CONCURRENT SESSION 7C - ENFORCEMENT II

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

WEIGH-IN-MOTION FOR ENFORCEMENT SCREENING OF TRUCKS

Koney Archuleta
California Department of Transportation

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

For further information contact:
Koney Archuleta
California Department of Transportation
1120 N. Street
Sacramento, CA 95814
Ph: (916) 654-7375

WEIGH-IN-MOTION FOR ENFORCEMENT SCREENING OF TRUCKS

KONEY ARCHULETA

CALIFORNIA DEPARTMENT OF TRANSPORTATION

The use of Weigh-In-Motion (WIM) and Automatic Vehicle Identification (AVI) are valuable tools for truck screening in weigh stations. The benefits of using these tools include:

- Reduce weigh station congestion and backup
- Automatic Screening for weight violations
- More time available to spot registration and safety violations
- Reduced delay for trucks
- Reduced air pollution

These are some of the benefits that WIM screening can provide when the system is installed correctly and calibrated. This paper will review the various types and configuration of truck screening systems that have been installed in California, their advantages and failures. It will describe the proper installation of WIM and AVI systems, traffic control and calibration. The paper will also describe the HELP, (Heavy Vehicle Electronic License Plate) "PREPASS" layout and operation in California.

COLORADO DYNAMIC DOWNHILL TRUCK SPEED WARNING SYSTEM

Richard Mango
Colorado Department of Transportation

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

COLORADO

DYNAMIC DOWNHILL TRUCK SPEED

WARNING SYSTEM

An Intelligent Transportation System Project
developed by the

ITS Program Office
of the

Colorado Department of Transportation

International Road Dynamics
and the

Federal Highway Administration

Richard Mango
Colorado Department of Transportation
ITS Program Office
1325 So. Colorado Blvd., Suite B-770
Denver, Colorado 80210

303-757-9801

January 1996

COLORADO

DYNAMIC DOWNHILL TRUCK SPEED WARNING SYSTEM

Introduction

The Colorado Department of Transportation (CDOT) is actively involved in efforts to improve the safety of commercial vehicle operations (CVO) in Colorado. As new safety technologies emerge, CDOT chooses projects that will provide the best applications for future implementation. One area related to commercial vehicle operations and truck safety, which is of major concern to the Department, is runaway trucks on Colorado's mountain highways.

The nature of the mountains and the grades of mountain highways force the Department to look particularly close at truck driver behavior on downgrades and its relationship to **CVO in** general. The Department has installed numerous signs and lights to regulate speed and has constructed slow, climbing lanes and runaway truck ramps all to help prevent serious truck accidents and driver injuries. Although these actions have improved the downhill situation, Colorado statistics still bear witness to many runaway trucks annually.

With the advent of Intelligent Transportation Systems (ITS) technologies we have the opportunity to test new innovative safety systems to address many of these problems. One concept that CDOT is currently testing is a dynamic truck speed warning system for long downgrades. The use of these new technologies for commercial vehicle detection and data management holds a great deal of promise as innovative solutions to many traffic safety improvement needs.

Colorado was awarded ITS **(IVHS) Field** Operational Test Funds in late 1993 for the development and implementation of a dynamic warning system for trucks to identify safe operating speeds for long downgrades. The project involves the use of weigh-in-motion technology and a computer algorithm to determine an appropriate downhill speed for trucks. Based **on the** configuration and weight of the vehicle, the system will recommend a safe downhill speed and flash a message on a variable message sign (VMS) to the driver just prior to his decent of the downgrade. The objective is to reduce runaway truck accidents through real-time driver information and modifying driver behavior. CDOT is working with the Colorado Motor Carders on a safety and education campaign to be implemented in concert with this project.

Project Description

The Dynamic Downhill Truck Speed Warning System is a project which seeks to affect driver behavior by providing drivers with an instant message which recommends a safe downhill speed for their specific truck. That information is developed from data collected at the site, just prior to the beginning of the downgrade. Colorado is blessed with the beautiful Rocky Mountains, but also must meet the challenge of managing traffic on steep downgrades. Because of the significant number of downgrades in Colorado, we believe this type of system has the potential to provide great safety benefits for the trucking industry and subsequently all other travelers.

The location of this project is on Westbound I-70 just west of the Eisenhower Tunnel at the very beginning of the long downgrade. The 12 mile length of this section of I-70, the 7% downgrade and the extreme weather conditions make this an ideal location to test the Dynamic Downhill Truck Speed Warning System. Not only is this a significant downgrade which presents problems for truck drivers, but it also will provide an extreme environmental test of the equipment and methodologies.

The Dynamic Downhill Truck Speed Warning System involves the use of new off-the-self detection technologies such as weigh-in-motion (WIM), automatic vehicle classification (AVC) and the incorporation of variable message signs (VMS). The element which makes this project relatively new is the integration of all these detection and management technologies into one system. This system integrates and manages these elements with a high speed computer and data communications. The computer runs special software to process vehicle detection, weighing, classifying and data storage. The computer also processes that data and sends any one of a number of fixed messages to the variable message sign. This information is for the truck driver. In fact the message is for that specific driver as he is about to begin the long downgrade. The speed message is based on the weight of the vehicle and the grade of the highway.

Here is how fhe system works... At the top of the long downhill grade, detection loop equipment in the pavement, senses the passage of a truck (see Figure I). Each axle of the truck is weighed and the vehicle is classified as to its configuration, and a data record of that vehicle is stored in the computer. The computer in turn uses this information in a special algorithm developed several years ago by the Federal Highway Administration (FHWA). The algorithm determines the safe downhill operating speed for that particular truck based on the truck's size and weight, and the downhill grade. This 'recommended speed' is added to the vehicle record in the computer, which queues up a message to be sent to the VMS. The VMS message is triggered by pavement loops, which flashes the recommended speed message to the driver of that specific vehicle. The message is displayed for about one second. The driver then can use this information to operate the vehicle at the recommended downhill speed. The system also includes another detection module several miles downhill that will be used for evaluation, and to determine whether the driver adheres to the recommended speed.

International Road Dynamics, Inc. (IRD) is a partner with CDOT on this project. IRD has extensive experience designing and installing WIM, AVC and VMS systems. The software that operates the system was developed by IRD. The vehicle data record in the computer contains a significant amount of information about each truck. The record has date, time, speed, classification, number of axles, weight by axle, distance between axles, pavement temperature, etc. It is a considerable amount of data, even so the computer's hard drive will store several months of data, depending on the traffic volume. A sample of data records is shown in Figure 2. Following a successful evaluation CDOT may modify the system to incorporate weather and basic automatic traffic recorded operations into the site. All the necessary communications and control functions are present in the system now.

The Colorado Motor Carriers Association (CMCA) is also a partner and will help market the project and educate truck drivers in the future. In the long-term, for the project to be successful, the support and concurrence of the trucking industry is essential. For this reason CDOT wants the truck association to be involved with the development and continued use of the system. Also the Ports of Entry has been very supportive with our calibration efforts and will provide an outlet for informational materials as needed in the future.

We appreciate the support of these transportation partners and express our thanks to all of them...

Current Status

CDOT was approved to use FHWA Operational Test Funds in late 1993. The project equipment was installed in mid 1994 on the downhill west side, in the westbound direction, of the Eisenhower Memorial Tunnel on I-70. The environment at the Tunnel is severe. It is located 11,000 feet above sea level and temperatures range from 90 degrees to minus 50 degrees Fahrenheit. We felt that this would provide an excellent location to test detection and processing equipment under extreme conditions. The equipment includes loops and peizo sensors installed in the roadway just before the long downgrade, which detect vehicles and identify them by configuration and weight. A computer and control box for this equipment, and variable message signs that flash the appropriate message to each truck driver are also part of the system.

Testing and calibration of the system took place in late 1994. The calibration effort used certain configured vehicles with known weights, which were identified at an upstream port of entry at Dumont, Colorado. Also, we used a loaded CDOT three axle single unit truck of known weight and dimensions. The system was made operational a few months ago and is currently functioning as designed. However, winter creates special operational problems for us in the mountains at that altitude. Snow pack sometimes changes lane operations. Bad weather, ice, snow and poor visibility on the downhill grade forces CDOT to close or restrict traffic during some storms. On occasion, all these things have interrupted the 'normal operation' of the dynamic warning system. Winter is not a good time to collect and process data in the system. We are seeking 4 to 6 months of generally consistent operation for our evaluation.

The evaluation mechanism is partly designed into the system. Information will be collected over the next 6 to 8 months to use in final evaluation. CDOT has contracted with the University of Colorado at Denver Engineering Department to conduct special evaluation procedures. This evaluation will include video monitoring, a driver survey and consistency analysis of the equipment. Our initial results to date have been anecdotal, but have proven encouraging. Trucks drivers have been responding to the speed message as shown on the VMS. Drivers seem to be demonstrating their compliance by modifying their travel speed. Brake lights are coming on with the flashing of the VMS.

The overall cost of the Dynamic Downhill Truck Speed Warning Project is approximately $243,000. This includes the evaluation. CDOT is currently trying to improve the system's operation and make final modifications. The system will operate through the summer of 1996 and the final evaluation will be completed shortly thereafter.

Figure 1

Colorado

Dynamic Downhill Truck Warning System

(I-70 Westbound)

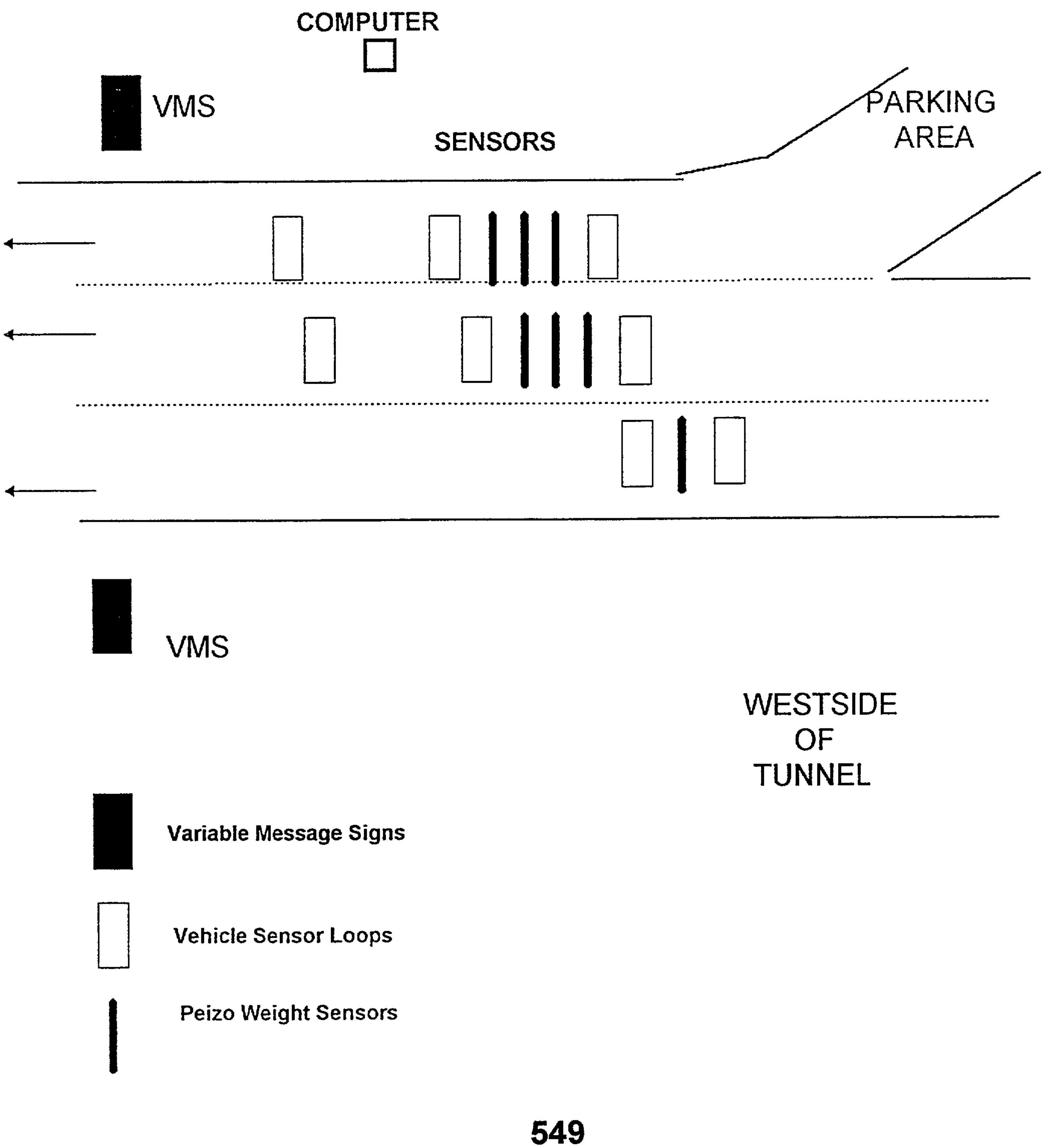


Figure 2

Dynamic Downhill Truck **Speed** Warning System
Data Record **Sample**

Raw Vehicle Data Sample

```
Site: I-70Tunnel Lanes: #1 #2 #3
Classification: COFHWA Start Class 0 End Class 13
Data Included: Vehicle Records
Vehicles Used: All
FROM: Fri Aug 16 00.00:00 1995 TO: Fri Aug 16 15:00:00

95,8,16,0,0,19,0.1,45,11,55.51.0.0.896,14.2,16.1.11.9,4.1,9.2,24.4,7.2,3.9,8.4,0.0,0.0,...   . ..0.0.35
95,8,16,0,0,58.0,2,54,11,67.8,~.3,1.55,9.0,i6.2,23.1,4.1,20.0,27.4,10.8,4.4,11.3,0.0.0.0   . . . . 0.0.35
95,8,16,0,2,15,10,1,0.0,0.0,0.0 , ......0.0,0.0,34
95,8,16,0.5,23,0.2,47,9.55,34.6.0.442,13.6,17.1,5.4,4.3.5.4,32.8,5.6,4.1,4.7.0.0,0.0,   . . . . . . . 0.0.34
95.8,16,0,24.11,0.1,49.3,27,4.5,0.000,1.8,9.8,1.6.11.6,1.1.0.0,0.0,......   0.0,34
95,8,16,0,35,21,2,59,13.63.93.9.6.751,15.8.15.6.18.9,4.3,21.0,3.5,0.5.4.0,1.1,25.5,16.6,4.1.19.7,3.8,0.3,0.0,0.0,   . . . _.. 0.0,,34
95.8.16,0.41.22.0.3.58.5.24,8.8.0.010.4.7,15.4.4.1,0.0.0.0.   ___ ___ 0-0.34
95,8,16,0,47.35.0,1,47,9,65,34.6,0.442,13.6,17.1,5.4,4.3,5.4,32.8,5.6,4.1,4.7.0.0.0.0,...   . ..0.0.34
95,8,16,1,3.5.5,4,0,0,0,0.0.0,0.0.......   0.0,33
95,8,16.1,10.45,21,1,61,13,69,90.3,5.734,14.9,15.0,15.9,4.3,19.5,3.3,0.8,37.1,18.7,4.1,19.2,7.6,1.3,0.0,0.0,   .._ . . . 0.0.33
95.8,16,2,11,23,0,2,50,5,22,11.1,0.041.3.7,12.2,7.5,0.0,0.0,......   0.0,33
95,8,16,2,0,58,0,2,54,11.67.8,77.3,1.55.9.0,76.2,~.1,4.1,20.0,27.4,10.8,4.4,11.3,0.0,0.0   . . . ...0.0.33
95,8,16,2,2,15,10,1.0.0.0.0,0.0 , ......0.0,0.0,33
95,8.16,2,12.12,221.1.65.13,64.70.4,2.543.13.0,9.0,11.6,4.2,12.2,7.5,0.4.27.0,14.4,4.2,18.3,3.7.0.3,3.8,0.1,0.0,0.0,...   ..0.0,32
95,8.16,2,14,19,0,2,45,11.55,51.0,0.896,14.2.16.1,11.9,4.1,9.2,24.4,7.2,3.9,8.4,0.0,0.0.   . . . . . . . 0.0.32
95.8,16,2,35,21,2.60.13,63,93.9,6.751,15.8,15.6,18.9.4.3,21.0,3.5,0.5,4.0,1.1,25.5,16.6,4.1,19.7.3.8,0.3,0.0,0.0,...   ._. 0.0,.32
95,8,16.2.41,22,0,3,53,5.24.8.8,0.010,4.7,15.4,4.1.0.0,0.0 , ...... 0-0,32
```

-

Raw Report File Format

The raw report is a listing of each vehicle record in a minimal format. Each vehicle record is a string of numbers separated by commas. An individual record will have the following general format:

<year>, <month>, <day>, <hour>, <minute>, <second>, <error number>, <lane>, <speed>, <class>, <length>, <GVW>, <ESAL>, <weight 1>, <axle spacing 1-2>, weight 2>, <axle spacing 2-3>, ... <weight 1 l>, <axle spacing 1 1-12>, <weight 12>, <temperature in C or F>

Source: International Road Dynamics, Inc.

PRELIMINARY RESULTS FROM THE SLOW-SPEED WEIGH-IN-MOTION (SWIM) ACCURACY TEST PROJECT

Speaker: Milan Krukar
Oregon Department of Transportation

Authors: Milan Krukar, et al.
Oregon Department of Transportation

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

PRELIMINARY RESULTS FROM THE SLOW-SPEED WEIGH-IN-MOTION (SWIM-) ACCURACY TEST PROJECT

Milan Krukar & Kenneth R Evert
Oregon Department of Transportation

-ABSTRACT-

In 1993, the Oregon Department of Transportation agreed to undertake a project, partially financed by the Office of Motor Carriers, Federal Highway Administration, to test the accuracy of a slow-speed weigh-in-motion system. The purpose was to test and verify the accuracy of a SWIM system so that the system could be used for enforcement purposes, i.e. writing citations. The system would be used in the "Green Light" CVO project and in developing a "robotic" weigh station demonstration project. The SWIM system was installed during 1994-95 at the Wyeth weigh station on I-84 westbound and is currently being tested. A sampling plan was developed by Portland State University for the collection of truck weight data Calibration results obtained over three different time horizons show that the weight differences between the SWIM system and the static scales are less than two percent for all axles at speeds between 3 to 7 miles per hour. The results are less consistent for steering axles and show more variability due to the nature of the steering axles dynamics, and heavy heavy vehicle characteristics. Nevertheless, the results are very encouraging, showing that SWIM performance is nearing the precision level required in Handbook 44 for weight enforcement by portable scales. Data will be collected during a twelve month period so that seasonal effects, if any, can be captured. In this paper the authors describe the project and present preiiiinary results.

P A P E R

INTRODUCTION

A. Truck Size and Weight Enforcement

Heavy vehicle size and enforcement in Oregon and elsewhere is both labor- and time-intensive. Weighmasters have to be present at the weighings in order to spot violations and write out citations. The weighing time alone takes up to 30 seconds, and if there any violations, the time can take as long as 15 minutes or more. If there is only one static scale at the ***weigh*** station, truck queues may form, depending upon the ramp length capacity and truck volumes, causing potential safety problems. This problem can be potentially **hazardous** if the trucks are backed up to the freeway or highway.

Presently, the weighmasters weigh heavy vehicles at ports-of-entry (p.0.e.) and weigh stations (w-s.) y letting them roll through the static scales at speeds of three to five miles per hour. This increases the number of vehicles going through the scale and slows down the queuing problem. However, if a weight violation is spotted, the weighmaster must have the vehicle completely stopped at the static scales and weigh it in order to write citations. This slows down the weighing process for the other vehicles.

Portable scale weighings are also labor- and time-intensive. It usually takes five minutes or more to obtain a single truck weighing, and a minimum of two weighmasters. Other trucks , potentially overloaded, are allowed to by-pass the portable system to minimize the queuing problem.

The weighing procedures must meet the National Institute on Standards and Technology (NISI) tolerances as presented in ***Handbook*** 44 (1). Acceptance tolerances for new static scales have to be within one tenth of 1.0 percent. Tolerances specified for portable wheel-loaders are ± 1% and ± 2% for acceptance and maintenance, respectively.-

B. Weigh-in-Motion Systems for Enforcement

Weigh-in-Motion (WIM) systems have been used **effectively** for data collection for pavement research and facility design, traffic monitoring, and weight enforcement for some 20 years. In weight enforcement, WIM systems are used to screen potentially overweight vehicles; candidate violators are then weighed on static scales, which are subject to precision tolerances specified by NET. WIM use for weight enforcement in Oregon has greatly reduced queuing at ports-of-entry and weigh stations, resulting in considerable savings for both truckers and enforcement agencies (2).

Our understanding of factors affecting WIM-measured axle and vehicle weights has improved due to field research, This **has** led to the development by ASTM of WIM installation and calibration procedures so that pavement and operational factors are, at best, minimized (3). Our knowledge on understanding how vehicle characterisrtics affect dynamic weighings has also increased over the years. Unfortunately, most vehicle **characteristics** affecting dynamic load variations cannot be reasonably controlled, only miniiized.

One factor that be controlled is speed. WIM scale measurements are affected by speed; the lower the speed the better the estimates of gross weights are in comparison with static scale weighings. Under 10 mph, WIM scale accuracy for gross weight has approached within ± 10% or better with 95% confidence levels. Various types of WIM scales from different manufacturers, tested under the same speed conditions, have shown thk same results. Thus the potential for direct use of slow-speed weigh-in-motion (SWIM) systems in weight enforcement appears to be feasible.

Nowhere in ***Handbook 44*** are acceptance and maintenance tolerances for WIM scales spelled out. As **previously** mentioned, tolerances for portable wheel-load weighers ***in Handbook 44 are*** **+** 1% and + 2% for acceptance and maintenance, respectively. WIM systems will need to achieve this minimum threshold for NIST certification for weight enforcement.

The Oregon Department of Transportation (ODOT) is presently involved in field trials to assess the potential for direct use of WIM scales in weight enforcementThis is the SWIM Accuracy Test Project. The successful demonstration of this WIM technology application would clearly have far-reaching consequences for enforcement (4) and planning (5).

PREVIOUS STUDIES

There are few field studies showing the precision of various WIM systems in measuring vehicle and axle weights at slow speeds. **Some** of these findings are based on calibration-data and therefore may not be representative of vehicles in the trafftc stream or affected by potentially relevant dynamic conditions. Nevertheless, the studies provide a general indication of the levels of precision that SWIM systems have achieved todate. The accuracy **issue** is not addressed, i.e. whether the differences between the sampled WIM and static mean weights are statistically significant, although a number of studies report these findings as well. In general WIM systems have been found to **be** capable of providing accurate (statistically significant) weightings.

Table 1 summarizes the levels of precision for axle weight and gross vehicle weight reported in eight studies (6,7,8,9, 1.0, 11, 12, 13, 14). Precision levels of + 10% for gross vehicle weight has been fairly consistently achieved at speeds under 10 mph, although about half the studies are based on calibration data. Only three studies (8,13, 14) recorded precision levels on gross vehicle weight under + 5%, and this was obtained in several calibration exercises reported and at different time periods.

Precision **levels** for axle weights are consistently worse than it is for gross vehicle weights. None of the studies reporting on axle weights in Table 1 achieved a precision level below C 10%. Under slow-speed conditions, it appears that precision ranges of zb 10 to 15% are typical. Therefore the precision achieved by **SWIM** systems todate have not been adequate in terms of tolerances that would be needed for direct weight enforcement. It should be noted that some of these **SWIM** studies tried to match the accuracy of the static scale (13,14) rather than a portable scale.

THE SWIM PROJECT

A. History

In 1993, ODOT submitted a successful proposal, asked by the FHWA-OMC, on the testing of a SWIM system (15). The project was divided into two parts: the fust part was the procurement, installation and testing of a SWIM system and the second part was the accuracy test which included the development of a sampling plan, collection of data over a one year period, and evaluation.

Part one went out for competitive bids. International Road Dynamics, Inc.(IRD) was the successful bidder. Part two was given to the Center for Urban Studies, Portland State University.

B. Site Description

The SWIM system was installed at the Wyeth Weigh Station, located at milepost 54.3 on I-84 westbound. This station has one static scale and is open on a random basis. The W.S. site layout is shown in Figure 1. An average of 232 trucks have been weighed at this site during an eight-hour shift. Average daily truck volume (24 hour period) for Cascade Locks P.O.E. (M-P. 44.2, I-84 EB). is 770, with high volumes peaks of 1,547 trucks and lows of 113 trucks. The volumes are similar for I-84 WB. Table 1 shows the 1994 estimated annual truck counts by type for the Wyeth W.S.

The weigh station is located in the Mid-Columbia River Basin. The area has weather seasonal@ with temperatures ranging from a high of 100 degrees during the summer to below 20 degrees in the winter. Snow and ice is common during the winter months.

C. Site Preparation

The entrance pavement was deeply rutted. Two 1 00-foot reinforced poxtland cement concrete slabs were put in to meet the **ASTM** standards on pavement smoothness for WIM systems (3). Parts of the pavement were ground and profilometer readings taken to make sure the smoothness standards were met.

D. SWIM System

The SWIM system was developed and installed by IRD. The system consists of two sets of bending plate scales, loops fore and aft, a 1 l-set Dynax Sensor Array, and 6 individual Dynax sensors. These sensors are used for accurately calculating vehicle lengths and speeds. Figure 2 shows the SWIM system configuration. The system was installed in May 1994 and then initially calibrated. Several of the bending plates and sensors failed and were replaced during 1995, after which the system was recalibrated.

WIM ACCURACY AND PRECISION

Evaluations of the accuracy and precision of WIM systems employ a fairly standard procedure. Axle weights are measured by WIM scales and compared to the corresponding weights recorded by static scales for a sample of vehicles. WIM scale accuracy can be calculated as follows:

(1) Accuracy = [(W, - WJ W,)] * 100, where

W, = axle or vehicle weight measured by a WIM scale; and W, = axle or vehicle weight measured by a static scale.

A WIM scale is defined to be accurate if the mean value of Equation (1) for a sample of weight observations does not differ significantly from zero. If the mean value of Equation (1) differs from zero, then systematic error, i.e. bias, exists in the WIM measure. Proper calibration of WIM scales-can potentially eliminate systematic error (9). Systematic error can be minimized if a representative sample of vehicles from the traffic stream are used for the WIM calibration.

Weight enforcement is not only concerned with WIM scales that provide an accurate estimate of weight for a population of trucks or axles, but that they provide accurate weight estimates for ***in&iduaZ trucks*** or axles. Therefore the variance of Equation (1) has to be small. In other words, the scale may be accurate but imprecise. The precision of Equation (1) can be defined as the range within which a specific percentage of all observations can be expected to fall as shown in:

(2) A f Zun * (S,/ 0.'), where

A = the mean percentage difference between the WIM and static weights; 2, = the critical value from the standard normal distribution associated with the level of confidence cr; S, = the standard deviation of A; and n = the number of observations.

The precision of a WIM scale depends upon its ability to consistently measure given dynamic forces. And these forces are greatly affected by vehicle, roadway, and operating conditions. If these factors can be reduced, dynamic load variations can be reduced thus directly improving WIM precision. Speed appears to produce the greatest reduction in load variation (9, 16). Table 3 shows the results from equations (1) and m

MEASUREMENT ERROR

The underlying assumption in Equations (1) and (2) is that static weights are true weights with zero variance, which are measured on static scales. It is possible that some variance may exist. This could at best be illustrated using inverse regression procedures to estimate static weights from WIM observations. Speed also introduces variance in the WIM scale readings. The regression can be estimated by obtaining observations on the WIM and static weights and on speed. The equation becomes

(3) $W_d = \alpha_0 + \beta_1 * W_S + \beta_2 * S + e$, where

W_d = WIM reading or dependent variable; W_S = static scale reading or independent variable; α_0 = the estimated intercept parameter; S = vehicle speed variable; β_1 = the estimated slope parameter; β_2 = the estimated speed parameter; and e = a random error term.

Equation (3) will allow the estimation of measurement errors due to the static scale and to vehicle speeds as shown in Table 4.

SWIM CALIBRATION DATA ANALYSIS

A. Time Periods

The SWIM scale was calibrated in November 1994 and again in March 1995 using trucks from the data stream. The November cahbration was comprised of two sessions. The fitst session was on November 1 & 2. Vehicle speed, axle and gross vehicle weights were recorded by the SWIM scale on a "slow-roll" basis, i.e. speeds between 2 to 10 mph, while axle weights were recorded on the static scale at a dead stop. The weights were measured from "Dynamic to Static" basis or D-S. Sample size was 77 trucks. In the session, November 3 & 4, vehicles proceeded over both scales at "slow-roll" speed, i.e. speeds between 2 to 10 mph. Sample size was 63 trucks. The measurements were taken in a "Dynamic to Dynamic" basis or D-D. Thus the first session compared SWIM weights to static weights under "Dynamic-Static" conditions, while the second 'calibration 'session addressed dynamic and vehicles weights as measured by both the SWIM and static scales, "Dynamic-Dynamic". Data from the /latter session are more relevant to issues other than enforcement, but are still useful here in illustrating how speed can affect scale accuracy and precision. The third calibration session was on March 20, 1995 and 27 trucks were sampled. The static scale weights were recorded under dead stop conditions as in the first session, i.e. D-S. The "slow-roll" speeds were similar as before, 2 to 10 mph.

B. Accuracy and Precision Analysis

Table 3 provides statistics on SWIM axle and gross vehicle weight accuracy and precision for the three calibration sessions (17). The mean percentage error between the SWIM and static scales weights differs significantly from zero in two out of twelve instances, i.e. steering axle in the fust session and the trailing axle in the second session. In these two instances significant systematic error appears to exist.

The 95 percent confidence intervals around the means errors reveal the SWIM scale measured within one percent of the static scale in seven out of twelve instances, including gross vehicle weight in all three sessions. Conversely, precision estimates exceeding the + 1% level were obtained at least once for the steering , drive, and trailing axles.

Since the session two data measure dynamic axles weights from both the SWIM and static scales, it should be expected that the precision obtained for this session is greater than it is for sessions 1 and 2. This appears to be the case. Although the trailing axles in this session does not achieve the target precision level, the problem can be attributed at least in part to systematic error. Nevertheless, it is noteworthy that the precision levels achieved in the "dynamic-static" calibration sessions are quite close to the levels achieved in the "dynamic-dynamic" session.

C. Measurement Error (Inverse Regression) Analysis

An inverse regression of the SWIM weight on static weight and speed was also estimated for the three data sets (17). Vehicle speed was recorded by the SWIM scale. All vehicles passed over the SWIM scale at 10 mph or less, and thus it was hypothesized that the effect of speed on dynamic weight measurement would be less pronounced.

The inverse regression results are given in Table 4. If SWIM and static weights correspond perfectly, the **estimated** static weight coefficient would be 1.00, and the speed coefficient, the intercept and standard error of the regression would be zero. Table 4 shows that these conditions were met for ten of twelve intercept estimates and nine of twelve estimates for both static weight and speed parameters. With respect to the static weight parameters, the estimates for the steering axle in session 1 and trailing axle in sessions 1 and 3 are all significantly less than 1 .00 at the 95% confidence level.

Although none of the samples vehicles exceeded 10 mph while passing over the SWIM scale, speed is nevertheless estimated to have a significant positive effect on SWIM weight measurements in four instances, two of which, the trailing axle and gross vehicle weights in session 2, involved measurement of dynamic weight on both the SWIM and static scales.

D. Sample Design (17)

The calibration data provided useful information in determining the sample size required to achieve a given level of precision. A the 95 percent level of confidence the sample size, n, required to achieve of precision of rt 1% is defined as follows:

(4) $n = (Z_{.025})^{**} g^{*}$, where

the Z term is the critical value from the standard normal distribution, and o* is the SWIM error variance. Table 2 shows that the trailing axle in session 2 had the greatest SWIM error variance, and thus a sample based on this variance would also satisfy the precision requirement for the other axles and gross weight. In this case the required sample size is:

(5) $3.84 * 16.73 \cong 64$

Precision may also vary by vehicle type. The vehicle type was not recorded during these three calibration sessions but will be in the future. The objective is to obtain at least 64 observations of each truck type shown in Table 2. The break point for achieving this goal is at the Type 6, three-axle, single unit truck,; 64 observations could be expected if the weigh station was in operation for fifteen g-hour shifts per month, i.e. one shift in six, over a year-long period.

DISCUSSION OF RESULTS

A. NIST Precision Standards

The precision results for the various calibration sessions indicate that SWIM technology can achieve the minimum level of precision for weight enforcement. The results show that the ODOT SWIM system would meet NIST standards for portable scales, but more work **is** needed. Future work will seek **to** provide information on the extent to which precision can be maintained under varying field conditions.

B. Speed Effects

Speed and WIM precision are directly related. The findings show in two ways how important the speed effect on precision is, even at fairly low speeds. First, the confidence intervals for the "dynamic-dynamic" calibration data were found to be somewhat smaller than their counterpart intervals from the "dynamic-static" calibration data. Second, in a third of the inverse regressions, speed was estimated to have a significant direct effect on SWIM weights.

Although not presented in this paper, the calibration results show that the accuracy and precision levels start to deteriorate at around 7 mph.

C. Axle Weight Precisions

Tables 3 and 4 show that the accuracy and precision weight levels for the steering axle are less than for the drive and trailing axles, and also gross weights. This may be a cause for concern since precision levels for all axles need to be meet Handbook 44 standards

Why do the steering axles show much more variance than the rear axles? There maybe three reasons. One, low speeds appear to impose more dynamic effects on the steering axle due to torque effects and braking. This may cause weight variances, increasing the standard deviation and making the mean error scatter higher-Two, vehicle configurations may play a major role in causing weight variance. Cab-over versus conventional cab configurations may cause different dynamic effects thus causing steering axle weight differences. Three, differences in rounding out the weights may be a very important factor. The SWIM computer automatically rounds the weight to the nearest hundred pounds upward. The weighmasters round the static weights to the nearest hundred pounds downward. This would increase the error and lower the precision on axles. This would affect the axles carrying lighter weights like the steering axles-more than the rear axles.

Very little can be done about the fust two conditions and one has to live with these two limitations. But something can be done about the weight rounding. In the future the rounding methodology will be the same for both SWIM and static weight readings.

D. Measurement **Error**

Static scales are subject to measurement error but this has not been assessed empirically. It is planned to check this error in the near future using an ODOT scale calibration truck. It is estimated that 30+ observations of this truck passing over the SWIM scale and then weighed at **a** dead stop on the static scale will be sufficient.

E. Sampling Plan

The sampling plan calls for over 7,500 vehicle observations over a year-long period, and considerably more axle observations. There may be a problem since present enforcement procedures do not require vehicles to come to a dead stop on the static scales except when a citation is being written. This test requires that all sample vehicles come to dead stop on the static scale. This could lead to queuing problems. A smaller sample may be required that would provide valid precision results. This could be done by collecting weight information during a part or parts of each sampled shift.

F. Future Work

The SWIM scales will be recalibrated and the data collection phase will start. This will be done over a year-long period so that seasonal effects, **if** any,can be captured. Temperature effects will be examined. The project is expected to be completed by April 1997 with a final report on the findings.

ACKNOWLEDGMENTS

The authors and ODOT acknowledge the financial grant given by the FHWA-OMC to pursue this project. The ODOT weighmaster staff at Cascade Locks Port-of- Entry helped in manning **and** collecting the data at the Wyeth weigh station. The IRD staff worked on the collecting and preliminary analysis of the data. Portland State University staff did most of the statistical analysis of the data. The rest are the responsibility of the authors.

REFERENCES

1. National Institute on Standards and Technology, **Handbook** 44, Washington, DC. 1990.

2. Krukar, M. and K.R. Ever-t, "Woodbum Port-of-Entry Automation Project, 19X6-1993", **Final Report, Experimental Features OR-86-01,** Research Unit, Engineering Services Section, Oregon Department of Transportation, July 1995.

3. American Society for Testing of Materials, "Standard Specifications for Highway Weigh-m-Motion (WIM) Systems with User Requirements and Test Method", **ASTM E 1318-92, 1992,76 l-771.**

4. Kmkar, M. and K.R. Evert, "Integrated Tactical Enforcement Network (Automated Enforcement Facilities **in** Oregon)", **Proceedings,** National Traffic Data Acquisition Technology Conference, Austin, Texas, 1990.

5. Hajek, J.J., G. Kennopohl and J.R. Billing, "Applications of Weigh-in-Motion Data in Transportation Planning", **Transportation Research Record 1364, 1992, 169-** 178.

6. Faghi A., RR Buddaraju and R. Nanda, "Statistical Accuracy Analysis for the I-95 Multi-State Traffic Monitoring Evaluation Project", Paper for the 75th Annual Meeting of the Transportation Research Board, Washington. D.C., 1995.

7. **Gillman, R.,** "Calibration and Adjustment of Weigh-in-Motion Data", **Transportation Research Record 1364,1992,186-192.**

8. Izadmehr, I., and C.E. Lee, "On-Site Calibration of Weigh-in-Motion Systems", **Transportation Research Record 1123,1987a.** 136-144.

9. Izadmehr, I. and C.E. Lee, "Accuracy and Tolerances of Weigh-in-Motion Systems", **Transportation Research Record 1123, 1987b,** 127-135.

10. Jacob, B., C. Maeder, L.A. George and M. Gallac, "Results of Weigh-in-Motion Project in France: **1989-1992", Transportation Research Record 1410, 1993, 115-122.**

11. Lee, C.E. and RB. Machemehl, "Weighing Trucks on Axle-Load and Weighh-in-Motion Scales", **Transportation Research Record 1048, 1985,74-82.**

12. Moore, RC., B-D. Stoneman and J. Prudhoe, "Dynamic Axle and Vehicle Weight Measurements: Weigh-in-Motion Trials", **Traffic Engineering and Control, 30:1,** 1989, 10-18.

13. Castle Rock Consultants, "Port-of-Entry Weigh-in-Motion Feasibility Study", Final Report, **Report Number FHWA** -AZS9-702, Arizona Department of Transportation, March 1989.

14. De **Nicholas,** M., "Slow Speed Weigh-in-Motion", Final Report, **Report Number FHWA-AZ89-328,** Arizona Department of Transportation, August 1989.

15. Krukar, M. and K.R Evert, "Slow-Speed Weigh-in-Motion (SWIM) Accuracy Test", **Work Plan,** Oregon Department of Transportation, January 1993.

16. Papagiannakis, A-T., W.A. Phang, J.H.F. Woodrooffe, A.T. Bergan and R.C.G. Haas, "Accuracy of Weigh-in-Motion Scales and Piezoelectric Cables", **Transportation Research Record 1215, 1989,** 189-**196.**

17. Strathman J.G., and R.L. Fountain, "The Oregon DOT Slow-Speed Weigh-in-Motion (SWIM) Project: Calibration Stage Accuracy and Precision Analysis", **White Paper,** for Oregon Department of Transportation by Portland State University, October 1995.

TABLE 1

SUMMARY OF WIM PRECISION STUDY FINDINGS

Reference	Speed	Vehicle Weight	Axle Weight	Comments
Faghri et al. (1995) (6)	N.R.*	28-46% within ± 5%	N.R.	Field test of 10 WIM systems on I-95
Gillmann (1992) (7)	N.R.	95% within ± 10%	N.R.	Calibration data from Kansas WIM system
Izadmehr & Lee (1987a) (8)	<10 mph	95% within ± 6.2%	95% within ± 13%	Weights on 86 trucks following calibration
Izadmehr & Lee (1987b) (9)	<10 mph	95% within ± 4-6.5%	95% within ± 1 1.8-13.3%	Findings from multiple calibrations
Jacob et al. (1993) (10)	25-50 mph	95% within ± 10%	95% within ±10%	Tolerances for French "Category B" WIM facilities
Lee & Machemehl (1985) (11)	"Slow & Steady"	95% within ± 6.3%	**95% within ±** 13.2%	Texas I- 10 traffic stream weighings
Moore et al. (1989) (12)	l0-50 mph	95% within ± 26%	95% within ±39%	Test of 6 WIM systems in UK
Castle Rock Consultants (1989) (13)	2.5 - 4 mph	96-100 % within ±2.0%	77-85% within ±2.0%	Ehrenberg POE, I-10, AZ DOT
DeNicholas (1989) (14)	<5 mph	96% within ±5.0%	N.R.	Ehrenberg POE, I-l 0, AZ DOT

* - Not Reported

TABLE 2

1994 ESTIMATED ANNUAL HEAVY VEHICLE COUNTS, WYETH WEIGH STATION

Vehicle Type	Description	Number
Type 5	Two Axle, Six Tire, Single Unit	779
Type 6	Three Axle, Single Unit	398
Type 7	Four or More Axle, Single Unit	35
Type 8	Four or Less Axle, Single Trailer	0
Type 9	Five Axle, Single Trailer	30,836
Type 10	Six or More Axle, Single Trailer	3,777
Type 11	Five or Less Axle, Double Trailer	2,213
Type 12	Six Axle, Double Trailer	2,037
Type 13	Seven or More Axle, Double Trailer	3,422
Type 14	Seven Axle, Triple Trailer	3,251
Type 15	Eight or More Axles, Triple Trailer	125

TABLE 3

ODOT WIM CALIBRATION: ACCURACY & PRECISION RESULTS*

	Mean Error (%)	Standard Dev.	Confidence Interval (95%)
Steering Axle			
Dynamic - Static	.94	3.83	07 to 1.81
Dynamic - Dynamic	-.11	3.48	-.97 to .75
Dynamic - Static	-1.14	3.09	-2.36 to .08
Drive Axle			
Dynamic - Static	-.22	3.79	-1.08 to .64
Dynamic - Dynamic	-.32	1.68	-.74 to .09
Dynamic - Static	.38	1.74	-.31 to 1.07
Trailing Axle			
Dynamic - Static	-.05	1.49	-.39 to .29
Dynamic - Dynamic	1.19	4.09	.17 to 2.22
Dynamic - Static	.53	1.43	-.99 to .03
Gross Vehicle Weight			
Dynamic - Static	.02	1.81	-.39 to .43
Dynamic - Dynamic	-.25	1.73	-.18 to .68
Dynamic - Static	.27	1.09	-.70 to .16

* The sample sizes for the calibration session are as follows:
Dynamic - Static (D-S), (November 1 & 2) = 77 trucks;
Dynamic - Dynamic (D-D), (November 3 & 4) = 63 trucks;
Dynamic - Static (D-S), (March 20) = 27 trucks.

TABLE 4

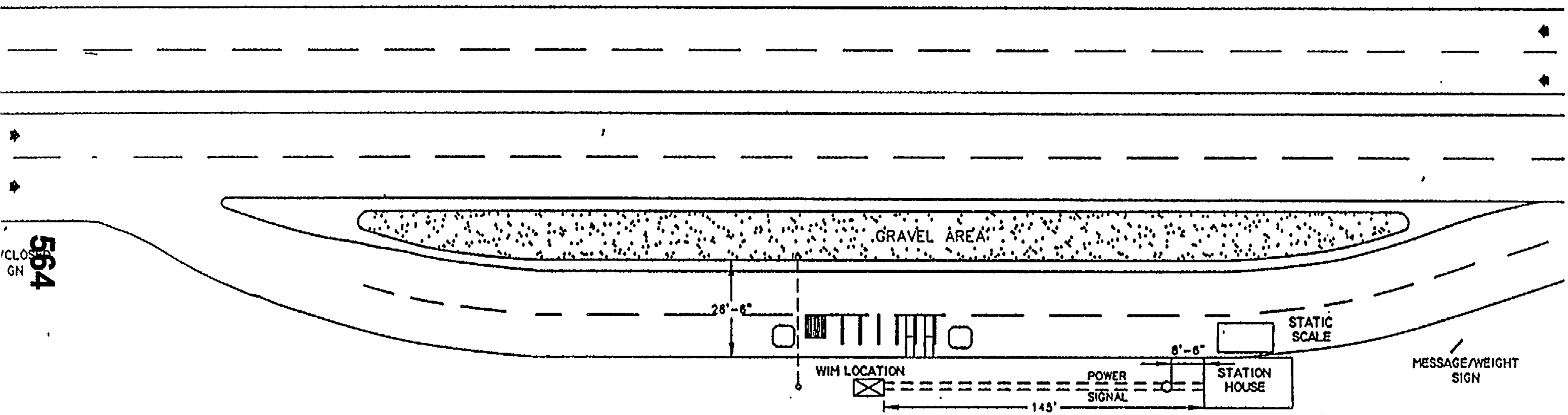
INVERSE REGRESSION PARAMETER ESTIMATES
(Dependent Variable = WIM Weight)

Axle/Test Date	Intercept	Static Weight	Speed	R^2	SEE **
Steering Axle					
November l&2 (D-S)	1.77	.83	.04	.72	.39
(t-value)	(2.61)*	(13.35)*	(2.15)*		
November 3&4 (D-D)	-.73	1.06	.02	.852	.38
	(-1.19)	(18.38)*	(1.23)		
March 20 (D-S)	.42	.95	.0l	.75	.35
	(.33)	(8.53)*	(.49)		
Drive Axle					
November l&2 (D-S)	-.37	1.01	.03	.85	1.10
	(-.23)	(20.14)”	(.69)		
November 3&4 (D-D)	-.1l	1.00	.02	.999	.43
	(-.5 1)	(144.25)*	(.82)		
March 20 (D-S)	-.42	1.00	.08	.98	.55
	(-.41)	(31.06)*	(2.08)*		
Trailing Axle					
November l&2 (D-S)	1.36	.96	-.0l	.97	.44
	(2.16)*	(47.92)*	(.29)		
November 3&4 (D-D)	-.41	1.01	.08	.996	.88
	(-1.16)	(90.21)*	(2.09)*		
March 20 (D-S)	.94	.97	-.03	.99	.40
	(1.94)	(62.72)*	(1.12)		
Gross Vehicle Weight					
November l&2 (D-S)	2.42	.96	.07	.93	1.29
	(1.03)	(30.38)*	(1.11)		
November 3&4 (D-D)	-.97	1.01	.14	.999	1.02
	(-1.88)	(146.58)*	(3.35)*		
March 20 (D-S)	.45	.99	.06	.99	.83
	(.30)	(48.19)*	(1.02)		

* Significant at the .05 level.
* * Standard Error of the Estimate for regression equation.

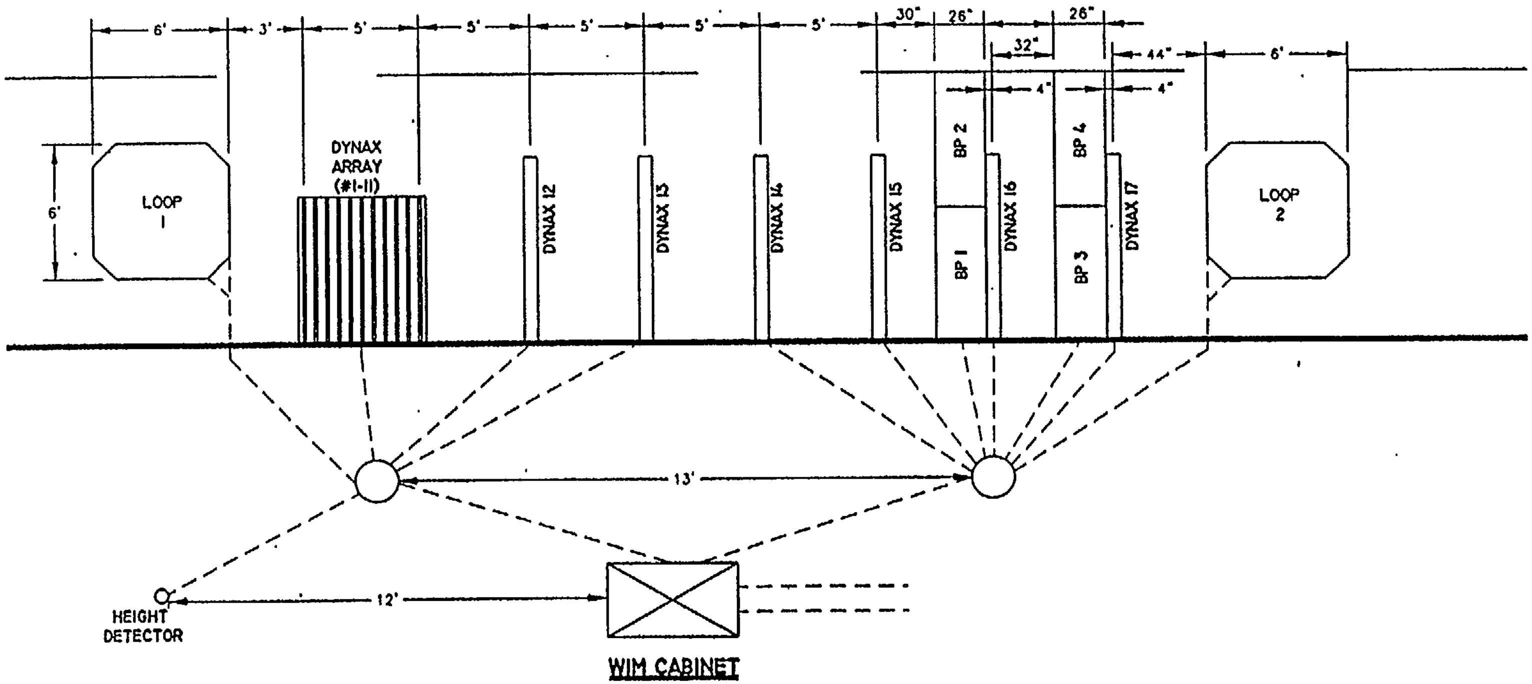
FIGURE 1: SWIM SITE LAYOUT

Wyeth Weigh Station; I-84 Westbound



565

FIGURE 2: SWIM SYSTEM CONFIGURATION



MEASURES OF EFFECTIVENESS
(M.O.E.'S OF TRUCK WEIGHT ENFORCEMENT)

Fred R. Hanscom
Transportation Research Corporation

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

MEASURES OF EFFECTIVENESS (M.0.E.s) OF TRUCK WEIGHT ENFORCEMENT

by
Fred R. Hanscom, P.E.
Director, Transportation Research Corporation

BACKGROUND

Truck weight enforcement programs were initiated to limit the amount of damage to the infrastructure and to promote public safety. The level and value of truck weight activities are currently gauged by statistical measures such as the number of trucks weighed, the number of violators detected, and the amount of fines collected. Continuing to use such statistical measures may demonstrate level of effort, but will not indicate ***what is actually being accomplished as a*** result ***of that effort.*** A true measure of effectiveness of any truck weight enforcement activity would indicate what, if any, real effect is being achieved.

NCHRP Project 20-34 is in the process of developing and validating measures of effectiveness (M.O.E. s) of truck weight enforcement activities. The use of such M. O.E. s are expected to provide a procedure for realistically quantifying what is accomplished by weigh enforcement activities.

RESEARCH PROJECT OBJECTIVES

The objectives of NCHRP Project 20-34 are as follows:

1. To develop and validate truck weight enforcement measures of effectiveness (i.e., indicating what is accomplished as the result of enforcement activity).

2. To document fmdings in a user guide formatted to explain appropriate data collection methods, how to apply these methods, and how to interpret their results.

h3ETHODOLOGICA.L OVERVIEW

Consideration is first given to truck weight enforcement goals and procedures. Candidate M.0.E.s were then developed, evaluated, and ranked, based on the consensus of an expert panel. Ongoing field activity is underway, i.e., the comparison of collected data under actual enforcement conditions, in order to determine the validity of the M.0.E.s This field evaluation has not been completed and, therefore, is not reported in this paper. Finally, a software tool whereby highway agencies will apply the M.O.E. procedure to access truck weight enforcement effectiveness is described at the end of this paper.

Truck Weight Enforcement Goals and Procedures

Truck weight is enforced for two reasons: (1) to avoid excess damage to the roadway and structures caused by overweight loads, and (2) to assist the safe operation of trucks and other vehicles in the vicinity of trucks.

Goals of state enforcement agencies which operate truck weight enforcement activities are the following:

1. to deter truck operation in an overweight condition and/or operating with inappropriate axle-spacings,
2. to control pavement and bridge damage from overweight trucks,
3. to protect the public from safety risks associated with overweight trucks, and
4. to protect law-abiding truck operators from illegal competition.

Truck Weight Measure of Effectiveness (M. 0. E.)

Measures of Effectiveness (M.O.E. s) of a weight enforcement activity or program are defined as:

> Determinable quantities of what is achieved as the result of truck weight enforcement activity or program. Their application also quantifies the contribution that activity makes toward achievement of one or more of the enforcement goals.

Historically, measures of effectiveness have used indices such as the number of trucks weighed, number of overweight trucks pulled off the road, size of the overloads detected, amount of fines imposed, number of prosecutions, trends with time, and compliance ratios. In many cases, these indices do not express the effectiveness in meaningful terms that relate to overall goals, e.g., the number of overweight trucks detected does not relate to preservation, punishment or prevention.

DEVELOPMENT OF CANDIDATE MEASURES

The designation of candidate measures must address one central question: what needs to be measured (and how) in order to reliably determine overweight violations?

Candidate measures were identified through independent contributions of NCHRP Project 20-34 team members. These individuals are as follows: (1) the project Principal Investigator who based his assessment on his review of the literature, 23 years of traffic operational research experience which includes the conduct of numerous truck operational safety studies and addition to WIM reliability determinations; (2) UMTRI's Thomas D. Gillespie, Ph.D. who has 28 years of highway safety research experience emphasizing heavy vehicle characteristics and their effects on pavements; and (2) Benjamin H. Cottrell who has 15 years of experience in traffic engineering research including the development of a truck weight sampling plan using ***the Traffic Monitoring Guide.***

The development of candidate measures first considered the primary truck weight objective, i.e., to deter truck operation in an overweight condition. Second, the question of candidate M.O.E. development then addressed manpower and equipment resources available to enforcement and highway agencies. Finally, a list of potential measures was based on current and foreseeable data-gathering capabilities, given likely agency resources, and what measures are most efficacious given these resources.

Candidate M. 0.E. Evaluation and Ranking Procedures

The evaluation of derived candidate M.0.E.s was conducted via application of the following criteria:

A. Practicality of M. O.E. application Of primary importance is state agency data collection ability, efficiency, cost requirements, and ease of measurement as applied to each candidate M.O.E. For example, high priority was given to M.0.E.s which can be readily derived from existing data sources, e.g., WIM devices, shipping records.

B. Reliability of candidate M.O.E. Reliability refers to measurement precision, e.g., confidence that repeated measurement will yield consistent results. A reliable M.O.E. is one which correctly represents the true distribution of weights, classification, percentage of overweight trucks, percent of bridge formula non-compliance, etc. within the study region. This concept is of paramount importance in assessing the performance of technologies applied in truck weight measurement and classification activity.

C. Support state-wide random sampling. Traffic monitoring in the vicinity of weigh stations (including alternate truck routes) presents a limited perspective of overweight hauling practices. Therefore, monitoring procedures, designed to achieve state-wide random weight sampling and consistent with Safety and Pavement Management System technologies, was designated to gather M. 0.E. data. It was therefore necessary that designated M.O.E. s be comprised of variables which can be derived from these systems.

D. Absence of bias with regard to enforcement/monitoring procedure. It is imperative that the applied M. 0. E. data-gathering procedure not be biased with regard to either a weight enforcement program or a particular traffic monitoring method. Applied M.O.E. s must be generally sensitive to prevailing truck characteristics regardless of enforcement activity. Furthermore, care must be taken to ensure that overweight truck presence is not influenced by specific traffic-monitoring or weight-enforcement installations.

Therefore, M. 0.E. selection criteria considered the susceptibility of candidate M. 0. E.s to potential bias.

E. M.O.E. compatibility with state agency data collection methods. The designated procedure for states' measurement of enforcement effectiveness must be achieved within the state's data collection capabilities. Therefore, emphasis was placed on emerging technologies, i.e., Safety and Pavement Management Systems, in order that the developed M. 0. E. assessment procedure have future applicability. SHRP WIM installations were considered a primary data source, therefore variables collected by this system were given high priority.

F. Sensitivity to Infrastructure Damage One objective of truck weight enforcement is to control pavement and bridge damage from overweight trucks. Certain truck loading conditions, e.g., excessive axle-weight as opposed to excessive tandem-weight are more conducive to pavement damage. This consideration is important with regard to assessing the merits of candidate M.0.E.s.

G. Applicability to future technology The use of Pavement Management Systems, Bridge Management Systems, Maintenance Management Systems, and Safety Management Systems present an emerging technology in many states. An objective of NCHRP Project 20-34 is to enable highway agencies to efficiently assess the effectiveness of truck weight enforcement programs. Therefore, designated M . 0 . E. s included those measures which can be determined via use of these systems.

Each candidate M.O.E. was evaluated on the basis of each of the above criteria. In order to rank candidate M.O.E.s, a numerical rating scheme was applied in the evaluation process. As each criterion was applied to each candidate M.O.E., the suitability of the M.0. E. was assessed on the basis of each criterion using the numerical scale indicated in Exhibit III-1 on the next page.

Numerical Score	Assessment of Criterion
0	No value whatever
1	Insignificant worth
2	Some utility
3	Moderately useful
4	Significantly valuable
5	Superior merit

Exhibit 1. Applied Numerical Rating Scheme
to Evaluate Candidate Measures-of-Effectiveness

Using the above scale, the average rating across **the** six criteria was assigned to each M. 0.E. to determine the final ranking.

CANDIDATE M.0.E.s

The development of this M.O.E. set considered both the capabilities of potential data sources, e.g., commercially available WIM equipment and SHRP LTPP data output, along with the functional requirements of M. O.E.s, e.g., the need to apprise enforcement agencies of target truck characteristics.

M.0.E.s are derived from WIM. system output. Commercially available equipment from commercial manufactures directly supports most of the developed M. 0. E. s. All of the following seven candidate M.0.E.s can be derived from software programming of output from this equipment.

I. ***Proportion of Overweight Trucks in Sample*** - The fraction (or percentage) of the truck sample exceeding the applicable weight limit based on any of the parameters listed below, based on a statistically valid sample size.

a. Gross Vehicle Weight
b. Individual Axle Weight
c. Individual Axle-grouping Weight
d. Truck Type(FHWA 13-classification scheme)

The M.O.E. significance of each of the above parameters is as follows. The impact of trucks on pavement deterioration varies according as to how the stress is applied. Therefore, gross truck weights, as well weights exerted by individual axles and axle-groupings, are important. Furthermore, whether a particular classification of truck is more (or less) prone to overweight violations may be of assistance to enforcement agencies due to visual characteristics associated with specific truck types.

This M.O.E. was evaluated in terms of receiving a ranking (using the scheme given in Exhibit 1) for each of the previously discussed M.O.E. evaluation criteria. Results of the ranking procedure are discussed for each criterion as follows.

*A. Practicality **of** M. 0. E. Application*
Ranking: 5 Superior. Commercially available WIM equipment generates data for easy computation of this measure.

*B. Reliability **of** Candidate M.O. E*
Ranking: 4 Significantly valuable. Commercially available equipment is becoming increasingly reliable.

C. Supports State-wide Random Sampling
Ranking: 4 Significantly valuable. Commercially available WIM equipment is commonly applied in state-wide sampling procedures.

*D. Absence **of** Bias with Regard to Enforcement/Monitoring Procedures*
Ranking: 3 Useful. Subject to the same bias as any weighing operation.

E. M. 0. E. Compatibility with State Agency Data Collection Methods
Ranking: 4 Significantly valuable. This measure is compatible with emerging technology.

F. Sensitivity to Infrastructure Damage
Ranking: 2 Some Utility. This measure may be associated with pavement/bridge damage.

G. Applicability to Future Technology
Ranking: 5 Superior. This measure is highly amenable to emerging technology.

2. ***Severity of Overweight Violation*** - The extent to which collected data on any of the parameters listed below exceeds the allowable legal weight limit, expressed as a percentage exceeding the allowable legal weight, grouped by range to indicate 5, 10, 20, 30, and 40+ percent overweight).

a. Gross Vehicle Weight
b. Individual Axle Weight
c. Individual Axle-grouping Weight
d. Truck Type(FHWA 13-classification scheme)

This M.O.E. was evaluated in terms of receiving a ranking (using the scheme given in Exhibit 1) for each of the previously discussed M.O.E. evaluation criteria. Results of the ranking procedure are discussed for each criterion as follows.

*A. Practicality **of** M. 0. E. Application*
Ranking: 5 Superior. Commercially available WIM equipment generates data for easy computation of this measure.

*B. Reliability **of** Candidate M. 0. E*
Ranking: 4 Useful. Commercial equipment is becoming increasingly reliable, yet this M.O.E. demands precision.

C. Supports State-wide Random Sampling
Ranking: 4 Significantly valuable; Commercial WIM equipment applied in state-wide sampling procedure, yet this M.O. E. demands precision.

D. Absence of Bias with Regard to Enforcement/Monitoring Procedures
Ranking: 3 Useful. Subject to the same bias as any weighing operation.

E. M. 0. E. Compatibility with State Agency Data Collection Methods
Ranking: 4 Significantly valuable. This measure is compatible with emerging technology .

F. Sensitivity to Infrastructure Damage
Ranking: 5 Superior. Severity of overweight violations is highly sensitive to pavement/bridge damage.

G. Applicability to Future Technology
Ranking: 5 Superior. This measure is highly amenable to emerging technoIogy.

3. *Distribution* of *Overweight Trucks in Sample* - While the two M. O.E. s noted above are essential to describe the overweight truck problem to enforcement and highway agencies, simple distributions, e.g., the numbers of overweight trucks and associated excess loadings over legal limits, are necessary for dispatching enforcement personnel to locations in which enforcement operations can be conducted in the most cost-effective manner.

This M.O.E. was evaluated in terms of receiving a ranking (using the scheme given in Exhibit 1) for each of the previously discussed M.O.E. evaluation criteria. Results of the ranking procedure are discussed for each criterion as follows.

A. Practicality of M. 0. E. Application
Ranking: 5 Superior. Commercially available WIM equipment generates data for easy computation of this measure.

B. Reliability of Candidate M. 0. E
Ranking: 4 Significantly valuable. Commercially available equipment is becoming increasingly reliable.

C. Supports State-wide Random Sampling
Ranking: 5 Superior. Commercially available WIM equipment is commonly applied in state-wide sampling procedures.

*D. Absence **of** Bias with Regard to Enforcement/Monitoring Procedures*
Ranking: 3 Useful. Subject to the same bias as any weighing operation.

E. M. 0. E. Compatibility with State Agency Data Collection Methods
Ranking: 4 Significantly valuable. This measure is compatible with emerging technology.

F. Sensitivity to Infrastructure Damage
Ranking: 2 Some Utility. The proportion of overweight trucks is marginally sensitive to pavement/bridge damage.

G. Applicability to Future Technology
Ranking: 5 Superior. This measure is highly amenable to emerging technology.

4. ***Bridge Formula Violations*** - Axle-spacing information, in combination with individual-axle and axle-grouping weights, applied to spacing criteria specified by the applicable Bridge Formula.

This M.O.E. was evaluated in terms of receiving a ranking (using the scheme given in Exhibit 1) for each of the previously discussed M.O.E. evaluation criteria. Results of the ranking procedure are discussed for each criterion as follows.

*A. Practicality **of** M. 0. E. Application*
Ranking: 4 Significantly valuable. Much commercially available WIM equipment generates data for easy computation of this measure.

*B. Reliability **of** Candidate M. 0.E*
Ranking: 4 Significantly valuable. Commercially available equipment is becoming increasingly reliable for axle-spacing data.

C. Supports State-wide Random Sampling
Ranking: 4 Significantly valuable. Commercial WIM equipment applied in state-wide sampling procedure, yet this M . 0 . E. demands measurement specificity.

*D. Absence **of** Bias with Regard to Enforcement/Monitoring Procedures*
Ranking: 3 Useful. Subject to the same bias as any weighing operation.

E. M. 0. E. Compatibility with State Agency Data Collection Methods
Ranking: 4 Significantly valuable. This measure is compatible with emerging technology.

F. Sensitivity to Infrastructure Damage
Ranking: 5 Superior. By definition, the Bridge Formula is sensitive to pavement/bridge damage.

G. Applicability to Future Technology
Ranking: 5 Superior. This measure is highly amenable to emerging technology.

5. ***Equivalent Single Axle Load (ESAL)*** - This measure is a predictor of pavement consumption caused by an axle or group of axles, based on the loaded weight of the axle group, as a function of pavemement consumption due to a single axle weighing 18,000 pounds. This M. O.E. provides a direct measure of pavement wear exhibited by a single truck. The usefulness of this measure derives from the fact that pavement design life is determined in terms of ESALs.

This M.O.E. was evaluated in terms of receiving a ranking (using the scheme given in Exhibit 1) for each of the previously discussed M.O.E. evaluation criteria. Results of the ranking procedure are discussed for each criterion as follows.

A. Practicality of M.O.E. Application
Ranking: 5 Superior. Commercially available WIM equipment generates data for easy computation of this measure.

B. Reliability ***of*** *Candidate M. 0. E*
Ranking: 4 Significantly valuable. Commercially available equipment is becoming increasingly reliable.

C. Supports State-wide Random Sampling
Ranking: 5 Significantly valuable. Commercially available WIM equipment is commonly applied in state-wide sampling procedures.

D. Absence ***of*** *Bias with Regard to Enforcement/Monitoring Procedures*
Ranking: 3 Useful. Subject to the same bias as any weighing operation.

E. M. 0. E. Compatibility with State Agency Data Collection Methods
Ranking: 4 Significantly valuable. This measure is compatible with emerging technology.

F. Sensitivity to Infrastructure Damage
Ranking: 5 This measure is highly sensitive to pavement/bridge damage.

G. Applicability to Future Technology
Ranking: 5 Superior. This measure is highly amenable to emerging technology .

6. ***Excess ESALs*** The definition of excess ESALs as determined by the Wisconsin study (Stein, 1988) is “excess ESALs equal the sum of the total ESALs attributable to the legal portion of the individual single or tandem axle group.” The significance of application of this M.O.E.is that forty percent of observed ESALs on Wisconsin’s Rural Interstate System were attributable to excess ESALs. This M.O.E. is to be gathered by vehicle class.

This M.O.E. was evaluated in terms of receiving a ranking (using the scheme given in Exhibit 1) for each of the previously discussed M.O.E. evaluation criteria. Results of the ranking procedure are discussed for each criterion as follows.

*A. Practicality **of** M. 0. E. Application*
Ranking: 5 Superior. Commercially available WIM equipment generates data for easy computation of this measure.

*B. Reliability **of** Candidate M.0.E*
Ranking: 4 Useful. Commercial equipment is becoming increasingly reliable, yet this M.O.E. demands precision.

C. Supports State-wide Random Sampling
Ranking: 4 Significantly valuable. Commercial WIM equipment applied in state-wide sampling procedure, yet this M.O.E. demands precision.

D. Absence of Bias with Regard to Enforcement/Monitoring Procedures
Ranking: 3 Useful. Subject to the same bias as any weighing operation.

E. M.O.E. Compatibility with State Agency Data Collection Methods
Ranking: 4 Significantly valuable. This measure is compatible with emerging technology.

F. Sensitivity to Infrastructure Damage
Ranking: 5 This measure is highly sensitive to pavement/bridge damage.

G. Applicability to Future Technology
Ranking: 5 Superior. This measure is highly amenable to emerging technology.

7. ***Projected Distance Traveled by Overweight Truck*** - Pavement wear is obviously more severe for overweight trucks traveling longer distances. Application of WIM surveillance devices on corridors of known truck travel patterns will enable enforcement agencies to prioritize enforcement operation in a manner to minimize regional pavement wear.

This M.O. E. was evaluated in terms of receiving a ranking (using the scheme given in Exhibit 1) for each of. the previously discussed M.O.E. evaluation criteria. Results of the ranking procedure are discussed for each criterion as follows.

*A. Practicality **of** M. 0. E. Application*
Ranking: 3 Useful. Commercially available WEM equipment generates data useful for computation, however manually generated travel distance factor must be applied.

*B. Reliability **of** Candidate M. O.E*

Ranking: 2 Some Utility. Application of travel distance factor comprises a reliability threat, e.g. not possible to determine travel distance for entire truck sample; estimated from planning data.

C. Supports State-wide Random Sampling

Ranking: 2 Some Utility. Estimation requirement presents problem.

*D. Absence **of** Bias with Regard to Enforcement/Monitoring Procedures*

Ranking: 2 Some Utility. Subject to more bias than other weighing operations.

E. M. 0. E. Compatibility with State Agency Data Collection Methods

Ranking: 2 Some Utility. This measure requires integration of WIM technology and travel estimation techniques, a process which produces a barrier to its application.

F. Sensitivity to Infrastructure Damage

Ranking: 2 Some Utility. Distance travelled has secondary impact on pavement/bridge damage.

G. Applicability to Future Technology

Ranking: 2 Some Utility; Applicable emerging technology, e.g., AVI, is slow to materialize and may induce bias with regard to this measure.

8. Distribution of Above Measures by Day-of- Week, Hour-of-Day The Issue of whether to collect temporal distributions of the above M.0.E.s was based on the ability to assist enforcement agencies with manpower-allocation decisions to facilitate the optimization of resources.

This M. 0.E. collection strategy was evaluated in terms of receiving a ranking (using the scheme given in Exhibit 1) for each of the previously discussed M.O.E. evaluation criteria. Results of the ranking procedure are discussed for each criterion as follows.

*A. Practicality **of** M.O. E. Application*

Ranking: 4 Significantly valuable. Most applicable data collection methods, e.g., automated devices, rely on temporal observations.

*B. Reliability **of** Candidate M. 0.E*

Ranking: 4 Significantly valuable. Commercially available equipment has proven reliable in terms of temporally recording data.

C. Supports State-wide Random Sampling
Ranking: 4 Significantly valuable. Random sampling with commercially available WIM equipment is readily applied in state-wide sampling procedures.

D. Absence ***of*** *Bias with Regard to Enforcement/Monitoring Procedures*
Ranking: 3 Useful. Temporal observation is not expected to complicate any bias problem.

E. M. 0. E. Compatibility with State Agency Data Collection Methods
Ranking: 5 Superior; Commercially available WIM equipment readily generates data by day-of-week and hour-of-day.

F. Sensitivity to Infrastructure Damage
Ranking: 2 Some Utility. Pavement/bridge damage is marginally affected by temporally-related usage.

G. Applicability to Future Technology
Ranking: 5 Superior. This measurement strategy is highly amenable to emerging technology.

The six M.O.E. evaluation criteria were defined earlier in this paper. Applied criteria were as follows.

A. Practicality of Application
B. Measurement Reliability
C. Supports State-wide Random Sampling
D. Absence of Enforcement-induced Bias
E. Data Collection Methods Capability
F. Sensitivity to Infrastructure Damage
G. Applicability to Future Technology

Ranking of M.0.E.s was achieved by assessing the applicability each M.O.E. to truck weight enforcement procedure via assigning a point value based on each criterion. Points were assigned to assess the utility of each M.O.E. as follows.

No points	No value whatever
1 point	Insignificant worth
2 points	Some utility
3 points	Moderately useful
4 points	Significantly valuable
5 points	Superior merit

The average rating across the six criteria was assigned to each M.O.E. to determine the candidate M.O.E.'s final ranking.

Numerical results of the applied rating procedure and M.O.E. rankings in each category are shown in Exhibit 2. The list of measures shown in the exhibit comprises proposed M.O.E.s for further field evaluation.

M.O.E.s	Practicality of Application	Measurement Reliability	Supports State-wide Random Sampling	Absence of Enforcement-induced Bias	Data Collection Methods Capability	Sensitivity to Infrastructure Damage	Applicability to Future Technology	TOTAL SCORE	FINAL RANKING
Excess ESALs	5	4	4	3	4	5	5	30	1
Severity of Overweight Violation	5	4	4	3	4	5	5	30	2
Equivalent Single Axle Load (ESAL)	5	4	4	3	4	4	5	29	3
Bridge Formula Violation	4	4	4	3	4	5	5	29	4
Proportion of Overweight Trucks	5	4	4	3	4	2	5	27	5
Distribution of Violation by day-of-week, hour-of-day	4	4	4	3	5	2	5	27	6
Projected Distance Travelled by Violator	3	2	2	2	2	2	4	17	7

EVALUATION CRITERIA

Exhibit 2. Ranking of Candidate M.O.E.s

USER GUIDELINES

The principal objective of NCHRP Project 20-34 is to generate user guidelines for application of validated measures. Developed guidelines will provide operational M.O.E. definitions, consisting of non-ambiguous explanations of appropriate traffic flow and truck-descriptive parameters.

The guideline format will include a software package whereby data input is accepted for applicable observation locations. The software package will compute, summarize, and compare M.O.E. values for user-defined enforcement conditions.

Truck Weight Enforcement Evaluation Software Tool

A software package is under development to assist highway agencies in determining the effectiveness of truck weight enforcement programs. The software reads WIM data and applies specific M.O.E.s which are validated in the ongoing research effort. The title of the software is ***Truck Weight Enforcement Evaluation Tool (TWEET)***. A major feature of this program is the extensive use of "Help" screens which afford users with detailed explanations of the M.O.E. evaluation procedure and its application.

The software is designed to run on any version of Windows. The program's operating speed will depend upon a number of factors, e.g., vehicle sample size and operating characteristics (e.g., the megahertz rating) of host computers. Using a 486 desk computer, a single run can process M.O.E. computations on up to 32,000 trucks in approximately three minutes.

A summary of the software's operation is as follows.

Select Units The user selects the system of units of measure, i.e., English (feet, pounds) or Metric (meters, kilograms) to the applied in the analysis. The software defaults to English.

Set Legal Limits The user designates legal gross, single-axle, and tandem weight limits. The software defaults to currently accepted Federal Highway Administration *Traffic Monitoring Guide* limits.

Designate Data Format The user specifies how data files are formatted in the WIM data base. The software defaults to the current FHWA Card-7 format.

Truck Classification Scheme The user can designate any truck classification scheme. The software defaults to the current FHWA 13-type Classification Scheme.

Designate Enforcement Condition The program is designed to compare two enforcement conditions, e.g., a baseline with a given enforcement strategy. The user inputs enforcement strategy descriptors associated with given data samples.

Designate M.0.E.s The user chooses truck weight enforcement M.0.E.s of interest. The available M. 0. E. selection includes: (1) compliance percentage, e. g . , includes Bridge Formula; (2) severity of violations, i.e., gross, axle, and tandem weights; (3) violations by day-of-week and time-of-day; and (4) ESAL (Equivalent Single Axle Loading) values. The user is also given a choice of whether to conduct an analysis of enforcement effects on pavement life.

Input Pavement Characteristics If the user elects to conduct a pavement-life analysis, the following data are input.

A. Rigid (Portland Cement Concrete) Pavement
   1. Layer thickness
   2. Modulus of Rupture (defaults to common values)

B. Flexible (Asphalt) Pavement
   1. High- or Low- stability asphalt
   2. Base and sub-base thicknesses
   3. Strength Coefficients (defaults to common values)

The software will determine pavement design life in ESALs, given the parameters noted above.

<u>Displav Results</u> The software first displays summary information, i.e., enforcement condition, highway type, total vehicle, and truck sample.

The following M.O.E. calculation results are displayed for each study condition:

1. Percentages of trucks in the sample which violate gross, axle, tandem, and Bridge Formula limits.

2. Violations by truck classification (number, percentage, and severity).

3. Violations by day-of-week and time-of-day.

4. Average ESAL calculations using the FHWA *Traffic Monitoring Guide* procedure according to the number of axles.

The software then makes statistical comparisons between study conditions. Calculated differences will demonstrate enforcement effects on M.O. E.s and pavement life.

ACKNOWLEDGEMENT

The research reported in this paper was conducted under sponsorship of the National Cooperative Highway Research Program) Project 20-34.

REFERENCE

Stein, P. P., et al *The Overweight Truck in Wisconsin: Its Impact on Highway Design, Maintenance, and Enforcement Planning,* Wisconsin Department of Transportation, Madison, WI, December, 1988