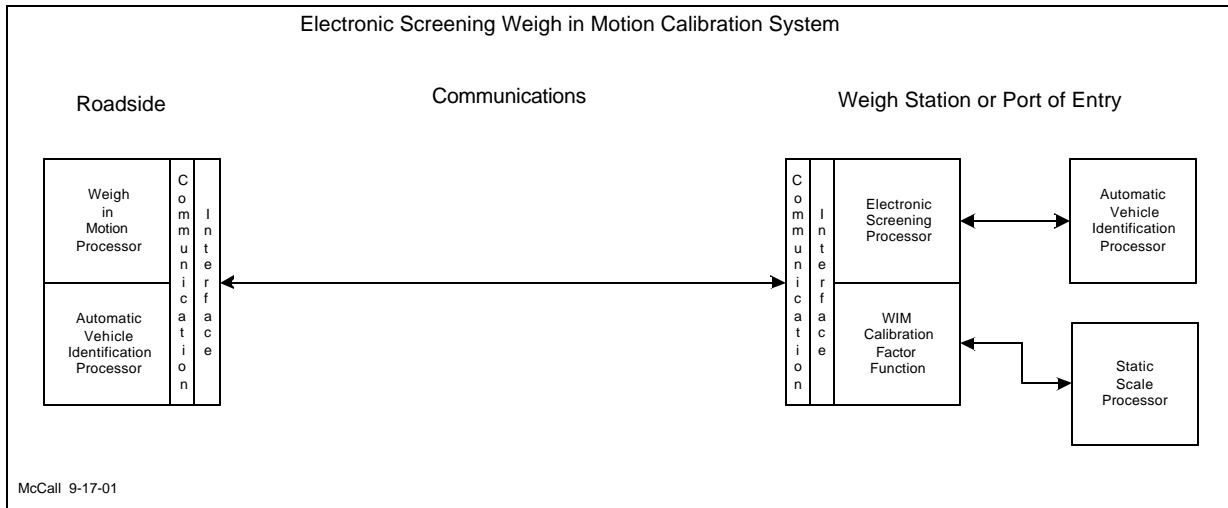
## 2.4 WIM Calibration

Calibration is used to ensure that the estimation of the static weight produced by the WIM system is as close to the static weight as possible. WIM is calibrated to offset the effects of site conditions, such as pavement temperature, vehicle speed, and pavement conditions. These factors can influence the weight estimated by the system. Calibration may be done by comparing the estimation from the WIM system to the actual static weight of a number of different types of trucks typically observed at the weigh station location. The American Society for Testing and Materials (ASTM) Standard Specification E 1318-94 concerning highway WIM systems lists the ASTM recommendations for the calibration procedure. However, a calibration procedure that is capable of supporting 24/7 roadside enforcement must be rigorous and produce WIM static weight estimates that are within a tolerance that is acceptable to law enforcement, trucking, and judicial communities. In areas that are using WIM systems for direct enforcement applications (i.e., Eastern Europe, South America, Asia), the precision standard commonly employed for direct enforcement applications of WIM scales is  $\pm 5\%$  at the 95% level of confidence, (Curnow, 1998). This standard could be applied in the USA as well as it meets the ASTM Standard E 1318-94.

The current WIM calibration process requires manual intervention. Trucks crossing the WIM scales are manually identified at the WIM site, and the weight data are recorded at the WIM site. The identified truck is directed to the weigh station static scales and weighed. The trucks are again identified manually to make sure the same truck weighed on the WIM is being weighed statically. The WIM estimate and the static weights are compared and the calibration factor calculated. The calibration factor is manually entered in the WIM to correct estimates. The process is time consuming and expensive and therefore, enforcement agencies are reluctant to calibrate the WIM site. As site conditions change, the WIM system must be recalibrated.

The proposed concept, using a "feedback loop", removes manual intervention, can be automated, and can be done frequently. Electronically connecting the WIM calibration factor calculation to the weigh station static scale weighing is called a "feedback loop". Figure 2, Electronic Screen Mainline WIM Calibration System, is a logical diagram of the proposed electronic screening calibration system. The feedback loop will use the same system that supports electronic screening with the addition of a WIM calibration function in the electronic screening processor. Further, the static scale processor is connected to the electronic scale processor.

As is current practice, a statistically valid sample of trucks, based on the site's average daily traffic count, is weighed on both the WIM scales and on the static scales at the weigh station, over a selected period of time. When applying the feedback loop, the trucks are automatically identified at both the advanced AVI reader and the static scale AVI reader. The WIM estimated weight and static scale weight are compared, and the calibration factor is calculated. The calibration factor is transmitted through the communications system to the advanced AVI reader and WIM system. The newly calculated WIM calibration factor is automatically entered in the WIM system. Either a WIM calibration factor change threshold can be set to activate the automated calibration factor calculation or the calculation can be scheduled. The feedback loop WIM calibration system promises to reduce the differences between static weight and WIM estimates at a much lower cost.



**Figure 2 - Electronic Screening Mainline WIM Calibration System**

A WIM manufacturer has recently developed and installed a feedback loop feature in a ramp WIM screening system. The feedback loop feature is operating at several locations and is now a standard feature in their ramp WIM screening system. This feature performs a seamless and continuous calibration of the WIM system based on static weights. The weigh station system tracks vehicles as they move from the ramp WIM screening system through the facility. Vehicles are directed to the static scale or directed to by-pass the static scales. The feedback loop calibration system combines the WIM data with the Static data on vehicles that were directed to the static scale and these data are stored for calibration. The feedback loop feature was designed to eliminate costly manual calibrations and compensate for uncontrollable dynamic factors. Periodic manual calibration checks have been performed at these locations and not once have the WIM scales required manual calibration adjustments. Not only has this eliminated the need to perform costly manual calibrations, but the overall accuracy of the WIM scales has performed well beyond the ASTM type III requirements. See table below.

This type of loop feedback can also be implemented with mainline applications.

Axles	ASTM III	Feedback Loop Feature
Gross	6%	3.5%
Drive Tandem	10%	4.5%

Trailer Tandem	10%	6.5%
Steering	15%	7%

**Figure 3: Accuracy of Feedback Loop Calibrations v. ASTM III**

### 3. Current Law Modifications To Support 24/7

Two general legal issues currently do not support 24/7 automated unmanned enforcement at weigh stations. WIM sites have not proven accurate enough to support automatically issuing weight citations. Current commercial motor carrier regulations typically provide for enforcement at manned roadside enforcement stations and do not provide for automatically issuing citations based on current electronic screening technologies.

In developing new regulatory concepts, the resources necessary to enforce the laws and regulations using conventional techniques must be addressed. Most jurisdictions have difficulty effectively enforcing the existing size and weight laws at present due to shrinking resources. Making the enforcement of these laws more efficient is necessary. “Without effective enforcement...weight limit laws are meaningless.” (USDOT 1995)

WIM site precision is important because the measured weight serving as the basis of a citation must be capable of withstanding legal challenges. Frequent calibration is necessary to establish and maintain WIM accuracy. Currently, WIM sites are not calibrated frequently, because calibration is expensive and time consuming. The closed loop calibration method will support frequent WIM calibration. The frequency of automated closed loop calibration will depend on site conditions and changes in those conditions.

With respect to enforcement, precision is important because the measured weight serving as the basis of a citation must be capable of withstanding legal challenges. Knowledge of the precision of a WIM scale can be used to calculate "deductions" from measured WIM scale weights to minimize the likelihood of an inappropriate citation. A statistical analysis of the accuracy of slow speed weigh in motion systems in Oregon by Stratham calculated a deduction factor of 7.05 percent and concluded that in only one case in a thousand will a WIM scale weight, minus this deduction, exceed the "true" underlying weight. (The mean speed for trucks in this study was 5.3 miles per hour.) Should the level of confidence be relaxed to one in five hundred, the deduction would shrink to 5.84 percent, and for the case of one in one hundred, the deduction would be 5.26 percent. (Stratham, 1998)

Automated, 24/7, weigh station enforcement using the closed loop technique is unlikely to be adopted until WIM accuracy satisfies law enforcement and judicial authorities. Therefore,

implementing 24/7 operations may take place in phases led by representatives from the enforcement, motor carrier, and judicial communities. Phase 1 will include technology testing to establish an acceptable WIM site tolerance. Phase 2 will include developing draft laws supporting 24/7 enforcement operations. Phase 3 will include implementing 24/7 operations at selected test sites. Phase 4 will include finalizing the draft laws and adopting the laws. Phase 4 will include implementation of the automated 24/7 enforcement operations.

#### 4. Conclusions

Unmanned, 24/7, automated roadside enforcement activity is necessary to enforce motor carrier regulations more efficiently and effectively with the limited resources available. Adopting unmanned, automated, 24/7, roadside enforcement activity depends on WIM systems producing estimated weights within a tolerance acceptable to the enforcement, motor carrier, and judicial communities. The “feedback loop” WIM calibration method has great potential for developing a WIM calibration factor, frequently recalibrating and enabling the WIM system to produce an estimate of truck static weight within an acceptable tolerance. Frequent recalibration will reduce the effect of changing site conditions including variability of vehicles, pavement, environmental, and sensors. Finally, current laws must be modified to accommodate automated, unmanned, roadside enforcement.

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