SECOND NATIONAL *WEIGH-IN-MOTION* CONFERENCE

VOLUME TWO

ATLANTA, GEORGIA

1985

conducted by the

Georgia Department of Transportation

in corporation with the

Federal Highway Administration

SECOND NATIONAL CONFERENCE
ON
WEIGH-IN-MOTION TECHNOLOGY & APPLICATIONS

Atlanta, Georgia
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VOLUME TWO

Conference Conducted by the
Georgia Department of Transportation

Conference Coordinator:
M. Ken Copeland, Chief
Permits & Enforcement Office, Georgia DOT

in cooperation with the
U. S. Department of Transportation
Federal Highway Administration

and sponsored by the
Rural Transportation Assistance Program

SECOND NATIONAL CONFERENCE
ON
WEIGH-IN-MOTION TECHNOLOGY & APPLICATIONS

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A Status Report on:

"Federal Highway Administration
Weigh-in-Motion Research Program
Past -- Present -- Future"

Presented at:
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on Weigh-in-Motion
Technology and Applications

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Federal Highway Administration
Weigh-in-Motion Research Program
Past -- Present -- Future

by

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INTRODUCTION

For more than three decades, researchers around the world have searched for an efficient means to accurately weigh and classify vehicles as they travel down the highway. This preoccupation with in-motion weighing technology has been demonstrated in other transportation modes as well. In point of fact, similar techniques have been investigated to weigh rolling railway cars loaded with coal and other bulk commodities, to monitor and record heavy hauling operations at construction or mining sites, and to document air and ground freight movements. A major portion of the research effort expended through the years has been devoted to development of weight sensors suitable for highway use. The weighing transducers which have been investigated may be classified into five basic categories: (1) large massive platforms, (2) small lightweight platforms or plates, (3) surface mats or pads, (4) embedded cables, (5) existing bridge spans.

In the early 1950's, the Bureau of Public Roads (now the Federal Highway Administration) initiated weigh-in-motion research using a massive concrete platform installed in a highway near Washington, D.C. The platform was installed in the pavement and supported by strain-gaged columns at each corner. This technique was pursued by several northern States until the 1960's when it was abandoned. At about the same time as the BPR work, researchers in Mississippi and Texas began investigating use of steel platforms for in-motion weighing. These investigations have continued in the

United States as well as a number of other countries including England, West Germany, Canada, and South Africa. The platforms typically consist of rigid steel plates(s) supported by 1, 2, or 4 load cells mounted in a load frame recessed into the pavement. Research efforts have led to development of the Radian and Streeter-Richardson systems in the U.S., the Weighwrite system in England, and the IRD system in Canada. Two slightly different approaches were developed in West Germany. One, the PAT system, uses bending of the steel plate and strain gages thus requiring a shallower pit in the pavement. The other is a hydraulic method with oil sealed between two steel plates. Another technique for sensing loads involves the use of capacitance-type pads on the surface of the pavement. This research began in South Africa in the late 50's and has resulted in the Viatec System. A similar technique is currently being researched in the U.S. by Golden River. Both systems employ an elastomeric pad and traffic loops to weigh and classify vehicles. The potential of load or pressure sensitive cables for sensing and weighing axles is currently receiving much attention in the U.S., England, and Germany. These piezo-cables are embedded in pavement slots and offer considerable potential especially as a permanent axle sensor for classification purposes. The final technique for in-motion weighing utilizes existing bridges as the weight transducer. In this case, the bridge is instrumented with portable strain transducers and no other site preparation is required. Research on the bridge concept has taken place primarily in the U.S. over the past 10 years.

Since the early 1970's, the Federal Highway Administration (FHWA) has played a major role in the development of the bridge weigh-in-motion concept. This WIM research program will be reviewed in what follows. Completed research projects will be summarized, the status of ongoing studies will be presented, and plans for the future outlined. Related activities will also be addressed for completeness.

PAST RESEARCH

For many years, FHWA has sponsored as well as conducted extensive research addressing the design, response, and behavior of highway bridge structures. FHWA has also monitored and coordinated bridge research conducted by other researchers and in other countries. Field and laboratory testing of bridges and bridge components has been a major part of this program. Such investigations have provided considerable insight into the response of structures to loads. In the process of conducting these studies, testing techniques have been refined and sophisticated instrumentation systems have been developed.

In the early 1970's, a critical need for more complete information on the truck population was becoming apparent. In the past, bridge tests were primarily conducted to evaluate structural response to both controlled as well as random traffic loadings. Why not turn this approach around and use a calibrated bridge response to determine loads? To answer this question, FHWA initiated three short term research projects in 1974 to investigate the feasibility of utilizing existing bridge structures to weigh trucks in motion.

FCP 35F4-052 Feasibility of Utilizing Highway Bridges to Weigh Vehicles in Motion (exotic sensors on deck)

Contractor: Integrated Systems, Inc. Start Date: 6-12-74
Investigator: J. W. Fothergill Duration: 6 months

The objective of this study was to investigate the feasibility of using newly developed sensor technology on bridges for weighing trucks in motion. To accomplish this end, the contractor was required to conduct a literature search aimed at identifying new and innovative sensors resulting from defense, space, or other R&D programs. Two basic forms of load sensors were identified: direct-contact form which would sense directly from the wheel contact; and indirect forms which would measure a resultant bridge response.

A total of nine direct-contact sensors were examined including megneto-restrictive, peizoelectric, pneumatic, and capacitive types. Of the indirect sensors, only seismic were investigated in depth. Supporting sensors for measuring associated traffic characteristics were also considered and included optical, acoustic, video, laser, radar, ultrasonic, induction, and magnetic devices. This research resulted in comprehensive recommendations which define instrumentation requirements, system configurations, and data reduction logic. The research conclusions emphasize the need for careful test and evaluation of proposed sensors.

FCP 35F4-062 Feasibility of Utilizing Highway Bridges to Weigh Vehicles in Motion (strain gages at bridge bearings)

Contractor: ASE, Inc. Start Date: 6-12-74
Investigator: H. J. Siegel Duration: 6 months

The objective of this study was to investigate the feasibility of using strain gages innovatively on bridges for weighing trucks in motion. In this case, the contractor was required to review literature while focusing on bridge/vehicle interaction theory and previous bridge testing experience. The contractor gave special consideration to bridge and vehicle dynamics and identified parameters important to the weighing application. Bridge testing techniques were evaluated to determine the optimum locations for strain gage sensors. It was determined that strain gages located at the bridge bearings would provide the greatest potential for weighing axles. Inductive loops and pneumatic tubes were considered for measuring the traffic properties. The research concluded with complete recommendations regarding instrumentation layout, data acquisition and processing logic, system block diagrams, and hardware requirements.

FCP 35F4-072 Feasibility of Utilizing Highway Bridges to Weigh Vehicles in Motion (strain gages on girders)

Contractor: Pile Dynamics, Inc. Start Date: 6-12-74
Investigator: G. Goble, F. Moses Duration: 6 months

The objective of this project was to investigate the feasibility of using conventional bridge testing techniques, with strain gages mounted on the bridge girders, for weighing vehicles in motion. Literature documenting previous weigh-in-motion research and bridge load history studies was reviewed. Methods for measuring bridge bending moments and using these measurements to predict vehicle axle loads were developed. As was the case with the other feasibility studies, this research concluded with recommendations defining a proposed system configuration.

Upon completion of the three feasibility studies, FHWA initiated a comprehensive review of the findings. Each proposed concept and instrumentation configuration was examined to access its complexity, potential for success, and prototyping costs. Although each idea had its own merits, a decision was made to pursue the approach recommended by Pile Dynamics, Inc. While this decision was being made, a related research effort was initiated at Lehigh University.

FCP 45F4-022 Use of Bartonsville Bridge to Weigh Trucks in Motion

Contractor: Lehigh University | Start Date: 10-7-75
Investigator: J. H. Daniels | Duration: 20 months

This Pennsylvania HP&R study had three main objectives: (1) to design two instrumentation setups which make use of the Bartonsville Bridge on I-80 for weighing trucks, (2) to field test the systems for functionality, (3) to use the systems for collecting data useful in evaluating the extent of overloads on I-80. Data acquisition was intended to be accomplished in a manual fashion. One system consisted of strain gages installed on all girders at two cross-sections of a simple span while the second employed deflection gages at the same locations. Since sensor signals were summed, each system had a single output which was recorded on chart paper and later processed by hand. Although this system was not automated, it did clearly demonstrate the potential for using bridges to weigh trucks.

FCP 35F4-012 Weigh-in-Motion Instrumentation

Contractor: Case Western Reserve University — Start Date: 5-12-76
Investigator: F. Moses — Duration: 24 months

The objective of this research project was to design, fabricate, test, and deliver a prototype instrumentation system which is capable of monitoring heavy vehicle dynamic forces and static weights as well as traffic characteristics during the normal passage across a structural steel and concrete slab highway bridge. The instrumentation system developed was to be automated and capable of continuously monitoring the following: truck type, arrival time, headway distributions, vehicle velocities, bridge lane occupancy, vehicle gross weight, axle weights, axle spacing, number of axles/vehicle, and dynamic loads. The system resulting from this research effort consisted of a Varian V77-200 minicomputer for system control, a nine-track digital tape drive for data storage, a teletype console for user interface, custom self-balancing signal conditioning for strain gage input, custom circuitry for tape switch and button box signals. Strain gages had to be bonded to the bridge girders at midspan and three tape switches (two for vehicle velocity and axle spacing and one for starting strain sampling) had to be installed in the traffic lane. An observer was required to count axles on the vehicle and initiate data acquisition by entering the count with a button box. In this configuration, the instrumentation was capable of monitoring only one traffic lane. Data analysis had to be performed using a main frame computer and specially developed software. The prototype bridge weigh-in-motion system was prooftested by the contractor and delivered to FHWA in mid-1978.

Prior to delivery of the instrumentation, FHWA initiated an in-house staff study to evaluate the newly developed technology. Arrangements were made with the Virginia DOT to instrument an Interstate 95 bridge near Dumfries, Virginia and to make use of a nearby fixed weigh station. Arrangements were also made for installation of temporary power at the bridge site. Shortly after completion of the CWRU project, a small purchase order was awarded to Dr. Moses for technical services and advice as needed.

FCP 25L3-032 Field Evaluation of (Bridge) Weigh-in-Motion Instrumentation

Contractor: FHWA
Start Date: 4-1-78
Investigator: H. R. Bosch
Duration: Ongoing

This staff study was initiated in April 1978 to evaluate, develop, and demonstrate bridge weigh-in-motion instrumentation on in-service highway bridges. Since initiation, this project has been extremely active and productive. It has served as a means to evaluate instrumentation systems and concepts resulting from related contract efforts. To date, five bridge weigh-in-motion systems have resulted from contract or HP&R work and all have been carefully reviewed under this project. Weighing accuracies were compared with weigh station, velocity accuracies compared with radar and speed counters, axle spacings compared with fixed measurements. Reliability, portability, and ease of use were also evaluated.

The project has served as a means to improve bridge weigh-in-motion instrumentation and advance the state-of-the-art. During the course of this study, many changes have been made to both hardware and software. Commercially available signal conditioning with auto-balance capability was located and implemented. New "button-box" circuitry and signal conditioning center were designed and fabricated. A portable, self-contained "input/junction box" was designed and fabricated to allow summing and averaging of strain signals from the bridge. A lane switching system was designed and fabricated to allow multiple lane data acquisition. Portable, reuseable clamp-on strain transducers were developed and implemented for routine use. Computer programs and analysis techniques were developed for evaluating system performance and displaying data for review and inspection. Numerous revisions have been made to existing computer software to improve system efficiency and extensive new software has been developed to extract structural information contained in the data.

This staff study has served as technical support to a number of other related studies. During the course of the project, an extensive data base has been assembled on truck characteristics and bridge response data. This information is not readily available elsewhere. It has been provided to the University of Maryland for use on several HP&R studies. The information is also available for use on FHWA truck weight studies (TWS) and cost allocation studies as needed. A number of computer programs have been developed to enable this transfer of data.

The project has served as a means to provide technical assistance to State highway agencies and foreign highway officials interested in WIM technology. Project staff have served as consultants to a number of interested parties. State highway agencies such as Wisconsin, Minnesota, Utah, Pennsylvania, Maryland, Texas, and Georgia have been given advice and assistance on the purchase of new WIM equipment. Other highway agencies such as Maine and South Dakota have been given detailed information and guidance in developing their own WIM systems. As a by-product of this research, a number of hardware devices and computer programs have been developed which are quite useful in other applications. Various highway agencies and foreign visitors have requested information regarding strain transducers, summing boxes, etc.

The project has also served as a means to demonstrate this rapidly evolving technology to interested parties. Bridge WIM instrumentation and periodic enhancements of this instrumentation have frequently been demonstrated to State highway agencies and foreign visitors. These demonstrations have been conducted at the Turner-Fairbank Highway Research Center (TFHRC), TRB annual meetings, and at bridge field sites during actual testing and evaluation.

Finally, this project has served as a means to discover new applications for WIM technology and instrumentation. Currently, WIM instrumentation is being studied as a tool for evaluating structural performance. Various portions of WIM instrumentation are being used in other technical areas. For example, self-balancing signal conditioning is being used in aerodynamic studies at TFHRC. The summer box is being used in developing turbulence signals for controlling active simulation of large-scale turbulence in the FHWA wind tunnel. Clamp-on strain transducers are being used to measure response of long span structures to control loadings. The microcomputers have been linked with other peripherals to copy data to different media, to assist in data acquisition on other projects, and to provide data processing capabilities for a variety of other applications.

FCP 35L3-132 Weigh-in-Motion Instrumentation Modifications and Improvements

Contractor: F. Moses   Start Date: 9-1-78
Investigator: F. Moses   Duration: 20 months

The objective of this purchase order was to obtain technical assistance from Dr. Moses in evaluating various instrumentation difficulties which were encountered during the early stages of the staff study. System documentation was improved, wiring problems were identified and fixed, software bugs were located, and set-up techniques were refined as a part of this effort. In addition, recommendations were made regarding upgrade of the Varian computer and the addition of multi-lane capability to the existing system. Dr. Moses also provided a general review of data collected by the system.

Concurrent with our WIM staff study, Ohio Department of Transportation (ODOT) decided to initiate a State research effort to develop a second generation bridge weigh-in-motion system. This project was to build upon experience and information becoming available through use of the prototype.

FCP 45L3-062 Weighing Trucks-in-Motion Using Instrumented Highway Bridges

Contractor: Case Western Reserve University   Start Date: 2-27-79
Investigator: F. Moses   Duration: 36 months

The objective of this Ohio study was to implement a stand-alone bridge weigh-in-motion system which would be capable of not only acquiring data but also processing it for truck weights. Although the Varian computer chosen for the prototype bridge WIM system had the potential for processing field data to provide weights and vehicle classifications, it was intentionally not configured to do so. FHWA saw a need to separate field activities and processing activities during the developmental stage to enable a clearer focus on the many technical problems associated with this complex application. The Ohio research led to the selection of a smaller, more portable computer, Dec Minc 11/03, for use as the system controller and data processor. Data processing programs developed for use on mainframes were converted from Fortran to Basic and implemented on the new minicomputer. Various types of reuseable, clamp-on strain transducers were investigated. These transducers simplify installation at the bridge site and provide greater sensitivity for measuring bridge response. Data acquisition software was enhanced to include axle counting and vehicle detection capability. This meant that it was no longer necessary for an observer to count and input the number of axles for each vehicle weighed. The WIM system was delivered to ODOT and the research team instructed ODOT personnel on its use and application.

In late 1980, midway through the Ohio study, FHWA awarded a major bridge WIM contract to the newly formed Bridge Weighing Systems, Inc. of Warrensville Heights, Ohio. This research effort was one of many studies awarded then to support the FHWA 3-year highway cost allocation study required by the Surface Transportation Assistance Act of 1978. Specifically, the WIM contract was to provide the cost allocation team with accurate information regarding the current truck loading spectrum. At about the same time, Maine Department of Transportation (MEDOT) initiated an HP&R study to investigate the potential of this rapidly evolving bridge WIM technology.

FCP 35L3-052 Loading Spectrum Experienced by Bridge Structures in the United States

Contractor: Bridge Weighing Systems, Inc. Start Date: 9-30-80
Investigator: G. Likins Duration: 38 months

The objective of this effort was two-fold: (1) to determine the actual spectrum of loading on U.S. highway bridges based upon a representative sampling of current traffic conditions, and (2) to assemble this information into a comprehensive format which would enable a detailed and accurate assessment of the effects of current heavy vehicle loadings on the life of the highway system. To accomplish this, three new (third generation) bridge WIM systems were designed and fabricated for use during the project. Each system was a bit different from the previous one, incorporating the latest enhancements or researching new techniques. With these new systems, one saw the appearance of faster and more extensive software developed entirely in Fortran, repackaging of support electronics including debouncing and summing circuitry, simplification in cabling schemes while increasing set-up flexibility, and introduction of new strain transducers. Much of this technology was shared with the Ohio study. Detailed truck data was collected at 33 bridge sites in seven States. The sites were carefully selected to provide a representative sampling of traffic from a variety of highway facilities. At the same time, an attempt was made to use a variety of bridge types to enable evaluation of WIM system capabilities and limitations. The second of the three systems fabricated for this project was delivered to FHWA shortly after assembly. It was to be used as part of FHWA's ongoing staff research. The remaining two systems were delivered to FHWA at the conclusion of the project.

FCP 45L3-152 Weigh-in-Motion Instrumentation of a Bridge

Contractor: Maine DOT Start Date: 7-1-80
Investigator: J. Wyman Duration: Ongoing

The objective of this HP&R study is to use a bridge to obtain truck weight data in an undetected manner and apply the data in determining structure and pavement maintenance requirements. The general approach has been to investigate various aspects of the bridge weigh-in-motion concept a step at a time without prematurely committing to purchase of an entire system. MEDOT has installed permanent strain gages on all girders of the North Channel Bridge over the Kennebec River in Skowhegan. This structure experiences a large number of heavily loaded logging trucks. Strain signals from each bridge girder are summed and the total is recorded on strip-chart. Data recording and processing is a manual operation, but works quite well in this application. The State has purchased a microcomputer and is currently investigating requirements for automating their system. In addition, they have recently purchased clamp-on strain transducers so that other bridge sites may easily be instrumented.

Upon completion of the first ODOT bridge WIM study, interest was redirected to focus more specifically on the question of bridge loadings. Early in 1982, a State research project was initiated to study methods for measuring extreme bridge loads resulting from multiple vehicle events. One year later, a second concurrent study commenced to evaluate bridge load data and develop load models.

FCP 45L3-132 Instrumentation for Weighing Trucks-in-Motion for Highway Bridge Loads

Contractor: Case Western Reserve University Start Date: 1-1-82
Investigator: F. Moses Duration: 32 months

The objective of this HP&R project was to utilize the bridge WIM concept and weight prediction methods to provide data on the distribution of maximum bridge loadings. To accomplish this end, the WIM system was first modified to enable weighing with more than one vehicle on the bridge at a time. This activity involved simulation of combined strain records based upon examination of existing strain data followed by extensive software modifications and testing. In this configuration, the system requires a more complex and time consuming bridge calibration procedure since girder distribution factors need to be established as well as the normal calibration factor. Additionally, data requirements dictate that acquisition be more of a continuous operation resulting in more information to be processed. A larger portion of system time in the field must be devoted to acquisition and processing becomes much more complex. Bridge WIM modifications were tested and demonstrated on several bridges and ODOT personnelwere instructed in use of this new configuration. Load data collected during the bridge tests was evaluated to determine the frequency of extreme loads, truck headway, lanal distribution, stress ranges, etc.

FCP 45A1-212 Comprehensive Study of Bridge loads and Reliability

Contractor: Case Western Reserve University   Start Date: 1-3-83
Investigator: F. Moses   Duration: 24 months

The purpose of this HP&R study is to coordinate and assess in a reliability-based framework, bridge loading data which has recently become available through the use of bridge WIM equipment. A major emphasis in this research has been to organize existing load information into a comprehensive format that is suitable for researchers, designers, and code writers alike. Load modeling has involved simulation, closed form predictions, and evaluation of design approximations. Procedures for applying load spectra to fatigue analysis and maximum load assessment were developed.

CURRENT RESEARCH

The first decade of FHWA WIM research (1974-1983) saw the bridge weigh-in-motion technology evolve from a feasibility concept into a useful research and planning tool for evaluating traffic as well as bridge loads. Nearly every study related to this development has been either directly or indirectly sponsored by the Federal Highway Administration. This represents an investment of $1.2 million ($700,000-FHWA research, $500,000-State HP&R) to develop a new technology. Bridge WIM research is continuing and current activities are focusing on refining, implementing, and applying this new technology to satisfy a wide range of highway engineering needs. On a broader scale, there is an increasing awareness in the highway community regarding the overall utility of WIM technology for addressing critical issues of truck size and weight, cost allocation and taxation, bridge and pavement design and rehabilitation, truck and transport safety, weight and safety enforcement, bridge formula enforcement, and general research needs. This is resulting in growing WIM P&R activity within other FHWA offices as well as other agencies.

FCP 35L3-092 Structural Evaluation of In-Service Bridges Using WIM Technology

Contractor: Lehigh University Start Date: 9-30-83
Investigator: J. H. Daniels Duration: 30 months

An important part of the integrity of highway structures is determined by the lifetime loading it experiences. Pavement stresses are due primarily to individual truck axle loads. Bridge structures, on the other hand, respond to a complex array of parameters such as gross weight and axle loads, axle spacing and load distribution, truck volume and velocity, as well as bridge static and dynamic structural characteristics. The fatigue cracking of highway structures is a result of millions of load repetitions and their incremental damages prior to failure.

The objective of this research is to determine what bridge response and truck loading information is necessary for a detailed evaluation of structural performance. Methods are being developed to use WIM technology to obtain the required data. An FHWA bridge WIM system is being modified to enable acquisition of more extensive bridge response information. System software is being extended to provide for evaluation of structural performance under known load conditions. Four structures will be tested and evaluated using the new system configuration.

FCP 35N3-000 Development of a Low Cost Truck Weighing System

Contractor: Metro Systems Engineering Start Date: 10-1-83
Investigator: W. Cunagin Duration: 24 months

The objective of this project is to develop a portable, low cost and effective traffic classification system based upon weighing the axle forces of vehicles moving in normal traffic flow over highway pavements. This research involves review of literature and current WIM technology to identify the best approaches available, lab and field testing of equipment and methods, development of a low cost pavement transducer, and fabrication of a prototype system.

Progress on the study has advanced to the point where a concept for the prototype has been developed and assembly of a system is underway. The transducer will be capacitive, portable (or expendable) and will be connected to a small battery powered data acquisition system to record weights, vehicle classification, and times on a magnetic digital cassette tape in the conventional manner (probably using the Streeter-Richardson system). A threshold sensing device can be used to trigger an alarm. Present development results are very encouraging.

NCHRP Synthesis Topic 16-02 Use of Weigh-in-Motion Systems for Data Collection and Enforcement

Contractor: Texas Transportation Institute Start Date: 3-1-84
Investigator: W. Cunagin Duration: 18 months

The state of the art of weigh-in-motion equipment has developed rapidly. Electronics and computer breakthroughs have made traditional techniques for collecting traffic data and truck weight enforcement obsolete. Historically, reliable data on truck weights, axle weights, speed, and vehicle classification have been very expensive to collect. WIM allows for the collection of large volumes of data without additional personnel, and for easier enforcement and monitoring of weight programs.

The synthesis will determine what kinds of data can be obtained from the present WIM equipment. Questions to be addressed by the synthesis include: How is WIM equipment currently being used in the United States and in other countries? How can WIM equipment be most efficiently employed? What are the advantages and the problems? What hierarchy of WIM and traffic equipment would give the most data with minimum cost? How accurate is WIM equipment and how can it be correlated with fixed scales? Any problems (together with the solutions) encountered in the use of WIM system will be identified. This project is approximately 50 percent complete and the first draft of the synthesis report has been submitted for review.

NCHRP Project 10-15 Structural Strength Evaluation of Existing Reinforced Concrete Bridges

Contractor: Engineering Computer Corporation
Investigator: R. Imbsen

I - Start Date: 4-1-80
Duration: 20 months
II - Start Date: 4-1-84
Duration: 18 months

The objective of this project is to develop improved methodology for evaluating the structural capacity of existing reinforced concrete bridge superstructure and to present it in a specification format suitable for consideration by AASHTO. The final report on the first phase of research includes findings and recommendations related to methods of predicting structural capacity for loadrating concrete highway bridges. The limit-state approach to bridge evaluation recommended in this report appears to be promising; however, some of the factors included in the report are not well documented, and the recommended approach is not yet ready for widespread application. The second phase of research has as its objective further development of the limit-state approach to evaluate the structural capacity of reinforced concrete bridge superstructures. The recommended procedures will be presented in a format suitable for consideration by AASHTO. This research includes reviewing bridge inventory statistics, conducting a sensitivity analysis, evaluating available test results (including WIM data), calibrating the proposed method using the information collected, and comparing the results with those obtained using current procedures. Phase II progress is behind schedule with only 40 percent of the work complete.

FCP 45K2-262 Weigh-in-Motion Applied to Bridge Evaluation

Contractor: Case Western Reserve University   Start Date: 9-4-84
Investigator; F. Moses   Duration: 12 months

This Ohio HP&R study has many similarities with the Lehigh contract described earlier. Over 100,000 bridges in the United States are thought to be structurally deficient. Many of these bridges were designed and constructed in a manner that achieved greater strength than recognized in code checking provisions. Current evaluation and rating methods emphasize bridge condition and member dimensions. Inspection methods, however, rarely measure bridge loadings or member responses. Developments in bridge weigh-in-motion technology make it feasible to investigate existing bridges and provide more accurate load data for the evaluation process.

This study involves testing a number of existing bridges using bridge WIM equipment to obtain information useful for bridge evaluation and rating. Data on truck axle loads, impact, load distribution, extreme loads, and stresses is being acquired and incorporated into an improved rating analysis. Several previously rated bridges have been instrumented so far and data processing is underway. Results will be compared with other rating methods and ODOT personnel will be instructed in use of the new techniques.

FCP 45K2-282 Implementation of a Continuous Fixed Site Bridge WIM Operation

Contractor: Bridge Weighing Systems, Inc. Start Date: 11-1-84
Investigator: R. Snyder Duration: 18 months

The Ohio DOT has been using the bridge weigh-in-motion method for acquiring truck weight and traffic data. This approach uses existing bridges to provide equivalent static weights of vehicles moving at normal speeds. To date, more than eight States and Federal agencies intend to use this method. In addition to being a discrete weighing operation, the system was developed to be mobile, allowing personnel to easily survey many sites. A limiting factor for long-term surveys of sites for weekly or seasonal variations in weight data is that the system requires two operating personnel. Thus, there is a need for extending the system to operate unmanned for continuous periods of time.

This study will provide ODOT with an operational WIM system, installed at a bridge site for continuous unattended operation. This new system will complement the State's existing portable WIM system which could be used to check by-pass routes or to identify the sites for long-term interval weighing. Although this study has just begun, some progress has been made toward identifying various system requirements.

FUTURE RESEARCH

NCHRP Project 12-26 Distribution of Wheel Loads on Highway Bridges

Contractor: Engineering Computer Corporation Start Date: Pending
Investigator: R. Imbsen Duration: 27 months

Wheel load distribution on highway bridges is one of the key elements in determining member size and consequently, strength and serviceability. It is, therefore, of critical importance both in the design of new bridges and in the evaluation of the load-carrying capacity of existing bridges. Empirical distribution factors for stringers and longitudinal beams have been present in the AASHTO Standard Specifications for Highway Bridges with only minor changes since 1931. Recent additions to these specifications have included more rational load distribution factors for particular types of superstructures based on tests and mathematical analysis. Recent research efforts have produced a substantial amount of information on various bridge types indicating a need for further revisions of the AASHTO Bridge Specifications.

This research project will review the latest truck load and bridge response information available from truck weight studies, weigh-in-motion studies, laboratory and field tests, and analysis to establish more realistic load distribution criteria applicable to all common types of bridges and materials. The new load distribution criteria developed will include simplified methods of analysis including code formulas as well as more comprehensive analytical models suitable for computer application. Recommended code revisions will apply to both service load and strength design methods as well as structural evaluation of existing bridges.

NCHRP Project 12-28(1) Load Capacity Evaluation of Existing Bridges

Start Date: Estimated late 1985 Duration: 24 months

The elements fundamental to the process of estimating the load capacity of existing structures are distinct from design elements that have been generalized for applicability to a wide range of structure types and service conditions. This generalization, when extended to the evaluation of existing bridges, often results in overly conservative estimates of load capacity and may result in unjustified actions such as the replacement of adequate structures. Refinements in assumptions concerning loading and resistance can be justified because the cost of evaluation is only a fraction of the bridge replacement cost. A more detailed and flexible methodology for the evaluation of the load capacity of existing bridges is required.

The load capacity of existing bridges can be determined most reliably and economically through a multilevel procedure. A large number of existing bridges is clearly capable of accommodating modern highway loads, and changes in the present rating procedures are not required in these cases. However, bridges found to be deficient under the present rating procedures should be reevaluated using higher level methods. This higher level rating system should permit selection of safety levels in a rational manner based on the effort expended on inspection, maintenance, and evaluation. This system should take into account the states of deterioration and distress of the bridge and permit the owner to make informed decisions about the payoff in terms of higher load ratings resulting from such measures as additional load control, inspection, and calculation effort.

This new study is very closely related to NCHRP project 10-15 which is providing recommendations on the limit-state approach to bridge evaluation for reinforced concrete bridges. The objective of this project is to extend the application of the limit-state approach to load capacity evaluation of various common bridge types, primarily steel and prestressed concrete.

NCHRP Project 12-28(3) Fatigue Evaluation Procedures for Steel Bridges

Start Date: Expected May 1985 Duration: 24 months

The fatigue provisions in the current AASHTO Standard Specifications for Highway Bridges are based on approximations of actual conditions in steel bridges. These provisions combine an artificially high stress range with an artificially low number of stress cycles to produce a reasonable design. Furthermore, the current AASHTO provisions were intended for design applications and not for rating or assessing remaining fatigue life of existing steel bridges, especially those built before the present provisions were adopted.

In recent years, much information has been developed on (1) variable-amplitude fatigue behavior, (2) high-cycle (long-life) fatigue behavior, (3) actual traffic loadings, (4) load distribution for fatigue, (5) inspection and assessment of material properties and structural conditions, and (6) other pertinent parameters. This new information, together with the extensive information previously accumulated on the fatigue behavior of various details, is sufficient to permit the development of realistic procedures for the fatigue evaluation of bridges.

The objective of this research is to develop practical procedures that more accurately reflect the actual fatigue conditions in steel bridges, and that can be applied for fatigue evaluation of existing or new bridges. Specifically, the procedures shall permit determination of fatigue-load ratings and estimation of remaining life for existing bridges.

FCP 35K2-078 Truck Weight Monitoring Using the FHWA Bridge WIM System

Contractor: Washington DOT | Start Date: Pending
Investigator: M. Hallenbeck | Duration: 15 months

The FHWA Structures Division and Implementation Division are coordinating a task order R&D effort with the following objectives: (1) demonstrating new bridge weigh-in-motion technology to State highway agencies, (2) enabling these agencies to gain hands-on experience with instrumentation, (3) providing a means for evaluating and improving the WIM concept. Since this initial effort will include purchasing and outfitting a field instrumentation van suitable for housing and transporting the system, there will be cost-sharing between FHWA and the selected State. Future efforts of this type will likely be arranged through the State HP&R program.

For this study, FHWA will instruct the State DOT on use of instrumentation and evaluation of data collected by the system. Following installation of the FHWA system in the new field van, the State will use it at several bridge sites and evaluate its performance. Results of these tests will be compared with other weighing techniques currently being used. A report will be prepared which documents research findings, comments on system performance, and makes recommendations for improvements.

FCP 31U4-132 Calibration of Weighing-in-Motion Systems

Start Date: Estimated mid 1985 Duration: 12 months

The objective of this study is to examine a range of approach pavement roughness profiles and their effect on measurement accuracy of various WIM systems. Controlled laboratory tests will be performed to determine effects of different truck configurations, suspensions, speeds and loadings. Field tests will be performed to validate and calibrate the findings obtained form the controlled laboratory tests. The research includes selection of sites for controlled tests and field tests, development of test plans, and analytical estimates of effects of pavement roughness on WIM equipment. This study will also analyze the feasibility of using several scales in series at specified separations to overcome variations in individual WIM scales on unimproved roads. FHWA intends to use the results of this study in a forthcoming regulation on the National WIM Program dealing with individual scale site location.

FCP (not programmed) Strategies for Truck Transport

Start Date: Estimated mid 1986 Duration: Not determined

A considerable amount of research has been conducted in the past dealing with truck size and weight and with pavement impacts. Much of the work, however, has been fragmented and was accomplished to serve different purposes and goals. The objective of this program, proposed for FY 1986, is to recommend optimum strategies for truck transport. This objective requires the combined evaluations of the level and cost required for road strengthening and improvement which will accommodate various types of truck axle suspension-tire characteristics and loads. A range of solutions will be sought so that strategic decisions may be made concerning: (1) the level of road strengthening nationwide, (2) allowable axle and gross weights, and tire types and pressures, and (3) guidelines for new truck design features.

Such strategic decisions must be based on factual and reliable information generated through a coordinated R&D program. The program proposed will be geared to include past research developments and work being conducted through other agencies. The program will generate new studies applicable to FHWA contracts, staff, HP&R, NCHRP and SHRP. The new studies will be formulated to close the gap between theory and practice so that strategic decision-making on this topic area can be made.

NCHRP Project 3-34 The Feasibility of a National Heavy-Vehicle Monitoring System

Start Date: Estimated mid 1986 Duration: 24 months

Various types of information on heavy vehicles are collected by Federal, State, and local governments to support highway planning and design activities, as well as to carry out weight enforcement programs and tax administration. Collecting and processing this information is extremely costly from the viewpoint of both government and private industry, and in many cases the data are not as complete or as accurate as desired for the intended purpose. In addition to actual dollar costs, the present system suffers from burdensome paperwork (as currently being studied by the National Governors' Association), operator inconvenience and potential hazard, lack of enforcement uniformity, and inconsistency among the individual States. International inconsistency is also a concern.

New technologies in automatic vehicle identification (AVI), automatic vehicle classification (AVC), and weigh-in-motion (WIM) are considered to potentially offer a more cost-effective approach to the collection of heavy-vehicle data.

There is a need to evaluate the feasibility of applying these relatively new technologies at the national and/or regional levels and to build on the existing knowledge from the Crescent Project and other related studies. Institutional issues such as privacy, access to competitive information, and potential for manipulation and evasion of the system will be major determinants of feasibility and acceptability.

The objective of this research is to identify and evaluate the needs, issues, requirements, and feasibility of using an automated system (AVI/AVC/WIM) as a cost-effective, statistically sound replacement and/or supplement to existing heavy-vehicle data collection systems. This research will encompass: (1) the identification of different system-design configurations for the integration of AVI, AVC, and WIM to provide appropriate levels of monitoring and related confidence levels, (2) amount of equipment/automation to achieve different objectives, (3) site location criteria on a State, regional, and nationwide scale, (4) an economic analysis of the alternative levels of monitoring, and (5) the full range of issues associated with implementation and operation.

NCHRP Project 12-28(8) Improving Bridge Load Capacity Estimated by Correlation With Test Data

Start Date: Estimated mid 1986 Duration: 24 months

A great deal of knowledge has been gained by physical testing of bridges and their components, much of it indicating that bridges resist loads in ways not always considered. Some causes of these differences in behavior are: unintended composite action, load distribution effects, participation of elements such as parapets and railings, two-way slab action where only one-way was assumed, participation of the floor system with chords of trusses, the difference between actual and assumed material properties, participation of bracing and secondary members, effectiveness of shear keys, confinement, support characteristics, and unintended continuity.

More realistic modeling of this behavior in existing structures will make it possible to better evaluate load capacity. With such refinements, more bridges will continue in service and provide adequate load capacity with or without modifications and repairs.

The objective of this research is to assemble domestic and foreign test data to identify, quantify, and report significant aspects of observed behavior that are not now considered in load capacity estimates.

Schedule of Weigh-in-Motion and Related Research - First Decade

STUDY TITLE / YEAR	74	75	76	77	78	79	80	81	82	83
Feasibility of Utilizing Highway Bridges to Weigh Vehicles in Motion	22K									
Feasibility of Utilizing Highway Bridges to Weigh Vehicles in Motion	24K									
Feasibility of Utilizing Highway Bridges to Weigh Vehicles in Motion	13K									
Use of Bartonsville Bridge to Weigh Trucks in Motion			26K							
Weigh-in-Motion Instrumentation				109K						
Field Evaluation of (Bridge) Weigh-in-Motion Instrumentation							100K			
Weigh-in-Motion Instrumentation Modifications and Improvements						10K				
Weighing Trucks-in-Motion Using Instrumented Highway Bridges							206K			
Loading Spectrum Experienced by Bridge Structures in the U.S.									389K	
Weigh-in-Motion Instrumentation of a Bridge									40K	
Instrumentation for Weighing Trucks-in-Motion for Hwy. Br. Loads										65K
Comprehensive Study of Bridge Loads and Reliability										134K
Structural Evaluation of In-Service Bridges Using WIM Technology										
Development of a Low Cost Truck Weighing System										

Schedule of Weigh-in-Motion and Related Research - Second Decade

STUDY TITLE YEAR	84	85	86	87	88	89	90	91	92	93
Field Evaluation of (Bridge) Weigh-in-Motion Instrumentation		100K								
Weigh-in-Motion Instrumentation of a Bridge		90K								
Comprehensive Study of Bridge Loads and Reliability	134K									
Structural Evaluation of In-Service Bridges Using WIM Technology		300K								
Development of a Low Cost Truck Weighing System	250K									
Use of WIM Systems for Data Collection and Enforcement	40K									
Structural Strength Evaluation of Existing Reinforced Conc. Bridges	100K									
Weigh-in-Motion Applied to Bridge Evaluation		84K								
Implementation of a Continuous Fixed Site Bridge WIM Operation		87K								
Distribution of Wheel Loads on Highway Bridges			300K							
Load Capacity Evaluation of Existing Bridges			225K							
Fatigue Evaluation Procedures for Steel Bridges			200K							
Truck Weight Monitoring Using the FHWA Bridge WIM System			70K							
Calibration of Weighing-in-Motion Systems										
Strategies for Truck Transport										
Feasibility of a National Heavy-Vehicle Monitoring System				400K						
Improving Bridge Load Capacity Estimated by Correlation/Test Data				200K						

The South Dakota

Bridge Weigh in Motion System

by

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Abstract

Following completion of Federal Highway Administration sponsored research in high speed weighing of vehicles using instrumented bridges as the load sensing element, the South Dakota Department of Transportation became interested in the technology as an appropriate means to gather truck weight information. After unsuccessful efforts to obtain a prototype system from the FHWA, the Department decided to develop its own bridge weigh in motion system in late 1982. Electronic equipment was purchased, weighing software was designed and written, and a motorhome was purchased to house and transport the system. Two bridges were permanently instrumented and used for weighing in 1983.

While based on research published during the FHWA sponsored contracts, the system has developed independently and differs in some respects from those systems. Strain gages permanently attached to structures are used instead of removable transducers, photocells rather than tapeswitches are used to sense axles, and site calibration procedures are different.

As of summer, 1985, eighteen bridge weigh in motion sites in South Dakota are being used to conduct the state's Truck Weight Study on interstate, main rural, secondary and urban highways.

1.0 History

In 1982, research sponsored by the Federal Highway Administration in weigh in motion technology--a method of weighing vehicles as they pass over instrumented highway structures--was being completed. One aspect of the research contracts involved development and delivery to the FHWA of three prototype systems which would later be made available to state agencies for purposes of evaluation and demonstration.

When the South Dakota Department of Transportation became aware of the prototype systems, an evaluation of the concept was made. Bridge weigh in motion seemed appropriate for use in South Dakota because of its portability, because of the large number of potential sites available throughout the state, and because the state's relatively low traffic volumes were consistent with the system's limitations at that time. The decision was made to pursue acquisition of one of the prototype systems primarily for collection of unbiased highway design and planning data, with possible enforcement applications.

The Department requested that the FHWA make one of the prototype systems available on either a permanent or temporary basis. Other states had also made requests, however, so when timely acquisition seemed rather unlikely, the decision was made to develop a system independently. At the time the decision was made, commercially available systems appeared to have some shortcomings, particularly with regard to supplying weight information in formats consistent with already established Department procedures. The development decision was practical because technical expertise already existed within the Department.

Equipment acqisition and system development occurred mainly during the winter of 1982-1983, and first weighing was accomplished in the spring of 1983. While the system was not completed in time for use in the state's 1983 Truck Weight Study, it was used for accuracy studies and demonstrations throughout 1983 and 1984. Following its present use for the 1985 Truck Weight Study, the system will be used to extend understanding of truck weight information, especially with regard to effects of time of day, week and year.

2.0 Bridge Weigh in Motion Theory

Bridge weigh in motion methods are unique in that the load sensing element is a highway structure to which strain measurement instrumentation has been attached. Determination of vehicle gross and axle weights requires considerable computation, primarily because of the bridge's great length. First, because the vehicle's axles are not individually present on the structure, each axle's contribution to strain must be isolated from the total. Secondly, each axle's contribution to strain depends not only upon its weight, but also upon its location on the structure at the time the measurement is taken. It is therefore necessary to measure or predict the location of each axle all the while the vehicle occupies the bridge. This section will consider the theoretical aspects of weight and axle location determination, as well as the methods of structure calibration and in motion vehicle classification.

2.1 Vehicle Position and Geometry Measurement

Because a load's effect on the structure depends on its location, it is necessary to determine the position of each of the weighed vehicle's axles at the times at which girder strain measurements are made. More specifically, it is necessary to determine the vehicle's axle configuration and spacing as well as an equation of motion which relates vehicle position to time. These may be determined from the times recorded when each axle passes each of two sensors which are spaced a known distance apart.

If the vehicle's equation of motion X(T) is assumed to be a polynomial in time T, then X(T) may be expressed:

$$X(T) = Xf + \sum_{j=1}^{J} C_j T^j \qquad (3.1.1)$$

where Xf is the coordinate of the first axle sensor, and J is the order of the approximating polynomial.

The distance from axle 1 to each other axle may be computed as the difference between the vehicle's coordinate when axle 1 was detected by the first axle sensor and its coordinate when the other axle was detected there. The axle distances may be expressed:

$$Df(a) = X(Tf(a)) - X(Tf(1))$$

$$= Xf + \sum_{j=1}^{J} C_j \, Tf(a)^j - Xf - \sum_{j=1}^{J} C_j \, Tf(1)^j$$

$$= \sum_{j=1}^{J} C_j \, Tf(a)^j \qquad (3.1.2)$$

where Tf(a) is the time at which axle a is detected by the first sensor and Tf(1), the time at which axle 1 is detected at the first sensor, is taken as zero.

Alternatively, the same axle distances may be computed using times at which the axles were detected by the second sensor. If Ts(a) is the time at which axle a is detected at the second sensor, the axle distances may be expressed:

$$Ds(a) = X(Ts(a)) - X(Ts(1))$$

$$= X(Ts(a)) - X(Tf(1)) + X(Tf(1)) - X(Ts(1))$$

$$= X(Ts(a)) - X(Tf(1)) + Xf - Xs$$

$$= Xf - Xs + \sum_{j=1}^{J} C_j \, Ts(a)^j \qquad (3.1.3)$$

If the polynomial expression for X(T) is of degree less than the number of axles, these equations are redundant and the coefficients C_j cannot in general be determined explicitly. A solution can be found, however, which minimizes the disagreement between distances determined from sensor 1 transition times and those determined from sensor 2 transition times. If the error function E is defined to be

$$E = \sum_{a=1}^{A} \{Dsa - Dfa\}^2$$

$$= \sum_{a=1}^{A} \{Xf - Xs + \sum_{j=1}^{J} [C_j(Ts(a)^j - Tf(a)^j)]\}^2$$

$$= \sum_{a=1}^{A} \{Xf - Xs + \sum_{j=1}^{J} C_j Ha_j\} \qquad (3.1.4)$$

where A is the total number of axles, and

$$Ha_j = Ts(a)^J - Tf(a)^J \qquad (3.1.5)$$

the coefficients C_j which minimize E may be found by setting partial derivatives with respect to each unknown equal to 0. We have

$$0 = dE/dCk$$

$$= \sum_{a=1}^{A} \{ Xf - Xs + \sum_{j=1}^{J} [C_j Ha_j] \} (-2Hak)$$

$$= Yk - \sum_{j=1}^{J} \{C_j Z_jk\} \qquad (3.1.6)$$

where

$$Z_jk = \sum_{a=1}^{A} \{Ha_j Hak\} \qquad (3.1.7)$$

and

$$Yk = \sum_{a=1}^{A} \{(Xf - Xs)*Hak\}. \tag{3.1.8}$$

Because this equation is true for every k, a system of equations is defined which may be written in matrix notation as CZ=Y. Because Y and Z are known from sensor geometry and axle detection times, it is possible to solve for the vector C which specifies the polynomial coefficients C_j which determine axle spacing and the vehicle's equation of motion.

The physical interpretation of this method is as follows. The axle transition times measured at the two sensors provide more information than is required to solve for a polynomial equation of motion of order less than the number of axles. The method finds the polynomial coefficients which insure the greatest consistency between axle spacing determinations based upon all of the time measurements. Equivalently, the method determines the equation of motion most consistent with the measurements, providing both axle spacing and vehicle speed as end products.

2.2 Axle Weight Determination

When a load is present on a structure, it induces bending moment dependent on its magnitude and location on the structure. The total moment induced in a steel or concrete girder structure by a vehicle at any position p is distributed among the individual girders, so the sum of girder moments must equal total moment. The moment in each girder is related to the girder's strain by the relation

$$Mgp = Eg\ Sg\ Ugp \qquad (3.2.1)$$

where Eg is the girder's modulus of elasticity, Sg is its section modulus, and Ugp is the strain measured in the girder at that vehicle position. If another term Mo is introduced to account for constant offsets related to temperature and instrumentation errors, the total apparent moment Mp measured by an instrumentation system may be expressed as

$$Mp = Mo + \sum_{g=1}^{G} Mgp \qquad (3.2.2)$$

In terms of axle weights and locations, the predicted moment may be expressed as

$$M'p = \sum_{a=1}^{A} Wa\ I(Xap) \qquad (3.2.3)$$

where Wa is the weight of axle a. I(Xap) is the moment influence value of the structure at the coordinate Xap occupied by axle a--that is, the amount of moment induced at the measurement location per unit load applied. The unknown values Wa and Mo may be found by minimizing the error function defined by the squares of differences between measured and predicted moment summed over all vehicle positions:

$$E = \sum_{p=1}^{P} \{Mp - M'p\}^2$$

$$= \sum_{p=1}^{P} \{ Mo + \sum_{g=1}^{G} Mgp - \sum_{a=1}^{A} Wa\ I(Xap) \}^2 \qquad (3.2.4)$$

If we define Mo equal Wo and define I(Xop) = -1, this equation may be written

$$E = \sum_{p=1}^{P} \{ \sum_{g=1}^{G} Mgp - \sum_{a=0}^{A} Wa\ I(Xap) \}^2 \qquad (3.2.5)$$

Values of offset and axle weights which minimize E may be found by differentiating the expression with respect to each unknown and equating to zero:

$$0 = dE/dWb$$

$$= \sum_{p=1}^{P} \{\sum_{g=1}^{G} Mgp - \sum_{a=1}^{A} Wa\ I(Xap)\}[-2I(Xbp)]$$

$$= Yb - \sum_{a=1}^{A} Wa\ Zab \qquad (3.2.6)$$

where

$$Yb = \sum_{p=1}^{P} Mp\ I(Xbp) \qquad (3.2.7)$$

and

$$Zab = \sum_{p=1}^{P} I(Xap)\ I(Xbp). \qquad (3.2.8)$$

In matrix notation, equation 3.2.6 may be written Y = WZ. Matrix algebra can be applied to solve for the offset and axle weight vector W given the vector Y and matrix Z which are known from the structure's moment influence line, the girder strain measurements, and axle position information.

Because the weighed vehicle is in motion, dynamic load components resulting from interaction between its suspension and the road, approach and bridge profile are significant (Figure 1). It is important to understand that the axle weight determination method finds weights which would generate moments most consistent with the record observed over the entire bridge length rather than at any one point on the structure. This feature has the effect of greatly diminishing the dynamic loading effects in the axle weight computation.

2.3 Structure Calibration

The method of axle weight determination assumes that the bridge's moment influence line is known. In practice, it is necessary to either define the line theoretically or determine it empirically. Because the actual behavior of a structure may deviate significantly from theoretical behavior, an empirical calibration method has been chosen.

If the moment influence line is approximated by a piecewise linear function, calibration can be accomplished by measuring the strains induced by a vehicle of known axle spacing and weight at various positions on the structure. Specifically, if the line is specified by a set of moment influence values I_j defined at coordinates X_j, the moment influence value at any axle coordinate X_{ap} on the structure may be expressed

$$I(X_{ap}) = \sum_{j=1}^{J} I_j R_{jap} \qquad (3.3.1)$$

where

$$R_{jap} = (X_{j+1} - X_{ap})/(X_{j+1} - X_j) \quad \text{for } X_j < X_{ap} < X_{j+1}$$

$$= (X_{j-1} - X_{ap})/(X_{j-1} - X_j) \quad \text{for } X_{j-1} < X_{ap} < X_j$$

$$= 0 \quad \text{otherwise} \qquad (3.3.2)$$

The equation for total moment at position p may then be written

$$M'_p = \sum_{j=1}^{J} \sum_{a=1}^{A} W_a I_j R_{jap} \qquad (3.3.3)$$

and the error function of equation 3.2.4 may be written

$$E = \sum_{p=1}^{P} \{M_o + \sum_{g=1}^{G} M_{gp} - \sum_{j=1}^{J} \sum_{a=1}^{A} W_a I_j R_{jap}\}^2 \qquad (3.3.4)$$

If we let $I_o = M_o$, and define

$$H_{jp} = \sum_{a=1}^{A} W_a R_{jap} \quad \text{for } j=1,J$$

$$= -1 \quad \text{for } j=0 \qquad (3.3.5)$$

the error function can be generalized to

$$E = \sum_{p=1}^{P} \{ \sum_{g=1}^{G} M_{gp} - \sum_{j=0}^{J} I_j H_{jp} \}^2 \qquad (3.3.6)$$

Values of I_j, the unknown offset and moment influect values, can be found which minimize the error E by differentiating with respect to each variable and equating to zero:

$$0 = dE/dI_k$$

$$= \sum_{p=1}^{P} \left\{ \sum_{g=1}^{G} M_{gp} - \sum_{j=0}^{J} I_j H_{jp} \right\} (-2H_{kp})$$

$$= \sum_{p=1}^{P} \sum_{g=1}^{G} M_{gp} H_{kp} - \sum_{p=1}^{P} \sum_{j=0}^{J} I_j H_{jp} H_{kp}$$

$$= Y_k - \sum_{j=1}^{J} I_j Z_{jk} \qquad (3.3.7)$$

where

$$Y_k = \sum_{p=1}^{P} \sum_{g=1}^{G} M_{gp} H_{kp} \qquad (3.3.8)$$

and

$$Z_{jk} = \sum_{p=1}^{P} H_{jp} H_{kp} \qquad (3.3.9)$$

Equation 3.3.7 may be expressed in matrix notation as Y=IZ, and may be solved for the unknown offset and moment influence values Im. It is clear that the calibration method is related inversly to the vehicle weighing method. In the former, axle weights are known and influence values are determined; in the latter, influence values are known and axle weights are determined.

In order for the piecewise linear moment influence line to be valid, moment influence points must be determined at locations of curve discontinuity. Points are therefore required at span endpoints and at the strain measurement location. In addition, influence points are spaced fifty percent more densely on the strain measurement span than on other spans. A total of 25 to 30 moment influence points will define the moment influence line of a three span structure very completely, as is illustrated by Figure 2.

2.4 Vehicle Classification

When trucks are weighed, it is desirable to also obtain as much vehicle classification information as possible. While axle spacing and weights are determined from strain and axle sensor measurements, additional raw information and analysis is required to specify the vehicle, body and hauled commidity types.

For purposes of the Truck Weight Study, vehicle type is defined to be a six digit number specifying the vehicle's overall configuration and axle grouping. Automobiles are assigned a code of 100000, while trucks, tractor semitrailer, truck trailer and tractor semitrailer trailer combinations are assigned codes of 200000, 300000, 400000, and 500000 respectively. In the case of heavy trucks, the second through sixth digits are used to specify the vehicle's axle configuration. For example, a five axle tractor semitrailer is assigned a code of 332000, specifying a three axle tractor and a two axle semitrailer. A tractor semitrailer trailer combination may have a vehicle code of 532400, specifying three tractor axles, two semitrailer axles, and four axles on the trailer. Finally, in the case of light vehicles, a separate towed trailer will modify the vehicle code, as the code for a car towing a cargo trailer 100300 illustrates. In every case, if the vehicle and trailer types (single unit, tractor semitrailier, etc.) are specified from visual observation, axle distance and grouping information can be added to completely and unambiguously specify the vehicle code.

Likewise, a two digit code is assigned on basis of body type. Here, the code specifies whether the vehicle was a car or pickup body, a flatbed, tank, hopper, grain, van or any other of fifty-three distinct body types. While these body types can only be specified by visual observation, correct identification is generally possible even at high vehicle speeds.

Finally, a five digit commodity code consistent with the system developed by the Bureau of the Budget for transporation reporting purposes is assigned to the load. Because it is not possible to observe enclosed cargoes as they pass by a weighing location, uncertainty may exist in the code assignment. In the case of open cargoes, accurate assignment is generally possible.

The scheme developed for use with the weigh in motion system utilizes as much visual information as is possible to gather in the brief observation period to specify vehicle, body and commodity codes. In general, a vehicle is identified by up to three mnenomics of three characters each. The first identifies the general vehicle type--car, pickup, single unit truck, tractor semitrailer, and so forth. If the vehicle is some kind of heavy truck, a body code is also entered; in the case of cars, pickups, and other light vehicle, the vehicle mnemonic itself defines the body code. Finally, if a separate trailer is towed, a trailer mnemomic is entered. A list of possible codes and their meaning is given as Figure 3.

The scheme may be illustrated by a limited number of examples. The single mnemonic "CAR" specifies that the weighed vehicle is an automobile, while the paired mnemonics "CAR/CGO" designate a car pulling a cargo trailer. Similarly, the mnemonic pairs "SUT/GRN", "TST/LUM" and "2TC/REF" designate a single unit grain truck, a tractor semitrailer hauling lumber, and a refrigerated tractor semitrailer trailer combination. Most probable commodity codes are assigned on the basis of body type, so that a commodity code of 01100 corresponding to "field crops" is assigned to the grain truck, a code of 24200 corresponding to "lumber and dimension stock" is assigned to the tractor semitrailer, and a code of 20000 corresponding to "food and kindred products" is assigned to the refrigerated tractor semitrailer trailer combination.

A variation to the system described above is necessary where traffic volumes preclude manual description of every vehicle. If motorcycles, cars, and pickups are automatically classified on the basis of vehicle length and weight, the requirement for manual identification is greatly lessened. Because of the large overlaps between car and pickup weights and dimensions, such a classification is only approximate, however.

3.0 System Description

The weigh in motion system consists of instrumented and calibrated structures, strain and vehicle position measurement electronics, a digital computer which executes weighing software written by SDDOT, and a motorhome which houses the electronics system. Figure 4 illustrates the general layout and location of components described below.

3.1 Structures

Because highway bridges are used to sense vehicle loads, they must be listed first in the system description. As of July, 1985 eighteen steel girder structures have been instrumented and calibrated for weighing in South Dakota. Concrete girder structures have been considered for use, but because of the relatively large number of steel structures, none have been instrumented to date. All of the instrumented structures have been three span structures, varying in length from 117 feet to 337 feet, with six girders or fewer. While both simple and continuous span structures have been used, all have had strain gages installed on one of the endspans and influence lines have been computed for the entire bridge length. Some of the structures have had exterior girders whose cross section varied from that of the interior girders; estimates of the girders' design section moduli have been made to compensate for these differences.

The loads passing across an instrumented bridge induce moments which generate strains in each of the structure's girders. Strain magnitudes depend on the magnitude and location of the loads as well as the strength and geometry of the structure, but typically strains of -50 to +200 microstrain will be observed as a single vehicle moves across the bridge.

3.2 Strain Measurement Instrumentation

Electrical resistance foil strain gages are attached to the upper side of the lower flange of each girder, at points equidistant from the girder ends. Two gages are mounted in a half-bridge configuration at each location; a longitudinally oriented gage measures the girder's strain while a transversely oriented gage measures a negative strain (equal to the longitudinal strain multiplied by Poisson's ratio) and provides temperature compensation. Two gage types have been successfully used. The first is an array of two perpendicularly oriented gages which are bonded to the girder with epoxy. The second consists of two gages which have been already bonded to a piece of thin metal stock; this type is spot welded to the girder by a portable, low power welding unit specifically designed for the task. In either case, leadwires are soldered to the gages after their attachment to the girder, and the gage location is sealed with a polyurethane coating. Finally, layers of butyl and neoprene rubber approximately 1/8" thick are placed over the gage location to provide additional protection from moisture and mechanical disturbance. A useful life of approximately 10 years can be expected from this type of installation.

The leadwires are run to the end of the structure and terminated with waterproof connectors. During operation, the girder's leadwires are connected to a junction box attached to one or two hundred feet of multipair shielded cable which is run to the instrumentation located in the instrumentation vehicle.

Each girder's gages are powered and its signals amplified by individual variable excitation, variable gain strain gage amplifiers. With strain gage factors of 2.0 and excitation voltages of seven to fifteen volts, gains of approximately 2500 to 5000 are required to amplify the strain signals to levels consistent with the analog-to-digital converter's input range of plus or minus five volts. The amplifiers are self balancing--that is, they will automatically balance themselves when a single button is pushed or a remote balance signal applied. In practice it is necessary to rebalance approximately twice per hour to accomodate drifts caused by temperature variations. This task is easily accomplished by the operator attending the system. While the amplifiers were manufactured with switch selectable 10, 100, 1000, and 10,000 Hz six pole lowpass filters, a filtering frequency between 10 and 100 Hz is more suitable for bridge weighing purposes. By changing filter capacitor values, the 10000 Hz filter was changed to a 30 Hz filter which is used during weighing.

The output signal of each of the six amplifiers is displayed on a digital panel meter in the instrumentation vehicle. While not required for weight calculation, the meters provide positive indication of proper amplifier balance and strain measurement.

3.3 Vehicle Speed and Geometry Instrumentation

Photocells positioned in the structure approach lanes detect the passage of axles through the bridge. Two infrared retroreflective photocells are placed on each lane's shoulder a known distance, usually ten feet, apart. Low profile reflective pavement markers are placed in mid-lane, at identical distances from the structure as the photocells. When no vehicle is present, the photocell's beam is projected to the pavement marker, then reflected back to the photocell's detection circuit. When a vehicle's axle is present, the beam is blocked and no reflected beam is detected.

To minimize the effect of ambient light conditions, the infrared beam is modulated and the detected beam filtered and demodulated to eliminate constant light level contributions. The output circuitry of the photocell is an uncommitted NPN transistor which is electrically equivalent to a mechanical switch contact. When the infrared beam is interrupted, the transistor conducts, as would a normally open switch. Digital counters inside the instrumentation vehicle indicate the current status and the number of axles counted by each photocell in each lane, enabling verification or troubleshooting of photo-cell operation.

3.4 Weigh in Motion Computer

A minicomputer continuously monitors girder strain and axle sensor signals, then computes vehicle speeds, axle spacings and weights from the measurements. The minicomputer consists of a central processing unit, 128 kilobytes of semiconductor memory, dual 512 kilobyte floppy disks for storage of programs and data, a console terminal for operator interaction, and a small line printer on which weight, moment or strain data may be printed or plotted.

Transitions of photocell state between the open or blocked condition are detected by an optoisolated digital input interface. Each input circuit is debounced to eliminate multiple transitions, then converted to logic levels consistent with the computer's bus. When any transition occurs at any photocell, the interface interrupts the computer so that the times of transitions may be immediately and accurately recorded by a programmable clock interface.

While a vehicle is on the bridge, each girder's strain signal is digitized by the system computer's multichannel twelve bit analog to digital converter once every 32 milliseconds, a time interval corresponding to a distance of 2.4 feet for a vehicle travelling 55 miles per hour. These measurements are taken and stored in the computer's memory until the vehicle's last axle has left the bridge. After the vehicle's entire strain record has been recorded, it is combined with vehicle speed and geometry information, and individual axle weights are estimated.

3.5 Video Vehicle Identification System

Although South Dakota has a limited number of sites which allow vehicle access beneath an instrumented structure, this method of concealing weighing is used where possible. In order to provide visual information concerning the vehicle's body type and configuration, a portable television camera and video recorder are stationed alongside the highway. Traffic may be observed on a video monitor located in the instrumentation vehicle.

To speed classification, all of the vehicle and trailer type mnemonics and twenty four of the body type mnemonics may be entered by striking single function keys on the operator's console keyboard.

3.6 Motorhome

A standard 22 foot recreational vehicle houses the electronics and provides workspace for the operator. It was purchased complete with refrigerator, stove, water heater, and bath because the price of a standard configuration compared favorably to that of a stripped down, custom built vehicle. The only modification required was to remove one of the captain's chairs to make room for an electronic instrumentation cabinet. Both the standard four thousand watt gasoline powered electrical generator and air conditioner have proved to be more than adequate to run the instrumentation system in a controlled climate. To minimize the possibility of passing traffic recognizing the weighing operation, the motorhome is not marked with transportation department ensignia.

4.0 Performance

Some indicators of system performance--cost, accuracy, and limitations of use--have been evaluated. Evaluation of other indicators, such as percentages of vehicles not weighed, numbers of overweight vehicles detected, and overall cost effectiveness will not be possible until additional use of the sytem has occurred.

4.1 Costs

Approximate costs of the weigh in motion system, exclusive of manpower cost of development and test, are summarized as follows:

Minicomputer and interface modules............	$12,000
Strain gage amplifiers......................	8,000
Gages, cables and connectors.................	2,000
Photocells and reflectors....................	1,000
Motorhome equipped with generator............	22,000
Total......................................	$45,000

The cost of installing permanently attached strain gages to a structure is between $100 and $200, depending on the number of girders and exclusive of manpower costs. Approximately two man days are required for installation.

While the system could be operated by one person, two man operation has been chosen for purposes of safety and convenience. The crew consists of a permanently assigned technician and one seasonal assistant.

4.2 Accuracy

In tests to date, the accuracy of vehicle dimension (axle spacing) determination has been found to be plus or minus 0.1 feet within all normal vehicle operation speeds, except when a vehicle stops or accelerates from a stop immediately in the bridge area. The ten foot photo-cell spacing used in the accuracy tests is normally used during weighing operations.

Gross weight accuracy can be described in terms of a probability distribution. In tests to date, eighty percent of in motion gross weights have been found to be within five percent of statically determined weights. Fifty percent of gross weights are within three percent of static weights and thirty percent are within two percent. Individual axle weight accuracy is much worse, primarily because of vehicle dynamics, and especially on structures with rough bridge approaches. Individual axle error probability distributions have not been compiled to date.

While vehicle and body type determinations are presumed quite accurate, first verifications against static observations will first occur in fall of 1985. Evaluation of the commodity code assignment method will be particularly valuable during this period.

4.3 System Limitations

South Dakota's version of the bridge weigh in motion system does have some problems, some of which will require further system revision and development. First, the photocell and pavement reflector axle sensors will not operate in rains. High speeds vehicles, especially trucks, throw a spray behind their wheels which effectively block the photocell's beam, making correct axle count impossible. While rains are infrequent in South Dakota, the problem is serious enough to warrant development of an alternate axle sensor.

The permanent strain gage installations have been attacked by vandals at two different sites located in or close to towns. Steps can be taken to make the leadwires less accessible, but detachable sensors may be required if vandalism persists.

Finally, the current version of weighing software only allows for weighing of vehicles which were alone on the structure for a major fraction of its weighing period. While most of the sites have low traffic volumes (less than 400 vehicles per hour) which minimize the probability of multiple vehicle presence, a significant portion of traffic at two Interstate 90 sites is unweighable because of this limitation. The software can be extended to allow weighing of simultaneous vehicles if moment influence lines are computed for individual structure girders.

5.0 Future Plans

1985 marks the beginning of sustained production use of the bridge weigh in motion system. Knowledge already gained has prompted new questions and desires for increased system performance. Likewise, questions concerning the use of collected information also arise.

5.1 1985 Truck Weight Study

The most immediate use of the bridge weigh in motion system, already in progress, is to complete South Dakota's 1985 Truck Weight Study. Trucks are being weighed and classified at interstate, main rural, secondary and urban sites. The entire study will be performed at in motion weighing sites; portable scales used in previous studies will not be used.

5.2 Expanded Use in Weighing

Expansion of weighing coverage, both in terms of number of sites and times of weighing activity, will be possible with the system. While the 1985 Truck Weight Study is being conducted at approximately the same number of sites as previous studies, and during approximately the same time periods, many more potential weigh in motion sites exist. Repeated visits to already calibrated sites during other seasons than summer will increase understanding of seasonal traffic and weight variations. And for the first time, twenty-four hour weighing activity is possible, allowing observation of time of day effects on loading, particularly with regard to overweight detection.

All of these options are presently being considered subject to information need and operational and manpower constraints.

5.3 System Modification

As previously mentioned, the photocells' inability to function in rain will make development or acquisition of an alternate axle sensor desirable. Preliminary work has been done using coaxial cable sensors, but these are not yet entirely operational.

Modification of system software to allow weighing of vehicles simultaneously present on the structure is of medium priority. While no changes in system hardware would be required, the software would require changes at all levels. No decision has yet been made to add this capability.

Finally, development of a portable system capable of unattended operation would seem extremely beneficial, especially for use on very low volume highways. While the system would not enjoy the benefit of an operator's observation of the weighed vehicle's body type, its ability to weigh vehicles for several days would increase the statistical validity of the weights at decreased operator cost. While no final design has been proposed, it is probable that such a system, which would use already instrumented structures, could be assembled for under $20,000.

5.4 Accuracy and Error Analysis

Analysis of system accuracy should be an ongoing aspect of any weigh in motion program. During the fall of 1985, in motion weights will be compared on a vehicle by vehicle basis with weights obtained by Highway Patrol portable and permanent port of entry scales. The data will be analysed for both bias and variance in gross and individual axle weights. In addition, the accuracy of axle spacing determination and vehicle, body and commodity code assignments will be checked in conjunction with the weight accuracy studies.

Beyond cross checking weights and dimensions with other scale systems, it would be highly desirable to build validity checking into the weigh in motion system itself. The method of axle weight solution, for example, is very similar to the problem of multiple regression; the unknown axle weights correspond to the unknown regression coefficients. Statistical methods which allow for the calculation of uncertainty in the regression coefficients could perhaps be applied to compute the uncertainty in the weight calculations. Highly suspect in motion weights could be flagged and selectively included or excluded from data. To date only preliminary work has been conducted in this area.

5.5 Weight Data Implications

Perhaps the most significant future efforts will concern reevaluation of pavement designs and load predictions. While the Truck Weight Study is not yet complete, it is very likely that the loads weighed by in motion equipment will average heavier than loads previously measured at portable installations because of less truck avoidance. Still, the weights will have a certain level of uncertainty attached to them. Questions of whether design procedures should be altered to accomodate the new level of information will become very important. The results of the truck weight study should at least raise these questions, if not provide their answers.

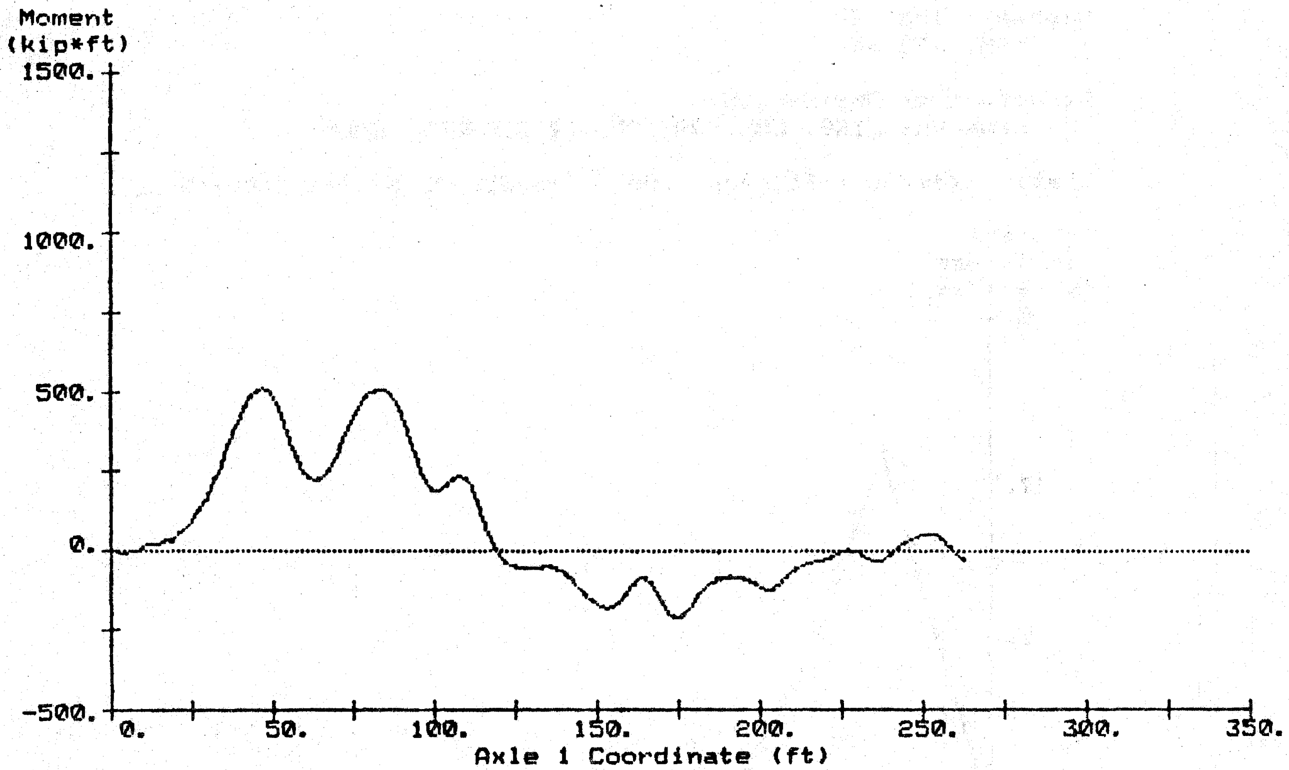
6.0 Conclusion

The bridge weigh in motion system developed by the South Dakota Department of Transportation has proved itself capable of sustained weighing with accuracies comparable to other in motion systems. Its continued use beyond the 1985 Truck Weight Study will open up new possibilities for improving the quality of truck weight information throughout the state.

WIM001: SDDOT Bridge Weigh in Motion System 10-AUG-85 17:46:05
Vehicle Induced Moment Record

Highway: 1038 E System: 2
MRM: 368.34 Station: 312

Structure #: 50-184-195



Coord (ft)	Moment (kip*ft)	Coord (ft)	Moment (kip*ft)	Coord (ft)	Moment (kip*ft)	Coord (ft)	Moment (kip*ft)	Coord (ft)	Moment (kip*ft)	Coord (ft)	Moment (kip*ft)	Coord (ft)	Moment (kip*ft)	Coord (ft)	Moment (kip*ft)
-3.9	-1.5	29.6	162.6	63.1	219.4	96.7	227.1	130.2	-54.9	163.9	-82.2	197.5	-97.7	231.2	-12.4
-1.8	-8.9	31.7	217.1	65.2	230.5	98.8	194.2	132.3	-52.0	166.0	-94.9	199.6	-111.5	233.3	-25.5
0.2	0.2	33.8	258.7	67.3	253.7	100.9	186.4	134.4	-45.7	168.1	-127.3	201.7	-119.4	235.4	-31.5
2.3	-5.8	35.8	324.4	69.4	286.1	102.9	197.5	136.5	-51.2	170.2	-167.6	203.8	-117.8	237.5	-27.3
4.4	-5.3	37.9	377.7	71.5	340.4	105.0	216.8	138.6	-60.1	172.3	-203.0	205.9	-102.6	239.6	-13.0
6.5	0.8	40.0	426.7	73.6	393.2	107.1	233.2	140.7	-76.8	174.4	-215.4	208.0	-80.2	241.7	4.8
8.6	1.4	42.1	476.9	75.7	434.3	109.2	230.7	142.8	-97.3	176.5	-204.2	210.1	-61.2	243.8	23.7
10.7	19.1	44.2	498.3	77.8	472.3	111.3	203.7	144.9	-123.0	178.6	-178.1	212.2	-47.5	245.9	36.5
12.8	19.6	46.3	515.6	79.9	496.9	113.4	150.2	147.0	-144.1	180.7	-142.8	214.3	-39.0	248.0	46.3
14.9	20.8	48.4	507.7	82.0	506.7	115.5	88.4	149.1	-162.1	182.8	-117.5	216.4	-32.8	250.1	54.5
17.0	39.3	50.5	472.7	84.1	509.8	117.6	31.9	151.2	-176.6	184.9	-99.2	218.5	-30.4	252.2	53.6
19.1	31.2	52.6	426.3	86.2	498.1	119.7	-10.2	153.3	-180.3	187.0	-86.2	220.6	-24.4	254.3	49.9
21.2	60.4	54.7	353.0	88.3	468.2	121.8	-34.2	155.4	-173.3	189.1	-81.6	222.7	-11.9	256.4	31.5
23.3	72.3	56.8	298.9	90.4	417.0	123.9	-47.2	157.6	-150.7	191.2	-79.4	224.9	0.4	258.5	5.7
25.4	101.7	58.9	251.3	92.5	350.4	126.0	-52.2	159.7	-121.5	193.3	-80.2	227.0	4.8	260.7	-17.0
27.5	137.4	61.0	227.6	94.6	286.7	128.1	-54.5	161.8	-96.6	195.4	-87.3	229.1	0.7	262.8	-30.5

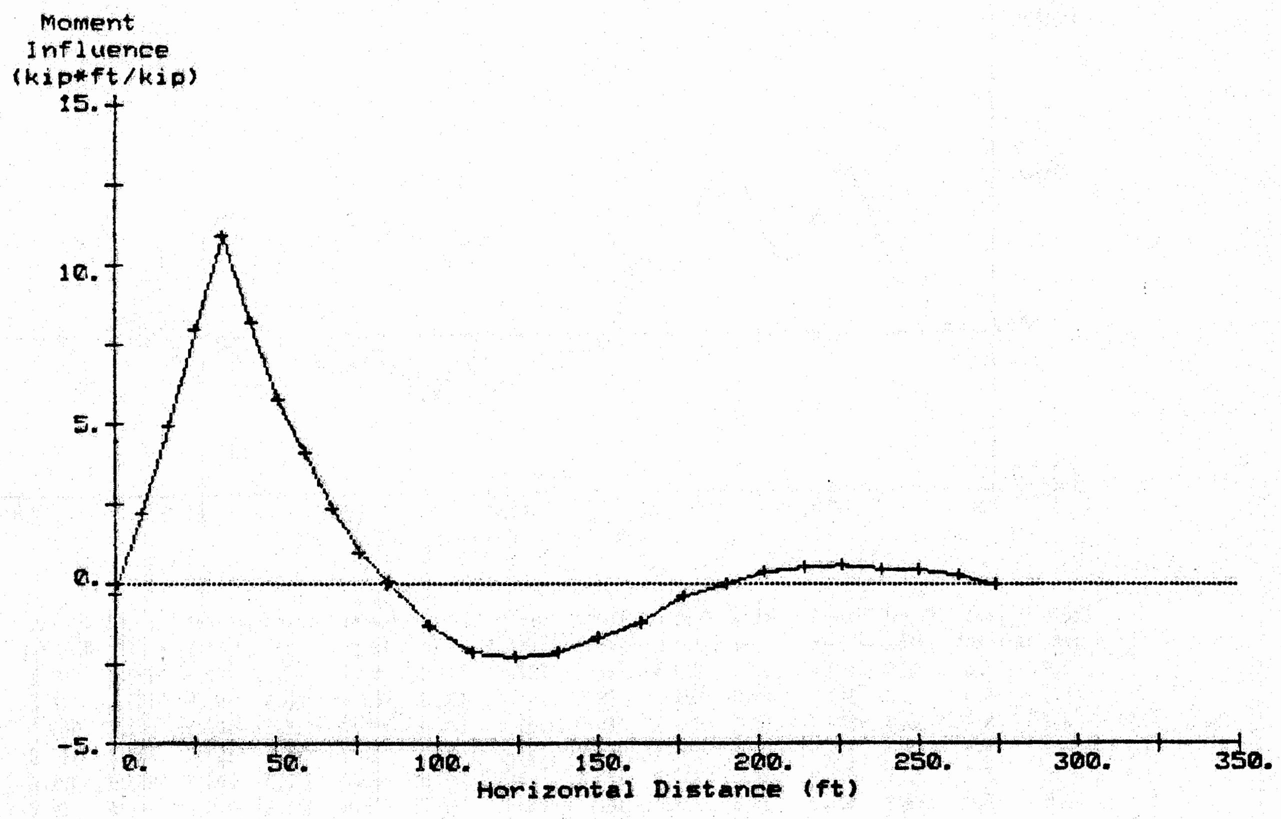
Figure 1. Record of total moment induced at strain gage locations during passage of a five axle truck semi-trailer combination. Note the dynamic components due to vehicle suspension and highway profile interaction.

WIM001: SDDOT Bridge Weigh in Motion System 10-AUG-85 17:55:32
Bridge Moment Influence Line Document

Highway: 1038 E System: 2
MRM: 366.34 Station: 312

Structure #: 50-184-195
Remarks: FIRST CALIBRATION, 60 DEGREES, CALM

Static Moment Influence Line on 28-JUN-85 08:34:22-09:19:52



Coordinate (ft)	Moment Influence (kip*ft/kip)	Coordinate (ft)	Moment Influence (kip*ft/kip)	Coordinate (ft)	Moment Influence (kip*ft/kip)	Coordinate (ft)	Moment Influence (kip*ft/kip)	Coordinate (ft)	Moment Influence (kip*ft/kip)
0.0	-0.295	50.7	5.750	97.7	-1.287	163.4	-1.199	225.9	0.576
8.4	2.194	59.2	4.062	110.0	-2.124	176.5	-0.402	237.9	0.478
16.9	4.916	67.6	2.359	124.0	-2.277	189.6	-0.017	250.0	0.446
25.3	7.952	76.1	1.007	137.1	-2.152	201.7	0.359	262.1	0.303
33.7	10.902	84.6	0.093	150.2	-1.693	213.8	0.520	274.2	-0.029
42.2	8.196								

Figure 2. Moment influence line determined from calibration using a vehicle of known axle spacing and weight. Maximum is attained at strain gage location. Zeros occur at span endpoints.

Mnemonic	Vehicle Type
MOT	Motorcycle
CAR	Car
PUP	Pickup
PUC	Pickup with camper
PNL	Panel
CYL	Carryall
LUT	Light utility
PNC	Personnel and cargo
SUT	Single unit truck
TST	Tractor-semitrailer
TTR	Tractor-trailer
2TC	Tractor-semitrailer-trailer

(a)

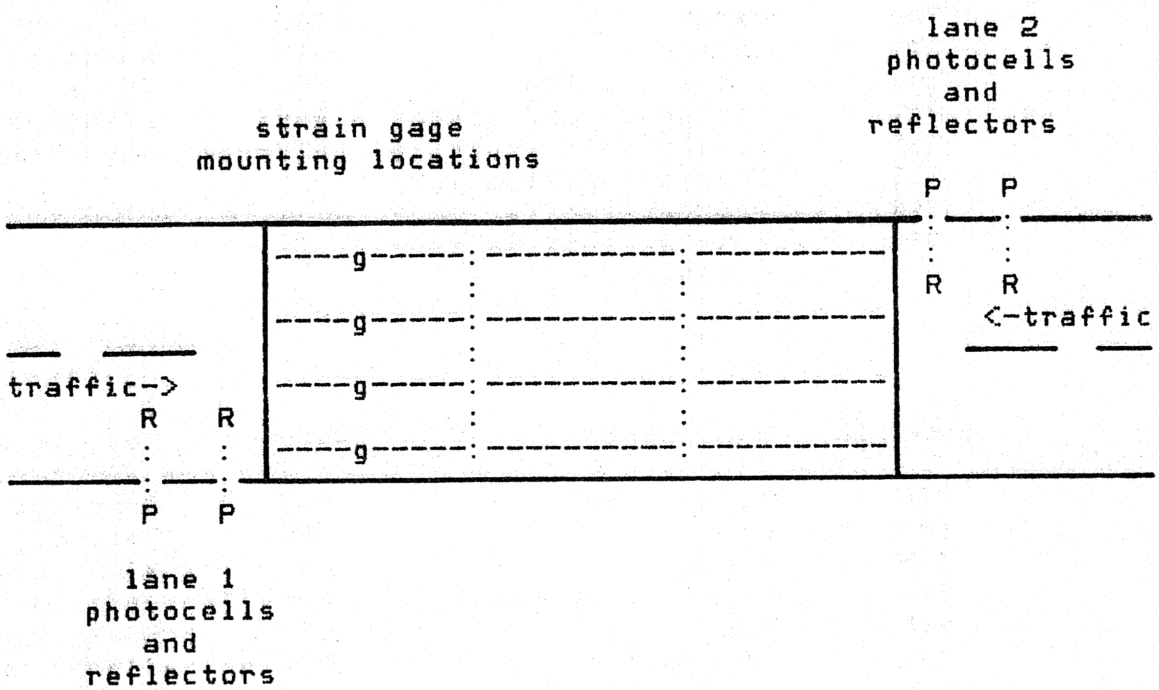
Mnemomic	Trailer Type
CAM	Camping
MOB	Mobile home
CGO	Cargo
BTT	Boat trailer
EQU	Equipment
ATO	Automobile
TRK	Truck
SLB	Slantback
ANY	Any other

(b)

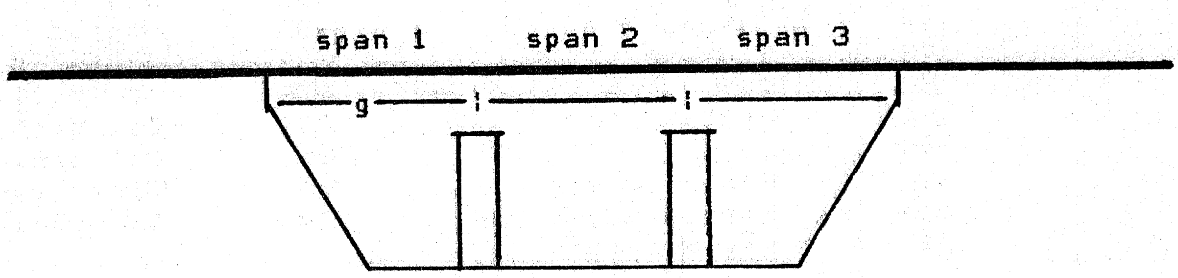
Mnemonic	Body Type	Mnemonic	Body Type
MOT	Motorcycle	BOT	Beverage bottler
CAR	Car	DEL	Delivery
PUP	Pickup	AUT	Auto carrier
PUC	Pickup with camper	ARM	Armored
PNL	Panel	BTC	Boat carrier
CYL	Carryall	MIX	Cement mixer
LUT	Light Utility	WRK	Wrecker
PNC	Personnel and cargo	UTL	Utilities
FLT	Flatbed	GAR	Garbage
LOB	Lowboy	CON	Container
RAK	Rack	EQP	Equipment
STK	Stock	CHS	Bare chassis
RIG	Drill or oil rig	SHP	Shop
LUM	Lumber	DWL	Dwelling
LOG	Log carrier	BUS	Bus
CNP	Canopy	HOP	Hopper
EXP	Express	ELG	Empty log trailer
BOX	Box	NTR	No trailer
GRN	Grain	DST	Oil distributer
DMP	Dump	OIL	Oil tanker
VAN	Enclosed van	TNK	Other tank
REF	Refrigerated van	CHM	Chemical
MOV	Moving van		

(c)

Figure 3. Vehicle (a), trailer (b) and body (c) type mnemonics and corresponding meanings. The operator may enter one mnemonic of each type to completely identify the weighed vehicle.



(a)



(b)

Figure 4. Plan (a) and profile (b) representations of a typical three span, four steel girder bridge, showing the locations of strain gages and axle sensing photocell and reflector pairs.

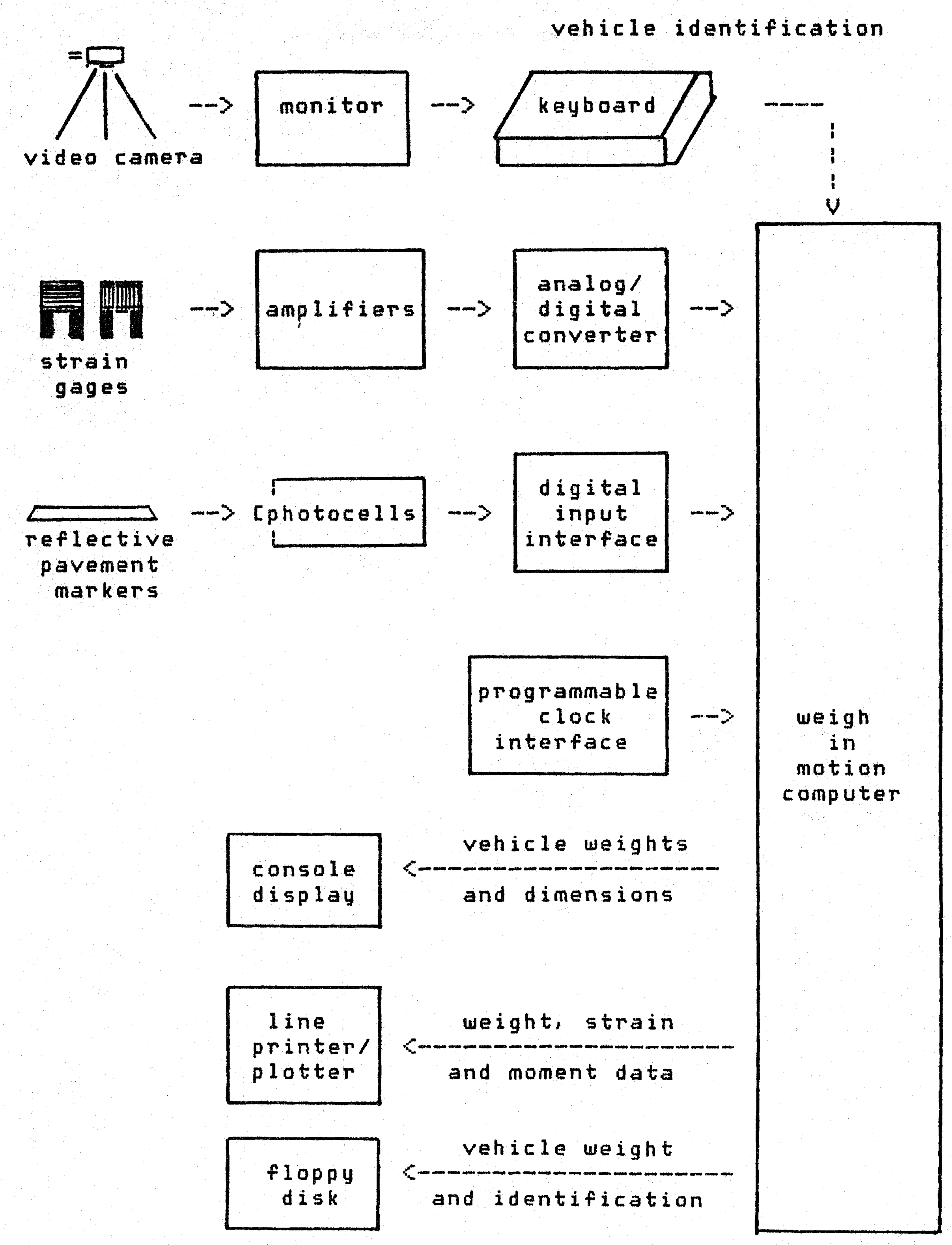


Figure 5. Functional diagram of weigh in motion instrumentation system.

A REPORT ON "THE FIELD EVALUATION OF FHWA VEHICLE CLASSIFICATION CATEGORIES"

A Paper Presented At
The Second National
Conference On W.I.M.
At Atlanta May 20-24, 1985

Prepared By:

John H. Wyman
Materials & Research Division
Maine D.O.T.

TABLE OF CONTENTS

1.0 INTRODUCTION

Vehicle classification data are extremely important as planning information for use by the various States' Transportation Departments in their efforts to allocate costs associated with highway damage and repair. Such data is also important for use by the Road Planning and Design Engineers. The volume of such data required makes automatic collection of it imperative, as manual collection becomes a much too lengthy and costly operation.

The Maine Facility under a study entitled, Evaluation of Vehicle Classification Equipment, Lyles and Wyman, September 1982 reviewed five possible classification schemes. Classes in these five schemes ranged from 7 to 32 categories. A scheme with 14 categories and called scheme "E" was selected as the most likely candidate to provide the best compromise for collection of data with the optimum number of vehicle classes of interest.

The FHWA Office of Highway Planning and the various states reviewed the vehicle classes chosen in scheme "E". After this review certain changes and additions to the scheme were suggested.

The FHWA Office of Highway Planning then requested an agency to review the proposed changes and also undertake a study of the accuracy and quality of the available equipment to record such data in the field.

The Materials and Research Division of the Maine Department of Transportation received a contract to perform this study.

2.0 STATEMENT OF WORK

The object of this project study was to evaluate the ability of presently available automatic vehicle classifiers to accurately identify the vehicle types in the FHWA classification scheme.

In addition a review of the scheme "E" was required with attention to any possible corrections and changes needed to bring the scheme into conformity with the changes suggested in the FHWA review. Scheme "E" is shown in detail in Table 1.

After revision of the scheme as required, development of decision rules shall be undertaken to permit the writing of logic programs for each system to permit sorting of vehicles to the final scheme.

TABLE 1
CLASSIFICATION SCHEME "E"

Vehicle Categories	Description	Proposed Rule
E-1	Passenger cars, light trucks, vans	Axles = 2 and wheelbase ≤ 10'
E-2	Heavy-duty pick-ups, delivery trucks, 2A6T's	Axles = 2 and wheelbase > 10'
E-3	Cars and light trucks with one-or-two-axle trailers	Axles = 3 or 4 and 1,2 spacing ≤ 10' and 5.5' < 2,3 spacing < 22'
E-4	Three-axle SU trucks	Axles = 3 and not E-3
E-5	Trucks and semi-trailers - 2S2	Axles = 4 and not E-3 and 3' ≤ 3,4 spacing ≤ 10'
E-6	Four-axle SU trucks	Axles = 4 and not E-3 and 3' ≤ 2,3 spacing ≤ 5'
E-7	Other four-axle combinations	Axles = 4 and not E-3, E-5, and E-6
E-8	Trucks and semi-trailers - 3S2	Axles = 5 and 2' ≤ 4,5 spacing ≤ 10'
E-9	Other five-axle combinations	Axles = 5 and not E-8 and 3' ≤ 2,3 spacing ≤ 5'
E-10	Trucks and semi-trailers plus full trailers - 2S1-2	Axles = 5 and not E-8 or E-9
E-11	Trucks and semi-trailers plus full trailers - 3S1-2	Axles = 6 and 5,6 spacing > 7'
E-12	Trucks and semi-trailers - 3S3	Axles = 6 and not E-11 and 4,5 spacing ≤ 6'
E-13	Other six-axle combinations	Axles = 6 and not E-11 or E-12
E-14	Other seven-or-more-axle combinations	Axles = 7 or more

Undertake an evaluation of the equipment supplied by five companies who had agreed to supply their systems with logic programs either to scheme "E" or with the changes suggested by the FHWA.

The companies are:

1. Golden-River Corp.
2. I.R.D.-C.M.I. Dearborn
3. Sarasota Automation
4. Streeter-Amet
5. G.K. Instrument Co. Ltd.

The equipment is to be evaluated by two means. One, by a check to determine the classification accuracy and two, by a longer term test of approximately one to two weeks of operation, to determine the ability of the equipment to operate over typical field data collection periods, without problems or failures.

Tests are to be run on a rural two lane road and on the Interstate system.

3.0 SYSTEMS AVAILABLE FOR TEST

Table 2 shows the characteristic of the five systems available for test. Lane capacity, type of sensors used, approximate cost, and data available on read out are provided in chart form with other characteristics of interest.

In order to provide data inputs from the road for processing by the microprocessor systems certain in road sensors are required. Technical details of the operation of inductance loops and other sensors are given in considerable detail in a report by Lyles-Wyman, FHWA/Pl/80/006 dated August 31, 1980 entitled, "Evaluation of Speed Monitoring Systems" conducted by the Maine Facility, Materials and Research Division of the Maine Department of Transportation and sponsored by the FHWA Office of Highway Planning under contract DOT-FH-11-9401.

Briefly, in order for a system to provide a classification ability an axle count and the speed of the vehicle must be available to the system.

Several different methods are used to collect such data. The I.R.D. system uses two inductance loops to obtain speed information and a permanently installed magnetic type axle counter. This axle counter also provides information on dual wheels.

TABLE 2
CHARACTERISTICS OF SYSTEMS

SYS. #	COMPANY & MODEL	# CLASS.	LANES CAP.	APPROX. COST**	SENSORS	RECORDING MEDIUM	POWER SOURCE	PRINT OUT Ind. Veh.	PRINT OUT Sum. Tables	READOUT	
1	C.M.I. Dearborn IRD Class.	14	2 4 6	21,000 24,500 30,500	Ind. Loops Axle Counter	Solid State Bat. Protected	120v 60 Hertz A.C.	yes	yes	Class	Speed Length Axle Spacing
2	Golden River Weighman MK-3	14	1*	25,000	Ind. Loops Axle Counter	Solid State Bat. Protected	6v D.C. Bat.	yes	yes	Class	Speed Weight Length
3	Streeter-Amet 141A 140A	13	1	3,875	Pneu. tubes	Cassette Tape	12v D.C. Bat.	no	yes	Class	--
4	G.K. Instrument Model 6000	14	1	3,090	Pneu. tubes	Solid State	12v D.C. Bat.	no	yes	Class	--
5	Sarasota VC 1900	7	1	4,600	Ind. Loops	Solid State	12v D.C. Bat.	no	yes	Lengths	Speed

* One lane per pad.
** See appendix II for details of costs. Cost of installation of permanent axle counter not included in estimate.

The Golden-River system uses two inductance loops and a pad type axle counter. (This pad also permits axle weight recording, but an evaluation of this ability was not conducted as a part of this study).

The Streeter-Amet and the G.K. Instrument systems use two pneumatic tubes or hoses stretched across a single lane.

The Sarasota system uses two inductance loops and thus classifies by vehicle lengths only.

4.0 REVIEW OF CLASSIFICATION SCHEMES

As a result of the study of the comments received on the FHWA and the states review of the original scheme "E" a new scheme labeled for reference scheme "F" was developed so as to provide the correction of some logic errors in the original scheme "E" and also to permit the addition of motorcycles and buses to the classification list. Scheme "F" is shown in flow chart form on Tables 3 thru 3F.

5.0 EVALUATION

The testing and evaluation consisted of three phases. One, an initial review of each system to ascertain that all systems worked as received. All systems had some problems which were resolved during this phase. Phase two, which was called 'Proof Testing', was a check made of each systems' ability to classify correctly. Testing for this phase was conducted on U.S. Route 2 at the Maine Facility where a trailer for recording equipment and photographic equipment was available. This test was done on each system by observing the passage of approximately 500 vehicles of all classes thru the system and photographs were also made where required and analyzed to aid in clarifying decisions as to classification categories.

Since each system uses slightly different logic; i.e., some use scheme "E" and some incorporated the additions of scheme "F", the test was performed to check each systems' ability to classify correctly to its own logic scheme.

Phase three, the volume test runs, were conducted over several 24 hour periods either on U.S. Route 2 for the permanent I.R.D. and the semi-permanent Golden-River system or on Interstate 95 northbound at Pittsfield for the road tube systems. Inductive loops for the Sarasota system were available at the Route 2 site so the volume tests on this system were also carried out there. The results of these tests are summarized on Table 4.

SCHEME "F" FLOW CHART

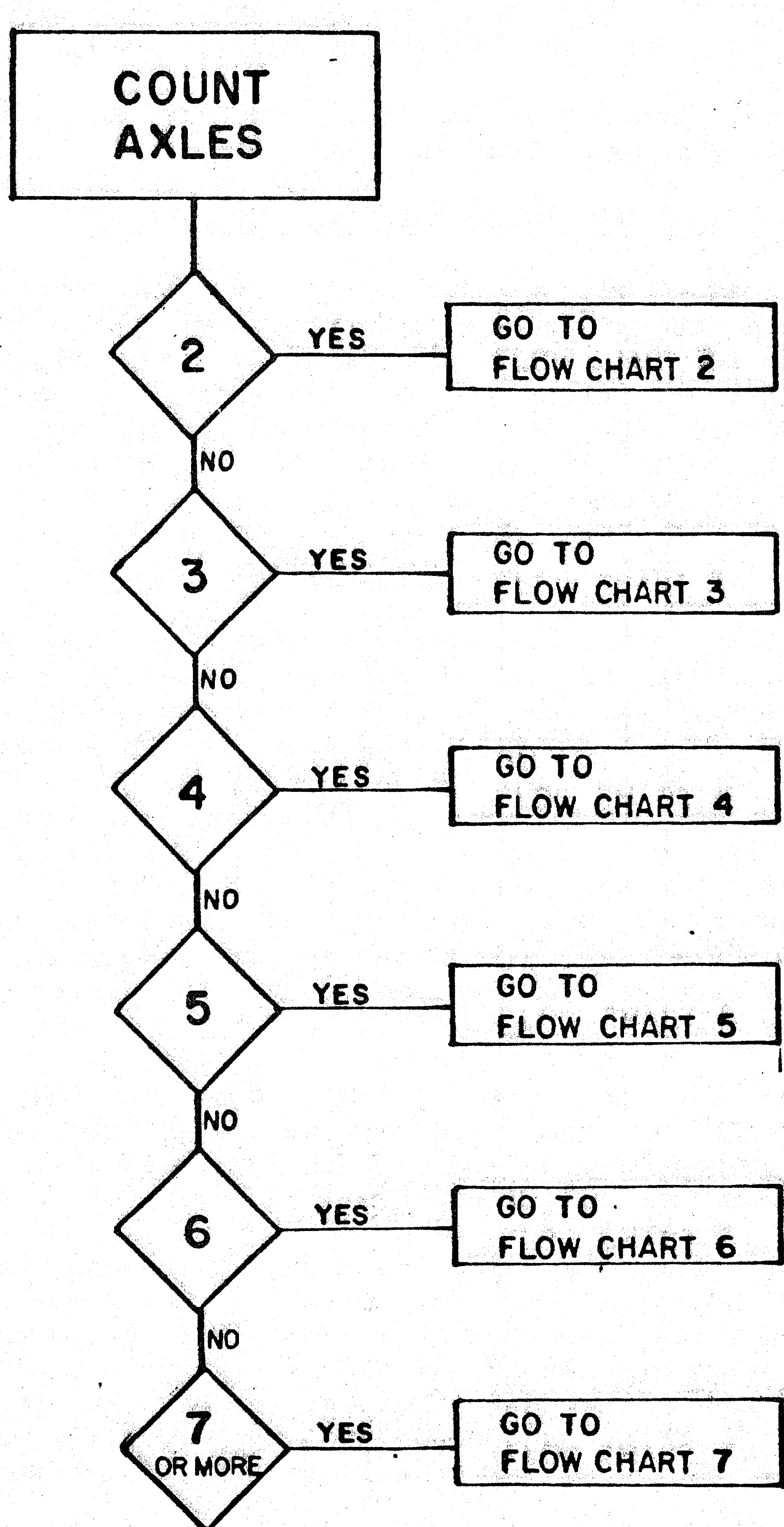


TABLE 9

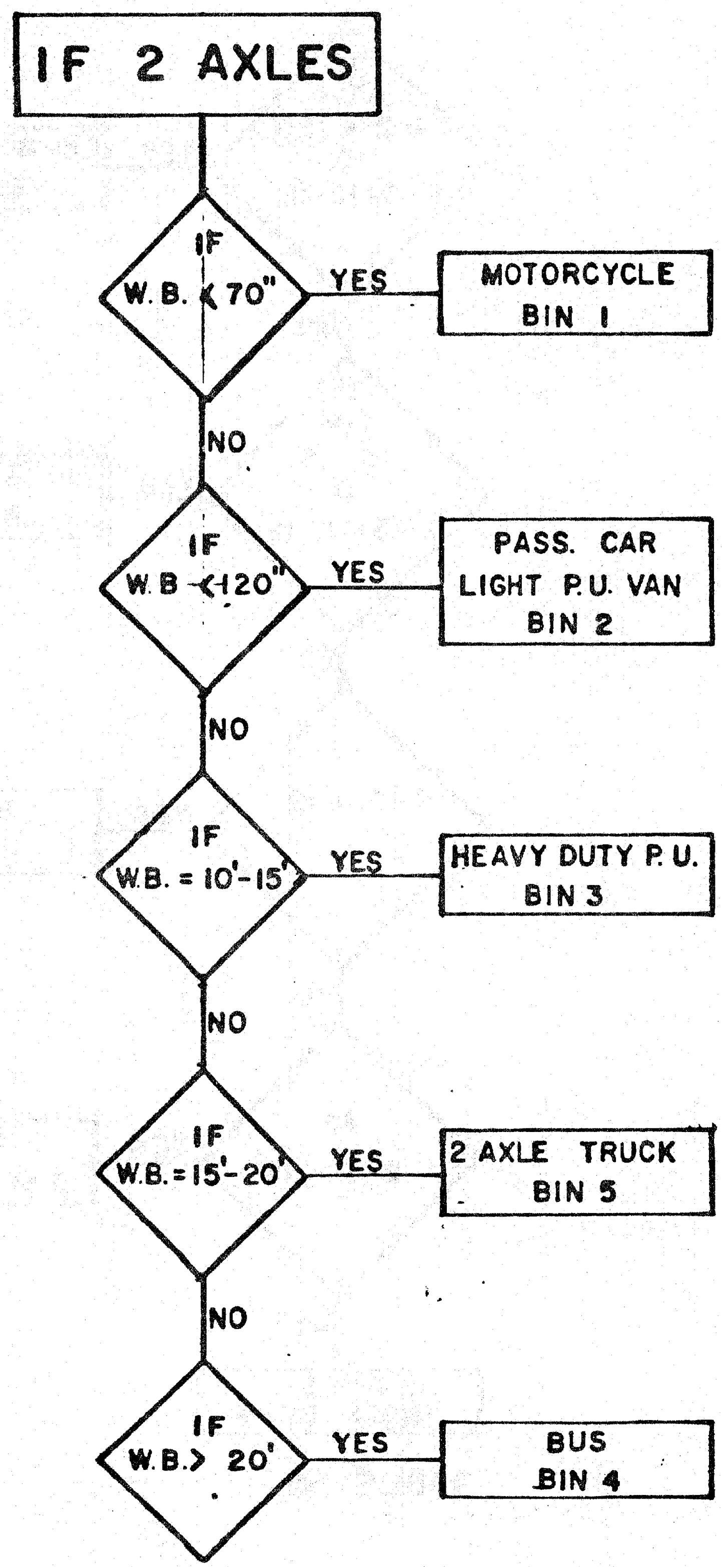

IF 2 AXLES
IF W. B. < 70"
YES
MOTORCYCLE BIN 1
NO
IF W. B < 120"
YES
PASS. CAR LIGHT P.U. VAN BIN 2
NO
IF W.B. = 10'-15'
YES
HEAVY DUTY P. U. BIN 3
NO
IF W.B. = 15'-20'
YES
2 AXLE TRUCK BIN 5
NO
IF W.B. > 20'
YES
BUS BIN 4

TABLE 3a

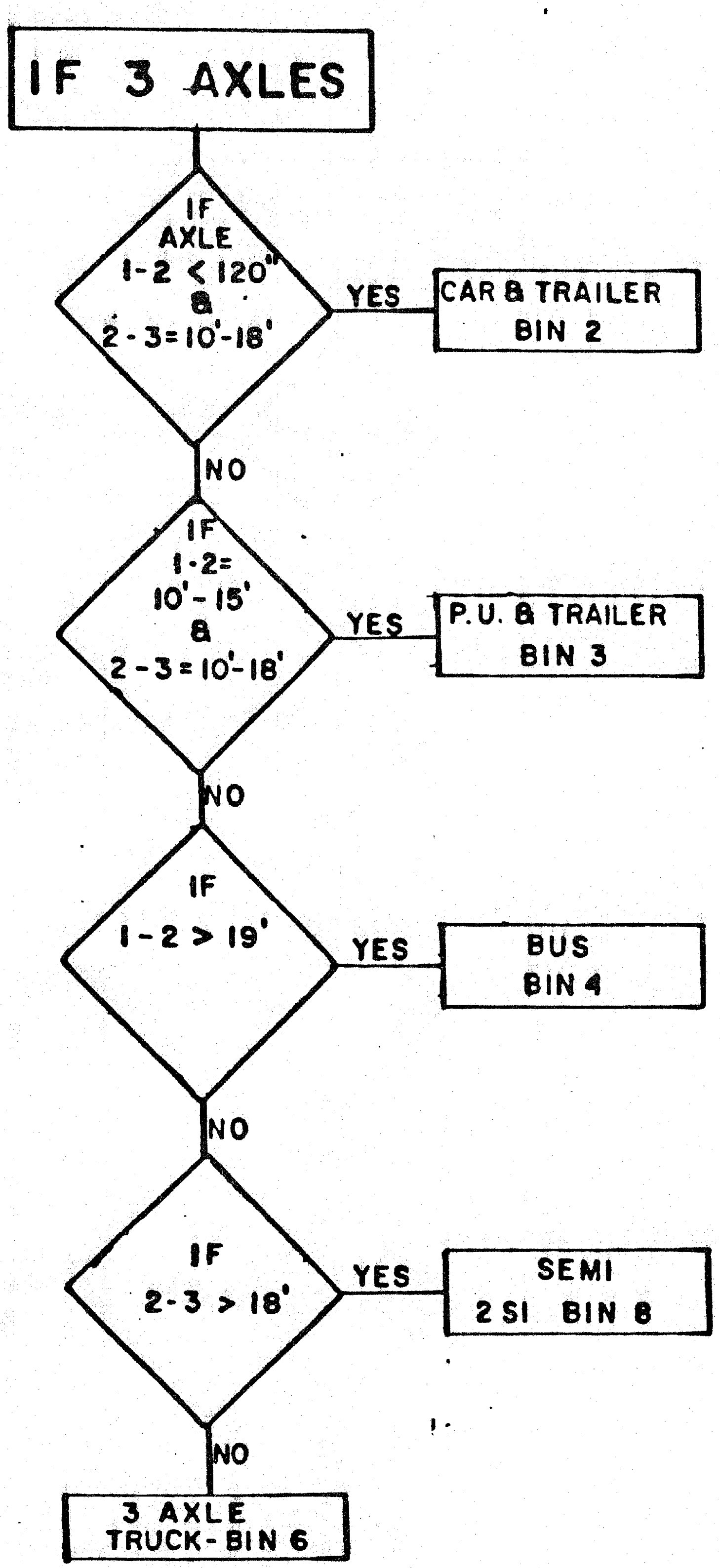

IF 3 AXLES
IF AXLE 1-2 < 120" & 2-3=10'-18'
YES
CAR & TRAILER BIN 2
NO
IF 1-2= 10'-15' & 2-3=10'-18'
YES
P.U. & TRAILER BIN 3
NO
IF 1-2 > 19'
YES
BUS BIN 4
NO
IF 2-3 > 18'
YES
SEMI 2 SI BIN 8
NO
3 AXLE TRUCK-BIN 6

TABLE 3b

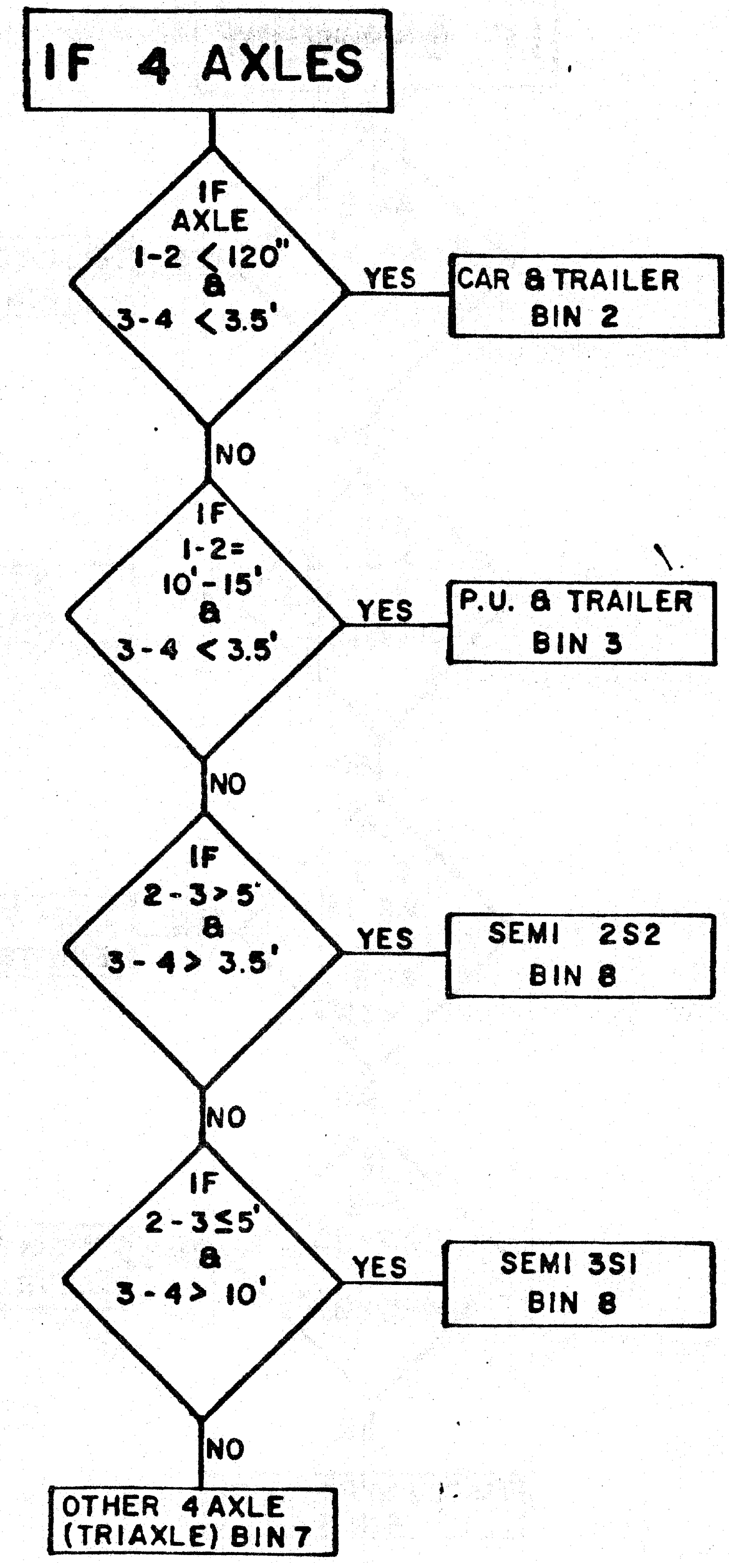

IF 4 AXLES
IF AXLE 1-2 < 120" & 3-4 < 3.5'
YES
CAR & TRAILER BIN 2
NO
IF 1-2= 10'-15' & 3-4 < 3.5'
YES
P.U. & TRAILER BIN 3
NO
IF 2-3 > 5' & 3-4 > 3.5'
YES
SEMI 2S2 BIN 8
NO
IF 2-3 ≤ 5' & 3-4 > 10'
YES
SEMI 3S1 BIN 8
NO
OTHER 4 AXLE (TRIAXLE) BIN 7

TABLE 3c

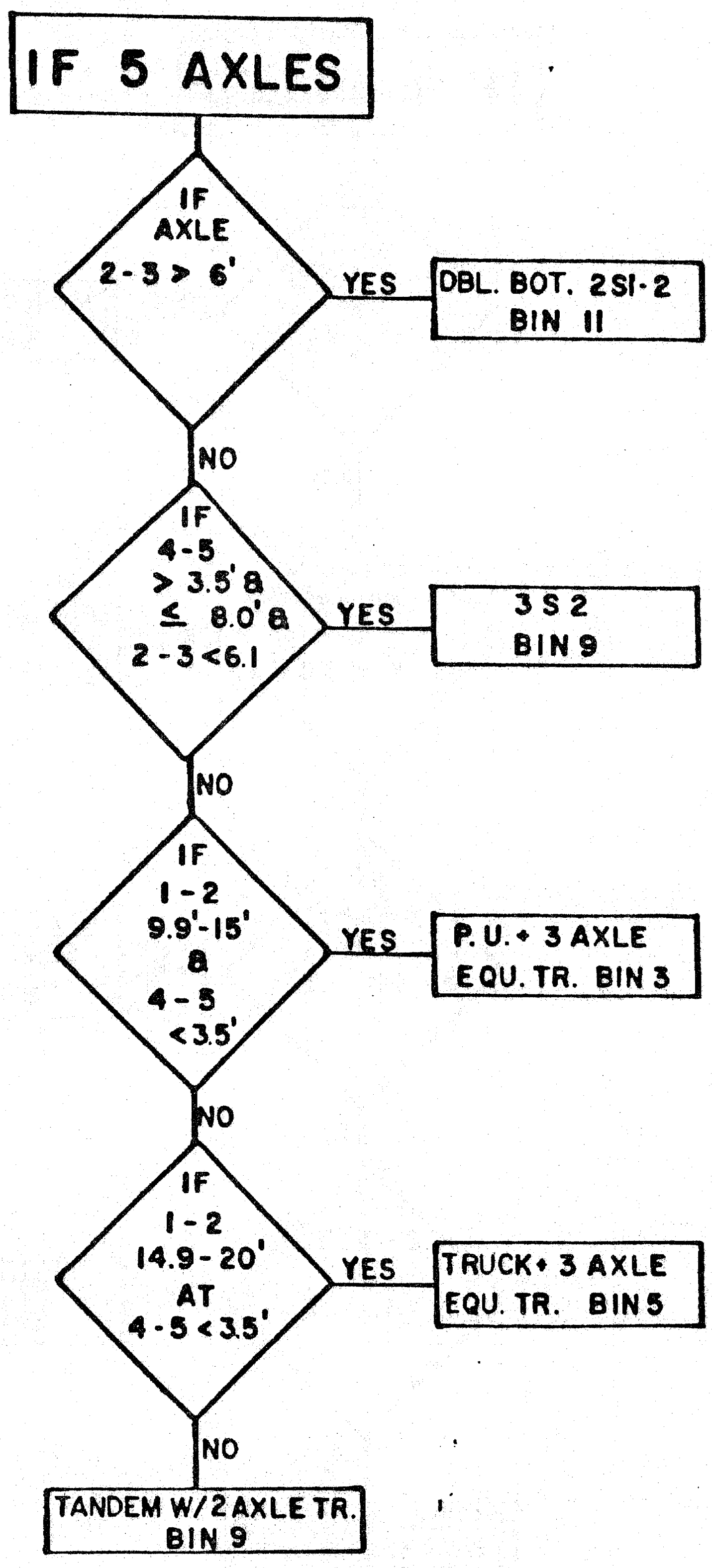

IF 5 AXLES
IF AXLE 2-3 > 6'
YES
DBL. BOT. 2SI-2 BIN 11
NO
IF 4-5 > 3.5' & ≤ 8.0' & 2-3 <6.1
YES
3 S 2 BIN 9
NO
IF 1-2 9.9'-15' & 4-5 <3.5'
YES
P.U. + 3 AXLE EQU. TR. BIN 3
NO
IF 1-2 14.9-20' AT 4-5 <3.5'
YES
TRUCK + 3 AXLE EQU. TR. BIN 5
NO
TANDEM W/2 AXLE TR. BIN 9

TABLE 3 d

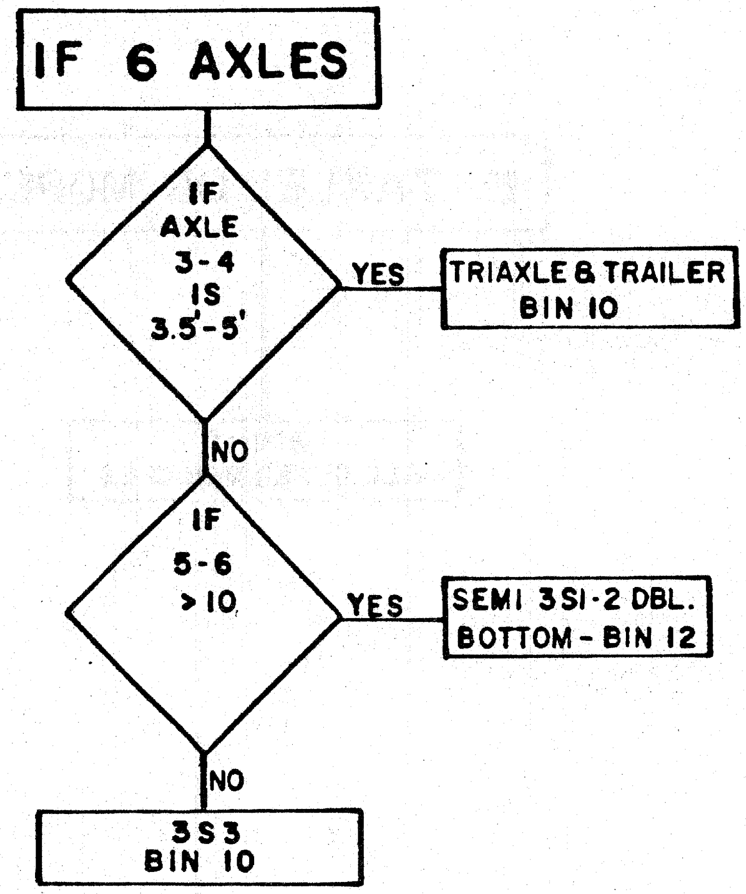

IF 6 AXLES
IF AXLE 3-4 IS 3.5'-5'
YES
TRIAXLE & TRAILER BIN 10
NO
IF 5-6 > 10
YES
SEMI 3S1-2 DBL. BOTTOM - BIN 12
NO
3S3 BIN 10

TABLE 3e

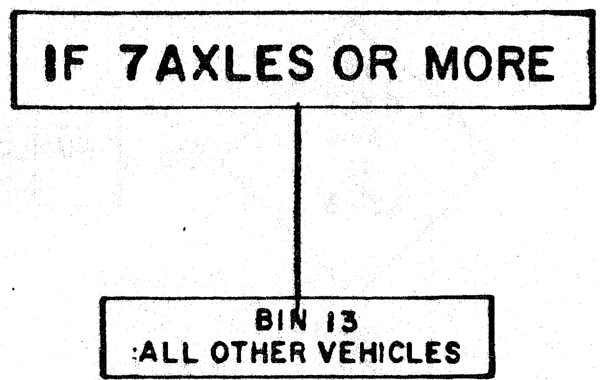


TABLE 3f

TABLE 4

AVAILABLE EQUIPMENT SUMMARY

System	Portability	Lanes	Environment	App. Cost[7]	Data Line Modem	Can Use Scheme "F"	Ind. Veh. Printout	Proof Test % Class Correct	Road Test Qual.[6]
I.R.D. Classifier	Permanent[1]	2 4 6	Year round	21,000 24,500 30,500	yes	yes	yes	91.2	OK
Golden River Weighman	Semi-[2]	1	Clear Roads	25,000	yes	yes	yes	95.9	OK
Streeter-Amet Traficomp 141A[5]	Portable-Tubes	1	Clear Roads	3,875	yes	yes	no by bins	93.5	OK
G.K. Instrument 6000	Portable-Tubes	1	Clear Roads	3,090	yes	yes	no by bins	95.5	OK
Sarasota VC-1900	Seni-Loops[3]	1	Year round	4,600	yes	no by veh. lengths only[4]	no by bins only	98.4	OK

Note 1: Loops and permanent axle counter. Cost of installation of permanent axle counters not included in cost estimates.

Note 2: Loops and removable axle counter.

Note 3: Loops only - temp. surface loops can be used.

Note 4: Sarasota informs us that they will have A1900 system operating on pneumatic tubes, classifying to Scheme "F" by Jan. 1985.

Note 5: Streeter-Amet will have available a traficomp II model 24 system using solid state programming and memory instead of the cassette type programming and memory device. Unfortunately the system was not available in time for evaluation.

Note 6: Road test qual. (quality) indicates systems performance rating under volume runs.

Note 7: See Appendix II for details of costs.

All systems survived both the phase two and the phase three tests without electronic failures. All systems had problems with missed counts. The road tube types, the Streeter-Amet and the G.K. Instrument were particularly susceptable to missed counts at slower speeds (under 20 mph) and when in queues. This problem is delt with at length in the full final report.

The I.R.D. system is a year round permanent system as is the Sarasota system (vehicle lengths only). The three other systems are clear road systems only.

Results of the testing indicate that scheme "F" is an acceptable classification system and one for which suitable logic programs can be developed for those systems using micro-processor techniques.

The FHWA Office of Highway Planning ran a computer check of scheme "F" using data supplied by the State of Washington on some 12,927 vehicle classified by types. One error in logic in scheme "F" was identified and corrected. The data was again compared by computer which indicated that scheme "F" would provide an acceptable classification system having an accuracy averaging well over 95% and better in the larger truck types.

In summary then, within the limitations spelled out in the full report, the four systems that classified by axles should provide acceptable systems for use in collecting field classification data. Where classification by length is acceptable the Sarasota system would provide an acceptable year round system.

6.0 RECOMMENDATIONS FOR EQUIPMENT IMPROVEMENT

While three different types of axle sensors were tested during this evaluation all three had serious limitations. Either high cost (the I.R.D. permanent sensor and the Golden-River axle pad, or seasonal use the pad and pneumatic tubes). The road tubes also have a short life as reported in the previous study, but they tend to fail gradually during a test run making the data collected during the run suspect.

Clearly, it is apparent that the development of a low cost, preferably permanent or at least all weather axle counter, should be high on the agenda for future FHWA or industry support.

It is recommended that work be funded for development in this area. With the FHWA requirement that the various states provide vehicle classification data on a routine basis a system with a more reliable axle counter should have top priority.

Such a sensor should be able to withstand the higher A.A.D.T.'s and also be impervious to deliberate attempts by vehicle operators to damage it.

In conclusion the importance of further work being undertaken by research or manufacturing facilities should be stressed. The classification accuracy needs improvement. The missed vehicle count problem needs investigation and finally instrument programming and data retrival systems need to be further simplified to provide more foolproof systems for easier field set up and operation.

SECOND NATIONAL CONFERENCE ON WEIGH–IN–MOTION TECHNOLOGY & APPLICATIONS
ATLANTA, GEORGIA
MAY 20 – MAY 24, 1985
AUTOMATIC VEHICLE CLASSIFICATION
AS PRESENTED
FRIDAY MORNING, MAY 24, 1985
8:30 a.m. – 12:00 Noon
Clarence Startz – Kansas

The Streeter Amet Traficomp System, including Model 141–4 Recorders was purchased in March 1981 for use in collecting data for the annual certification of the National 55 MPH Speed Limit. Affer two highly successful years of operation it was decided to investigate the possibility of expanding the use of the equipment to other areas. These areas include the following:

1. Volume Counting
2. Turning Movement Program
3. Length Classification Program
4. Vehicle Type Classification Program

In the summer of 1983 Kansas evaluated the 14–Channel Vehicle Type Program developed by Streeter Amet using two roadtubes spaced 11.5 feet apart. This program was very accurate but was used only sparingly during the evolution of the 13 FHWA classes. (SLIDE 1). This slide shows the wheel base for the two axle vehicles in the classification scheme of the original 14 Types. The axle spacings for all 14 Types are shown on page 1 of your handout. As can be noted in the slide there are differences between these 14 classes and the 13 vehicle classes recently adopted by the FHWA for standarization in reporting shown on page 2 of your handout.

During the summer of 1984 Kansas evaluated another Streeter Amet Program to classify vehicles into the 13 FHWA classes (SLIDE 2). This slide shows the wheel base spacings for only the two axles vehicles. Again complete axle spacings for all 13 types is shown on page 2 of your handout. This program was accurate in classifying the three axle or more heavy trucks but there were problems with cars, pickups and 2 Axle/6 Tire Trucks – Classes 2, 3, and 5, respectively.

Kansas then made an analysis of the wheel bases of the pickups and 2 axle/6 tire vehicles using data from the 1981 and 1983 truck weight studies. The wheel bases of cars were also studied for those listed in the 1984 NADA used car guide. The wheel bases for cars were in general 10 feet or less.

(SLIDE 3) This slide shows a frequency distribution of the wheelbases for the pickups weighed during the 1983 truck weight survey. As can be noted, the majority cluster around 11.0 feet with only 11 percent in the 11.5–17.3 foot range specified in the original program for the 13 FHWA classes. The 2 Axle/4 Tire vehicles in this exhibit have a mean of 11.0 feet and a standard deviation of 0.94 of a foot. (SLIDE 4) This slide shows a wheelbase frequency distribution for pickups weighed during the 1981 Truck Weight Survey. This is an almost mirror image of the previous slide only there is a little more pronounced peak in this data at 11.0 feet. These vehicles in 1981 had a wheelbase mean of 11.1 feet and a standard deviation of 1.07 feet. (SLIDE 5) This slide is a frequency distribution of the wheel bases of the 2 axle/6 tire trucks weighed during the 1983 truck weight survey. There is no single clear cut peak in this frequency distribution with several of about the same magnitude between 11.5 and 17.0 feet, only about 15 percent are in the 17.3 to 23.0 foot range which is specified for Class 5 on page 2 of the handout. These vehicles have a mean wheel base of 14.6 feet and a standard deviation of 2.54 feet. (SLIDE 6) A similar frequency distribution of wheel bases for the 2 Axle/6 Tire trucks is shown for those weighed in 1981. What the previous slides show is that there is a major undercount of 2 Axle/6 Tire Trucks in the initial program for the 13 FHWA types. The first five classifications of the FHWA 13 vehicle classes are all within the two axle group. It was determined that the axle spacing break points within the program needed to be adjusted carefully to obtain the most accurate breakdown between motorcycles, automobiles, pickups, 2 axle/6 tire trucks, and busses. Particular emphasis needed to be given to the pickups and 2 axle/6 tire vehicles. Based on our analysis, recommendations were developed for optimum axle spacing breakpoints to allow for the most accurate classification of vehicles. The analysis included development of what can be called "cancellation factors" whereby the number of longer wheel base automobiles (Type 2) incorrectly classified as pickups (Type 3) would be offset by the number of shorter wheelbase pickups incorrectly classified as automobiles. Similarly, the number of extra long wheelbase pickups incorrectly classified as 2 Axle/6 Tire Trucks would be offset by the number of extra short 2 Axle/6 tire trucks incorrectly classified as pickups. A factor was developed for the 2 Axle/4 Tire vehicles (Slide 7) this factor was applied to all 2 Axle/4 Tire trucks weighed during the 1983 truck weight survey. A factor could have been developed for the 2 Axle/6 tire trucks just as easily by interchanging the numerator and denominator and the factor would have been about 0.066. (SLIDE 8) This slide shows an insert from a table with the factor applied to the 2 Axle/4 tire vehicles (Column 6).The table extends upward to the vehicle with the smallest wheel base and downward to the vehicle with the largest wheelbase. The 2 Axle/6 tire trucks are in Column 7. These two columns are then summed and placed in column 8. Column 9 is an accumulation of column 8 from large to small wheelbase. What we are looking for is the break point between 2 Axle/ 4 Tire and 2 Axle/6 tire vehicles which is the number of 2 Axle/6 tire trucks weighed which is 316 as we move from bottom to top. We find this breakpoint to be at 13.0 feet.

To check the results, the analysis was repeated using the 2 Axle/4 tire and 2 Axle/6 tire vehicles weighed during the 1981 Truck Weight Survey. Even though the computed factors are considerably different–8.80 for 1981 and 15.14 for 1983 the 13.0 foot break point was verified. The data that Kansas analyzed and the recommendations resulting from that analysis were sent to Streeter Amet. The Streeter Amet Company developed a program based on the axle spacing recommended for the 13 vehicle types. The company was extremely meticulous in developing the program and expended considerable effort analyzing the data provided.

After the wheel bases for the two axle vehicles were established, the axle spacing for the three or more axle vehicles fell into place. (SLIDE 9) this slide shows the axle spacings for the 2 axle vehicles as established and programmed by Streeter Amet. Complete axle spacings for all 13 types is shown on page 3 of your handout. Note that the end points of all spacing are divisible by three and one–third.

The new program tape for the traficomp recorder 13–channel vehicle type program provides vehicle classification for one lane of traffic using two roadtubes spaced 13 feet, 4 inches apart. This roadtube spacing is a change from the roadtube spacing in the previous programs of 11 feet, 6 inches. The recorder has the data storage capacity for 160 hours using the hourly recording interval.

A test was conducted in the outside traffic lane on the interstate near Topeka. It was obvious, after a short observation period of two hours, that the machines programmed with the new tape would be satisfactory for machine vehicle classification. It correctly classified 60 eighteen wheelers (Type 9) and accuracy on other vehicle types was also observed. There was no hesitation in using the machines for the Winter Cycle of the 1985 Kansas Vehicle Classification Study. Later, the machines were set at a western Kansas Interstate location. The roadtubes for four machines were placed in each lane and a one hour visual classification check was performed for each lane. (SLIDE 10) This slide shows the results of this one hour check. Exact matches between visual classification and machine classification are shown by the figures in the diagonal, which includes 89.4 percent of the 218 vehicles. The diagonal is highlited in the slide projection to my right.

The cancellation effect makes the machine recordings even more accurate. What we are looking for is close agreement between the row totals (visual classification) and the column totals (machine classi–fication) for each vehicle type. Ninety–eight passenger cars (Type 2) were visually observed while the machines recorded 93. Forty–seven (47) pickups (Type 3) were visually observed while the machines recorded 54. Four 2 Axle/6 tire trucks (Type 5) were visually observed and because of the cancellation effect, four were also machine recorded. Fifty–eight (58) eighteen wheelers (Type 9) were visually recorded while the machines recorded 56. Similar results were obtained at four other locations. The highlights of the accuracy check at the five locations are as follows:

1. 88.2% of all vehicle types are in the diagonal.
2. 449 Autos were visually observed while the machines recorded 437.
3. 178 Pickups were visually observed while the machines recorded 186.
4. 14 Two Axle/Six Tire Trucks Type 5 were visually recorded while the machines recorded 11.
5. 83 Eighteen wheelers were visually recorded while the machines recorded 81.
6. The percent heavy commercial was 16.0% by the visual method and 16.5 as recorded by machine.
7. The 18–Kip equivalent single axle loadings were computed separately for the vehicles classified visually and by machine and were found to be within two percent.

One of the features of the program is that if a vehicle does not meet the specifications for any of the 13 types it is recorded in the hourly total only, which results in a accurate volume count. A check of the first few weeks data from the machines reveals that less than one percent of the total vehicles are being recorded outside the 13 basic vehicle types.

Some limitations of machine classification are that the roadtubes must traverse only one lane of traffic, although this cannot necessarily be considered a disadvantage. The program will only operate properly in free flow traffic, with separation between vehicles. A constant vehicle speed of at least 20 MPH is required for accurate classification, although some accurate recordings were observed for cars travelling a uniform rate of speed less than 20 MPH. The inability to count turning movements unattended is a disadvantage when compared with visual classification. Equipment malfunction could be a problem. The machines do not allow as broad of a classification as with the visual method. The visual method can also note special circumstances such as funerals, convoys, etc., which is not possible using machines. The use of roadtubes has not been a problem as is evident from continuous operation of six machines for almost 4 months. The only problem encountered was when a battery went bad on the last day.

Preventive maintenance is an important factor in getting reliable data from the machines. The inside of the roadtubes should be cleared of foreign matter with air pressure on a regular basis. Road–tubes need to be kept in matched pairs of the same length. Kansas is considering using hoses with a 60 foot length which would result in less pressure on the diaphragm of the solid state air switches. One hour accuracy counts are suggested on a regular basis for all machines. This accuracy check would spot problems with a machine early and after a long period of time factors could be developed for those vehicle types – under or overcounted, if desired. Another important factor is to use an expe–rienced person to set the machines. One of our top field persons is assigned this task.

The main advantage of the machine classification is its economy. Approximately 3.5 visual persondays are required to do the same amount of vehicle classification as one person–day using machines. This does not consider the loss of turning movements by using machines. This 3.5 to 1 machine over visual advantage was established using six machines and one person. The ratio can probably be increased when the optimum number of machines is available for one person. This is estimated to be between 6 and 10 machines. Classification consistency is also an advantage when using machines.

Weighing the advantages and disadvantages of machines for vehicle classification, the advantages far outweigh the disadvantages.

This concludes my speech. I would like to thank the Georgia DOT and the FHWA for sponsoring this conference. Being invited will always be a most memorable occasion for me. Thank You.

SLIDE 1

VEHICLE TYPE CLASSIFICATION CRITERIA (ORIGINAL 14 TYPES)

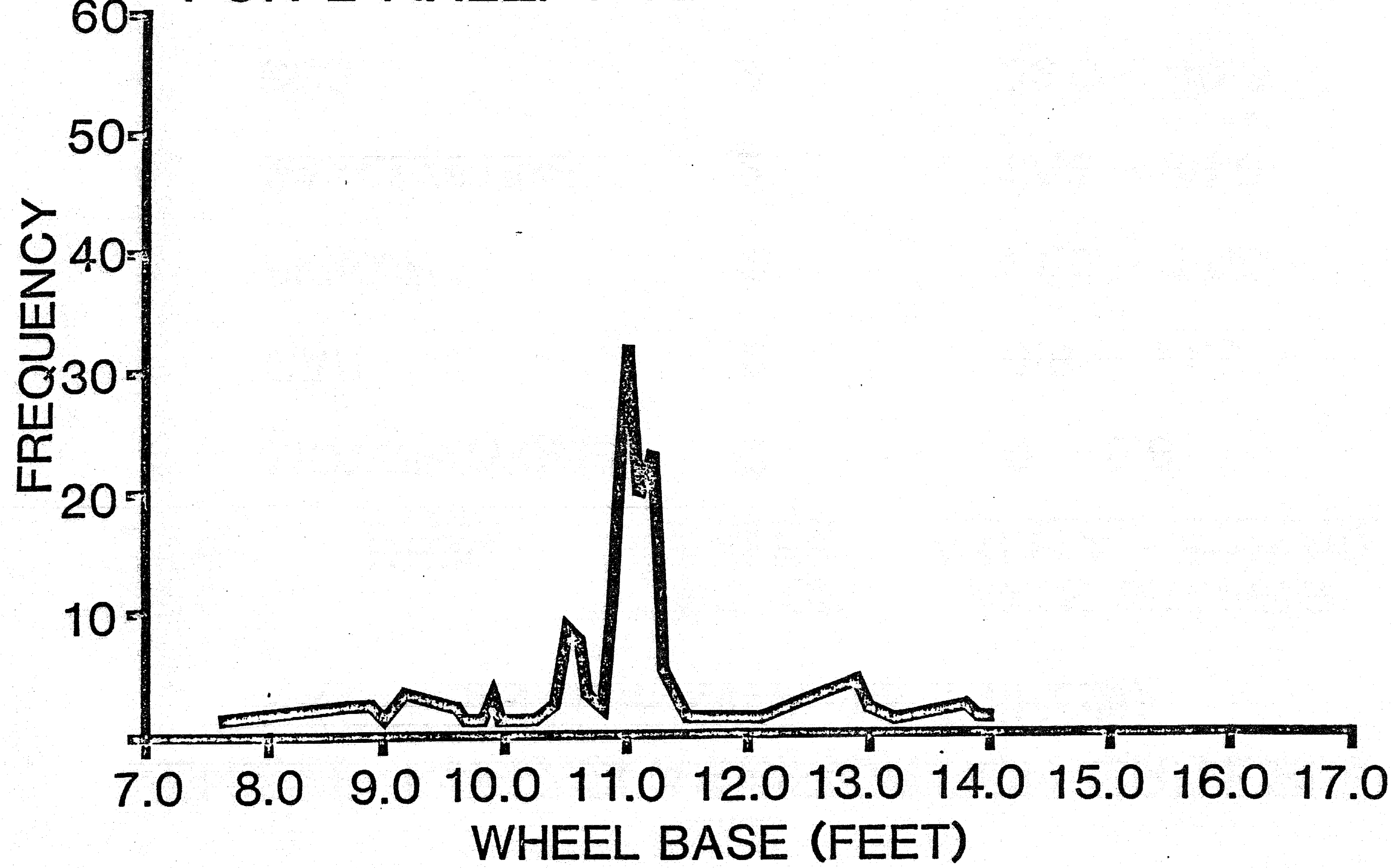
VEH. TYPE	DESC.	NO. OF AXLES	AXLE SPACING AXLE A – B (Feet)
1	SUBCOMPACT	2	5.8 – 8.6
2	CAR, PICKUP, VAN	2	8.6 – 11.5
3	2AXLE/6TIRE	2	11.5 – 23.0
4	BUS	2	23.0 – 40.3

VEHICLE TYPE CLASSIFICATION CRITERIA (ORIGINAL FHWA 13 TYPES)

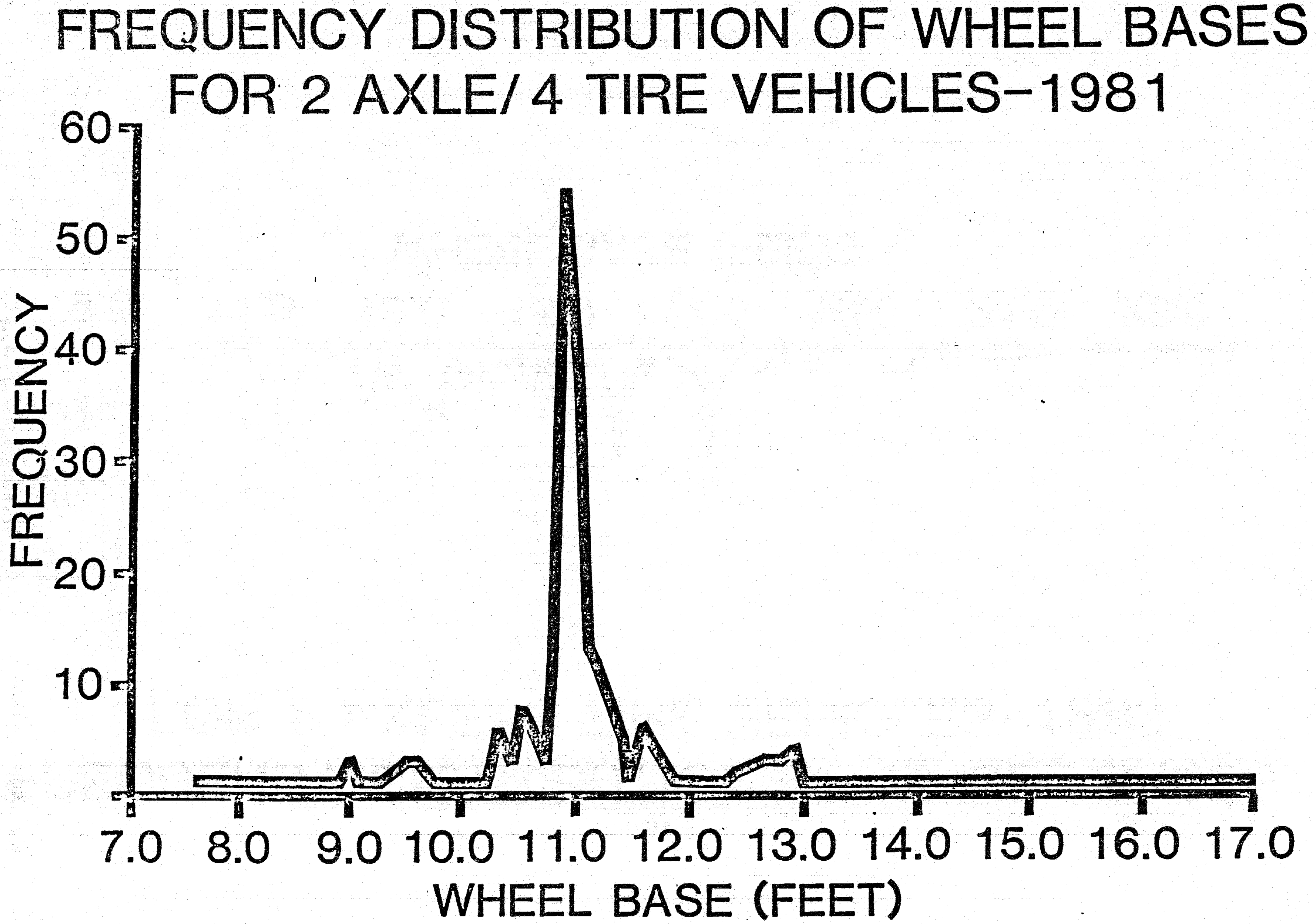
VEH. TYPE	DESC.	NO. OF AXLES	AXLE SPACING AXLE A - B (Feet)
1	MOTORCYCLE	2	0 - 5.8
2	CAR	2	5.8 - 11.5
3	PICKUP	2	11.5 - 17.3
5	2AXLE/6TIRE	2	17.3 - 23.0
4	BUS	2	23.0 - 40.3

SLIDE 3

FREQUENCY DISTRIBUTION OF WHEEL BASES FOR 2 AXLE/4 TIRE VEHICLES–1983

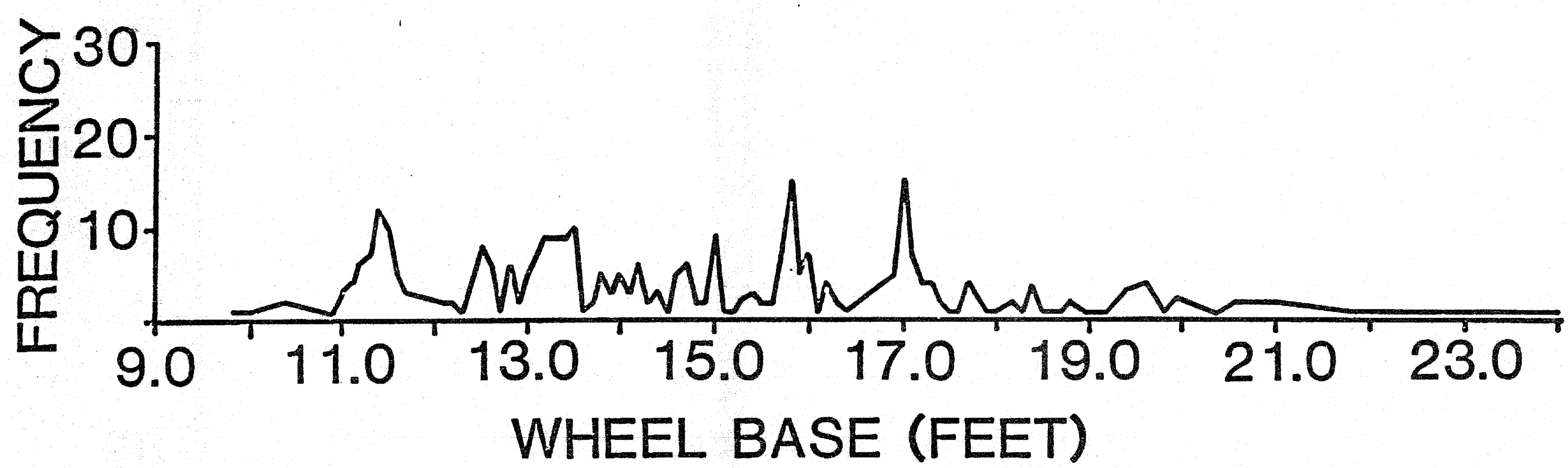


SLIDE 4


FREQUENCY DISTRIBUTION OF WHEEL BASES
FOR 2 AXLE/4 TIRE VEHICLES-1981
FREQUENCY
60
50
40
30
20
10
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
WHEEL BASE (FEET)

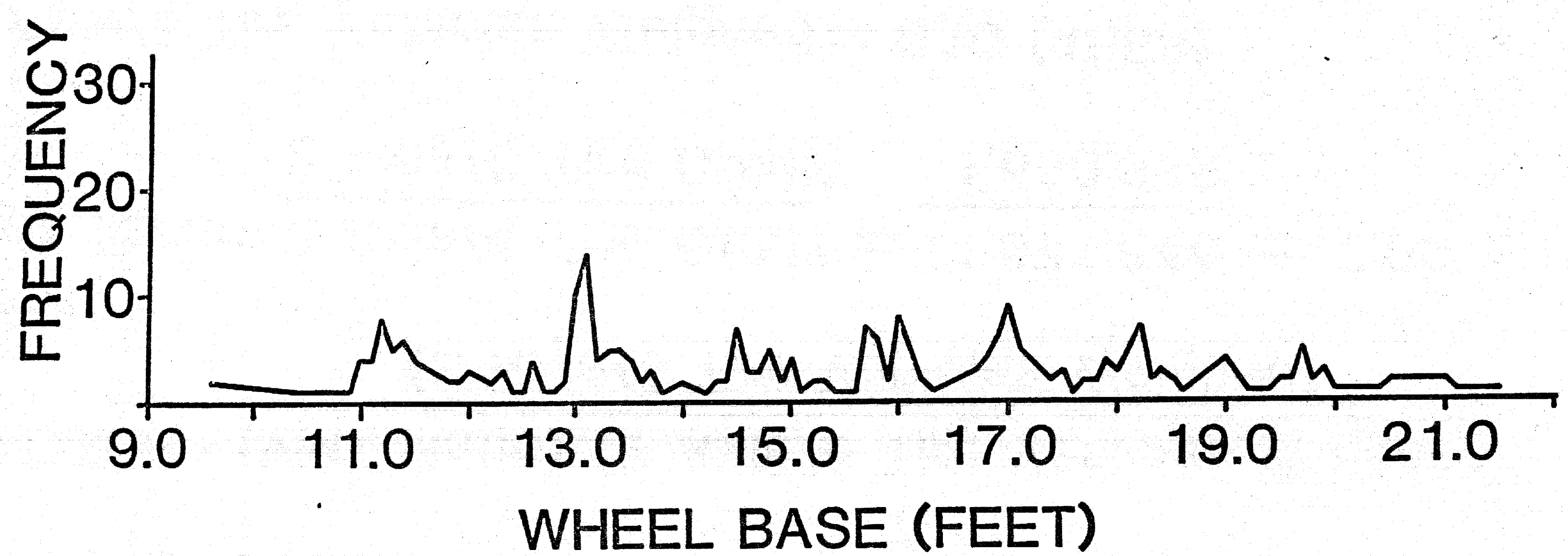
SLIDE 5

FREQUENCY DISTRIBUTION OF WHEEL BASES FOR 2 AXLE/ 6 TIRE VEHICLES–1983



SLIDE 6

FREQUENCY DISTRIBUTION OF WHEEL BASES FOR 2 AXLE/ 6 TIRE VEHICLES-1981



SLIDE 7

FACTOR FOR 2 AXLE/4 TIRE VEHICLES

$$\text{FACTOR} = \frac{(\text{VMT Ratio})\ (\text{2 Axle/6 Tire Vehicles Weighed})}{(\text{2 Axle/4 Tire Vehicles Weighed})}$$

$$\text{VMT Ratio} = \frac{\text{2 Axle/4 Tire DVMT}}{\text{2 Axle/6 Tire DVMT}} = \frac{11{,}371{,}644}{1{,}603{,}379} = 7.09$$

2 Axle/6 Tire Vehicles Weighed = 316 (1983)

2 Axle/4 Tire Vehicles Weighed = 148 (1983)

$$\text{FACTOR} = \frac{(7.09\ (316)}{148} = 15.14$$

FACTOR = 1.00 (2 Axle/6 Tire)

SLIDE 8

FREQUENCY DISTRIBUTION OF WHEEL BASES
1983 TRUCK WEIGHT SURVEY

(1) WHEEL BASE	(6) 2 AXLE 4 TIRED	(7) 2 AXLE 6 TIRED	(8) TOTAL	(9) ACCUMULATE LARGE TO SMALL
12.6		6.0	6.0	413.5
12.7		1.0	1.0	407.5
12.8		6.0	6.0	406.5
12.9	60.6	2.0	62.6	400.5
13.0	30.3	5.0	35.3	337.9
13.1		7.0	7.0	302.6
13.2	15.1	9.0	24.1	295.6
13.3		9.0	9.0	271.5
13.4		9.0	9.0	262.5
13.5		10.0	10.0	253.5

VEHICLE TYPE CLASSIFICATION CRITERIA (REVISED FHWA 13 TYPES)

VEH. TYPE	DESC.	NO. OF AXLES	AXLE SPACING AXLE A – B (Feet)
1	MOTORCYCLE	2	0.0 – 6.7
2	CAR	2	6.7 – 10.0
3	PICKUP/VAN	2	10.0 – 13.3
5	BUS	2	13.3 – 20.0
4	2AXLE/6TIRE	2	20.0 – 40.0

SLIDE 10

LOCATION–2 MILES W. of WAKEENEY ROUTE I–70

MACHINE CLASSIFICATION

VISUAL CLASSIFICATION

VEH. TYPE ➤ / ▼		1	2	2	2	3	4	5	6	7	8	8	8	9	9	10	11	12	13	TOTAL
	NO. OF AXLES	2	2	3	4	2	2	2	3	4	3	4	4	5	5	6	5	6	7	
1	2																			
2	2		86			9														95
	3			2							1									3
	4																			
3	2		5			41		1												47
4	2						1		1											2
5	2					2		2												4
6	3					1			2											3
7	4																			
8	3																			
	4											1								1
	4					1							2							3
9	5							1		1				56						58
	5																			
10	6																			
11	5																1			1
12	6																	1		1
13	7																			
TOTAL			91	2		54	1	4	3	1	1	1	2	56			1	1		218

HANDOUT

FOR

VEHICLE CLASSIFICATION PROGRAM

PRESENTATION: MAY 24, 1985

TABLE OF CONTENTS

14-CHANNEL VEHICLE CLASSIFICATION PROGRAM

VEH. TYPE	CODE	DESCRIPTION	NO.OF AXLES	AXLE 1 - 2	AXLE 2 - 3	AXLE 3 - 4	AXLE 4 - 5	AXLE 5 - 6	AXLE 6 - 7	TOTAL WEELBASE
1	------	SUBCOMPACT	2	5.8- 8.6						8.6
2	200000	CAR, PICK UP	2	8.6-11.5						11.5
	210000	VAN								
3	220000	2-AXLE LIGHT TRUCK	2	11.5-23.0						23.0
4	------	BUS	2	23.0-40.3						40.3
5	------	CAR W/1 AXLE TRAILER	3	5.8-11.5	5.8-17.3					28.8
6	230000	3-AXLE S.U. TRUCK	3	5.8-23.0	0.0- 5.8					40.3
7	321000	2S1 TRACTOR TRAILER	3	5.8-17.3	17.3-40.3					46.0
8	------	CAR W/2 AXLE TRAILER	4	5.8-11.5	8.6-17.3	0.0- 5.8				40.3
9	240000	4 AXLE S.U. TRUCK	4	5.8-23.0	0.0- 8.6	0.0- 5.8				40.3
10	331000	3SI TRACTOR TRAILER	4	5.8-17.3	0.0- 5.8	5.8-40.0				57.5
11	322000	2S2 TRACTOR TRAILER	4	5.8-17.3	17.3-40.3	0.0- 5.8				57.5
12	332000	3S2 OR 3S2(S)	5	5.8-17.3	0.0- 5.8	11.5-40.3	0.0-11.5			57.5
	337000	TRACTOR TRAILER								
13	432000	OTHER 5 AXLE	5	5.8-17.3	0.0-23.0	0.0-23.0	0.0-23.0			69.0
	521200									
	±									
14	333000	6 OR MORE AXLE	6	5.8-17.3	0.0- 5.8	0.0-40.3	0.0-23.0	0.0-11.5		69.0

13-CHANNEL VEHICLE CLASSIFICATION PROGRAM
MAINE TEST

VEH. TYPE	CODE	DESCRIPTION	NO.OF AXLES	AXLE 1 - 2	AXLE 2 - 3	AXLE 3 - 4	AXLE 4 - 5	AXLE 5 - 6	AXLE 6 - 7	TOTAL WEELBASE
1		MOTORCYCLE	2	0.0- 5.8						5.8
2	090000	CAR	2	5.8-11.5						11.5
2	090X00	CAR W/1-AXLE TRLR	3	5.8-11.5	5.8-17.3					28.8
2	090X00	CAR W/2-AXLE TRLR	4	5.8-11.5	8.6-17.3	0.0-5.8				40.3
3	200000	PICK UP/VAN	2	11.5-17.3						17.3
4	190X00	BUS	2	23.0-40.3						40.3
5	220000	2-AXLE/6-TIRE	2	17.3-23.0						23.0
6	230000	3-AXLE S.U.	3	5.8-23.0	0.0- 5.8					40.3
7	240000	4-AXLE S.U.	4	5.8-23.0	0.0- 8.6	0.0- 5.8				40.3
8	321000	2S1	3	5.8-17.3	17.3-40.3					46.0
8	331000	3S1	4	5.8-17.3	0.0- 5.3	5.8-40.3				57.5
8	322000	2S2	4	5.8-17.3	17.3-40.3	0.0- 5.8				57.5
9	332000	3S2	5	5.8-17.3	0.0- 5.8	11.5-40.3	0.0-11.5			69.0
9	432000	3-AXLE W/TRLR	5	5.8-17.3	0.0- 5.8	5.8-23.0	11.5-23.0			69.0
10	333000	6-OR MORE AX.SGL TR	6	5.8-17.3	0.0- 5.8	0.0-40.3	0.0-11.5	0.0-11.5		69.0
11	521200	5-AXLE MULTI-TRLR	5	5.8-17.3	11.5-23.0	5.8-17.2	11.5-23.0			69.0
12	531200	6-AXLE MULTI-TRLR	6	5.8-17.3	0.0- 5.8	11.5-23.0	5.8-17.3	11.5-23.0		69.0
13	531300	7-AXLE MULTI-TRLR	7	5.8-17.3	0.0- 5.8	0.0-23.0	0.0-23.0	0.0-23.0		69.0
14		TOTAL ALL VEHICLES INCLUDING ANY NOT MATCHING ONE OF THE ABOVE								

13-CHANNEL VEHICLE CLASSIFICATION PROGRAM
KANSAS TEST

VEH. TYPE	CODE	DESCRIPTION	NO.OF AXLES	AXLE 1 - 2	AXLE 2 - 3	AXLE 3 - 4	AXLE 4 - 5	AXLE 5 - 6	AXLE 6 - 7	TOTAL WEELBASE
1		MOTORCYCLE	2	0.0- 6.7						6.7
2	090000	CAR	2	6.7-10.0						10.0
2	090X00	CAR W/1-AXLE TRLR	3	6.7-10.0	6.7-16.7					26.7
2	090X00	CAR W/2-AXLE TRLR	4	6.7-10.0	6.7-13.3	0.0- 6.7				30.0
3	200000	PICK UP/VAN	2	10.0-13.3						13.3
4	190X00	BUS	2	20.0-40.0						40.0
4	190300	BUS	3	20.0-40.0	0.0- 6.7					46.7
5	220000	2-AXLE/6-TIRE	2	13.3-20.0						20.0
6	230000	3-AXLE S.U.	3	6.7-20.0	0.0- 6.7					26.7
7	240000	4-AXLE S.U.	4	6.7-20.0	0.0- 6.7	0.0- 6.7				33.3
8	321000	2S1	3	6.7-16.7	16.7-40.0					53.3
8	331000	3S1	4	6.7-20.0	0.0- 6.7	10.0-40.0				66.7
8	322000	2S2	4	6.7-16.7	13.3-40.0	0.0- 6.7				66.7
9	332000	3S2	5	6.7-20.0	0.0- 6.7	10.0-40.0	0.0-13.3			66.7
9	432000	3-AXLE W/TRLR	5	6.7-20.0	0.0- 6.7	6.7-26.7	10.0-26.7			66.7
10	333000	6-OR MORE AX.SGL TR	6	6.7-16.7	0.0- 6.7	10.0-40.0	0.0-10.0	0.0-10.0		80.0
10	334000	6-OR MORE AX.SGL TR	7	6.7-16.7	0.0- 6.7	13.3-40.0	0.0-13.3	0.0-13.3	0.0-13.3	80.0
11	521200	5-AXLE MULTI-TRLR	5	6.7-16.7	13.3-26.7	6.7-16.7	10.0-26.7			66.7
12	531200	6-AXLE MULTI-TRLR	6	6.7-16.7	0.0- 6.7	13.3-26.7	6.7-13.3	10.0-26.7		80.0
13	531300	7-AXLE MULTI-TRLR	7	6.7-16.7	0.0- 6.7	10.0-26.7	6.7-13.3	0.0-40.0	0.0- 6.7	80.0
14		TOTAL ALL VEHICLES INCLUDING ANY NOT MATCHING ONE OF THE ABOVE								

LOW-COST WIM : THE WAY FORWARD

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INTRODUCTION

The US Department of Transportation's Federal Highway Administration (FHWA) has supported the collection of truck weight data by the individual states since 1936. The data have been used to provide a basis upon which to make decisions on design criteria, equitable tax structures, regulation of vehicle operation, and the determination of the relative position of highway transportation in the national economy (1).

The truck weight data collected annually by the states are used at the national level to:

1. Estimate the annual travel by each type of truck;
2. Estimate the ton-miles of cargo hauled by highway;
3. Detect year-to-year changes in axle and gross weights and distributions; and
4. Compare the characteristics of actual usage with administrative policies (1).

The results of the state surveys are used at both the state and national levels for:

1. Consideration of transportation policy;
2. Allocation of highway costs and revenue;
3. Development of size and weight regulations;
4. Establishment of geometric design criteria related to the size and weight of vehicles;
5. Development of pavement design procedures and criteria; and
6. A variety of special administrative, planning, design, and research studies (1).

At the state level, truck weight data are used in calculating equivalent axle loads for pavement design and in bridge loading analysis in terms of both bending moment and fatigue. The criticality of accurate axle weight estimates is illustrated by information from the American Association of State Highway Officials (AASHO) road test. That is, roadway damage increased exponentially with axle load so that, for example, one 42,000-pound single axle does as much damage to the pavement as thirty-two

18,000-pound axles.

The annual reporting by each state of consistent and reliable truck weight, vehicle classification, and volume data which are representative of truck usage of the various highway and street systems is essential to the continuation of reliable output from these studies and analyses (1).

Until recently, the manual used for designing and conducting truck weight studies has been the "Guide for Truck Weight Study Manual," published by the FHWA in April 1971 (1). Recognizing that the existing truck weight studies had several significant deficiencies, the FHWA initiated an internal review in 1980. The final report of the FHWA's Truck Weight Study (TWS) Task Force was published in November 1981 under the title "Truck Weight Study Evaluation: Final Report". This document described the Truck Weight Study as it existed at that time, as well as recent changes, and identified six deficiencies:

1. It is not designed on a sound statistical basis.
2. It provides only limited functional system coverage.
3. It does not provide seasonal coverage.
4. Its temporal coverage (time of day and weekday versus weekend) is extremely limited.
5. Bias may exist in much of the current data.
6. The cost-effectiveness of the data collection process needs improvement.

The first through fifth deficiencies have been partially addressed. In June 1984, the FHWA's Office of Highway Planning issued a draft edition of its "Traffic Monitoring Guide". This publication provides a statistically sound sample design procedure which allows data precision to be related to the intensity of monitoring. The states which are participating in the Truck Weight Study now have a tool to use in designing a statistically sound truck weight data collection program, with particular emphasis on weigh-in-motion (WIM) equipment.

The last deficiency of the TWS is the subject of this paper; low cost WIM. Current research and other efforts ongoing in the US and in Europe will be outlined after a brief review of WIM development.

STATE ACTIVITY

Prior to 1970, nearly all truck weighing in the U.S. was done using static scales. The data were obtained by using portable wheel load weighers or by "borrowing" permanent enforcement scale sites. It was not until 1974 that dynamic weighing equipment was first used to collect data for the Truck Weight Study (in the State of Florida). However, field experiments with WIM technology were reported as early as 1952 by Normann and Hopkins of the US Bureau of Public Roads (BPR) (2). The sensor comprised a reinforced concrete slab 12 x 3 x 1 foot in size supported on four strain gauge load cells. Installation of the sensor required construction of a large pit beneath the road surface. Electronic instrumentation was used to monitor the load cells and to process the data. Similar devices were installed and operated in the 1950s in the states of Iowa, Minnesota, Oregon, Michigan, Indiana, and Illinois and used for truck weight surveys, sorting suspected overweight vehicles for law enforcement, and pavement research studies (3).

Some success in these early WIM efforts was reported, but weigh-in-motion operations were abandoned by most of the above states by the late 1950. As reported by Lee (4), there were several problems which brought about this result, including:

1. Lack of portability.
2. Relatively large mass and inertia of the weighing platform, preventing measurement of dynamic effects.
3. Leveling and lateral translation of the platform.
4. Moisture action on the load cells.
5. Extensive construction and maintenance requirements at the weighing site.
6. Axle loads rather than wheel loads being detected.
7. Analog instrumentation and information display.

Further research utilizing large platform scales was carried out in the US and Europe. Investigators in one project at the University of Kentucky, jointly sponsored by the Kentucky Department of Highways and the BPR, attempted to address the deficiencies of massive platforms by preloading them with coil springs and steel rods (3). These attempts were not successful. In 1958, the Michigan Department of State Highways and Transportation began a 16-year undertaking to investigate in-motion weighing and dimensioning of highway vehicles (5). Four large platform electronic scales were installed over a 70-foot distance in advance of a static mechanical scale. The instrumentation and data display were significantly advanced over previous efforts and included some closed-circuit television surveillance.

Most of the WIM systems in use in the states today are portable or semiportable devices. Early work on a portable wheel load transducer was done at Mississippi State University beginning in 1952 (6). Research continued in the US, as well as Sweden, England, West Germany, and South Africa over the next three decades (9-12). By 1974, the following transducer concepts had emerged as having practical significance:

1. Change in electrical capacitance between two conductors as force deforms a separating dielectric.
2. Change in pressure in a deforming hydraulic chamber as force is applied.
3. Change in electrical resistance of a bonded strain gauge as force deforms the elastic structural member to which the gauge is affixed.

In 1974, the Florida Department of Transportation began collecting its Truck Weight Study data using weigh-in-motion equipment. The equipment installed was manufactured by Unitech (now Radian Corporation) and the Rainhart Corporation using a design developed by Dr. Clyde Lee of the

University of Texas. As of July 1984, 33 states had purchased and/or installed WIM systems produced by Radian, PAT, IRD and others.

CURRENT RESEARCH AND PROJECTS

Current research and other efforts now ongoing in the US and Europe are directed toward: improving WIM technology; assessing the suitability of commercial WIM products for both data collection and enforcement; collection and dissemination of WIM information; and developing systems which incorporate WIM equipment as a subsystem.

The principal public effort directed at improving WIM technology is an FHWA-sponsored study entitle "Development of a Low-Cost Truck Weighing System." This research is intended to produce a prototype portable surface mounted WIM system which will have an accuracy of $\pm$ 10% for heavy axles at a target price of $5,000. The study began in September 1983; the prototype system will be delivered to the FHWA by September 30, 1985.

The authors of this paper have been responsible for much of the research and development on the above FHWA sponsored study and a brief review of the work undertaken is presented below.

Following an extensive literature and product search, a range of technologies were identified which were considered suitable for the development of a low-cost weigh-in-motion sensor. Careful evaluation of the alternatives on the basis of technical merit and cost-effectiveness was carried out and three preferred approaches selected for further investigation. Such factors as the fundamental properties of weight sensitive element, the practicalities of sensor mounting, durability of the sensor and the complexity of signal processing were all considered in the evaluation process. The costs of sensor raw materials, fabrication and signal processing hardware were also examined. The constraint of the contract period was recognized in deciding which of the three approaches to WIM system design which could be usefully developed under the contract terms of reference.

The three approaches that were selected for further examination were as follows:

1 Bending mats;
2 PVDF sensors; and
3 Capacitive sensors.

An evaluation of the preferred approaches was undertaken by the testing of various prototype sensors under laboratory conditions. Piezo electric sheet or PVDF (Poly Vinylidene Fluoride) was relatively new and although some preliminary work had already been performed on this potential weight sensor by the research team, it was necessary to carry out laboratory tests on the fundamental characteristics of the material. Similarly an in-depth study of the behaviour of temporary bending weighmats was required. Research on capacitive devices concentrated on strip designs with the aim of producing a sensor of lower cost than the present capacitive sensors.

Bending Mats

The original bending weighmat concept was an adaptation of a strain-gauged bending plate system. It consisted of a series of strain gauges mounted to the underside of a thin steel plate, within a flexible mat. The plate was supported by steel strips on the leading and trailing edges of the mat and deflected under load. A layer of rubber sandwiched between the top and bottom plates acted as a support for the upper plate during wheel passages. The deflection of the top plate was measured by connecting the gauges so they formed one arm of a Wheatstone Bridge circuit.

Several prototype bending mats were developed using different types of strain gauges, a variety of strain gauge positions on the underside of the plate and different hardnesses of rubber. In all combinations, fundamental problems were encountered in the behaviour of the mat when subjected to load applications. Non-uniformity along the sensor length, changes in output due to varying contact area for a constant load and poor repeatibility were the most noticeable problems during the laboratory testing of the bending plate systems. Due to poor results the development of this option was discontinued at an early stage of the contract.

PVDF Sensors

Poly Vinylidene Fluoride (PVDF) is a relatively new material consisting of a thin film of plastic which exhibits piezo-electric properties. A charge is generated in response to changes in loading.

During the early stages of the contract seven sensors incorporating PVDF film were constructed and tested. The sensors were various composite constructions of steel sheet, rubber, paper, polyester adhesive and PVDF film. Generally the sensors were made in the form of narrow strips capable of covering one wheel track. Metalized PVDF film 2 inches wide and 25 microns thick was used throughout. Each of the sensors was compressively loaded in a hydraulic testing machine. The majority of the tests were a simulation of the dynamic loading condition which would arise from the passage of a loaded wheel over the sensor.

Typical results of dynamic load tests at varying positions along the sensor length gave standard deviations in output ranging from 14% to 3.9%. In Figure 1 the results of one of the better strips is shown, which possessed standard deviations in output of 6% and 7% at 10 kN and 20 kN loads respectively. Generally the results showed an approximately linear relationship between applied load and charge generated and a noticeable pyro-electric effect.

A further generation of PVDF sensors has since been tested comprising a combination of rubber-faced steel sheets and steel sheets faced with MYLAR, a rigid polyester film with a high quality surface finish. All sensors have been tested in a moving wheel facility to determine their output characteristics with a real wheel load. Results indicated that although the PVDF sensors show considerable promise for low-cost WIM monitoring, the performance of the sensors is sensitive to the construction techniques. Moving wheel tests have shown that more rigid mounting methods may be required to reduce bending effects in the sensor. Road trials with the most promising of these designs also indicated that temperature-related drift in the output signal was a significant problem.

The results on PVDF sensors are generally encouraging, with reasonably desirable characteristics emerging in most cases. However, before the film can be used as a low-cost weight transducer, further research is required into sensor construction and mounting techniques. Within the timescale and budget of the FHWA contract, the approach outlined below appeared to offer the greatest potential to meet the contract objective.

Capacitive Sensors

Capacitive mats have already proved to be a viable approach to portable, relatively low-cost WIM systems. Their performance accuracies are already close to the specified level of ± 10%, but their main disadvantage is the high cost of the capacitive transducer. It was decided to investigate two plate mat and strip designs on the basis of potentially lower manufacturing costs that the present commercially available three plate mat.

In the literature search a reference was discovered on a capacitive mat, made up of seven capacitive strips, fabricated by Lund Institute of Technology, Sweden, in 1976 (13). This prototype mat was obtained from Sweden together with a report containing fabrication drawings. Subsequent laboratory tests revealed that the sensor had deteriorated and could not be used for load discrimination. Results from tests in Sweden had indicated that the change in the mat capacitance was directly proportional to the applied load and accurate to ± 1.2 KN.

As such promising results had been achieved with this design, a series of similar prototypes were constructed.

The prototypes were again evaluated in a hydraulic loading frame and a moving wheel test facility. From tests to determine the uniformity of sensor output for various loading positions along the sensors, the coefficient of variation ranged from 3.5% to 12.9%.

The output from two-plate strip sensors was encouraging but the results did indicate significant interference problems. The tests also demonstrated that the performance of the sensors is sensitive to the materials used in the construction of the sensor and the fabrication techniques adopted. Sensors constructed with carefully selected materials and closely controlled fabrication techniques have shown promising results in terms of their response to load and uniformity along their length.

A three-plate capacitive strip design has since been evaluated and a preferred design chosen. Following consultations with the manufacturers of the present mat, a high quality, professional prototypes are being produced in co-operation with an established manufacturer of rubber and steel composites. Development and appraisal of the preferred design will continue in the final stages of the project.

EUROPEAN DEVELOPMENTS

The authors have also been actively involved in European R & D work on WIM technologies. The main development work on WIM has been on low-cost permanent sensors utilizing piezo-electric cable. Among the countries involved are France, Holland and Britain, through the Transport and Road Research Laboratory (TRRL). Work performed by the authors on behalf of TRRL is described below, summarizing a paper presented at the International Conference on Road Traffic Data Collection in London, England, December 1984 (14). Further details were presented at this conference by Mr R C Moore of TRRL (15).

Studies of the basic properties of piezo-electric axle sensors began in 1981, after trials at TRRL and elsewhere showed considerable variations in the signals produced by known axle loads passing over mounted sensors. Earlier work in France and West Germany had suggested that a low-cost axle load sensor based on piezo-electric cable should be practicable, so the initial emphasis was to provide an understanding of the fundamental behavior of the material, before and after mounting. The aims of the work were to study the fundamentals of piezo-electric materials, their composition and the theory of operation associated with the axle load sensor and also, to investigate the causes of variations in sensitivity between sensors for given dynamic loadings.

Piezo electricity is 'pressure electricity'. When a force or pressure is applied to certain parallel faces of a piezo-electric crystaline material, electrical charges of opposite polarity appear at the parallel faces. The size of the piezo effect depends upon the direction of the force in relation to the axes of the crystal. Another characteristic is that the piezo effect is dynamic, in that charge is generated only when the forces are changing. Should a constant force be applied, the initial charge will decay.

Vibracoax comprises a piezo-electric material in the form of a compressed powder which acts as the dielectric of a copper-sheathed coaxial cable, 3 mm in diameter. During manufacture, the powder is poled by a radial electric field applied between the inner and outer conductors, producing a piezo-electric response to radial stress. When the piezo-electric cable is disturbed, for example by flexing, compression, or vibration, a potential difference is developed between the sheath and the central copper conductor. According to the manufacturer, if a length of cable L is subjected to a pressure change ΔP over a part of its length ℓ, the resulting potential V between the inner and outer conductor is given by:

$$V = K\Delta P\,(\ell / L)\,\frac{C}{C + C_m}\,\exp(-t/\tau)$$

where t is time, τ is the time constant of the sensor plus measuring equipment, K is the sensitivity constant, and C, Cm are the capacitances of the sensor and measuring circuit.

During the first part of the study, tests were carried out on a total of ten sensors, obtained in three batches. The sensors were generally 3 m long with lengths of connecting cable already attached. Four were unmounted; two were mounted in extruded aluminium sections; two were mounted in aluminium sections with a hard rubber surround; and two were encapsulated in an epoxy resin.

A number of simple mechanical tests were conducted to establish the resistance of the unmounted piezo cable to load. The copper sheath was found to be highly work-hardened, and appeared to possess the durability necessary to survive under heavy traffic loadings in any reasonable mounting.

The main series of tests involved the application of dynamic loads, simulating wheel passages across the piezo sensor element. These tests were carried out in an electronic servo-controlled hydraulic load testing machine with a maximum load capacity of 50 kN. Pulsed or continuous sinosoidal dynamic loads were superimposed on a static background load which held the cable flat and assisted with control of the test rig. Some variations in output along unmounted sensor lengths and at different axes of rotation were evident in every case. An example of the variation in output along the length of an unmounted sensor from the first batch is shown in Figure 1, whose coefficient of variation ($\sigma/\bar{x}$) is about 5%. Subsequent batches showed greater variations along the lengths of sensors.

Other tests carried out on unmounted sensors at this time showed that the peak output from the sensor is almost independent of load duration and ambient temperature. Varying the loading width, however, for applications of a given dynamic load produced a distinct trend, with higher outputs from narrow loaded widths. This implies that the sensor would respond differently to single or double tires carrying a given load. Later tests indicated that this undesirable width trend might be reduced or eliminated by the adoption of appropriate mounting techniques.

Dynamic load tests on mounted sensors showed much greater variations in output along the sensor lengths than those observed for the unmounted cable. Figure 1 shows the response of the rubber and aluminium composite sensor to loads applied at different points along its length. The cable is located above the neutral axis of the composite assembly and responds more to tension or compression along its length induced by bending, than to direct pressure. The change of sign of the output at each end shows that the aluminium strip acts as a cantilever rather than a sagging beam in these areas.

Several more sensor mountings were developed and tested of which the most promising appeared to be locating the cable in a flexible tube. This has the effect of minimising the sensor's response to bending of the pavement, while preserving its sensitivity to direct load. Bending causes the cable to slide within the tube, rather than being placed into longitudinal tension or compression.

The main priority of the work carried out in the second part of the study concerned the causes of the variations in sensitivity between sensors for applications of known dynamic loads. The work involved electron microscopy; studies of internal sensor geometry, mass and capacitance; further work on the effects of tire width; tests with low or zero background loads; and some controlled bending tests on the piezo-electric cable. This programme was adopted in view of the fact that without understanding the causes of the remaining variations in unmounted sensor sensitivity, the development of mounted sensors would have only limited value.

Optical microscopy of sensor cross-sections previously carried out revealed clear variations in wall thickness and eccentricity of the central conductor. Examination of the piezo-electric powder at selected positions indicated an absence of any voids, and an apparent uniformity of particle sizes and packing density. The piezo-electric power was further examined by scanning electron microscopy carried out at sections of cable with high and low responses to load. No clear relationship was found between the particle size distributions and sensor sensitivity.

An examination of the effects of sensor geometry on the piezo-electric cable's response to load was carried out by load-testing a sensor and then cutting it at eighteen cross-sections. After careful cleaning and polishing, the cut sections were photographically enlarged and measured. A computer analysis of the resulting data using stepwise multiple linear regression indicated a degree of correlation between output voltage and factors such as eccentricity and diameter of the central conductor. These variations may be related to minor wrinkles in the copper, produced by the manufacturing process.

Some controlled bending tests were later carried out on sections of piezo-electric cable, to see if bending and straightening the sensor could have an effect on its uniformity of response to load. Marked changes in output of up to $\pm$ 17% were produced by quite modest bending of the sensor, similar to that which occurs when coiling or straightening the cable by hand. The magnitude of the changes would be sufficient to explain most of the sensitivity variations observed in unmounted sensors. This finding is significant in view of the manufacturer's practice of coiling the cable during fabrication and prior to dispatch or mounting.

In addition seven new mounted sensors were fabricated; these were tested in the servo-hydraulic dynamic load testing rig, and in a 'moving wheel' pavement test facility. Six of the designs were based on prototypes developed earlier, whilst the seventh adopted a dual sensor element design. The preferred concept from the first part of the study, of mounting the piezo-electric cable in a flexible tube, still appeared to show promise, though problems with variation in output along sensor lengths remains to be solved.

The third and final part of the sensor development has involved the design of a permanent piezo-electric axle load sensor mounting with an operational life expectancy of greater than two years. A preferred design has been selected after a series of laboratory tests, and further work is now required to verify its performance by field testing.

CONCLUSION

Truck weighing in the US has evolved from the relatively simple use of static, permanent and portable weighing devices to the utilization of sophisticated dynamic weighing (WIM) technology (16). Portable integrated systems for traffic volume counting, vehicle type categorizations, and accumulation of axle weight distributions are now within reach. Similar systems which can communicate directly with a central computer are also now feasible. These circumstances present the possibility to create and maintain data bases for roadway design to an extent which was hitherto impossible. There is no doubt that WIM systems will continue to grow in importance in truck weighing in the US and in Europe, particularly with the development of low-cost systems such as those described in this paper.

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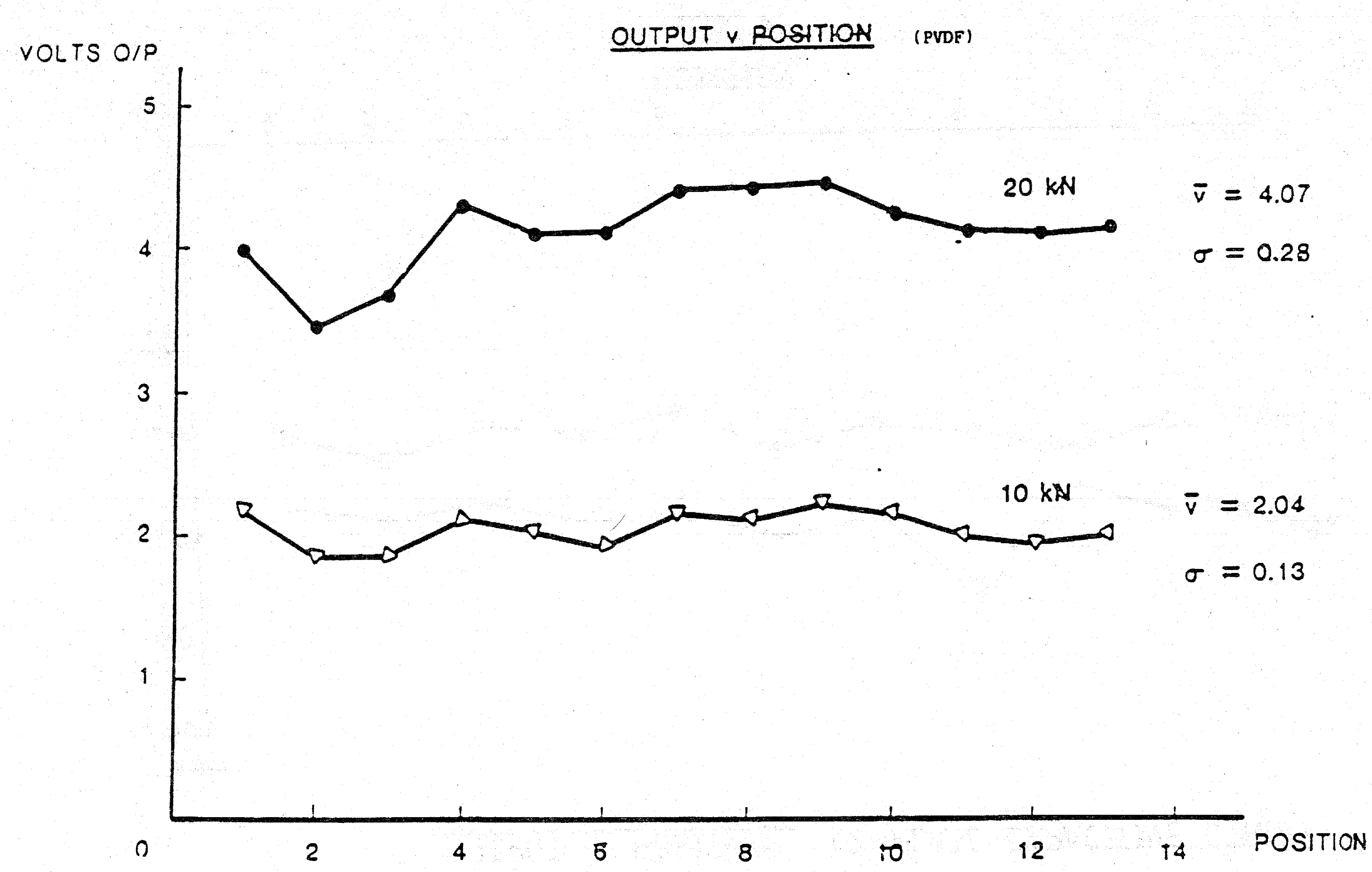
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3
2
1
0
2
4
6
8
10
12
14
POSITION
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10 kN
v̄ = 4.07
σ = 0.28
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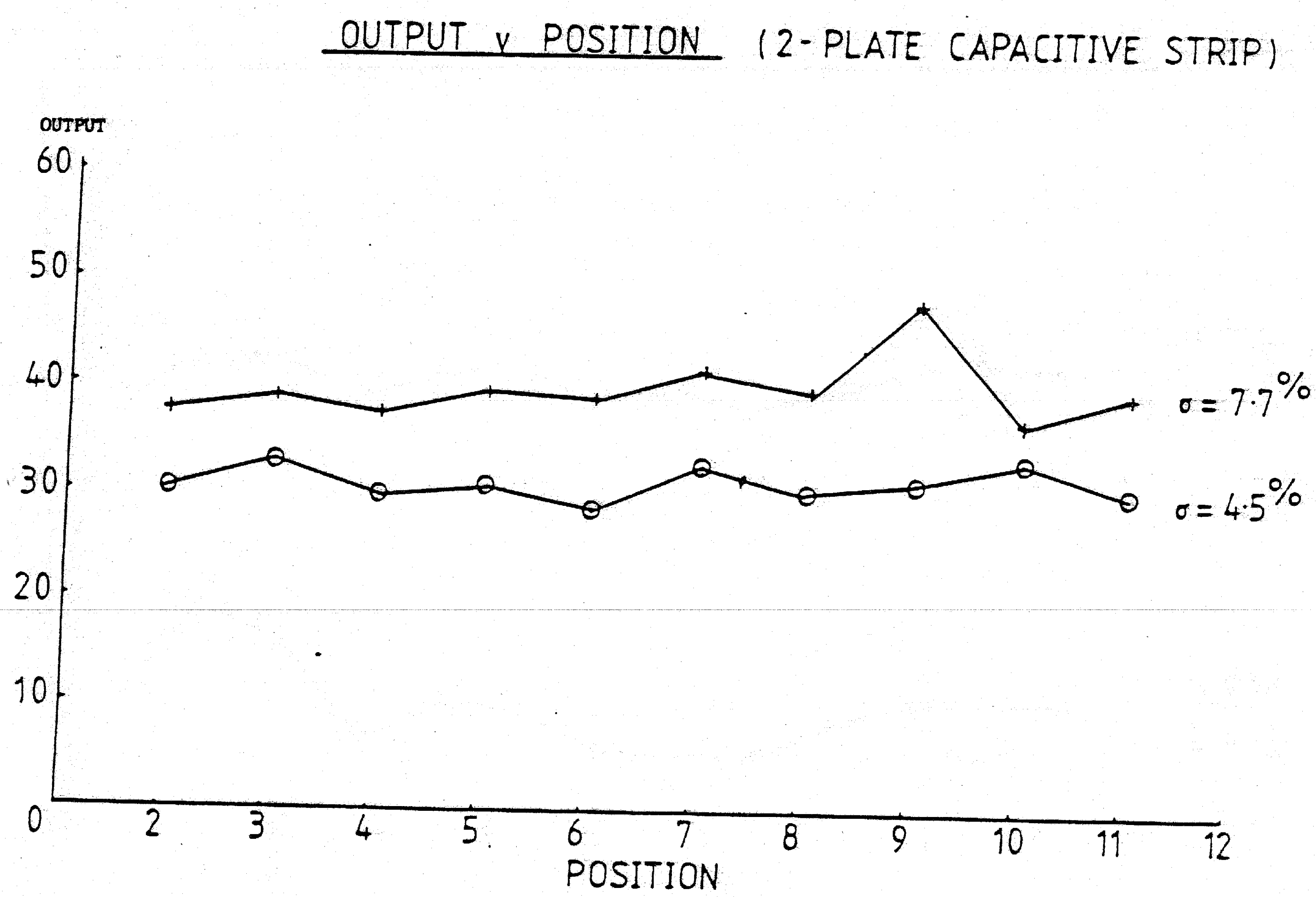
σ = 0.13

FIGURE 1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OUTPUT
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50
40
30
20
10
0
2
3
4
5
6
7
8
9
10
11
12
POSITION
σ = 7·7%
σ = 4·5%

FIGURE 2

CONFERENCE WORKSHOP SUMMARIES AND CLOSING

Enforcement Workshop Summary
by Fred Juba, Pennsylvania DOT (Chairman)

I've learned the meaning of southern hospitality, it's unbelieveable. I was honored to chair the enforcement committee and think it was quite successful. Having so many states with so many various experiences and different types of systems has proved to be very worth while. Many people have indicated they've picked up on alot of information that wouldn't be possible by combing other state agencies and hoping to run into that particular person with a particular experience.

Roch Bergeron of Quebec indicated they had a concept using video in the enforcement end for the aid of traffic control in their system. That's always been a question of how do you control mainline traffic when you're using WIM for mainline sorting. They seem to have a handle on it in their particular application.

The FHWA has compiled a computerized listing of states and the various systems that they are presently using. This is available to us and includes contacts in the various areas of WIM use such as enforcement and planning.

For portable systems, there's a necessity for fast set-up and tear-down, calibration and protection from traffic. This should be emphasized to manufacturers. Also recommend that there is uniformity in calibration and its format for comparisons from state to state.

One suggestion was to explain to the trucking industry what the weigh-in-motion system's function is (at weigh stations) so as to avoid confusion, misdirections and needless delays.

The impact on enforcement operations through planning efforts was addressed. Statistical studies in some cases do not take into account permitted loads. The results may be interpreted by administrators that the enforcement programs are not as effective as they should be, and they should be updated with alot of money. The planning organization should work with the permitting organization and develop some way to account for permitted loads in these statistical studies for more accurate representation of enforcement efforts.

I appreciated the opportunity to exchange information on present technology and to get updated on future technology. I'm looking forward to the next conference. Thank you all very much.

<u>Design Workshop Summary</u>
by James Cable, Iowa Department of Transportation (Chairman)

If anything came out of the days we were here from the design standpoint, was the fact that alot of us are using design procedures that leave alot to be desired or are using numbers that have been there for 10 or 15 years. The speakers in our group pointed to areas where WIM can provide those numbers, give you new 18 kip equivalent axle load data and provide that designer with a better feel for waht's happening out there. It behooves each of us when we go home and whether we're in enforcement, design or planning to walk across the hall and talk to that other fellow. If anything came out of the discussions, it's a gap in communication between the various offices within a department.

You can have a positive influence very quickly if you take a look at the data collection design guide that the FHWA is proposing and how it impacts the weight collection. There's also the design guide for pavement structures that's being reviewed at this time. Look at it and how it influences the traffic weight program and how WIM might be able to help you.

Another thing that came out of the discussion was we run out with a new WIM device and collect a lot of data quickly and right away we want to use those numbers to change the road design. Be careful because there's peaks and valleys in that data and you can jump to the wrong conclusions.

WIM will help you in the long run but use it as an additional tool and don't change your whole procedure until you've got several years of data or you can statistically say that the data you have is valid. It is a valuable tool and it's something that you need to talk to each other about. Don't hold it in your part of the agency as it can help the whole agency. Thank you.

Planning Workshop Summary
by Pat Savage, FHWA, Washington, D.C. (Co-Chairperson)

Wiley Cunagin was the Chairman of this session and I assisted him. I'd like to present an overview of what we did discuss in the session. The planning workshop included discussion on a wide range of issues, including the weighing-in-motion programs in Iowa, Illinois, New Mexico and Wisconsin as well as a discussion of the draft traffic monitoring guide.

Bill McCall discussed Iowa's RTAP program, and presented an overview of their current and future truck weight data collection plan. He described Iowa's experiences in the selection of the WIM equipment for their RTAP project. They decided on the Bridge Weighing System using IRD loop axle detectors. He decided the implementation of WIM in Iowa was to depend on the type of equipment and the type of people they would have to operate it.

Larry Shouldel presented Illinois' plans to install six WIM sites throughout the state. The first two of these locations are to use Streeter Richardson equipment and they are now operational.

Robert Mares of New Mexico described his state's use of Radian WIM equipment since they've been using since 1974. He brought out that they have a technician who can work with the equipment and if the equipment should go down, they don't have to send it back to get it fixed. This was felt to be very important. He also covered some of the operational procedures problems that they've come across in the eleven years they've been using it.

Lang Spicer worked with the implementation of Wisconsin's Bridge Weighing System under the RTAP program. He showed a video tape that explained how WIM was being used in his state and how WIM was viewed by people in the DOT.

Stan Gee with the FHWA Division 1 in Albany, New York presented a summary on the traffic monitoring guide. He referred to the possible impacts within individual states. There is to be a traffic monitoring guide course coming out. Thank you.

<u>Closing Remarks</u>
Ken Copeland, Georgia DOT (Conference Coordinator)

Ladies and gentlemen, we're real happy to have you here with us in Georgia and hope each of you have learned more and have become more informed as to weigh-in-motion. Everyone that's here has my blessing and thanks. You've all attended the meetings well. All the programs have gone off great. The clear weather or practically clear weather Wednesday was certainly a relief to me when we had some very fine displays on the outside. It's really a pleasure to have all of you here in Georgia. We surely hope you'll come back and we hope to see you at the next conference.

Leon Larson, Regional Administrator, FHWA, Atlanta

I want to on behalf of the Federal Highway Administration especially thank the State of Georgia, the Georgia DOT, and Ken Copeland and his staff for putting together a most effective and interesting and informative conference in this very important weigh-in-motion area. This is important to the people across a broad spectrum in the highway program, whether you're in planning, design, or enforcement. It's something all of us have to work together on to get a better handle on these very important issues because it not only deals with the roads we have out there today but the roads we're going to have in the future.

I especially want to thank the industry people for participating and making this conference a success, also our division office here in Georgia, and all of you for fully participating and making the conference meaningful, and Georgia for its good hospitality. Thank you.

VI. ENFORCEMENT WORKSHOP SESSION

OTO PERSPECTIVE ON WEIGHT ENFORCEMENT AND WIM

by: Jonathan D. McDade, Highway Engineer
FHWA, Office of Traffic Operations
Washington, D.C.

for: Second National Conference on WIM Technology and Applications
Atlanta, Georgia
May 20-24, 1985

It is truly a privilege for me to represent the FHWA Office of Traffic Operations at the Second National Weigh-In-Motion Conference here in Atlanta, Georgia. It is a double privilege for me because I spent one of my Highway Engineer Training Program assignments here in our regional office during 1980-81, and this is the first opportunity I have had since then to return to Atlanta.

One of the benefits of a conference like this is it allows us to look around. To see what is going on in WIM today, to see what others have done, are doing, or are planning to do. To find out what is working and what is not. While many of us would not be considered experts in either WIM or its applications, we are involved and want to know more. Others of us may just be getting started. So we all need to take full advantage of the opportunity this week to exchange information and just look around.

During these two workshop sessions we will be discussing an application of WIM that is important to the Office of Traffic Operations - Weight Enforcement. We hope to look at how WIM can enhance your enforcement efforts. So what I plan to do this afternoon is to give an overview from FHWA's perspective on the need for a systematic plan to collect reliable weight data for enforcement and how WIM is involved. I intend to listen closely to your experiences with and views on WIM, and how many of you are already adding WIM to your enforcement programs.

THE PROBLEM

I would like to begin by briefly previewing a few points from the presentation by FHWA Associate Administrator for Safety and Traffic Engineering, Marshall Jacks, whom you will hear tomorrow morning. His comments are indicative of the importance that FHWA is placing on the role of WIM in weight enforcement. We are all too aware of the growing concern over the increasing rate of deterioration of our nation's highways and bridges. And I'm sure most of you remember the July 1979 report by the General Accounting Office entitled, "Excessive Truck Weight: An Expensive Burden We Can No Longer Support." In this report the GAO charged the FHWA and the States to do something about the overweight truck problem, with a particular aim at improving the weight enforcement program throughout the United States.

Naturally we have to ask ourselves if there truly is a problem, and if so, how bad is it? In our search for answers, we find an increase in weight enforcement activities at the State level. However, the resulting weight data neither substatiates nor refutes the existence of a nationwide overweight truck problem. This could be attributed in part to a suspected significant level of scale avoidance by segments of the truck population rendering available data unrepresentative of the truck population. Consequently, one might conclude that only those trucks willing to be weighed are actually weighed.

For example:

(1) Reviewing 7 State studies on scale avoidance, as much as 22 percent of trucks bypass scales.

(2) Less than 1 percent of trucks weighed in 1983 using all types of equipment were cited for overweight violations.

(3) Wisconsin, through its WIM RTAP project, found 25 percent of trucks in violation of weight laws in 1983, while less than 1 percent were cited at fixed scales.

Keep in mind we are not claiming that the overweight truck population is around 25 percent, but rather that these examples are indications of the problem, and they illustrate how WIM equipment can be effectively used to enhance weight enforcement by providing more reliable and representative data.

THE ENFORCEMENT APPROACH

Responding to both the premature and rapid deterioration of our highways and bridges, FHWA's Office of Traffic Operations has initiated a three point plan to promote and encourage the use of more efficient equipment, techniques, and strategies for weight enforcement. The plan is to:

(1) Continue to use the RTAP project findings to illustrate the reliability and successful applications of WIM,

(2) Demonstrate the application of a systematic plan for determining the magnitude of overweight trucks and for developing enforcement strategies, and

(3) Continue to disseminate the findings nationwide and encourage all States to implement the successful components of enforcement plans.

THE USE OF WEIGH-IN-MOTION

One obstacle to more widespread use of WIM for enforcement has been the misconception that it is not really suited for enforcement. Despite the fact WIM is not certified for issuing overweight citations, Wisconsin's RTAP results, for example, illustrate its potential as a powerful tool. In addition, WIM, when used for enforcement, has spillover benefits for other purposes. For example, WIM can be used to:

(1) Estimate reliably the magnitude of overweight trucks,

(2) Provide continuous, undetected truck weight monitoring,

(3) Provide unbiased and representative truck weight data, and

(4) Develop stategies to utilize more efficiently the resources available for enforcement.

Clearly, these are applications which benefit not only enforcement functions, but highway planning and design as well.

And as many of you know, WIM equipment is already being used around the country to enhance enforcement efforts through:

(1) Weigh station ramp screening,

(2) High-speed sorting and screening,

(3) Scale avoidance studies,

(4) Long-term truck weight monitoring, and

(5) Statewide truck weight sampling.

Of course someone might say that some of these applications are not unique to enforcement programs. And that is exactly the point. Although vehicle screening is primarily an enforcement application, the others are not. The use of WIM equipment has the potential of providing more reliable weight data which can be used simultaneously for more than one purpose.

RELIABLE WEIGHT DATA

As I mentioned earlier, we are unable to substantiate whether or not an overweight truck problem exists today. Why? Because no data base currently exists that enables us to estimate reliably the magnitude and scope of the overweight truck population. We are also unable to quantify the amount of scale avoidance that occurs when enforcement and/or data collection weighing is in progress. So despite the vast amount of data collected by enforcement agencies each year, we still do not know what the truck weight population is like on our highways.

The approach the FHWA is encouraging States to take is the development of statewide sampling plans for truck weights, supplemented by a second plan to measure scale avoidance behavior. Once implemented, these data collection efforts would provide statistically valid samples representing the truck weight activity within a State's borders. This information would enable a reliable estimate to be made of the overweight truck population, provide input for enforcement strategies, and provide the basis for judging the effectiveness of enforcement programs. Consequently, better more informed decisions could be made, and the management of the highway system in general should be improved. In addition, benefits would be derived not only for enforcement, but also for design, planning and other highway agency applications, as the data are shared and the uses coordinated.

As in any data intensive effort, a data collection plan is essential to collect reliable data successfully. It is the data collection plan that forces us to focus on what we need to know; the type of data, how much data, how it will be collected, how it will be used, and what to expect.

In developing a statewide truck weight sampling plan, it is recommended that the procedures in the FHWA Traffic Monitoring Guide be used which tie vehicle weights to vehicle classification and traffic volumes. In this way the plan will take into account the various highway classes, the various truck routes and corridors, points of entry, and VMT to produce a sample that best represents the truck activity in a given State. Such a plan would also consider all permanent weigh stations and weighing teams, and emphasize the use of WIM to maximize the concealment of the data collection.

The second plan supplements the statewide data with information on the avoidance of scales. This behavior not only affects enforcement activities, but also planning through unreliable projections, and design through unreliable pavement loading data. There are two basic types of scale avoidance. One is geographically-based, where trucks take alternate or by-pass routes. The other is time-based, where trucks wait out enforcement activities on the roadside or in truck stops. Such a plan would call for data collection of sufficient duration and quantity on the approaches to enforcement locations during hours of operation and nonoperation, as well as simultaneous data collection on potential by-pass routes.

As an example, let's consider the recommended minimum sample size for truck weight EAL's as contained in the FHWA Traffic Monitoring Guide. It is important to remember that these are minimum guidelines. If you wish to have greater confidence in your estimates, or provide more information on individual classes of highways, it will be necessary to increase your sample size.

EXAMPLE 1: SAMPLE SIZE

Minimum Sample = 90 Measurements at 48-Hours each over 3 Years
or 30 Measurements per Year

Minimum Strata = Interstate and Other Roads (Excluding Local Roads)

Recommended Minimum Strata	Number of Measurements (3-Year)	Annual Number of Measurements	Recommended Level of Confidence	Expected Level of Precision*
Interstate	30	10	95%	10%
Other Roads	60	20	95%	20%

* = Precision Based on a 3-Year Cycle For Estimate of 3S2 EAL's

NOTE: A compressed 1-year effort would still require 90 measurements

Remember also that these are general guidelines and the sample size that would be needed in a particular State will vary with the size of the State, and the variation of truck activity. Noting that the guide also calls for 48-hour continuous monitoring during each of the sessions, the case for automated equipment, such as WIM, becomes very strong. To be able to reliably weigh and classify trucks continuously for 48-hours requires automation. And so the need for WIM. Remember however, that the sample data will only tell you what the truck weight population and, consequently, the overweight population are like in your State. It does not in any way enforce the weight laws. Concealed WIM monitoring is not a substitute for enforcement. The information is used to refine enforcement strategies, and to provide the basis for determining the effect that enforcement is having.

Let's continue the example and estimate what the annualized cost per data collection session could be using a mobile Bridge WIM system. There is some difficulty in doing this in that the life expectancy of the equipment is not yet known. And as usual, the major cost involved is for personnel. Therefore increased automation through telemetry could result in significant cost savings. The availability of low-cost WIM equipment could produce even greater cost savings. The estimated costs will then be compared to the average session costs for speed monitoring.

As a word of caution, this example only illustrates a general cost approach to statewide sampling. The cost figures are merely estimates and should only be used in general terms.

EXAMPLE 2: ANNUALIZED COSTS PER SESSION
STATEWIDE SAMPLING vs. SPEED MONITORING (AVERAGE)

ASSUMPTIONS

(1) 48-hour monitoring per session
(2) 30 sessions per year on a 3-year cycle (90 Total)
(3) 10 sites per year monitored 3 times per year
(4) 2 persons at 4-days per session (including travel)
(5) Depreciate Bridge WIM evenly over 5 years
(6) 10 sets of strain gages good for 5 years

EQUIPMENT COSTS	
(1) Bridge WIM: \$100,000/(5-yrs x 30 sessions/yr)	\$ 700
(2) Strain Gages: (10 x \$2000/set)/(5-yrs x 30 sessions/yr)	\$ 150
PERSONNEL COSTS	
(1) Salary: 2 x (32 hrs + 1.5 x 8-hrs O.T.) x \$22.50/hr	\$ 1980
(2) Travel: 2 x 4 days x \$50/day	\$ 400
(3) Support Vehicle: \$50/day	\$ 50
TOTAL COST PER SESSION	TOTAL \$ 3280

(1) Statewide Sampling (Estimated): \$3280 Per Session
(2) Statewide Sampling (Range): \$3500 - \$5000 Per Session
(3) Speed Monitoring: \$930 Per Session

ANNUAL COST FOR PROGRAM

(1) Statewide Sampling: \$105,000 to \$150,000 Per Year (30 Sessions)
(2) Speed Monitoring: \$74,400 Per Year (80 Sessions)

The comparison indicates that statistically based truck weight sampling apparently is financially attainable. The use of a systematic WIM plan is not going to bankrupt your agency in the attempt to get reliable data. And as further automated elements are added, particularly telemetry, a complete interconnected system is possible that will count, monitor speeds, classify, and weigh (and all at the same location if desired). Once this kind of reliable data is readily available enforcement strategies can then be based on an accurate picture of the truck population. And it will then be possible to monitor the success of the strategies.

A FINAL CHALLENGE

In conclusion, there are three areas we would encourage the States to pursue. The first is the continued promotion of WIM technology through research and development efforts. This would include experimenting with low-cost WIM equipment and the interconnecting of WIM and other automated equipment. Through this effort we would hope to gain more insight into the reliability, accuracy, and service life of WIM. Second, we encourage you to share your experiences and disseminate the information you are gaining through your work with WIM in enforcement. We at FHWA as well as your colleagues in other States want to know what you have found. Areas to pursue, successes to follow, pitfalls to avoid. So publish your results, good or bad, and share what is happening. Third, we want to encourage you to apply the new technology we are learning both here and during our work each day. Implement sound statistical procedures and coordinate your uses of WIM. Avoid duplicating your data collection and make the data available to all involved parties, enforcement, design, engineering, planning, and R&D. Thank you.

PENNSYLVANIA WEIGHT HISTORY

AND

EXPERIENCES WITH WEIGH-IN-MOTION

ATLANTA, GEORGIA

FREDERICK R. JUBA
CHIEF
TRUCK WEIGHT ENFORCEMENT DIVISION
PENNSYLVANIA DEPARTMENT OF TRANSPORTATION
HARRISBURG, PA. 17120

PENNSYLVANIA TRUCK WEIGHT ENFORCEMENT HISTORY

The Commonwealth truck weight laws governing both axle as well as gross weights date back to 1929. While gross weights have been continually updated reflecting changing technology in truck design and construction, axle limitations have changed little. The reason being, axle weights were not arbitrarily chosen, but were determined to be the maximum weight roadways and structures could withstand without failing.

Truck weight enforcement was traditionally the responsibility of the Pennsylvania State Police.

In 1974, the Federal Highway Administration was required by Section 127, U.S. Code, to withhold highway construction funding from states unable to demonstrate that they had an effective truck weight enforcement program.

In order to protect Pennsylvania's 44,000 miles of highways and 15,500 bridge structures (1,000 are weight restricted) our Legislature updated the existing weight laws reflecting Pennsylvania's renewed seriousness. Fines for both axle and gross weights were increased.

In order to bolster enforcement activities, the Department agreed to cooperatively take part in this program for the first time. The Pennsylvania State Police assumed responsibility for traffic control and safety, vehicle selection and prosecution. The Department's responsibility was the supplying, maintaining and certifying of all equipment required for weighing and measuring vehicles. The Department agreed to furnish trained and certified agents that would operate equipment necessary to detect violations and determine what specific violation took place.

This new program commenced in October 1977 with a permanent scale facility in Monroe County, along Route 209. This facility was a low budget operation manned by two shifts per day of three agents and one trooper. It consisted of two static axle scales which could simultaneously weigh a set of tandem axles by utilizing platform decks on Metrodyne wheel load weighers located in pits and were interconnected to a central indicator.

By January 1978, two mobile teams joined the ranks by enlisting two agents and one trooper per team. Due to the monumental task of surveilling the highways and bridges, mobile teams were increased to eight teams in July of 1978. In 1979, the number of teams was expanded to a total of 28, two of which were assigned exclusively to the Interstate System. The T.R. 209 weigh station was abandoned in October 1980 as not being cost effective for the manpower involved. Manpower from this site was devoted to surveillance of the Interstate highways.

HISTORY OF WEIGH-IN-MOTION IN PENNSYLVANIA

In 1979 the Department purchased three PAT 100 portable weigh-in-motion systems. These one inch high, two weigh plate systems are used as sorting or screening scales on two Interstate mobile teams. The third set is shared by County mobile teams on primary highways. These original units had the capability of detecting cumulative axle weights at speeds from three to six miles per hour. Accuracy was found to be between ±4% to ±8%. At speeds between three and four miles per hour greater accuracy was optimized at ±4% to ±6% and consistency improved as well. Longitudinal grades reduced accuracy and the consistency due to either acceleration or braking by vehicles. Volumes of 400-600 vehicles/6 hour shift were common. The weigh plates and indicators gave excellent service having required five repairs in four years of daily use. Portable wheel load weighers are utilized for enforcement evidence. Problems encountered were: (1) moisture at cable juncture point which was corrected with dialectric compound, (2) grid failures occurring in six months (plywood was substituted), (3) difficulty in determining individual axle weights (Siemens-Allis 300 indicator has since replaced PAT 100 indicator yielding direct axle indications), and

(4) vehicle induced damage to interconnect cables.

In 1981 the Department dedicated its first of 16 planned permanent weigh stations. This weigh station is located on I-80 eastbound in Clarion County. This station includes a StreeterAmet 5150 Rollweigh Weigh-in-Motion Sorter scale. The scale is capable of measuring axle weights - 73% of axles are measured within ±5% and gross weights - 94% of which are within ±5% (See Attachment A). These measurements are accomplished at speeds up to 35 miles per hour. The 5150 also determines axle spacings and vehicle speeds.

The WIM mini computer compares individual axle weights with programmed single threshold and measured gross weight with gross weight threshold. Should threshold be exceeded, the computer signals the vehicle in violation by overhead lane control to proceed to a three section StreeterAmet platform scale to determine actual violation. Vehicles determined to be legal by WIM are returned to mainline. Volumes encountered at this site vary from 60 to 200 vehicles per hour. The weigh station is operated one 7.5 hour shift per day - 5 out of 7 days per week. This operation sorts 191,000 vehicles per year, of which 600 vehicles are cited for weight violations at an average fine of $490 per vehicle.

Drawbacks to the system are: (1) downtime - 25 WIM load cell and/or mini computer failures in three years have resulted in 87 work days lost, (2) inability of WIM computer to determine violations of Pennsylvania's various axle gross weight laws (system was designed prior to Pennsylvania's adoption of the Federal Bridge Formula), and (3) expense and inflexibility - the weigh station was constructed in 1981 at a cost of $1.9 million, excluding real estate, and because of the fixed location, operation becomes stagnet after the first several hours of operation.

FUTURE OF WEIGH IN PENNSYLVANIA

In 1982, after experiencing both portable weigh-in-motion systems used in conjunction with wheel load weighers in Interstate rest areas and the permanent weigh station, the Department questioned whether there might be a compromise capturing advantages of both systems. A new concept was contemplated by the Truck Weight Enforcement Division that would utilize medium speed WIM capable of: (1) accurately determining axle spacing and axle weights, and produce minimal erroneously indicated violators; such a system would use existing rest - picnic/parking areas to minimize costs, utilize inground pads and loops to minimize setup time and maximize accuracy at medium speeds, have a computer programmed to compare axle weights, axle spacings and classification and determine if the vehicle violated any of Pennsylvania's axle weights (fixed and Bridge Formula limited) or configuration of limited gross weights, (2) classify the configuration of vehicle by axles and axle and/or axle group spacings, and (3) contain computer in a mobile command center that could easily be transported from site to site to maximize flexibility and effectiveness. Such a system was conceptualized and titled "Semi-Permanent Weigh Stations (SPWS)." The system utilizes the Siemens-Allis 400 WIM system complete with micro-computer, CRT and printer. It utilizes four flush mounted in pavement weigh pads and two inductive loops per site. Loop and weigh plate signal is amplified by a site-located, vandal proof preamplifier to a junction point where the mobile command center is connected. The mobile command center is a motor home type vehicle, equipped with heat/cooling air suspension and shock mounts to maintain the necessary environment for the mini computer. The system has the following capabilities:

1. Weighs, measures and classifies vehicles from 3 to 40 miles per hour.
2. Weighs to the nearest 100 pounds
   A. Axle weights ±4% error with standard deviation not to exceed 7.
   B. Tandem axle weights ±4% with standard deviation not to exceed 5.

C. All other groups of axles on combination vehicles grossing more than 73,280 pounds as per Pennsylvania's Bridge Formula.

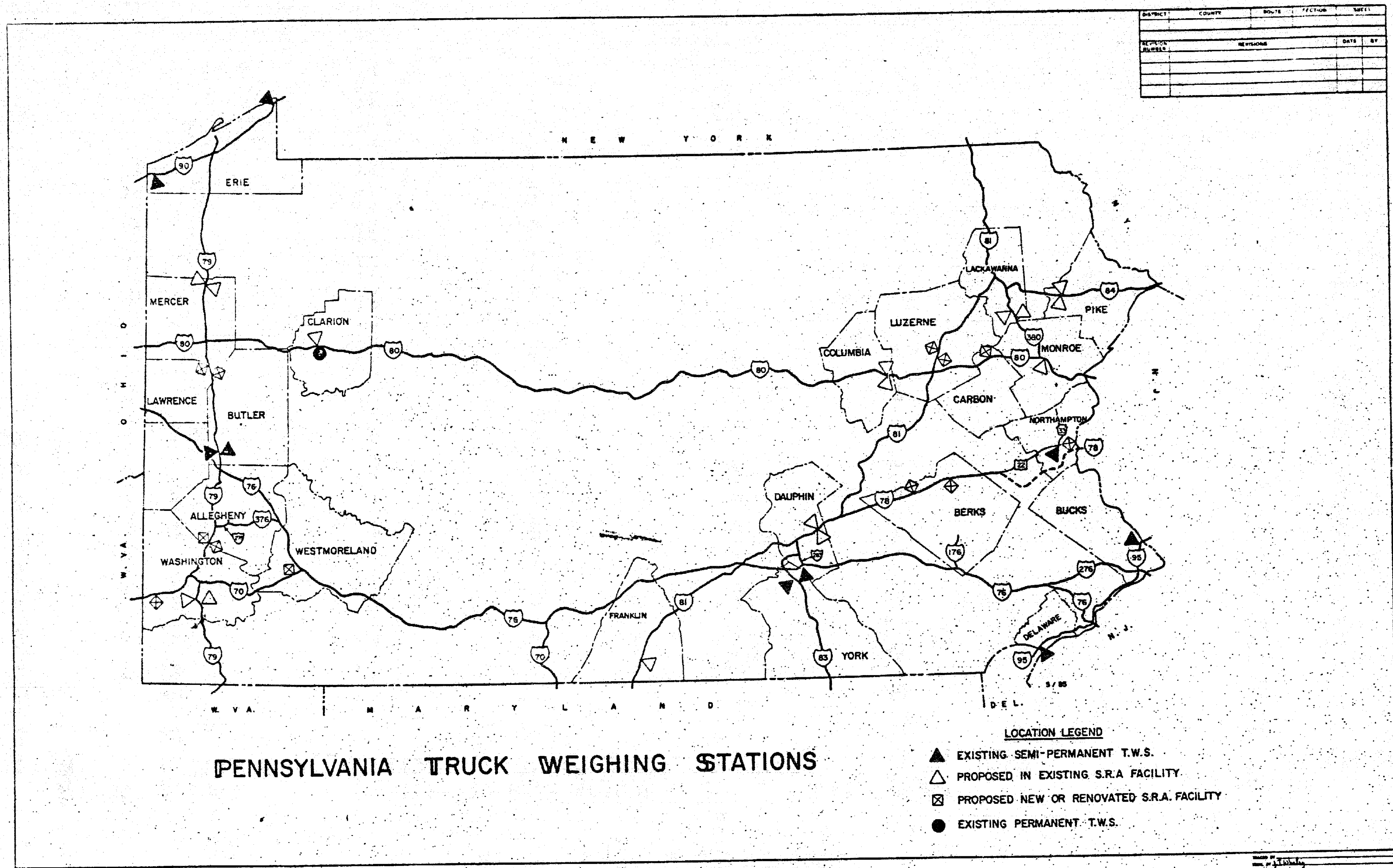
D. Gross weights ±4% error with standard deviation not to exceed 4.

3. Measures axle spacings ± .2 feet measured to the nearest .1 foot.
4. Measures speeds within ± .2 mph to nearest .1 mph.
5. Determines manipulation by truck operators such as acceleration of deceleration.
6. Detects off scale tracking of vehicles.
7. Classifies vehicles into 1 of 49 predetermined classes.
8. Signals terminal operator and/or provides outside audio signal identifying a violation.
9. Prints detailed weight and axle spacing information of violation.
10. Indicates violations on CRT screen.
11. Computer compatible to 30 weigh pad sites.
12. Computer programmed by operator to increase weight threshold in steps of 10, 20 or 30 percent.

Design was completed and the contract was let for ten sites and three mobile command centers in September 1984. The mobile command centers and the first three sites have neared completion. Two sites should be on-line by June 1985. A network of 35 sites are planned (See Attachment B). The cost advantages of SPWS allows the construction of more sites which increases weighing flexibility and productivity. Locations were selected by truck volumes while attempting to cluster sites to minimize down-time between sites. The first ten sites and three command centers will be constructed for less than the cost of constructing one permanent weigh station. Subsequent sites can be prepared and instrumented for less than $80,000 each.

Sites include full lighting, weigh station signing with manually activated open-closed panels. Portable wheel load weighers will be used to determine actual overweight evidence after vehicles have been screened by WIM. Complete activation or deactivation time is anticipated to be less than ten minutes, which should contribute to increased productivity while at the same time reducing the "alert" to trucks that takes place with lengthy set-ups.

It is believed that the SPWS concept will satisfy Pennsylvania's initiatives of greater enforcement on Interstate highways.



ATTACHMENT B

WEIGH STATION - PA I-80 EASTBOUND
WEIGH-IN-MOTION WEIGHT ERROR

Gross Weight

% Error	% Veh. Whgd.
< 1	23
1	30
2	16
3	13
4	9
5	3
7	1
8	2
9	2
19	1

Steering Axle Weight

% Error	% Veh. Whgd.
< 1	15
1	11
2	6
3	6
4	10
5	11
6	10
7	6
8	5
9	5
10	1
11	1
12	2
13	2
15	1
16	1
17	2
18	1
19	2
21	1
33	1

1st Tandem

% Error	% Veh. Whgd.
< 1	16
1	20
2	14
3	15
4	9
5	11
6	5
7	4
8	2
9	1
10	2
16	1

2nd Tandem

% Error	% Veh. Whgd.
< 1	25
1	18
2	13
3	9
4	4
5	7
6	9
7	6
8	4
9	1
11	1
12	1
17	1
21	1

ATTACHMENT A

SECOND NATIONAL CONFERENCE

ON

WEIGH-IN-MOTION

ATLANTA, GEORGIA

MAY 20 - 24, 1985

CONFERENCE SESSION: ENFORCEMENT

THEME: NEVADA'S USE OF WIM IN ENFORCEMENT ACTIVITIES

SPEAKER: D. KEITH MAKI, NEVADA NDOT

THE NEVADA DEPARTMENT OF TRANSPORTATION ACQUIRED A WIM SYSTEM FROM RADIAN CORPORATION IN 1978, TOTAL COST OF THE SYSTEM WHICH INCLUDED A 22 FOOT MOTORHOME, MODIFIED TO OUR SPECIFICATIONS, ALL WIM RELATED EQUIPMENT, AND HARDWARE FOR EIGHTEEN SITE INSTALLATIONS WAS APPROXIMATELY $90,000. ALSO PROVIDED BY RADIAN WAS THE NECESSARY SOFTWARE, AND TRAINING TO NDOT PERSONNEL ON SITE INSTALLATION AND SYSTEM OPERATION.

NEVADA'S SYSTEM IS SEMIPORTABLE, WITH TRUCK WEIGHT AND SIZE DATA ROUTINELY COLLECTED AT TWELVE STATEWIDE LOCATIONS. SHIFTS ARE SCHEDULED TO PROVIDE A SAMPLING OF ALL HOURS, DAYS, WEEKS AND MONTHS OF A YEAR. WEIGHTS ARE COLLECTED ONLY FROM THE OUTSIDE (RIGHT) TRAVEL LANE ON FOUR LANE ROADS. CURRENTLY, WE HAVE WIM SITES INSTALLED AT THREE INTERSTATE RURAL LOCATIONS, ONE INTERSTATE URBAN LOCATION, AND THREE RURAL PRIMARY LOCATIONS. THIS SUMMER WE PLAN TO REINSTALL FOUR INTERSTATE RURAL, AND A NEW FEDERAL-AID-URBAN SITE. THE RELOCATION/REINSTALLATION OF THE RURAL INTERSTATE SITES ARE IN CONJUNCTION WITH THE RECENT AND/OR PLANNED CONSTRUCTION OF SEVEN TRUCK INSPECTION STATIONS.

NDOT'S WIM SYSTEM WAS PURCHASED PRIMARILY TO OFFSET THE RISING COST OF THE ANNUAL TRUCK WEIGHT PROGRAM. IN ADDITION, THE SYSTEM WOULD PERMIT YEAR-AROUND WEIGHT ACTIVITY AND WE FELT COULD BE USED AS A SCREENING DEVICE IN NEVADA'S WEIGHT ENFORCEMENT PROGRAM. THE SYSTEMS USE IN WEIGHT ENFORCEMENT HAS BECOME A PRIMARY FUNCTION. THIS DOES, HOWEVER, RAISE SOME QUESTION AS TO THE SYSTEMS USEFULLNESS AS A MONITORING TOOL. IN OTHER WORDS DOES THE TRUCKER WHEN UNSURE IF WE ARE ONLY MONITORING OR ENFORCING WEIGHT LAWS AVOID IT, THE ANSWER IS, YES! A NUMBER OF TRUCKERS RECOGNIZE THE WIM VAN, PASS THE WORD ON, AND FROM OUR EXPERIENCE THE TRUCKER WILL DIVERT HIS ROUTE OR STOP AND WAIT US OUT ESPECIALLY IF HE KNOWS HE IS IN VIOLATION OF STATE WEIGHT AND/OR SIZE LAWS. THIS SITUATION HAS OCCURED THROUGHOUT NDOTS EXPERIENCE WITH THE ANNUAL TRUCK WEIGHT PROGRAM; MORESO, HOWEVER, WITH THE STATIC PROGRAM THAN WITH THE USE OF WIM. ONE SOLUTION IS THROUGH A TELEMETRY PROGRAM. GENERALLY, FOR THE INITIAL SEVERAL HOURS WIM IS VERY EFFECTIVE IN EITHER MONITORING OR ENFORCEMENT ACTIVITIES.

NEVADA DOES NOT HAVE PORTS-OF-ENTRY AND INSTEAD USE A ROVING PATROL OPERATION TO ENSURE THAT TRUCKS COMPLY WITH ALL ASPECTS OF THE LAW. ENFORCMENT IS PROVIDED BY THE MOTOR CARRIER DIVISION OF THE DEPARTMENT OF MOTOR VEHICLES. TO UNDERSTAND THE PROGRAM KNOWLEDGE OF THE NEVADA SETTING IS VERY IMPORTANT. WE'RE BORDERED BY FIVE STATES THAT HAVE PORTS-OF-ENTRY; AND OVER ONE-HALF OF THE TRUCKS DRIVING IN NEVADA HAVE NEITHER AN ORIGIN OR DESTINATION IN OUR STATE.

UNTIL 1978 NEVADA WAS CONDUCTING ONLY ABOUT A THOUSAND ENFORCEMENT WEIGHINGS IN A YEAR. IN DEFENSE OF OUR MOTOR CARRIER AGENTS, THERE WERE FEW PROFESSIONAL AND PERSONAL INCENTIVES TO WEIGHING TRUCKS. FIRST, THEY DID NOT HAVE THE EQUIPMENT - THREE SETS OF PORTABLE SCALES AND ONE PORTABLE PLATFORM SCALE WERE ALL THEY HAD TO COVER THE ENTIRE STATE. SECONDLY, UNTIL 1982 THE MAXIMUM OVERWEIGHT FINE WAS $500, AND AGENTS COULD GENERATE MUCH HIGHER REVENUES BY CONCENTRATING ON ENFORCING PERMITS AND REGISTRATIONS. THESE LATTER FEES ARE RETURNED TO THE HIGHWAY FUND TO SUPPORT OPERATIONS, WHEREAS WEIGHT VIOLATION FINES GO INTO THE STATE GENERAL FUND. LASTLY, NEVADA HAS A VERY POWERFUL TRUCKING AND MINING INTEREST LOBBY.

ALSO, NEVADA'S HIGHWAYS WERE IN GREAT SHAPE, AND IT WAS DIFFICULT TO CONVINCE ANYONE, INCLUDING MOTOR CARRIER AGENTS, COURT JUDGES, AND THE LEGISLATURE THAT MAJOR PROBLEMS WOULD OCCUR IF WEIGHTS WERE NOT CONTROLLED. ONE ASPECT OF THIS IS THAT THEY DID NOT COMPREHEND THE DESIGN PROCESS WHERE INTERIOR AXLE GROUPS HAD TO BE REGULATED.

FROM AN ENFORCEMENT VIEW, THE MOTOR CARRIER DIVISION WAS AWARE OF THE SHORTCOMINGS AND STARTED ASSIGNING MORE OF EACH FIELD AGENT'S TIME TO WEIGHT ACTIVITIES; HOWEVER, THEY DID NOT FEEL THEY COULD GAIN ADDITIONAL FUNDS TO BUY STATIC SCALES AND OTHER SUPPORT EQUIPMENT NEEDED TO BOOST TOTAL WEIGHINGS TO AN ACCEPTABLE LEVEL. AND THUS, THE PLANNING DIVISION

PRESENTED NDOT MANAGEMENT WITH COST ESTIMATES, AND A PROGRAM EMPHASIZING THAT NDOT COULD REDUCE MANPOWER COST FOR THE ANNUAL TRUCK WEIGHT STUDY, IMPROVE AND INCREASE ITS DATA BASE FOR DESIGN DESIGNATIONS, AND INCREASE ANNUAL WEIGHINGS FOR ENFORCEMENT. OUR MANAGEMENT OPTED FOR THE WIM PROGRAM, AND FHWA IS THUS FAR SATISFIED WITH BOTH OUR PLANNING AND ENFORCEMENT RESULTS. I'LL POINT OUT THAT WE DO USE WIM FOR MOST OF THE FHWA TRUCK WEIGHT STUDY. IN ADDITION, I MUST EMPHASIZE THAT THE MOST IMPORTANT ASPECT OF OUR PROGRAM IS THAT ANY WIM OPERATION IS DESIGNED TO FULLFILL A PLANNING NEED. AS SUCH THE DATA IS BEING COLLECTED BY NDOT PERSONNEL, WHO MAINTAINS CALIBRATION, AND CONDUCTS A VEHICLE CLASSIFICATION COUNT OF ALL TRAVEL LANES.

IN THE OFFICE, CLASSIFICATION COUNTS ARE INTEGRATED INTO OUR TRAFFIC COUNTING DATA FILES. WIM DATA IS EDITED, AND UNACCEPTABLE TRUCK WEIGHTS ARE DELETED. STATIC AND WIM DATA ARE BOTH ENTERED INTO COMPUTER FILES FOR USE IN DESIGN DESIGNATIONS, PAVEMENT MANAGEMENT, HIGHWAY COST ALLOCATION ANALYSES, AND OTHER PLANNING AND RESEARCH FUNCTIONS.

TOTAL NDOT WEIGHING PERSONNEL FOR STATIC AND WIM PROGRAMS CONSISTS OF TWO FIELD TECHNICIANS, ONE FIELD SUPERVISOR, AND AN OFFICE ANALYST. WE USE ELDEC PORTABLE PLATFORM SCALES FOR STATIC OPERATIONS, AND BY LAW A MOTOR CARRIER OFFICER MUST BE ON THE SITE. THE METHOD IN WHICH NDOT EMPLOYS ITS WIM SYSTEM FOR ENFORCEMENT IS QUITE SIMPLE. SCALES ARE LOCATED IN THE

RIGHT TRAVEL LANE APPROXIMATELY 2 MILES, PLUS OR MINUS, FROM A ROADSIDE PULL OFF AREA OF ADEQUATE SIZE TO PERMIT STATIC, EITHER PORTABLE PLATFORM OR "SUITCASE" SCALE, WEIGHING ACTIVITIES. TEMPORARY SIGNS (BLACK AND WHITE) ARE PLACED UPSTREAM OF THE WIM SITE TELLING THE TRUCKER TO MAINTAIN THE RIGHT TRAVEL LANE FOR THE NEXT ONE MILE AND TO MAINTAIN A CONSTANT 55 MPH VEHICLE SPEED. ANY SUSPECT VEHICLE OR ONE THAT AVOIDS THE SCALES, ITS DESCRIPTION IS RADIOED AHEAD, AND THE VEHICLE IS PULLED OFF AND WEIGHED STATICALLY. THESE CERTIFIED STATIC WEIGHTS ARE THEN RADIOED BACK TO THE WIM OPERATOR WHO MAKES IMMEDIATE CALIBRATION ADJUSTMENTS IF NECESSARY. THE CALIBRATION ADJUSTMENTS REQUIRES ONLY SECONDS TO MAKE. NDOT PERSONNEL WORKING WITH THE AGENTS RECORD A DUPLICATE WEIGHT SLIP WITH THE WIM CONTROL SERIAL NUMBER, THE WEIGHT SLIPS ARE RETAINED IN ORDER TO COMPLETE A QUALITY CONTROL ANALYSIS OF WEIGHT DATA COLLECTED AT EACH LOCATION.

AS TO ACCURACY, WE EDIT OUR WIM DATA PRIOR TO PERMANENT ENTRY ON OUR COMPUTER FILES. OVERALL, VEHICLE WEIGHTS ACHIEVED FROM OUR WIM SYSTEM WHEN COMPARED TO STATIC WEIGHTS RANGE FROM ± 4% FOR TANDEM AXLES, ± 4% FOR NON-DRIVER SINGLE AXLES, SINGLE DRIVERS RANGE UP TO ± 8% AND STEERING AXLES ARE CONSISTENTLY LESS THAN STATIC WEIGHT. INDIVIDAUL TRUCK GROSS WEIGHTS AFTER CALIBRATION ARE CONSISTENTLY WITHIN A ± 2% RANGE WITH A AVERAGE TOTAL GROSS WEIGHT FOR ALL TRUCK TYPES RANGING IN THE ± 1% RANGE. THIS LEVEL OF ACCURACY IS DEFINITELY ACCEPTABLE FOR OUR PLANNING

AND RESEARCH NEEDS. AS WITH ANY SYSTEM, OUR SYSTEM IS ONLY AS RELIABLE AS THE FIELD SUPERVISOR AND TECHNICIANS RESPONSIBLE FOR OPERATIONS. WITH OUR WIM WE HAVE INCREASED WEIGHINGS FIVE-FOLD, AND WE'RE GETTING A MORE ACCURATE REPRESENTATION OF THE WEIGHTS PRODUCED BY ANNUAL TRUCK VEHICLE MILES OF TRAVEL. IN ADDITION, OUR WIM PROGRAM ACCOUNTS FOR ONE-THIRD OF THE TRUCK WEIGHTS REPORTED IN CERTIFICATION.

WHERE DOES NEVADA GO FROM HERE? LIKE MOST STATES WE ARE UNDER FUNDING RESTRAINTS; HOWEVER, AS STATED PREVIOUSLY WE ARE COMMITTED TO CONSTRUCTION OF SEVEN TRUCK INSPECTION STATIONS ON OUR INTERSTATE SYSTEM BY NEXT YEAR. EACH WILL HAVE A WIM SITE INSTALLED. NDOT CANNOT PROVIDE ADEQUATE COVERAGE OF THESE NEW INSTALLATIONS WITH EXISTING PERSONNEL AND EQUIPMENT, SO AN ADDITIONAL WIM UNIT AND MANPOWER IS EXPECTED TO BE REQUESTED. THE MOTOR CARRIER DIVISION, PRESENTLY, IS NOT CONSIDERING THE PURSHASE OF THEIR OWN WIM SYSTEM, BUT HOPE TO CONTINUE THE PRESENT NDOT-DMV PROGRAM. ONE CHANGE THAT MAY EFFECT THE PRESENT PROGRAM IS THE CONSOLIDATION OF THE MOTOR CARRIER DIVISION INTO THE COMMERCIAL SECTION OF NEVADA'S HIGHWAY PATROL, THIS CHANGE IS PRESENTLY BEFORE NEVADA'S LEGISLATURE AND THE OUTCOME IS UNKNOWN BUT LIKELY TO SUCEED.

AS TO COST EFFECTIVENESS, THE NDOT WIM AND STATIC WEIGHT PROGRAM (ENFORCEMENT AND MONITORING) RUNS ABOUT $100,000 A YEAR, THE SAME LEVEL OF PROGRAM ACTIVITY USING STATIC SCALES ONLY WOULD BE AT LEAST THREE TIMES

THAT AMOUNT. THIS ESTIMATE IS BASED UPON A YEAR LONG STUDY, CONDUCTED QUARTERLY AND STATEWIDE. SPECIFICALLY, IN 1981 NDOT PARTICIPATED IN A TRUCK WEIGHT CASE STUDY UNDER CONTRACT WITH FHWA. THE OBJECTIVE WAS TO GATHER A SAMPLE OF WEIGHTS FOR ALL TRUCK TYPES, AND ON ALL FUNCTIONAL CLASSIFICATIONS OF ROADS. CONSIDERING ALL COSTS, THE COST PER TRUCK WEIGHED STATICALLY WAS $16.92 EACH AND BY OUR WIM SYSTEM $4.70 EACH. THE TOTAL NUMBER OF TRUCKS WEIGHED WAS 17,100 DURING 168 FIELD SHIFTS. IN 1984 NDOT WEIGHED ABOUT SEVEN THOUSAND TRUCKS WITH OUR WIM AND STATIC PLATFORM SCALES, 100% WITH ENFORCEMENT PERSONNEL PRESENT. WE COULD SUBSTANTIALLY INCREASE THE NUMBER OF WEIGHINGS IF WE SPENT MORE TIME ON THE INTERSTATE; HOWEVER, AS STATED OVER HALF THE TRUCKS ARE PROBABLY ALSO BEING WEIGHED IN ADJACENT STATES. OVER THE NEXT TWO YEARS MOST OF NDOTS EFFORTS WILL BE DIRECTED TO NON-INTERSTATE SITES, ON SYSTEMS WHERE NEVADA'S INTRA-STATE TRUCK MOVEMENTS ARE OCCURING.

THE REASONS FOR THIS ACTION ARE TWO FOLD; FIRST, NDOT IS GOING TO CONDUCT A TWO YEAR TRUCK AND COMMODITY MOVEMENT STUDY. SECONDLY, AS THE FOLLOWING DATA INDICATES WE HAVE AN INTRA-STATE TRUCK WEIGHT VIOLATION PROBLEM. THE PERCENT OF OVERWEIGHT* TRUCKS BY FUNCTIONAL CLASSIFICATION IN 1984 WAS:

	5 AXLE SEMI'S	AVG. TRUCK WEIGHT	ALL TRUCK	AVG. TRUCKS** WEIGHT
URBAN ARTERIALS	25.5%	55,762	24.2%	54,470
RURAL COLLECTORS	48.6%	76,863	44.7%	74,755
RURAL ARTERIALS	23.5%	55,885	21.1%	56,173
RURAL INTERSTATE	20.7%	60,724	19.9%	60,720
TOTALS	22.0%	59,266	20.5%	59,296

ALSO IN FY 83-84 THE MOTOR CARRIER DIVISION, DMV, AS A PERCENT OF TOTAL, ISSUED CITATIONS FOR THE FOLLOWING WEIGHT VIOLATIONS:

55%	TANDEM AXLES
34%	BRIDGE FORMULA
6%	GROSS WEIGHT
5%	SINGLE AXLE

* A WEIGHT VIOLATION IN ANY AXLE OR AXLE GROUP OF 100 LBS OR MORE OVER THE LEGAL LIMIT (DOES NOT INCLUDE INTERIOR BRIDGE FORMULA VIOLATIONS).

** THE COMPARISON DID NOT INCLUDE SINGLE UNIT TRUCKS, BUSES OR LEGAL COMBINATIONS WITH A VEHICLE LENGTH IN EXCESS OF 70 FEET, BUT DID INCLUDE 5 AXLE SEMI, TRUCK AND FULL TRAILER AND MULTIPLE COMBINATIONS LESS THAT 70 FEET.

OVERALL THE TRUCKS NDOT WEIGHED IN 1984 HAD AN AVERAGE WEIGHT OF 59,296 LBS.** THIS WAS A 3% INCREASE OVER THE AVERAGE WEIGHT OF TRUCKS WEIGHED BETWEEN 1976-82. THE 5 AXLE SEMI ACCOUNTED FOR 80% OF THE TRUCKS NDOT (3,159) WEIGHED (AVERAGE WEIGHT 59,266 LBS.) THE 5 AXLE SEMIS DISPLAYED A 19.3% INCREASE IN 18 KIP ESAL VALUES OVER THOSE 5 AXLE SEMIS WEIGHED BETWEEN 1976-82. BY FUNCTIONAL CLASSIFICATION THE BIGGEST INCREASE IN 18 KIP ESAL VALUES WAS ON URBAN ARTERIALS, RURAL INTERSTATE AND RURAL COLLECTORS.

AS THE DATA INDICATES NEVADA HAS AN INTRA-STATE AS WELL AS INTER-STATE TRUCK WEIGHT PROBLEM, AND ALTHOUGH OUR EFFORTS OVER THE NEXT TWO YEARS WILL BE FOCUSED PRIMARILY ON INTRA-STATE TRUCKS USING STATIC PLATFORM SCALES THE WIM SYSTEM IS INSTRUMENTAL IN OUR OVERALL TRUCK WEIGHT MONITORING AND ENFORCEMENT PROGRAM.

I'LL CLOSE BY SAYING THE WIM CONCEPT IS GREAT; OUR RADIAN SYSTEM HAS PERFORMED WELL AND NDOT IS SATISFIED WITH THE TRUCK WEIGHTS ACHIEVED AT HIGHWAY SPEEDS AND THE SEMIPORTABLE MODE OF OPERATION. ALSO THAT WITH OUR LIMITED STAFF, WE SIMPLY COULD NOT MAINTAIN AN ADEQUATE WEIGHING PROGRAM IF WE DID NOT USE WIM.

STATE OF DELAWARE

WEIGHT ENFORCEMENT

1985

302-736-5933
PHONE

JOHN F. CHADICK
TROOPER

DELAWARE STATE POLICE
P.O. Box 430 HQTRS
DOVER DELA 19903

DELAWARE IS KNOWN AS THE FIRST STATE BECAUSE IT IS THE FIRST STATE OF THE ORIGINAL 13 COLONIES. AS YOU ARE PROBABLY AWARE, DELAWARE IS ONE OF THE SMALLEST STATES, SECOND IN SIZE ONLY TO RHODE ISLAND. IF YOU ARE A TRUCK DRIVER WE ASK THAT YOU DRIVE SAFELY THROUGH OUR STATE, OBEY ALL OUR TRAFFIC REGULATIONS AND BE ESPECIALLY AWARE OF OUR TRUCK WEIGHT ENFORCEMENT POLICY. THE DELAWARE STATE POLICE ENFORCE THE WEIGHT LAWS WITH A WIDE RANGE OF EQUIPMENT. MOBILE WEIGHT ENFORCEMENT TEAMS ARE EQUIPPED WITH STATIC WHEEL AND AXLE LOAD SCALES. IF YOU HAPPEN TO BE TRAVELING NORTH ON ROUTE 13, YOU PROBABLY WENT THROUGH OUR WEIGH IN MOTION SYSTEM COMMONLY REFERRED TO AS WIM. WE ARE SORRY FOR THE DELAY, BUT WE DID WEIGH YOU IN THE .12 MINUTES IT TOOK YOU TO TRAVEL THROUGH THE STATION. WE CLOSED THE STATION DOWN SO THAT WE MAY OFFER YOU THESE PHOTOGRAPHS. THE SCENE BEING VIEWED NOW IS FROM THE WIM OBSERVATION DECK LOOKING SOUTH ON ROUTE 13. DIRECTLY IN THE CENTER OF THE SCREEN IS THE WEIGH IN MOTION EQUIPMENT. EAST OF RT. 13, AND TO THE TRUCKERS RIGHT, IS THE PARKING LOT. THE STATION IS LOCATED ABOUT 6 MILES NORTH OF SMYRNA ON THE NORTH BOUND LANE OF ROUTE 13. WE'LL TAKE YOU BACK AGAIN TO SHOW YOU WHAT TRUCK TRAFFIC LOOKS LIKE GOING THROUGH THE WEIGH STATION. PRIOR TO REACHING THE STATION, SIGNS REQUIRE THAT TRUCKS MOVE TO THE RIGHT HAND LANE, OTHER SIGNS SHOW THE DISTANCE TO THE WEIGH STATION. ONE MILE BEFORE THE WEIGH STATION A SIGN INDICATES THE STATION IS OPEN OR CLOSED. ANOTHER SIGN

INDICATES ALL TRUCKS MUST ENTER THE WEIGH STATION. AS VEHICLES APPROACH THE STATION, TRUCK DRIVERS ARE REQUESTED TO STAY IN THE RIGHT HAND LANE, AS A THIRD LANE OPENS UP AS AN ENTRANCE TO THE WEIGH STATION. NOTICE THE SCALE HOUSE IN THE CENTER, THERE ARE SIGNS INDICATING THE SPEED LIMIT AT 15 MILES AN HOUR, WHILE OTHER SIGNS REQUIRE 100 FOOT SEPARATION BETWEEN TRUCKS. AT 15 MILES AN HOUR, WITH A 100 FOOT SPACING, THE WEIGH STATION CAN PROCESS APPROXIMATELY 500 TRUCKS AN HOUR, SORTING THEM BACK TO THE HIGHWAY OR TO THE STATIC SCALE FOR FURTHER WEIGHT ENFORCEMENT. AS WE APPROACH THE WIM SYSTEM THE FIRST THING THAT IS OBVIOUS IS THE OVERHEAD DETECTOR. THE OVERHEAD DETECTOR IS SET FOR 13 FEET 6 INCHES AND WILL TELL THE WEIGH STATION OPERATOR A VEHICLE IS OVERHEIGHT. APPROACHING THE WIM AREA YOU WILL SEE TWO SETS OF WEIGHPADS PLUS TWO BUILT IN THE GROUND TRAFFIC LOOPS. ONCE VEHICLES PASS THE OVERHEIGHT DETECTORS THE WEIGHPADS BECOME MORE CLEAR. VEHICLES MUST MAINTAIN 15 MILES AN HOUR AS THEY PASS THE WEIGH IN MOTION SYSTEM. NOTICE THE WEIGHPADS ARE FLUSH TO THE GROUND. THIS IS A SECOND VIEW OF THE WIM SYSTEM. THIS TIME THE VIEW IS IT FROM THE SCALE HOUSE. AS A TRUCK APPROACHES THE WEIGHPADS, IT PASSES THE OVERHEAD DETECTORS AND NOW IT IS JUST ABOUT ON THE PADS. AS THE TRUCK GOES OVER THE PADS THE LEFT AND RIGHT TIRES ARE WEIGHED TWICE TO CONFIRM AN ACCURATE WEIGHT. THE SPEED OF EACH AXLE IS MEASURED. IF A TRUCK IS NOT CENTERED ON THE PADS OR IF THE TRUCK IS HEAVIER ON ONE SIDE, THE COMPUTER WILL DIRECT HIM

TO THE SCALE HOUSE VIA THE OVERHEAD TRAFFIC SIGNALS. NO EXTERNAL SWITCHES ARE USED TO IDENTIFY TRUCKS GOING AROUND THE WEIGHPADS SO SNOW PLOWING IS NOT A PROBLEM NOR IS THE COSTLY REPLACEMENT OF EXTERNAL SWITCHES NECESSARY. YOU ARE VIEWING THE FIRST SET OF THE WEIGHPADS. AT 15 MPH IT TAKES A TRUCK 1 1/12 SECONDS TO CLEAR THE 32 FOOT WEIGHPAD AREA, AND LESS THAN 20 MILLESECONDS FOR THE COMPUTER TO SET UP THE TRAFFIC LIGHTS. THIS TRUCK IS NOT OVERWEIGHT SO WE WILL SEE A GREEN ARROW DIRECTING IT BACK TO THE HIGHWAY. LOCATED IN THE WEIGHPAD AREA IS A WATERPROOF HOUSING THAT CONTAINS ALL THE ELECTRONIC CIRCUITS NECESSARY FOR THE WEIGHPAD SIGNALS. ALL THE SIGNAL CONDITIONING IS DONE AT THIS POINT AND SENT VIA UNDERGROUND CABLES DIRECTLY BACK TO THE SCALE HOUSE AND THE COMPUTER FOR FURTHER ANALYSIS. THE VEHICLE WE ARE DRIVING HAS BEEN DETERMINED BY THE WIM EQUIPMENT TO BE WITHIN LEGAL LIMITS AND WE ARE NOW DIRECTED BACK TO THE HIGHWAY. THIS GREEN ARROW INDICATES WE SHOULD FOLLOW THE TRUCK AHEAD OF US AND PROCEED DIRECTLY TO THE HIGHWAY. THE VEHICLE WE ARE IN DID NOT STOP TO BE WEIGHED, MAINTAINED 15 MPH AND WAS DIRECTED BACK TO THE HIGHWAY WITHOUT DELAY. LETS FOLLOW A VEHICLE NOW THAT IS OVERWEIGHT AND SEE HOW THE ELECTRONIC EQUIPMENT WILL SORT IT. THE VEHICLE APPROACHING THE LIGHTS RIGHT NOW IS OVERWEIGHT, AND HAS BEEN DIRECTED TO THE STATIC SCALES BY WIM SYSTEM. FOLLOWING THE OVERWEIGHT VEHICLE THE FIRST THING WE NOTICE IS THE OVERHEAD RED LIGHT IS ON STRAIGHT AHEAD. THIS INDICATES THE DRIVER IS NOT TO RETURN TO THE HIGHWAY BUT TO FOLLOW THE GREEN ARROW TO THE

RIGHT FOR THE STATIC SCALES. ALL THE DRIVER HAS TO DO IS FOLLOW THE GREEN ARROWS AND THE ELECTRONIC EQUIPMENT WILL DIRECT HIM DIRECTLY TO THE STATIC SCALES. THE VIEW YOU ARE SEEING NOW IS THE TRUCK APPROACHING THE STATIC SCALES. TWO WAY COMMUNICATIONS IS ESTABLISHED WITH THE DRIVER, AND THE WEIGH STATION OPERATOR ON THE SECOND FLOOR OF THE WEIGH STATION. THE OFFICER HAS A CLEAR VIEW AND DIRECTS THE TRUCK ONTO THE STATIC SCALE FOR WEIGHING. THE DRIVER IS DIRECTED TO PLACE THE CERTAIN WHEELS ON CERTAIN PORTIONS OF THE AXLE SCALE, AND THE WEIGHT OF EACH AXLE IS RECORDED. LOOKING DOWN FROM THE SECOND FLOOR, THE OFFICER HAS A CLEAR VIEW OF THE SCALES. THIS PARTICULAR STATIC SYSTEM HAS 3 INDIVIDUAL SCALES. IF THE DRIVER IS WITHIN LEGAL WEIGHT LIMITS HE IS DIRECTED BACK TO THE HIGHWAY. TRAFFIC LIGHTS AND TWO WAY COMMUNICATIONS WILL TELL THE DRIVER WHEN TO PROCEED. THIS PARTICULAR TRUCK IS OVERWEIGHT. IN THIS CASE THE WEIGH STATION OPERATOR HAS GONE OUT TO THE DRIVER AND REQUESTED HIM TO PARK HIS VEHICLE IN THE PARKING LOT. HIS REGISTRATION, PERMITS AND THE WEIGHTS INDICATED ON THE STATIC SCALE WILL DETERMINE IF A CITATION IS REQUIRED. THE CONTROL CENTER FOR THE SCALES IS LOCATED ON THE SECOND FLOOR OF THE SCALE HOUSE. NOTICE IN THE LEFT HAND SECTION OF THIS PHOTOGRAPH ARE THE STATIC SCALE READOUTS. LOCATED DIRECTLY IN THE CENTER IS THE STATION'S LAYOUT, SHOWING THE STATUS OF THE TRAFFIC LIGHTS THAT ARE MANUALLY CONTROLLED BY THE STATION OPERATOR. IN THE FOREGROUND IS THE WIM SYSTEM. THE WIM 400 SYSTEM THAT YOU ARE NOW SEEING HAS BEEN ENGINEERED

BY SIEMENS TO PRODUCE THE MINIMUM OF OPERATOR FATIGUE. ALL LEGAL TRAFFIC IS DIRECTED AUTOMATICALLY BY THE COMPUTER TO THE HIGHWAY WHILE ALL ILLEGAL TRAFFIC IS DIRECTED TO THE STATIC SCALES. EVERYTHING FROM THE CLEAR VIDEO MONITOR TO THE HIGH SPEED INK JET SILENT PRINTER IS DESIGNED, MANUFACTURED AND SUPPLIED BY SIEMENS. IN THE CENTER OF THE CONSOLE IS A KEYBOARD. ON THE OPERATOR'S LEFT HAND SIDE OF THE KEYBOARD IS A MAGNETIC CARD. THE MAGNETIC CARD IS PROGRAMMED SO THAT ONLY IDENTIFIED OPERATORS CAN CHANGE STATION PARAMETERS. FOR EXAMPLE; IF TRUCK TRAFFIC IS BECOMING A PROBLEM AND VEHICLES ARE PILING UP ON THE STATIC SCALE AREA ONLY THE SUPERVISOR WOULD BE ALLOWED TO CHANGE THE WEIGHT LIMITS THAT BRING IN OVERWEIGHT TRUCKS. THE SUPERVISOR CAN, BY PUSHING A BUTTON,SELECT AN INCREASE OF THE WEIGHT TOLERANCE BY 20, 30 OR 40%. ON THE LEFT HAND SIDE A KEY IS USED TO OPERATE THE STATION FOR SECURITY REASONS. TO THE RIGHT SIDE OF THE CONSOLE YOU WILL NOTICE BUTTONS THAT CONTROL THE TRAFFIC LIGHTS, START AND STOP THE CASSETTE OPERATION, CHANGE THE OPERATING LEVELS, AND PERFORM OTHER FUNCTIONS. ON THE UPPER RIGHT IS A STATION LAYOUT. THE STATION LAYOUT SHOWS THE STATUS OF ALL THE COMPUTER CONTROLLED TRAFFIC LIGHTS IN THE STATION AND IDENTIFIES THE VEHICLE THAT IS COMING INTO THE STATIC SCALE. A CLOSER LOOK AT THE STATION LAYOUT SHOWS THE TRUCK NOW CROSSING THE SCALE HAS A GREEN LIGHT TO RETURN TO THE HIGHWAY AND A RED LIHT TO ENTER THE STATIC SCALE. THE OVERHEAD LIGHT IS SHOWING THE VEHICLE IS OVER THE HEIGHT OF 13'6" BUT IN THIS PARTICULAR

CASE HAS BEEN OVERRIDDEN BY THE STATION OPERATOR. IN THE CENTER IS AN ESCAPE LIGHT. IF A VEHICLE DISREGARDS A RED LIGHT AND RETURNS TO THE HIGHWAY WHEN HE WAS DIRECTED TO THE STATIC SCALES THE LIGHT WOULD INDICATE A VIOLATION AND AN AUDIO ALARM WOULD SOUND ALERTING THE STATION OPERATOR. THE COMPUTER DOES MOST OF THE OPERATIONS AUTOMATICALLY BUT OCCASIONALLY AN OPERATOR WHO RESTARTS THE SYSTEM MAY HAVE TO ENTER THE DATE AND TIME THE STATION OPENS. HE MAY ALSO BE ASKED BY THE COMPUTER TO IDENTIFY THE STATION AND PROCEED WITH THE OPERATION OF THE STATION EITHER AUTOMATICALLY OR MANUALLY. IN THE NEXT SEVERAL SLIDES WE WILL SEE VARIOUS DISPLAYS ON THE VIDEO MONITOR. THE SCREEN ON THE VIDEO MONITOR IS DIVIDED INTO 3 SECTIONS. THE CENTER SECTION SHOWS TRUCK INFORMATION, WHILE THE STATUS SYMBOL IS IN THE TOP THIRD OF THE SCREEN. COMMUNICATIONS BACK AND FORTH WITH THE SYSTEM IS DONE ON THE LOWER SECTION OF THE SCREEN. DISPLAYED NOW ARE THE LAST 6 TRUCKS THAT HAVE PASSED THROUGH THE STATION. IDENTIFICATION IS DONE AUTOMATICALLY AND THE TRUCK INFORMATION WILL APPEAR ON THE SCREEN AS IT CLEARS THE WEIGHPADS. NOTICE, WE HAVE IDENTIFIED THE TRUCK WITH A NUMBER, THE TIME THAT IT WENT ACROSS THE SCALES AND THE INDIVIDUAL AXLE WEIGHTS. (AXLE 1,2,3,4 AND 5 UP TO 10 AXLES MAY BE DISPLAYED ON THE SCREEN) THE TOTAL WEIGHT AND A COLUMN MARKED OVERWEIGHT IF A TRUCK IS OUT OF THE PRE-PROGRAMMED OVERWEIGHT PARAMETERS, A NUMBER WILL APPEAR AND THE WIM SYSTEM WILL DIRECT THE TRUCK INTO THE STATIC SCALES. THE SPEED INDICATED IS THE SPEED THE TRUCK CROSSED THE

WEIGHPADS. THE CATEGORY COLUMN HAS A LOOK UP TABLE DEFINED IN FURTHER TABLES IN THE COMPUTER. IN THIS PARTICULAR CASE, A 53 TRUCK HAS 5 AXLES WITH 3 COMBINATIONS. THE LAST COLUMN INDICATES A MANIPULATION. MANIPULATION IS DEFINED AS THE DRIVER TRYING TO DRIVE AROUND THE WEIGHPADS, OR CHANGE SPEED,(THAT IS IF THE FRONT AXLE AND THE LAST AXLE OF THE TRUCK CHANGES SPEED BY MORE THAN 10%) THE COMPUTER DETECTS THESE MANIPULATIONS AND THE TRUCK WILL BE AUTOMATICALLY DIRECTED INTO THE STATIC SCALE LANE. THE WIM COMPUTER ALSO HAS THE CAPABILITY TO RECALL A DETAILED DESCRIPTION OF THE VEHICLEIF IT I REQUIRED BY THE STATION OPERATOR. VEHICLE INFORMATION CAN BE PRINTED ON PAPER AND/OR PRINTED ON THE SCREEN. ALL AXLE WEIGHTS, AXLES 2,3 IS THE COMBINATION OF AXLE 2 AND 3. WE HAVE SHOWN THE WEIGHT, AXLE SPACE, OVERLOAD AND ANY OTHER VIOLATION. WE HAVE ALSO IDENTIFIED GROSS WEIGHT, THE TRUCK NUMBER, THE VEHICLE LENGTHS BUMPER TO BUMPER, VEHICLE CLASS AS IDENTIFIED BY OUR LOOK UP TABLE AND THE VEHICLE'S SPEED. ALL OF THIS DETAILED INFORMATION ON THIS PARTICULAR TRUCK IS SHOWN IN THIS PARTICULAR MODE. BY SWITCHING MODES WE CAN LOOK AT THE STATISTICAL ANALYSIS OF THE STATION AT A PRE-PROGRAMMED INTERVAL OF TIME. THIS PARTICULAR PROGRAM IS WRITTEN FOR ONE HOUR, BUT CAN BE CHANGED UP TO 216 MINUTES. THE LOOK UP TABLES PROVIDE US WITH THE CLASS, THE NUMBER OF SINGLE AXLES, TANDOM LENGTHS, AND THE SPEED, ACCORDING TO PRE-PROGRAMMED CATEGORIES. NOTICE ON THE RIGHT HAND SIDE IS A LIST OF ALL VEHICLE CATEGORIES. TRUCKS IDENTIFIED IN THE SERIES ARE SHOWN IN

CLASSIFICATIONS AND THE TOTAL NUMBER PRINTED. 999 INDICATES A VEHICLE THE COMPUTER CANNOT IDENTIFY. THIS IS A VEHICLE WHICH HAS NOT BEEN PROGRAMMED INTO THE SYSTEM OR DOES NOT MATCH OUR LOOK UP TABLES. THE OPERATOR HAS SWITCHED MODES AND SELECTED THE COMPUTER'S MENU. WE HAVE 9 MODES OF OPERATION AND 4 TEST MODES. IN THIS PARTICULAR MODE WE CAN SEE THE SYSTEM MESSAGE ON THE BOTTOM OF THE SCREEN. IT SAYS THAT WE ARE IN A TEST MODE AND THE OPERATOR HAS MANUAL SIGNALING CONTROL OVER THE STATION. THE OPERATOR HAS CONTROL OVER THE PRINTER AND EACH INDIVIDUAL MODE. HE CAN SELECT EXACTLY WHAT HE WANTS PRINTED AND TRANSFER THAT INFOMATION DIRECTLY TO THE HIGH SPEED PRINTER. IN THIS PARTICULAR OPERATION, DELAWARE HAS ELECTED TO RECORD ON THE PRINTER EVERY VEHICLE GOING ACROSS THE WIM SYSTEM. IN SUMMARY, THE WIM SYSTEM HAS TAKEN VEHICLES AT A STANDARD 15 MPH SPEED AND SORTED THEM ACCORDING TO WEIGHT. THE VEHICLES THAT ARE LEGAL, HAVE BEEN SENT BACK TO THE HIGHWAY, WHILE STOPPING ONLY OVERLOADED VEHICLES WHICH ARE DIRECTED TO THE STATIC SCALE FOR FURTHER EVALUATION. THIS PARTICULAR SLIDE SHOWS A OVERWEIGHT VEHICLE APPROACHING THE STATIC SCALE.

THE WIM SYSTEM INSTALLED IN SMYRNA, DELAWARE IS AN EXCELLENT EXAMPLE OF WEIGH-IN-MOTION TECHNOLOGY. THIS PARTICULAR SYSTEM WILL SORT TRAFFIC AT 15 MPH OR FASTER, BUT LIMITATIONS DUE TO THE AMOUNT OF REAL ESTATE AND DRIVER REACTION TIME, LIMITS THIS PARTICULAR STATION TO 15 MPH. EVEN AT 15 MPH THE STATION HAS A CAPABILITY OF 500 TRUCKS PER HOUR; THAT IS 70 FOOT TRUCKS WITH 100 FEET SPACING

BETWEEN EACH VEHICLE. AGAIN THE PHOTOGRAPHS ILLUSTRATE THE CAPABILITIES OF THE SYSTEM TO FOLLOW TRUCKS, DIRECT THEM TO VARIOUS AVENUES, MAINTAIN SPACING AND ELECTRONICALLY WEIGH THEM IN MOTION. IN DELAWARE, AS IN MANY OTHER STATES, THERE ARE PROBLEMS WEIGHING HUGE NUMBERS OF TRUCKS JUST TO GET ONE OVERWEIGHT VEHICLE. THAT MEANS YOU MUST SORT OUT 98 LEGAL TRUCKS. THE WIM SYSTEM DOES THIS EFFECTIVELY, EFFICIENTLY AND SAFELY. THE SYSTEM INSTALLED IN SMYRNA IS THE SIEMENS 400 SYSTEM. SIEMENS HAS INSTALLED HUNDREDS OF WIM STATIONS THROUGHOUT THE WORLD. THIS PARTICULAR SYSTEM WAS INSTALLED IN 1982, AND FOR THE FIRST 2 YEARS LOST 1 DAY BECAUSE OF WIM EQUIPMENT FAILURE. THE WEIGHPADS THAT YOU HAVE SEEN IN PRIOR PHOTOGRAPHS ARE THE ORIGINAL WEIGHPADS INSTALLED WHEN THE STATION FIRST BECAME OPERATIONAL. THE ORIGINAL WEIGHPADS ARE STILL THERE AND OPERATIONAL. WE INVITE YOU TO VISIT THE SMYRNA WIM STATION AND REQUEST THAT IF YOU ARE COMING THROUGH THE AREA PLEASE GIVE US A CALL, WE'LL BE MOST HAPPY TO SEE YOU AND MAKE ARRANGEMENTS TO GIVE YOU A TOUR OF THE STATION.

PLEASE CONTACT CORPORAL JOHN CHADICK AT DELAWARE STATE POLICE HEADQUARTERS, P.O. BOX 430, DOVER, DELAWARE 19903 (302)736-5933.

STATE OF MARYLAND

MARYLAND STATE POLICE

Captain Murray J. Zepp, Commander - Truck Enforcement Division
Maryland State Police

Presentation - Second Annual Conference on Weigh in Motion Technology and Applications

I. Current Operational Agreement

A. Memorandum of Understanding between Department of Public Safety and Correctional Services/Maryland State Police and Maryland Department of Transportation/State Highway Administration (Five Year Plan)

1. Clarifies responsibilities - SHA maintains lighting, parking, ramps, semi-portable pits, and also responsible for all new capital projects. MSP maintains all fixed scale houses, scale equipment, and all enforcement operations - FY 85 MSP budget 3 million - fines collected - 3 million.

II. Existing Resources

A. Three fixed scales (US Routes) - 8 semi-portable sites - 13 roving/portable crews.

1. 5 semi-portable scales utilizing 2 Lodec 7 foot and 3 Loadometer 6 foot semi-portable scales.

2. 114 wheel load weighers - converting to Haenni low profile scales from MD 500 GEC type.

B. Authorized 81 personnel - 41 sworn, 38 cadets, and 2 clerical

1. Vehicles - total 40 - full sized marked and unmarked patrol cars, crew cab pickups with caps - converting to patrol cars (Haenni) and 15 passenger vans for semi-portable scale operations.

III. Plans

A. Fixed Scales

1. One located on I-70 west of Baltimore - each side of road - 15 miles apart (can observe closest by-pass route). 3 platform static scales and weigh in motion dynamic in deacceleration ramp (both Streeter-Richardson). Also contains inspection booth between truck lanes and 25 truck parking lot with walk down inspection pit. Under 3 million dollars - operational July 85.

2. One other scheduled for I-95 near existing toll booths (Susquehanna River) north of Baltimore. Currently in design stage. (different - I-70 due to large volume of vehicles) Planned for 1989 operation. Cost 7½ million.

III. Plans (continued)

3. Relocate existing fixed (Foy Hill) scales to toll booth US Route 40 (Susquehanna River) parallel to I-95 above (in outside lane of toll facilities - (weigh while paying toll) Purpose to force inspection of all commercial motor vehicles - Maryland's north east corridor - see semi-portable plans - cost ½ million.

B. Semi-portable - Low profile scale pit - construction plan

1. I-83 North of Baltimore - southbound lane - 1987 operational. Contains scale pits (semi-portable scales 7 or 12 foot) Decel and excel lanes with two full lanes for screening and weighing. Appropriate advance signing and overhead lighting. Ideal for portable weigh in motion - requested in next year's budget. Cost under ½ million.

2. Maryland Route 5 North of US Route 301 - operational 1987. By-pass route existing fixed scale on US Route 301.

3. I-68 Bowie - operational 1988 - route between Washington D.C. and Annapolis. Heavy truck route and by-pass route.

4. US Route 1 Conowingo Dam - operational 1989. This is the only by-pass route for the only other 2 heavily travelled north, south highways in the north east corridor of Maryland. The Susquehanna River presents geographical barrier for US Route 40, I-95, and US Route 1.

C. WIM- Weigh In Motion

1. Streeter-Richardson equipment being installed by prime contractor for purpose of screening vehicles approaching static scales at I-70 scale facilities - July 85

2. Continue design plans for "State of Art" WIM systems for planned I-95 facilities. Essential due to 11-12,000 ADTT (average daily truck traffic)

3. RTAP - Bridge Weigh System - continue working closely with SHA - gaining experience and sufficient data to determine selective enforcement programs. Good data not now available.

   a. After satisfactory data collected explore uses of bridge weigh system with enforcement operations - utilizing semi-portable and portable scales.

   b. Discuss one comparison weight case - bridge weigh 84,000 pounds and portable scales 83,700 pounds.

4. Within the next year acquire a portable WIM system to be used primarily for enforcement purposes.

III. Plans (continued)

a. Screen vehicles at semi-portable sites - would increase number of trucks weighed by at least 200% - current daily average semi-portable 200

b. Discuss current plans to use WIM at US Route 1, Conowingo Dam (Bridge weigh system) when I-95 and US Route 40 facilities completed

(1) Monitor with closed circuit TV at I-95 site - eliminates costly resources

5. Consider other systems

a. Dynamic bridge formula compliance analyzer

b. Static platforms equipped with dynamic weighing capability

IV. Documents Available

A. WIM specifications - current I-70 project

B. Site plans - I-70, I-95, and I-83

C. Truck enforcement locations map

D. Copy MSP weight records

HIGH SPEED SORTER AND DATA COLLECTION

«WIM» SYSTEM

HIGHWAY 20, ST-ROMUALD

PROVINCE OF QUEBEC, CANADA

Paper prepared for presentation at the second National Conference on Weigh-in Motion Technology and Applications.

MAY 1985
Revised on july 1985

Presented by:

Roch Bergeron, ing.
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Marc Robert, ing.
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DOT QUEBEC

1. INTRODUCTION

For Several years now, the DOT, quebec, has been studying weight in Motion systems and their possibilities of increasing the effectiveness of our road protection programs in order to extend the useful life of our road network.

For that purpose, we analysed different systems being used or proposed in Canada and here, in USA.

Our choice had to comply with our needs, our geography and our laws which includes our Civil Code (Napoleon code) and our Highway Safety Code.

We decided to experiment a WIM system, that while offering high speed sorting of heavy load vehicles in order to direct to a static weigh-scale only the overloaded trucks, would also gather statistics on full highway traffic movements.

The system we choosed is an IRD concept, that we installed in a small community called St-Romuald, situated across the St-Lawrence River from Quebec City. This WIM system is embedded in The Trans-Canada Highway (Autoroute 20). The construction started during the summer 1984 and was completely operational by March 1985.

2. DESCRIPTION

As mentionned previously, this installation is a two-purpose system, first to be used as a sorter for an axial-load scale (3040 ft) downstream, and as a statistics collector for vehicle movement.

.../2

Embedded in the main highway, this system has to operate under high-velocity traffic (90 to 100Km/hr, 55 to 60 miles/hr).

We choose this configuration for 3 reasons:

1- High-cost for placing the system on the static scale approaches.

2- Traffic volume allowed such a location.

3- Full possibilities of gathering statistics.

The physical arrangements of this system is as follows:

a) Weight sensors plates (IRD type) are in the right lane of this two-lane highway leading westerly to the approaches of the static scale, 1980 ft down-stream.

b) On the left lane, adjacent to the plates, there is an axle sensor (IRD type).

c) An electronic interface connected to a sorter computer at the same height as the plates, outside of the roadbed. (Model WIM-4, IRD).

d) A statistic computer situated in the static scale house (Digital model PDP 11/2) connected to the sorter computer in order to compile the statistics.

e) A video system composed of:

   a) a video camera aimed on the vehicles passing over the sensers (Model Hitachi FP-15).

   b) A video monitor in the scale house (Model JVC 1483).

   c) A video frame store at the scale house (Model Digital Video Systems, Phaser V). This allows to freeze in memory any unlawful vehicle either because of weight or inappropriate driving.

f) Road signs directing heavy-load vehicle to use the right lane.

g) A directionnal light system to instruct unlawfull trucks to drive to the scale house, (Model 3M-131). These lights are equipped with Fresnel lens, concentric and directionnal.

h) A terminal keyboard with CRT (Model Qume QVT-102A) at the scale house. This terminal is directly hooked to the WIM-4 allowing to issue commands for the sorting of vehicles.

The approximate cost of this set up is $ 225,000100 in canadian money, that is $ 165,000.00 for the material and $ 60,000.00 for man-power.

3. OPERATION

3.1 Sorting of vehicles

By pressing the following keys of the terminal keyboard in the scale house, the operator can issue any of the following commands:

View key: To look at the traffic flow, which gives the following informations for each vehicle:

a) lane used

b) total Weight

c) 18K-ESAL factor

d) axle spacing

e) axle weights

f) hour and date

Open Key

To start sorter operation

Normal Key

To sort vehicles according to the law at the time of operation. Regulations changes during thaw periods.

Thaw Key

To sort according to thaw regulations which reduces the weight allowances during these periods.

Plus and Minus Key

to ajust the permissable limit, over which the sorter will signify an overload situation.

Signal lights Key

To keep the directionnal lights open to force all trucks to drive to the scale house.

Close Key

To close sorter operation.

When a heavy vehicle passes over the road sensors, it could be pick-up for axial overload, total weight, driving around the sensor plates, or if brakes were applied over these sensors. In any of these situations, the picture of the vehicle is freezed on the video monitor and the directionnal traffic lights tells the trucker to drive to the scale house. When the truck enters the sscale's approaches, the operator in the scale house receives a message on the CRT telling him what's wrong with the approaching truck. Should a truck not enter or drive on the left lane of the highway, a bip is heard in the scale house so a policeman can go and pick him up.

To date, we are happy enough with the system, and we are confident that long term operation will prove this system to be a remarquable asset by increasing the effectiveness of our road control program.

3.2 Compiling statistics

The complete system is hooked up to our department's offices in Quebec City, where the gathering of informations is performed. Some features of these informations are also very useful to evaluate the effectiveness of our control. For example, for any period of time, we can get from the 40 heaviest trucks that passed the sensors (Whether the scale is in operation or not) their weights, their dimensions, time of day, etc. It's a good feedback to study.

4. LEGAL ASPECTS

In Canada, measuring and weighing is a federal government's jurisdiction and falls under «The Weights an Measures Act» which dictates the requirements any instrument shall meet in order to be used as a legal mesuring device if to be used for trade and commerce. However federal authorities have confirmed to the Provinces that weighing for road control was not a commercial act, and as such was falling under the jurisdiction of the different provincial governments.

In the light of this confirmation, the Quebec Provincial Government passed a law called «Code de sécurité routière» or «Highway Safety Code» which states that any scale which has been approved by the minister of transport of Quebec, can be used for road control.

It is the responsability of our office to determine which scales the minister could or should approve.

Our Highway Safety Code does not specify the degree of precision our road control scales should meet. This has allowed the use of axial load scales for road control by adding tolerances in the application of the law.

It may be wishful thinking but if in the future, WIM systems can become more accurate, probably by low speed measurements, WIM systems may become legal scales instead of just sorters.

Paul Simms - Arkansas

The Use of Weigh-in-Motion Systems to Collect Design Data

Presented at the
Second National Conference on Weigh-in-Motion
Technology and Applications

Atlanta, Georgia

May 20-24, 1985

The only weigh-in-motion (WIM) system in Arkansas is at the Lehi Weigh Station on Interstate 40 near West Memphis. The Department is using WIM equipment at that location because of the high truck volumes and the limited expansion area for the weigh station. Although the WIM system has facilitated the monitoring of truck weights, the enforcement of other state laws and regulations has become more difficult because the trucks are no longer weighed on static scales. Until this problem is solved, the Department will continue to be very reluctant to purchase additional WIM systems.

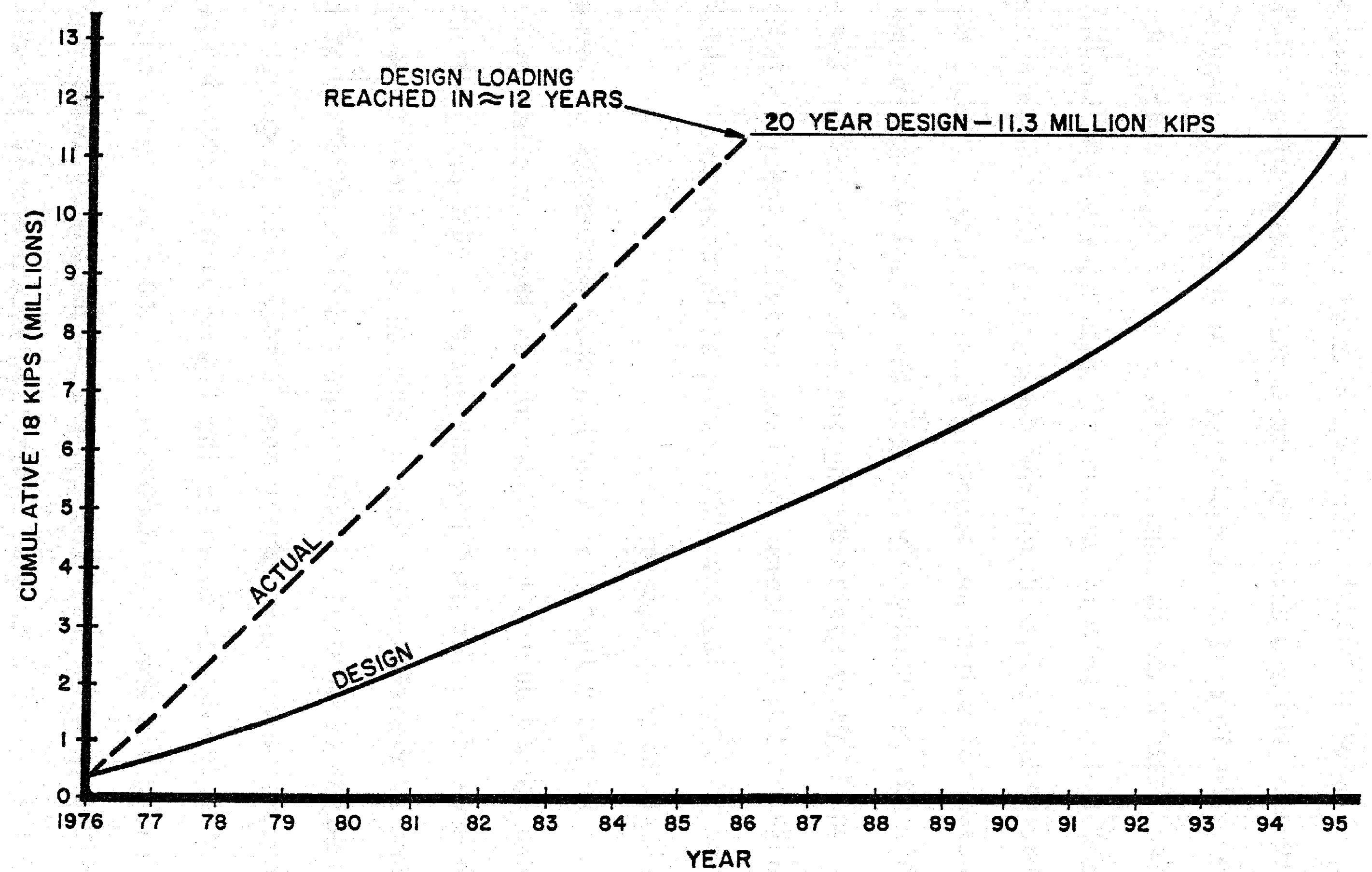
Value of WIM systems in the Collection of Truck Weight Data for Design

The value of utilizing WIM equipment to collect truck weight data and predict future design loadings is obvious. One strong argument in favor of the increased use of WIM equipment for design purposes is the lack of suitable locations to manually collect truck weight data in the urban environment. We lack data on trucks operating in urban areas, although a few stations are located on the fringes of urban areas and are reported as urban stations to the

FHWA. If urban truck weight data could be extracted using a WIM system, it is anticipated that lower truck weights would be observed on many routes. Consequently, lower average eighteen-kip equivalent axle loads (EAL's) per axle would be developed from these data and significant savings could be realized on the major reconstruction and widening projects which are programmed for urban freeways and arterial routes.

At the same time, the available evidence indicates that many of the rural arterial routes were designed with insufficient strength because the actual loadings were much higher than projected. The principal cause was the dramatic increase in the size and number of the large commercial vehicles on the major arterial and freeway routes in Arkansas. Commercial vehicles now account for approximately one-half of the traffic operating on most of our rural interstate highways. In addition to these unforeseen increases in volumes, significantly higher average vehicle weights have resulted from the increase in the legal size and weight limits in Arkansas and the drive for increased transportation efficiency. All of these factors have combined to cause pavements to experience a full measure of the design loadings long before the end of the design period. The figure on the following page illustrates the estimated remaining life of a highway pavement based on the EAL's experienced by that pavement. The design line refers to the projected EAL values which were developed from weight studies conducted prior to construction. The actual line refers to our best estimates of the EAL's being experienced by the new pavement. Please note that the design loadings which were projected for a twenty-year period occurred in approximately twelve years. Also, the number of overweight trucks which contributed to these design loadings is

JOB 11843
I-40 — HWY. 38 — SHEARERVILLE
COMPARISON OF 18 KIP DESIGN VS. ACTUAL



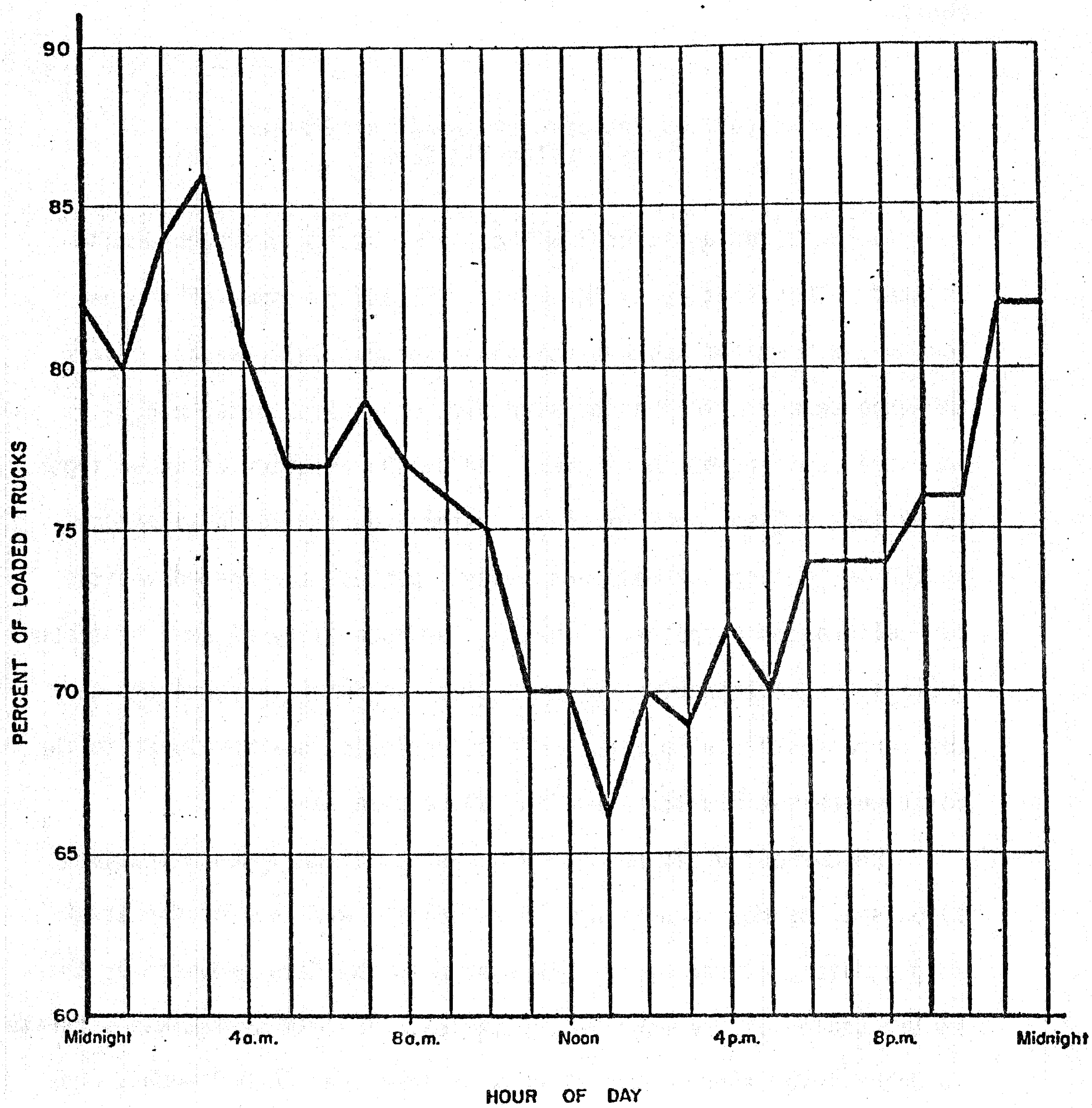
Prepared by Planning Division

insignificant because the Lehi Station is nearby and it operates twenty-four hours a day.

Assuming that better forecasts of commercial vehicle volumes are available, a more accurate means of determining average EAL's per vehicle must be established. In this regard, many pitfalls associated with the manual collection of truck weight data were examined. A primary concern is that truck weight studies have traditionally been conducted during daylight hours in the summer because of safety and economic considerations. Thus, the collected data may not accurately reflect the actual weights being hauled on the highway system during the remaining times of the year. Because of these concerns, we have conducted special studies to determine if significant variations exist in commercial vehicle operations by season or by time of day.

We determined that a much higher percentage of commercial vehicles were loaded during the winter months than any other time of year. This was true for each highway system. Similarly, variations in commercial vehicle operations by hour of day appear to be significant. Although commercial vehicle volumes decline slightly at night, these vehicles are significantly more likely to be loaded at night than during the day as shown by the figure on the following page. Normally, field crews work from 8:00 a.m. to 6:00 p.m.; thus, they are collecting weight data for the lowest hours of the day in terms of the percent of loaded 3-S-2 trucks. This significant hourly variation in commercial vehicle operations and the subsequent effect on EAL's is one of the reasons that Arkansas field crews will begin to collect 24 hours of weight data at enforcement station locations. Twenty-four hour truck weight data will still be unavailable for most of the

PERCENTAGE OF LOADED 3S2 TRUCKS BY HOUR OF DAY



SOURCE: HPMS Case Studies

primary highway system and all of the secondary highway system. A portable WIM system could supplement the truck weight study to account for these daily and seasonal variations and assist in determining the most economical design of the more than 5,000 miles of roads which will be rehabilitated during the next ten years.

Problems Encountered in Making Greater Use of the WIM Data

The need for additional WIM data for design has been demonstrated. This section of the paper will address some of the reasons why WIM system use has not been expanded in Arkansas. First, the expense and effort associated with operating portable WIM systems does not appear to be justified by the accuracy of these types of systems. Also, most of these systems require an on-site technician to monitor the data and several passes of a loaded vehicle for calibration purposes. Finally, the durability of some of these systems is questionable. At this time, we remain unconvinced that the current state of portable WIM technologies has developed to the point where satisfactory results can be obtained.

The current usefulness of WIM systems at permanent locations appears to be more promising. A comparison was made of the truck weight data provided by the WIM system to the data provided by the static scales at the Lehi Weigh Station. The WIM system was accurate in determining tandem axle weights of less than 30,000 pounds and all single axle weights. For tandem axles weighing more than 30,000 pounds, the WIM system was usually within ten percent of the weight observed on the static scales. However, in this high weight range, relatively minor variances can produce significant disparities in the calculation of EAL's. For a one-hundred-truck sample, the EAL's calculated from the weights recorded from the WIM scales were determined to be twenty-three (23) percent less than the EAL's calculated from the comparable static scales data.

The most common problem encountered in the collection of these WIM data resulted from drivers not maintaining the proper spacing between vehicles. Normally, this practice produced errors in the determination of axle configurations or axle weights. Thus, an observer must be at the weigh station to screen the WIM data and eliminate any obvious errors.

Future of WIM Systems in Arkansas

As previously discussed, the WIM system in operation has demonstrated its usefulness in the enforcement monitoring of truck weights. However, two obstacles to the increased use of WIM systems in Arkansas remain. From the enforcement perspective, some means must be found of determining if the vehicles passing the WIM station are being operated in accordance with the appropriate laws and regulations. A study is being conducted to evaluate the effectiveness of identifying commercial vehicles by means of a bar code system. This system would also provide data on the vehicle's registration and fuel tax payments. Until this type of identification system is developed, there is not much reason for the Department to invest in WIM systems at enforcement sites.

The development of an acceptable portable WIM system is the second obstacle to the increased use of WIM systems in Arkansas. If the results in other states have been similar to our experiences, then a great deal of work remains in the development of a portable WIM system which can provide accurate design data at a cost which is acceptable to the state.

EQUIVALENT AXLE LOADS FOR PAVEMENT DESIGN

By
Richard D. Warpoole
Civil Engineer Manager
Traffic and Safety Planning

Prepared For
Second National Conference
Weigh-In-Motion Technology and Applications
Atlanta, Georgia

May, 1985

EQUIVALENT AXLE LOADS
FOR PAVEMENT DESIGN
TENNESSEE

I. PRESENT METHODS:

A. Data Collection - Truck weight data is presently collected at fifteen locations: seven Interstate Rural, six FAP Rural and two FAP Urban systems every two years. Trucks are weighed with portable scales for an eight hour period, sampling trucks from the traffic stream by vehicle type based on percentages and numbers of vehicle types from previous classification counts. Data is collected for vehicle type, body type, commodity, axle weight and axle spacing.

B. Data Tabulation - The field data is keypunched, edited, and processed using computer programs from FHWA to print the W-Tables for the biannual truck weight report. The equivalent axle load (EAL's) rates per 1000 trucks weighed are taken from the W-4 Tables and used to estimate EAL's for each vehicle type.

C. EAL Factors For Design - EAL Factors for each vehicle type are plotted against previous years' rates and a trend or average value is estimated. Table 1 and Figure 1 show a typical plot of EAL's for a five axle or more tractor-trailer. The plot of the EAL's as of this date seems to indicate a constant or slight increase in value for EAL per 1000 trucks weighs. (See Table 1, Figure 1, and Table 3) The EAL's factors for each vehicle type are used along with the projected number of vehicle types to calculate the Average

Daily Loads (ADL's) for a location. Table 2 shows a typical calculation furnished to Design for ADL's.

II. PROBLEMS WITH PRESENT METHODS:

A. Inadequate Data - The most pressing problem is the lack of sufficient and accurate truck weight data. This is due to the small number of station locations. The time frame (usually six-eight hour operation), and the small sample of trucks which can be weighed with a manual operation. Data from one location must then be used to estimate manual flow on several hundred miles of highway systems.

B. Cost of Data - The present method of data collection is highly intensive manpower oriented requiring 8-12 persons per site to collect and record data. Office costs of coding, keypunching, and data adds to this cost.

C. Statistical Accuracy - The small amount of data collected (due to limited sites and time) leads to problems of accuracy and expansion of data to represent travel loads across the various highway systems. One of the major problems we have encountered in Tennessee are the differences in weights and Equivalent Axle Loads at enforcement locations (pit scales) versus locations where enforcement is not continuous. Tables 4 and 5 shows this comparison of enforcement vs non-enforcement locations. I believe the HPMS Truck Study also show differences between enforcement time frames (day and weekday) versus non-enforcement time frames (night and weekend) for truck weights.

III. PROPOSED METHODS:

A. New Equipment (WIMS) - Tennessee has recently purchased a portable truck weigh-in-motion system. This system consists of two weigh pads, portable computer with software, loops, data interface, generator and other auxiliary hardware. A description of the system and costs is attached to this report. I regret that we have not had the equipment long enough at this stage to adequately analyze the system. In fact the equipment is not yet 100 percent operational.

B. New Equipment, Problems and Needs - Most of the problems experienced so far with the new equipment has been in the quality control or assembly of the hardware components, i.e., connector pins not fasten to proper wires, loop amplifiers not working and circuit boards. Other areas of concern which would make the equipment more efficient are:

(1) Use of batteries instead of A.C. Generator for 24 hour operation

(2) Larger data storage at site

(3) Temporary loops need to be easier to remove

(4) Smaller equipment unit

(5) More software flexibility, i.e., load only programs required.

C. Procedure Changes - With the availability of the new (when it becomes operational) the system of data collection can be expanded both in time frame and system mileage. We should be able to meet the recommended guidelines from the FHWA in the Traffic Monitoring Guide for HPMS data sampling and collection.

Data can be collected cost efficiently for 24-48 hours, seasonal, for different functional systems (including Urban), and more importantly, by Vehicle Type.

D. Pavement Management Programs - With the new portable WIM system, data should be available to address:

(1) Pavement Design

(2) Resurfacing

(3) Overlays

(4) Pavement Evaluation

TABLE NO. 1
TENNESSEE TRUCK WEIGHT STUDY
18 KIP AXLE EQUIVALENCY FACTORS (RATE PER 1,000 TRUCKS WEIGHED)
PAVEMENT TYPE FLEXIBLE
HIGHWAY SYSTEM INTERSTATE RURAL

Vehicle Type	YEAR 1967	1968	1969	1970	1971	1972	1973	1974	1975	1976	1978	1980	1982	1984	Average	Trend
Panel and Pickup	2	3	2	4	3	2	4	5	6	5	9	9	3		4 •	10
Single Rear Tire	2	7	5	3	3	9	7	8	8	6	5	7	14*		6 •	10
Dual Rear Tire	227	242	214	202	203	207	113 1/	139	147	146	185	155	156		149 •	125
3-Axle or More	270*	227*	802	799	803	920	632 1/	620	596	521	806	407	668		607 •	430
Sub-Total Single Unit Trucks	92	101	113	107	107	98	62 1/	67	60	56	69	52	57		60	30
3-Axle Tractor Trailer	556	777	701	558	543	556	493	570	517	335*	675	770	734		621 •	900
4-Axle Tractor Trailer	562	634	713	611	677	570	573	660	630	590	617	553	496		607 •	470
5-Axle or More Tractor Trailer	632*	688*	827	888	911	832	902	902	825	877	1068*	868	920		875	970 •
Sub-Total Tractor Trailer Trucks	605*	680*	794	816	852	773	833	857	791	817	997*	836	878		825	990
Total All Trucks	339*	396*	486	501	520	434	436	458	401	382	471	466	481		456	460

* Not used in averages or trends
1/ Used 1973 to present
• FACTOR SELECTED FOR ADL

TABLE 1.

SYSTEM I.S. RURAL
PAVEMENT TYPE FLEXIBLE
VEHICLE TYPE 5 AXLE OR MORE TTST

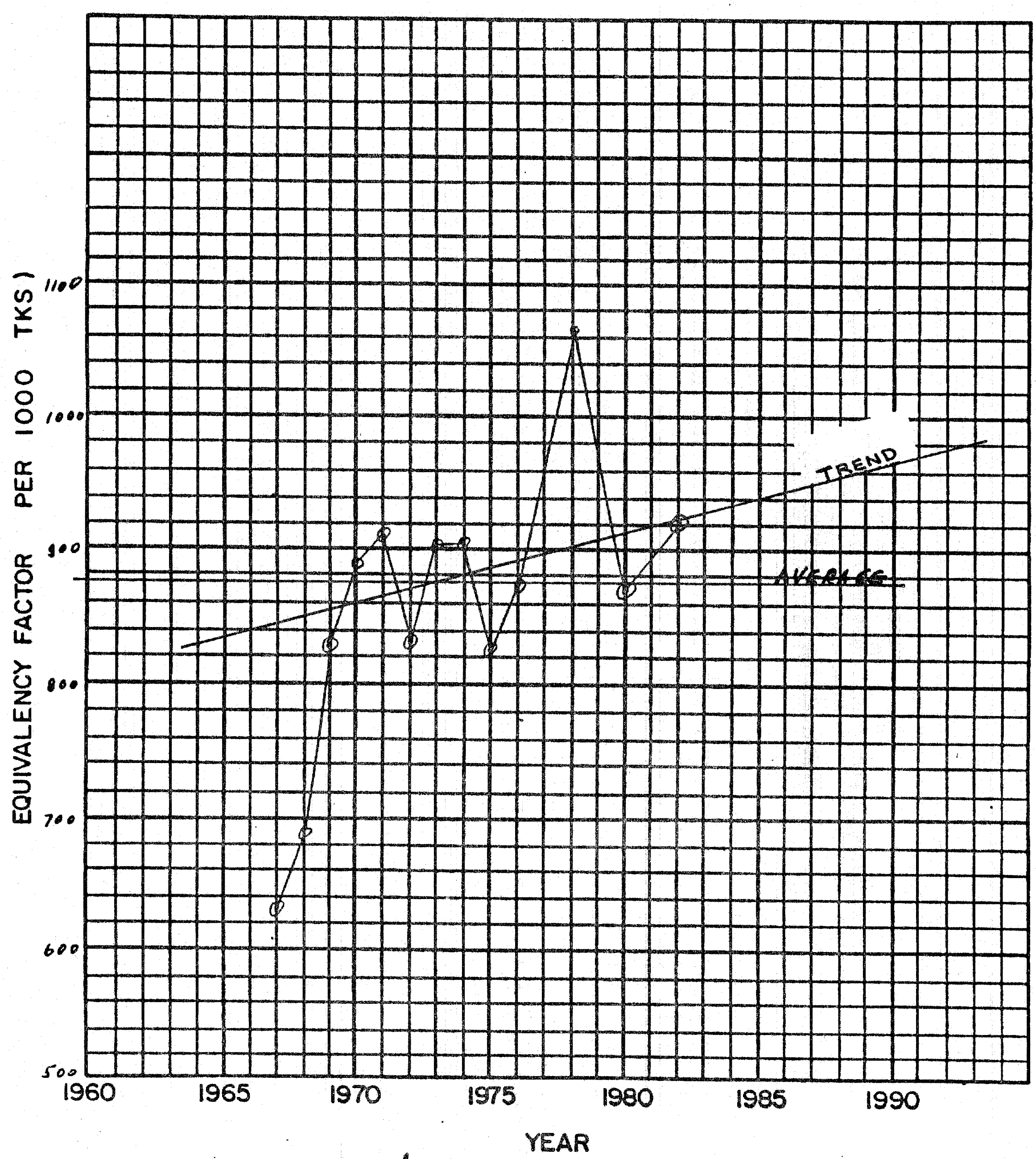


FIGURE 1

TENNESSEE DEPARTMENT OF TRANSPORTATION
MAPPING AND STATISTICS OFFICE
TRAFFIC AND SAFETY PLANNING SECTION

10/83

PROJECT NO. ______ ROUTE NO. I-24
COUNTY Montgomery CITY ______
PROJECT DESCRIPTION From SR-76 to Robertson County Line

Interstate Rural

Pavement Structural Design

Calculation of Equivalent Daily 18 Kip Single Axle Loads

	Type Vehicle	ADT (No. Counted)	Flexible 18-kip Factor	Flexible ADL	Rigid 18-kip Factor	Rigid ADL
	Pass. cars, and motorcycles	14831	0.001	14.8	0.001	14.8
	Buses	60	0.300	18.0	0.300	18.0
Single-Unit	Panel, and Pick-up Trucks	4576	0.004	18.3	0.005	22.9
Single-Unit	2-axle, 4-tire	190	0.006	1.1	0.010	1.9
Single-Unit	2-axle, 6-tire	961	0.170	163.4	0.170	163.4
Single-Unit	3-axle or more	387	0.700	270.9	1.000	387.0
Tractor Semi-Trail.	3-axle	24	0.700	16.8	0.880	21.1
Tractor Semi-Trail.	4-axle	250	0.700	175.0	0.780	195.0
Tractor Semi-Trail.	5-axle or more	2746	1.100	3020.6	1.780	4887.9
	Totals	24025		3698.9		5712.0

Suggested Percentages of Trucks in Design Lane

5,000 or less ADT	95%
5,000 - 10,000 ADT	90%
10,000 - 15,000 ADT	85%
15,000 - 20,000 ADT	80%
20,000 - 30,000 ADT	75%
30,000 - 40,000 ADT	70%
40,000 Plus	60%

No. of Lanes 4
% Trucks in Design Lane 75
ADL in Design Lane FLEX 0.5 X .75 X 3698.9 = 1387
RIGID 0.5 X .75 X 5712 = 2142

ADL Calculations By: Samuel A. Breeden Date: 4-12-84
Reviewed By: [signature] Date: 4-12-84

TABLE 2.

TABLE NUMBER 3

18 KIP AXLE EQUIVALENCY FACTORS

PER 1,000 TRUCKS WEIGHED

5 AXLE TRACTOR TRAILERS

RIGID PAVEMENTS

State	1972	1973	1974	1975	1976	1977	1978	1979	1980	Ave.
VA	1,146	1,157	1,175	1,222	-	1,315	-	1,315	-	1,222
NC	996	1,086	963	1,079	-	1,144	-	1,110	-	1,063
SC	1,303	1,394	1,493	1,299	-	1,305	-	-	-	1,359
GA	1,278*	1,661*	-	-			2,400*	2,952*	-	*
AL	986	799	836	986	-	-	1,274	-	1,312	1,032
MS	1,128	1,207	1,117	1,106	-	1,240	-	-	1,265	1,177
AR	1,122	1,088	1,109	1,364	-	-	-	-	1,050	1,147
MO	1,147	1,250	1,153	1,107	-	-	1,254	-	1,191	1,184
KY	1,229	1,254	1,318	1,344	-	-	1,429	-	1,486	1,343
TN	1,484	1,677	1,679	1,427	-	-	1,848*	-	1,497	1,553
OH	1,389	1,264	-	-	1,428	-	1,556	-	-	1,409
IL	1,001	971	1,090	1,101	-	1,205	-	1,133	-	1,084
IN	1,148	1,137	-	-	-	1,229	-	1,143	-	1,164
IA	1,345	1,345	1,360	1,333	-	1,394	-	1,394	-	1,362
KS	1,145	1,271	1,306	1,411	-	1,381	-	1,422	-	1,323
NB	1,530	1,438	-	-	-	-	1,615	-	1,567	1,538
OK	1,626	1,528	1,354	1,598	-	1,741	-	1,828	-	1,613
TX	814*	1,099*	919*	910*	-	1,948*	-	2,279*	-	936
AZ	4,315*	4,401*	739*	1,027*	-	-	1,653*	-	1,339*	*
CO	1,206*	1,748	1,676	1,894	-	1,794	-	1,973	-	1,817
Ave.	1,232	1,272	1,260	1,305	-	1,375	1,426	1,415	1,338	1,317

* Not used in Averages

TABLE NUMBER 4

COMPARISON OF ENFORCEMENT

SCALE TO PORTABLE SCALES

Station	System	Scale	5 Axle TTST Average Loaded Weight (1,000 lbs.)	Scale Average
9	01	No	64.3	
12	01	No	61.2	64.3
13	01	No	67.3	
11	01	Yes	59.1	
14	01	Yes	60.4	59.6
15	01	Yes	60.0	
17	01	Yes	58.9	
Sub-total	01		61.0	
2	02	No	63.2	
8	02	No	70.2	66.5
Sub-total	02		66.5	
3	06	No	72.6	
4	06	No	92.2	72.6
10	06	No	67.1	
Sub-total	06		72.6	
5	14	No	70.5	
16	14	No	51.9	62.9
Sub-total	14		62.9	

ENFORCEMENT SCALE AVERAGE = 59,600 lbs.
PORTABLE SCALE AVERAGE = 68,000 lbs.
DIFFERENCE = 8,400
PERCENTAGE = 14%

TABLE NO. 5

FLEXIBLE PAVEMENTS

18 KIP AXLE EQUIVALENCY FACTORS

5 AXLE TRACTOR TRAILERS

TENNESSEE, 1982

ALL SYSTEMS

STATION	FACTOR	
9	965	
13	1537	
11	844	Pit Scale
14	865	" "
15	880	" "
17	701	" "
2	1115	
3	1017	
4	825	
5	1322	
8	1042	
10	908	

Average = 1002
Sd = ± 232

Remove high and low values 1537, 701

Average = 978
Sd = ± 155

June 8, 1984

Mr. Doug Warpoole
State of Tennessee
Dept. of Transportation
3rd Floor, D.O.T. Building
Nashville, TN 37203

Subject: WIM System - Bid # 3576-000

Dear Mr. Warpoole,

It was a pleasure talking to you recently cocerning the subject Weigh-In-Motion System bid.

As we discussed, the approximate breakdown of the pricing is as follows:

One lane WIM system	$37,000
- Model 5150XT Portable Computer Controller Memory Unit	
- Field Scale Interface	
- One Mat with loops	
- One week installation and Start-Up Service	
- Generator	
2nd lane -	$10,000
- Addional Mat & Loops	
IBM-PCXT Host -	$11,500
- Includes software to transfer, store and maintain vehicle information	
- Includes 1200 baud modem	

	$58,500

Should you need further information, please do not hesitate to call.

Sincerely,

Susan O. Smith

Susan O. Smith
Product Manager
Traffic Data System

cc: J. H. Minor, StreeterAmet, Pittsburgh
W. L. Poe, StreeterAmet, Atlanta

StreeterAmet RollWEIGH®
MODEL 5150 XT
PORTABLE

STATE OF TENNESSEE

INTRODUCTION

The RollWEIGH® portable high speed truck weighing system provides in-motion truck weighing on interstate highways and freeways. Planning data is gathered and truck traffic can be screened for possible overloads.

The RollWEIGH® system measures all the individual axle weights and axle spacings as well as the speed of each truck. This data in turn is used to calculate tandem weights, gross weight and overall truck length (front to rear axle). In addition, this data can be used for overweight determination by axle, tandem axle, gross weight, bridge formula and vehicle classification.

Major benefits of the RollWEIGH® system include:

1. High volume weighing capability.

2. Provides speed, weight, and axle spacing data to fulfill FHWA requirements.

3. Automatic operation - minimum operator requirements.

4. Recording of all axle and length data on disk for later analysis.

SYSTEM CONCEPT:

StreeterAmet's new portable 5150XT RollWEIGH® Highspeed In-Motion Vehicle Weighing System has been designed to accurately weigh and classify highway trucks at highway speeds. The system is moved from site to site with suitable mobile equipment.

The 5150XT consists of a proven microprocessor instrument, a CRT terminal and a high response WIM weigh mat system. The axle and gross weights calculated by the system are also independent of vehicle type, axle spacing or vehicle speed.

This ease of installation of the sensor makes it suitable for use by law enforcement agencies to screen out potential overloads. Installation requires only about 20 minutes per lane of traffic. Removal takes only about 10 minutes. The site is left virtually unmarked and no repairs to the pavement are required.

StreeterAmet RollWEIGH®
MODEL 5150 XT
PORTABLE

SYSTEM DESCRIPTION

Portable Weigh In Motion Scale Equipment

The portable weigh in motion scale system consists of the following:

1. Weighing mat(s) and vehicle sensors
2. Digital Instrument (microprocessor-based) with CRT terminal and printer

Weigh-In Motion Platform

The dynamic platform consists of a low profile weighing mat placed laterally on the road. This mat detects the weight of individual wheels and calculates axle weights.

Two loop detectors attached to loops are provided. The loops are installed on the roadway adjacent to the weigh in motion mat(s).

Instrumentation

The digital weighing instrument consists of dual electronic loop detector(s) and the necessary electronics and interface circuitry to couple to the mat(s), the vehicle detection loops, the CRT terminal, and the printer. The weighing electronics include microprocessor-based digital electronics, control circuitry and a system power supply. The digital electronics include non-volatile memory to insure data retention in the event of power failure.

The digital electronics determine each wheel weight and compute the axle, tandem axle and gross weights for each vehicle. These weights are then compared with pre-established levels related to limits imposed by the enforcement agencies (and adjustable via the CRT terminal) to determine whether any weight exceeds the allowable limits.

StreeterAmet RollWEIGH®
MODEL 5150 XT
PORTABLE

Instrumentation (Cont'd):

The weigh in motion instrument electronics compute the velocity of each axle of the vehicle, based on inputs received from the speed sensor adjacent to the mat(s). The system then also calculates the spacing between adjacent axles, as well as the spacing between the first and the last axles (vehicle length).

The system can automatically detect and process traffic in two lanes. The system will provide data summaries from the individual vehicle data stored.

The digital electronics provides the time, date, year, sequence number and the number of axles, in addition to weight, velocity and length data and displays this information CRT.

The program and collected data in the microprocessor electronics is stored in non-volatile memory to retain the information in the event of power failure. The system will automatically resume operation upon restoration of power. The instrument also includes built-in diagnostics and test features which permit simple and rapid trouble shooting of the instrument from the CRT terminal.

Any overweight determinations are indicated by an asterisk after the displayed weight. Overspeed and off-platform errors are also indicated.

In summary, this system combines state of the art technology with efficiency and ease of use.

StreeterAmet RollWEIGH®
MODEL 5150 XT
PORTABLE

EQUIPMENT LIST

Control Memory Unit

- Portable unit
  approx. 20"W x 8½"H x 16"D
- 9" green CRT
  (25 lines x 80 char)
- One 360K disc drive for back-up and loading
- Detachable keyboard
- Parallel printer port
- Serial port to scale interface
- 512K non volatile memory (400K for data)
  Note: when non volatile memory is full, data is automatically written to disc to prevent data loss by overwriting

Field Scale Interface

- High speed scale interface circuits
- Power supplies
- Loop detectors
- Lightning protectors on all inputs and outputs

Dynamic Weighing Mat(s)

- 25 tons maximum axle loading (Based on ½ axle)
- Size: Approximately 20" x 71" x .031"
- Temperature Range: 32° F - 176° F (0° C - 80° C)
- System can monitor 2 mats simultaneously

SUMMARY:

Dynamic System, to include:

  - Weighing Mat(s)
1 - 5150 XT Microprocessor Weigher with CRT & Printer
  - Cable and Connectors (as required)
  - Dual Loop Detector(s) & Loops
2 - Operator and Instruction Manuals
  - Applicable Certified Drawings

WEIGH-IN-MOTION DATA APPLICATIONS
FOR ANALYSIS AND DESIGN
IN THE PAVEMENT MANAGEMENT PROCESS

prepared by

Thomas J. Koglin

Pavement Management Engineer

New Mexico State Highway Department

for presentation at

Second National Conference
on
Weigh-In-Motion Technology & Applications

Atlanta, Georgia

May 20-24, 1985

INTRODUCTION

Effective pavement management requires the ability to predict traffic loadings and to estimate the resulting pavement damage. One major problem experienced by all highway agencies is obtaining accurate vehicle and axle weights upon which to base loading predictions. An effective method of obtaining these weights is with weigh-in-motion equipment. Advancement in this equipment has been impressive. The technology is available. Now there is a reason to implement these programs: the nationwide pavement performance monitoring project to be undertaken as a part of the Strategic Highway Research Program.

In general, vehicle weight data have been collected by planners for use in estimating future pavement loadings. Static weights have been deemed acceptable for this purpose. However, it is widely believed that such weights are questionable because drivers tend to bypass scales (even temporary scales) when their vehicles are overweight. This results in a biased sample. This is a major problem for engineers studying pavement performance and attempting to attribute serviceability degradation to the various causal factors. Some highway agencies' planners have used vehicle weight data gathered from a limited number of locations to draw inferences regarding vehicle pavement loadings statewide. Pavement researchers require site-specific data to estimate pavement loadings.

This paper describes how the New Mexico State Highway Department (NMSHD) Planning Bureau's weigh-in-motion program was adapted to the needs of a pavement performance monitoring program. It also describes how the NMSHD program is being modified to make it more responsive to the specific needs of planners, pavement designers and researchers.

PAVEMENT LOAD MONITORING

In an ideal system to monitor pavement loadings, vehicle weights would be collected and analyzed. These historical data would be used to document pavement loadings. Engineers would monitor pavement serviceability degradation and perform analyses to attribute degradation to loadings and environment. Planners would analyze the weight data to determine trends in loadings by classes of vehicles; these trends would be projected to estimate future pavement loadings. These projected data would be used by engineers in pavement designs. Through a continuous cycling of this process, planners would improve forecasting methods, engineers would improve pavement design methods.

The process is not ideal. Some highway agencies may be doing an acceptable job of integrating the various elements of this process, but the existence of one research project: the Federal Highway Administration's (FHWA) Long-Term Pavement Monitoring (LTM) Program suggests that there are deficiencies.

The NMSHD obtained from FHWA a "clean bill of health" in regards to its truck weight data collection process. Weigh-in-motion data have been collected since 1975, have been processed and used in the annual truck weight report (discontinued after 1978), and have been filed; these data were not used until 1985 to refine the factors for estimating equivalent 18,000-pound single-axle loads (EAL's). The estimation of future EAL's for a roadway was based on factors that were modified previously in 1983. Present-day numbers of two-, three-, four- and five-axle vehicles are projected using a straight-line relationship. Constant EAL-per-vehicle factors are used to estimate vehicle impacts. This method has been demonstrated inaccurate. Work is underway to revise it.

PAVEMENT PERFORMANCE MONITORING

During 1982, NMSHD joined the LTM Program. Before 1982 the NMSHD had six weigh-in-motion sites. The sites are scattered geographically. Sites 2, 4 and 6 are on the Interstate system; Sites 1 (since discontinued), 3 and 5 are on the primary system. Following establishment of the LTM program, seven sites were added: Sites 9, 10, 11 (yet to be activated), and 12 on the Interstate system; Sites 7, 8 and 13 (yet to be activated) on the primary system. The weigh-in-motion sites are shown on the figure.

NMSHD selected 14 pavement sections to evaluate under the LTM Program. Primary consideration was given to three factors: existence of a loading history (as evidenced by proximity to a weigh-in-motion station) and availability of both construction and maintenance histories. It was assumed that the environmental history could be reconstructed from National Weather Service publications. In addition there were numerous recently constructed pavements available. It was necessary only to select which ones to study, install a weigh-in-motion station and begin collecting data.

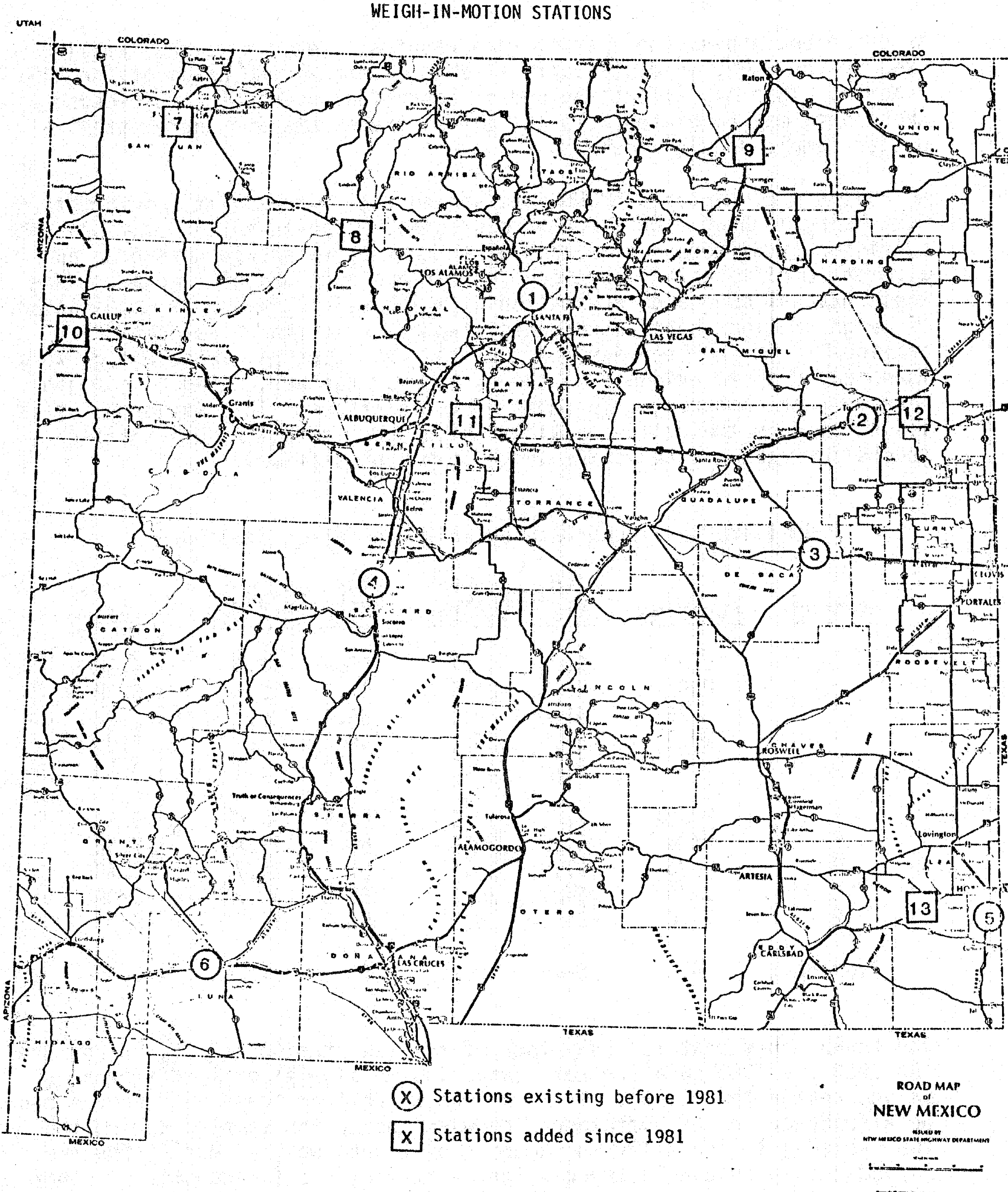
SAMPLING LOCATION AND FREQUENCY

The locations of the added weigh-in-motion sites demonstrates a potential conflict between researchers and planners: data collection site selection. The original sites were selected to provide a specific mix of data. The sample may now be biased because the new sites were not selected to maintain the balance established previously.

A constant problem that highway planners and engineers face is how often in time and space should samples be taken. For vehicle weights there are likely a few who would like to know the tire pressures, tire sizes, wheel weights and routings of every vehicle every day so that total pavement loadings of every section of roadway could be determined. This is not desirable for numerous reasons including expense, invasion of privacy and overwhelming quantity of data. This is a sampling problem just as is the process used to sample materials from the potential

NEW MEXICO STATE HIGHWAY DEPARTMENT

WEIGH-IN-MOTION STATIONS



(X) Stations existing before 1981

[X] Stations added since 1981

materials pits and to monitor quality during construction. It is necessary to adopt a sampling plan which will achieve an acceptable degree of accuracy.

As described above, the spatial (geographical) vehicle weight sampling used by the NMSHD is dictated to a large extent by the needs of the LTM Program. This may affect the use of consolidated weight data because these data may be biased. To the extent these data are incremental, a better sample should result.

An analysis of historic NMSHD data showed that site-specific information were being ignored. Data from the original weigh-in-motion stations are sufficiently different from each other that there should have been an attempt to differentiate between the various sections of roadway. This would have allowed a determination of which weigh station or combination of weigh stations best represented a specific section. As stated previously, it had been assumed that the EAL rates per vehicle type were identical despite evidence to the contrary. Further, there is not good year-to-year comparisons for most of the stations. This latter point is illustrated in the following table which shows data for semi-trailer trucks for each of the active weigh-in-motion stations.

Semi-Trailer Truck Data by Weigh-In-Motion Station

Station	Location	1982 weights Mean	1982 weights Std Dev	1983 weights Mean	1983 weights Std Dev	t value
2	I-40	53.7	11.7	50.4	12.4	4.10
3	US60	55.8	22.9	54.7	22.6	0.38
4	I-25	48.0	19.3	55.7	20.9	2.67
5	NM18	58.9	25.2	50.4	22.1	2.87
6	I-10	64.4	17.3	59.2	17.1	4.24
7	NM371	70.0	17.5	68.9	12.4	0.41
8	NM44	60.9	20.0	54.4	17.4	2.36
9	I-25	57.9	16.4	56.1	16.7	0.73
10	I-40	64.7	16.2	67.6	16.3	3.09
12	I-40	55.6	16.0	55.1	13.7	0.74
Average	All	58.9	18.2	58.7	17.7	0.42

The table shows that for only four of the ten stations (3, 7, 9, and 12) the 1982 and 1983 data are not statistically significantly different (t value greater than 1.96). It is not known whether these differences can be attributed to the differences between the months sampled during the two periods; to the differing numbers of trucks weighed during the two periods; to a change in truck weights attributable to economic or other factors; to changes in truck fleets; to changes in method of conduct of the weighing process; to differing methods used to edit the data; or, to some other factor(s).

Regarding satisfactory representation of a specific site with aggregated values, from 1983 data it was found that for only three sites (3, 6 and 9) could the EAL factors for semi-trailer trucks be approximated by the aggregated values. (The analysis is not included but is available on request.) It had been hoped that following installation of weigh-in-motion equipment at the new stations the data would show that each new station is similar to an existing station in terms of EAL factors per vehicle. If this were true, inferences could be made concerning historic loadings. This does not appear to be so simple. A more rigorous study is necessary to determine if such inferences are possible.

POSSIBLE IMPROVEMENTS TO THE PROCESS

A sound sampling procedure controls variables as possible and adequately accounts for all the others. An example of controllable variables are such things as equipment installation; load cell calibration; sampling frequency; duration of measurement period; training for data collectors; and, data editing procedures. Efforts must be taken to bring discipline to all these processes.

Variables that are not controllable must be accounted for by collecting sufficient data. Classification counts performed periodically during a year are used to expand vehicle weight data. One of the most common of the large vehicles is the semi-trailer truck for which some data are presented in the table. For the many types of vehicles that are less common, the numbers weighted may not be sufficient to represent the population of those types. The year-to-year differences as shown in the table exemplify the problem. It is possible that there is not sufficient weighing of even the semi-trailer truck. More study is necessary.

Assuming that more data are required, one possible solution is to gather data continuously. At least two states are doing that, but the equipment costs are high - at least $100,000 per site. If the national pavement monitoring program uses the 500 "design" sections as anticipated, the equipment costs for obtaining only vehicle weights would exceed $50 million. If this equipment is needed for all 2000 pavement sections to be monitored, the cost would exceed $200 million. This cost is large and in view of the variability inherent in all aspects of monitoring pavements, it is not likely necessary.

Due to the expense, using continuous weigh-in-motion stations will tend to limit the total number of stations. This limits availability of site-specific vehicle weights. It is clear from the table and the discussion that it is difficult to characterize the loadings at one site from weights taken at another. This must be subjected to a rigorous study to determine how loadings at a site are best estimated.

CONCLUSIONS

The process used to collect vehicle weight data can be improved by using weigh-in-motion technology. However, this is only the first step toward getting reliable vehicle weight data. It is also necessary to incorporate rigorous controls to assure that the data are not biased through sampling error or some systematic error such as faulty equipment installation or calibration.

It is not enough to just collect data; it must be used. Relying on some standard factors for vehicle EAL impacts when better data are available is not sound, and it is a waste. These data must be evaluated to determine trends that can be adopted to further improve the design process. The NMSHD Planning Bureau is doing this now.

It does not seem necessary to establish continuous weigh-in-motion sites. The expense does not justify the greater data reliability which could result from the additional quantity. Statewide, it should be possible to achieve greater data reliability by using our limited available resources to sample more locations rather than fewer.

The existence of and participation in the LTM program is evidence of the desire to improve the pavement design process; vehicle weight data are a part of this process. These data can be collected economically and once obtained, they should be used. Perhaps, the most effective method of improving the pavement design process is to improve communication between planners and engineers.

TRUCK WEIGHTS AS RELATED
TO PAVEMENT DESIGN IN ALABAMA

Presented By
F. L. Holman
Research Engineer
Alabama Highway Department

May 1985

TRUCK WEIGHTS AS RELATED TO PAVEMENT DESIGN IN ALABAMA

This paper is based on HPR No. 96 entitled "Truck Weights as Related to Pavement Design in Alabama", prepared by the Research Division, Bureau of the Materials and Tests, Alabama Highway Department in cooperation with the United States Department of Transportation, Federal Highway Administration.

Most pavements are designed by the State of Alabama Highway Department in accordance with the AASHTO Interim Guide for Design of Pavement Structures. Truck distribution factors computed from 1964 loadometer studies were used from 1964 to early 1983.

The truck distribution factor is defined as the average number of equivalent 18^k single axle loads per truck for a given terminal serviceability and structural number for flexible pavements or concrete thickness for rigid pavements. Vans, pickups, etc. are not considered as trucks in computing the truck distribution factors.

There was an intuitive belief within the Department for some years, that the truck distribution factors being used were low. As informal study of factors derived from available past loadometer studies in Alabama, especially since 1974, tended to confirm this belief and added incentive towards updating the truck distribution factors for pavement design purposes.

The slide shows the truck distribution factors computed from loadometer studies beginning in 1961.

The acquisition of Unitech weigh-in-motion equipment by the Highway Department offered the opportunity to more fully explore truck weights and distributions in Alabama as related to pavement design. A research study was initiated in 1982 to yield the following objectives:

1. To determine truck weight distribution factors from truck weights measured at all operating weigh-in-motion sites in Alabama and compare them with those presently used in pavement design.

2. To determine the total traffic count, percent trucks and lane usage (on multi-lane facilities) at each weigh-in-motion site.

Study Sites

At the time the study was done, there were ten operational weigh-in motion installations in Alabama. The geographical distribution of the sites is indicated in the slide.

In this report, sites are identified by the name of the nearest population center.

All the sites were on highways with four main roadway lanes except for Gosport, Selma, and Dothan, which were two lane facilities.

Procedure

The field work was a cooperative effort between the Bureau of Maintenance, Bureau of State Planning, and the Research Division of the Bureau of Materials and Tests of the State of Alabama Highway Department. There were no truck weight law enforcement activities carried on in connection with on immediately before or after the study.

The weigh-in-motion system was calibrated before each use with a truck of known axle weights.

Using weigh-in-motion equipment, truck axle weights were measured over approximately a twenty-four hour period in two lanes of the highway facility at each site. On four lane highways, the measurements were made in the outside lane of each roadway. A manual record was kept of the number of trucks using the inside or non-instrumented lanes of four lane highways. The slide shows the date and time of operation. With the exception of Florence, operation was begun at about 6:00 AM and shut down at 6:00 AM the following morning. Operation at Florence was begun at 10:00 AM and continued to 10:00 AM the following morning.

It should be noted that data was obtained in the Northbound roadway only for the Pine Level site. The Southbound roadway weighing sensors were inoperative.

It is also of interest to note that there were short periods of shutdowns at three sites (Gosport, Selma, and Dothan) due to local power failures. These occurred during late afternoon thunderstorms.

Pneumatic tube counters were used to determine the total number of axles passing each site during the periods of operation. The counts were lost at Alexander City and Dothan because of pneumatic tube failures.

The axle loads were manually taken from the weigh-in-motion equipment printouts, classified as single or tandem axles based on axle spacing, and grouped in 1000 pounds increments to establish an axle load frequency distribution for each site. The total number of trucks weighed was also determined. The slide shows a sample distribution.

A program was written for an Apple III microcomputer to compute the truck distribution factors. The total number of equivalent 18k single axle loads for each axle load frequency distribution was computed as described in the AASHTO Interim Guide for Design of Pavement Structures. The truck distribution factors were determined by dividing the total number of equivalent 18k single axle loads by the total number of trucks weighed.

It should be noted that only those trucks for which axle loads were weighed are included in the computation of the truck distribution factors.

Results

This slide shows the total traffic counted and percent trucks at each site. The traffic ranged from 2955 to 15583 vehicles and the percent trucks ranged from about 12% to 31%. The data for Alexander City and Dothan are not shown because of failure of the pneumatic tube counters.

This slide shows the percent of trucks in the outside lane of four lane facilities. This percentage corresponds to the lane distribution factor used for design purposes. The percentage ranged from about 79% to 92% and was 84% if data from all four lane sites were used. This data suggests the use of a minimum lane distribution factor of about 85% for four lane facilities.

The computed truck distribution factors for each site assuming a structural number of 4 for flexible pavement, a concrete thickness of 10 inches for rigid pavement and a terminal serviceability of 2.5 for both are shown in this slide. The factors ranged from 0.458 at Alexander City to 1.065 at Sumiton if flexible pavement is assumed. If all data were combined, the statewide truck distribution factor was 0.834. If rigid pavement is assumed, the truck distribution factor for 10 inch pavement ranged from 0.679 at Alexander City to 1.885 at Sumiton. Using all the data, the truck distribution factor statewide was about 1.379.

There were six sites classified as Other Rural, two sites classified as Other Urban and one each classified as Interstate Rural and Interstate Urban. Because of the small number of sites in three of the classifications, the truck distribution factors were not grouped by highway classification.

With the exceptions as previously described, the weigh-in-motion equipment was kept in continuous operation weighing trucks for approximately twenty-four hours at each site. Within the twenty-four hour time frame but during more normal working hours of about 10 AM to 6 PM (eight hours), the Bureau of State Planning used the data collected at each site except Dothan and Florence as part of their 1982 loadometer study. This data was processed by the Federal Highway Administration. Included in the computed printout was the average number of equivalent 18^k single axle loads per 1000 trucks at each site for a structural number of 5 for flexible pavement and a thickness of 9 inches for rigid pavement and assuming a terminal serviceability of 2.5. If divided by 1000, these numbers should be a measure of the same quantity as the truck distribution factor as used in this report.

However, the Federal Highway Administration computes the factors in a manner which includes the effects of panels and pickups, etc. If the effects of panels and pickups are removed, then the factors can be compared directly to the truck distribution factors determined in this study.

This was done to estimate the effect of a shorter weighing period on the truck distribution factors. The results are summarized in the slide for flexible and rigid pavements, respectively.

The eight hour (10 AM to 6 PM) weighing period truck distribution factors approximated those from the twenty-four hour weighing periods at most of the sites. There was a large difference in the factors, however, for the Sumiton site. This difference is probably due to the exclusion of some of the greatly overloaded axles in the 8 hour weight period analysis.

Conclusions

This study has confirmed that the truck distribution factors used for flexible and rigid pavement design from 1964 to early 1983 were too low. This is demonstrated in the slide. The truck distribution factors from this study are considerably higher than those determined in 1964. The 1964 factors shown were for the classification of Other Federal Urban which were higher than those of the other classifications.

The limitation of having only ten weigh-in-motion sites in operation in Alabama at this time of the study restricted the option of establishing different truck distribution factors for various highway classifications such as Interstate Urban, Interstate Rural, Other Urban, Other Rural, etc. For this reason the truck distribution factors computed from the collective data from all the sites in the study were adopted for pavement design purposes in Alabama effective in April, 1983. These factors are summarized in this Table for both flexible and rigid pavements.

It was recommended that the weighing period in future studies using the weigh-in-motion equipment be reduced to eight hours during normal working hours. This would tend to reduce personnel requirements and problems with local power failures which seem to occur mostly in the late afternoor or early evening.

The percent of total trucks using the outside lane of the four lane sites (except Alexander City) ranged from 79.1% to 92.0%. The six sites were classified as two urban and four rural highways. It is questionable whether there are enough sites of either classification to permit the determination of meaningful percentages in each classification. The percent of total trucks using the outside lane was 84.1% using the data from all six sites. It is recommended that the percent of total trucks using the outside lane be no less than 85% for pavement design purposes. Because of the small contribution made by cars, vans, and pickups to the total of the equivalent 18^k single axle loads for a pavement, the percent trucks in the design lane is equivalent to the lane distribution factor for design purposes.

ALABAMA HIGHWAY RESEARCH

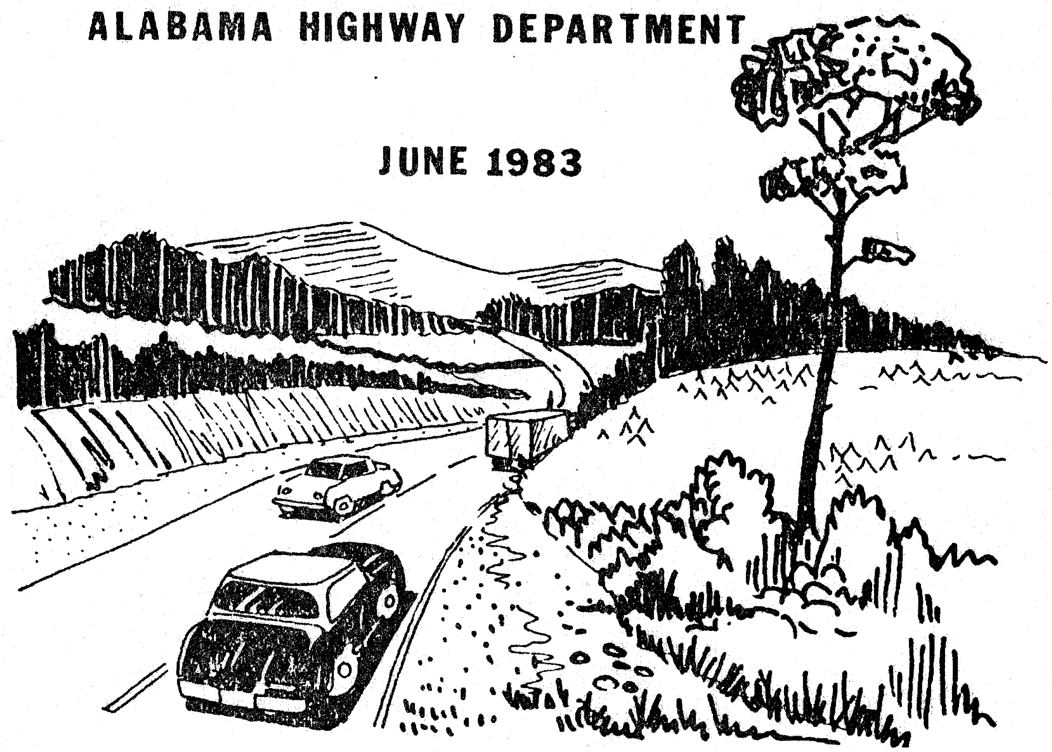
HPR NO. 96

PROJECT NO. 930-106

TRUCK WEIGHTS AS RELATED TO PAVEMENT DESIGN IN ALABAMA

BY: RESEARCH DIVISION
BUREAU OF MATERIALS & TESTS
ALABAMA HIGHWAY DEPARTMENT

JUNE 1983



SLIDE 2

TRUCK DISTRIBUTION FACTOR - THE AVERAGE NUMBER OF EQUIVALENT 18^K SINGLE AXLE LOADS PER TRUCK FOR A GIVEN TERMINAL SERVICEABILITY AND STRUCTURAL NUMBER FOR FLEXIBLE PAVEMENTS OR CONCRETE THICKNESS FOR RIGID PAVEMENTS.

SLIDE 3

STATEWIDE

TRUCK DISTRIBUTION FACTORS

YEAR	FLEXIBLE SN=4	RIGID D=10"
1961	.460	.527
1962	.466	.540
1963	.455	.545
1964	.462	.573
1965	.472	.609
1966	.481	.635
1967	.473	.641
1968	.511	.695
1970	.457	.656
1971	.515	.774
1972	.460	.687
1973	.390	.540
1974	.439	.620
1975	.487	.709
1976	.585	.852
1978	.607	.905

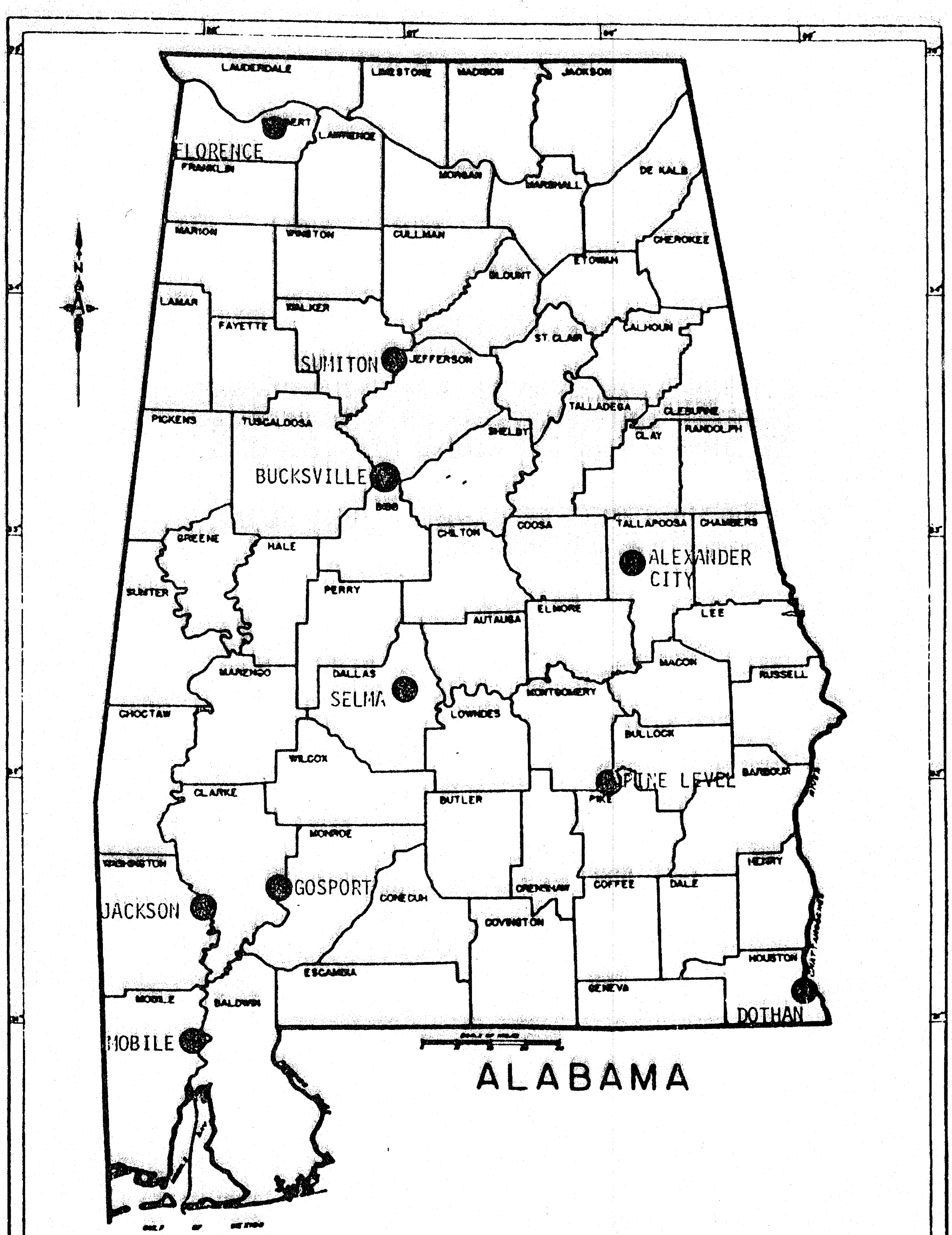
TERMINAL SERVICEABILITY = 2.5

SLIDE 4

OBJECTIVES OF STUDY

1. TO DETERMINE TRUCK DISTRIBUTION FACTORS FROM TRUCK WEIGHTS MEASURED AT ALL OPERATING WEIGH-IN-MOTION SITES IN ALABAMA AND COMPARE THEM WITH THOSE PRESENTLY USED IN PAVEMENT DESIGN

2. TO DETERMINE THE TOTAL TRAFFIC COUNT, % TRUCKS, AND LANE USAGE AT EACH WEIGH-IN-MOTION SITE



SLIDE 5 - Geographical Distribution of Weigh-In-Motion Sites

SLIDE 6

Dates and Times of Operation and Exceptions

Site	Time and Date Begin	Time and Date End	Exceptions and Comments
Bucksville	6:00 PM, 6/23/82	6:00 PM, 6/24/82	None
Gosport	6:00 AM, 6/1/82	6:00 AM, 6/2/82	(1)System down - power failure, 6:06 PM to 6:19 PM.
Pine Level	6:40 PM, 8/4/82	6:00 PM, 8/5/82	Data obtained in Northbound roadway only. Southbound roadway weighing sensors inoperative.
Jackson	6:00 AM, 6/3/82	6:00 AM, 6/4/82	None
Sumiton	6:00 AM, 6/22/82	6:00 AM, 6/23/82	None
Mobile	6:00 AM, 6/9/82	6:00 AM, 6/10/82	None
Selma	6:00 AM, 6/29/82	6:00 AM, 6/30/82	(1)System down - power failure, 4:54 PM to 5:00 PM.
Alexander City	6:00 AM, 7/29/82	6:00 AM, 7/30/82	No record taken of trucks using non-instrument lanes. Pneumatic tube axle counter was inoperative.
Dothan	6:00 AM, 9/8/82	6:00 AM, 9/9/82	(1)System down - power failure, 5:28 PM to 7:48 PM. Pneumatic tube axle counter was inoperative.
Florence	10:00 AM, 9/21/82	10:00 AM, 9/22/82	None

Note: (1)The number of trucks passing the site during times of power failure were recorded.

SLIDE 7

Distribution Factors SITE: Gosport BEGINNING HOUR: 24 Hr.

Single Axles			Tandem Axles		
Load(kips)	No. Axles	Percent	Load(kips)	No. Axles	Percent
2.5	26	3.46	4.5	2	0.22
3.5	55	7.31	5.5	16	1.74
4.5	47	6.25	6.5	44	4.79
5.5	42	5.59	7.5	69	7.51
6.5	89	11.84	8.5	63	6.86
7.5	201	26.73	9.5	63	6.86
8.5	171	22.74	10.5	65	7.07
9.5	68	9.04	11.5	58	6.31
10.5	17	2.26	12.5	34	3.70
11.5	7	0.93	13.5	25	2.72
12.5	4	0.53	14.5	13	1.41
13.5	9	1.20	15.5	11	1.20
14.5	2	0.27	16.5	13	1.41
15.5	3	0.40	17.5	7	0.76
16.5	6	0.80	18.5	6	0.65
17.5	5	0.66	19.5	6	0.65
			20.5	6	0.76
			21.5	5	0.54
			22.5	7	0.76
			23.5	11	1.20
			24.5	11	1.20
			25.5	8	0.87
			26.5	13	1.41
			27.5	9	0.98
			28.5	9	0.98
			29.5	16	1.74
			30.5	30	3.26
			31.5	29	3.16
			32.5	34	3.70
			33.5	29	3.16
			34.5	21	2.29
			35.5	27	2.94
			36.5	28	3.05
			37.5	22	2.39
			38.5	20	2.18
			39.5	19	2.07
			40.5	13	1.41
			41.5	10	1.09
			42.5	12	1.31
			43.5	8	0.87
			44.5	11	1.20
			45.5	5	0.54
			46.5	3	0.33
			47.5	2	0.22
			48.5	2	0.22
			49.5	1	0.11
			50.5	1	0.11
			51.5	1	0.11

Total number of trucks 600

SLIDE 8

TRAFFIC AND % TRUCKS

SITE	TOTAL NO. OF CARS, VANS PICKUPS, ETC.	TOTAL NO. OF TRUCKS	TOTAL NO. OF VEHICLES	% TRUCKS
BUCKSVILLE	10807	4776	15583	30.6
GOSPORT	2261	694	2955	23.7
PINE LEVEL	3402	766	4168	18.4
JACKSON	4550	1056	5606	18.8
SUMITON	10385	2843	13228	21.5
MOBILE	4789	1857	6646	27.9
SELMA	8015	1054	9069	11.6
ALEX CITY	-	-	-	-
DOTHAN	-	-	-	-
FLORENCE	8195	1872	10067	18.6

SLIDE 9

LANE DISTRIBUTION OF TRUCKS

SITE	TOTAL NO. OF TRUCKS	% TOTAL TRUCKS IN RIGHT OR OUTSIDE LANE
BUCKSVILLE	4776	84.4
PINE LEVEL	766	86.6
JACKSON	1056	79.1
SUMITON	2843	81.5
MOBILE	1857	92.0
ALEX CITY	-	-
FLORENCE	1872	81.6
ALL	13170	84.1

SLIDE 10

TYPICAL TRUCK DISTRIBUTION FACTORS

SITE	TRUCK DISTRIBUTION FACTORS FLEXIBLE PAVEMENT SN=4	RIGID PAVEMENT D=10"
BUCKSVILLE	.82193	1.31110
GOSPORT	.93827	1.76442
PINE LEVEL	.62591	.99394
JACKSON	.81001	1.38079
SUMITON	1.06494	1.88459
MOBILE	.73204	1.14783
SELMA	.53872	.81952
ALEXANDER CITY	.45776	.67883
DOTHAN	.84714	1.40475
FLORENCE	.97362	1.64194
STATEWIDE	.83380	1.37914

TERMINAL SERVICEABILITY = 2.5

SLIDE 11

SITE CLASSIFICATION

SITE	CLASSIFICATION
BUCKSVILLE	INTERSTATE RURAL
GOSPORT	OTHER RURAL
PINE LEVEL	OTHER RURAL
JACKSON	OTHER RURAL
SUMITON	OTHER RURAL
MOBILE	INTERSTATE URBAN
SELMA	OTHER URBAN
ALEXANDER CITY	OTHER RURAL
DOTHAN	OTHER RURAL
FLORENCE	OTHER URBAN

SLIDE 12

8 HOURS WEIGHING PERIOD VS 24 HOURS WEIGHING PERIOD

SITE	TRUCK DISTRIBUTION FACTORS: FLEXIBILE PAVEMENT 8 HOURS	FLEXIBILE PAVEMENT 24 HOURS	RIGID PAVEMENT 8 HOURS	RIGID PAVEMENT 24 HOURS
BUCKSVILLE	.8281	.7809	1.3332	1.2903
GOSPORT	1.0824	.9919	1.8574	1.7172
PINE LEVEL	.6108	.6025	.9679	.9765
JACKSON	.8115	.7921	1.3622	1.3513
SUMITON	.9616	1.0433	1.5483	1.8217
MOBILE	.7020	.6931	1.1269	1.1386
SELMA	.5274	.5082	.8256	.8121
ALEXANDER CITY	.4434	.4385	.6577	.6712

SLIDE 13

1964 TRUCK DISTRIBUTION FACTORS VS THOSE IN THIS STUDY

	FLEXIBLE PAVEMENT	
STRUCTURAL NO.	1964	THIS STUDY
2	.5055	.8690
3	.5008	.8760
4	.4695	.8338
5	.4566	.8045
6	.4617	.7998

	RIGID PAVEMENT	
THICKNESS	1964	THIS STUDY
8	.6184	1.3258
9	.6230	1.3528
10	.6302	1.3791
11	.6338	1.4002

TERMINAL SERVICEABILITY = 2.5

SLIDE 14

Truck Distribution Factors For
Flexible and Rigid Pavement Design
In Alabama

Flexible Pavement

Structural Number	Truck Distribution Factor at Terminal Serviceability 2.0	Truck Distribution Factor at Terminal Serviceability 2.5
2	.84219	.86904
3	.84245	.87687
4	.82381	.83380
5	.81259	.80447
6	.81218	.79977
7	.81551	.80490

Rigid Pavement

Structural Number	Truck Distribution Factor at Terminal Serviceability 2.0	Truck Distribution Factor at Terminal Serviceability 2.5
7	1.38195	1.31627
8	1.38652	1.32578
9	1.39958	1.35282
10	1.41230	1.37914
11	1.42240	1.40015
12	1.42962	1.41539

WEIGHT IN MOTION APPLICATION TO IOWA PAVEMENT DESIGN

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Pavement design in Iowa requires a knowledge of the state's geographic and environmental characteristics. The variance in elevation from 480 to 1670 feet above sea level, average annual rainfall of 32 inches and average snowfall of 30 inches each play a part in the performance of the pavements. Iowa's rich topsoil is essential to farm production, but it creates additional problems for the designer.

Of Iowa's 112,000 miles of roads and streets nearly one third of the system is paved, and the surfacing is evenly distributed between asphalt and portland cement concrete. Asphaltic concrete makes up 4,376 miles of the 10,000 mile primary system while some 5,654 miles are surfaced with portland cement concrete and 90 miles are surface treated. The vast majority of the municipal system is paved and over 13,000 miles of the county system is paved. The primary system will be the focal point of the remainder of this report.

Travel patterns play an important role in creating pavement design problems on all parts of the highway system. In 1982 the rural primary and secondary road travel accounted for 60 percent of the total travel in the state and accounted for 88 percent of the total highway mileage. The state road system accounted for just 9.3 percent of the total mileage, but carried 56.5 percent of the 1982 travel miles. In addition, primary roads accounted for 93.2 percent of the combination or heavy truck travel in 1982. This truck traffic includes the vehicles with three axles or more and has a very dramatic effect on the life of the pavement due to the large number of 18 kip equivalent axle loadings they produce. The accurate prediction of truck volumes, weights and sizes is critical to the design of the rehabilitation of these highways.

Much of the primary road system in Iowa was paved in the 1930's and was designed for a service life of 20 years. The county system paving began in the 1950's. In 1984 two percent of the primary roads were more than 59 years old. An additional 75 percent were between 20 and 59 years old. Only 23 percent of the mileage is less than 20 years old. If one carries this analysis to the year 2002, the mileage of roads over 59 years of age will account for 31 percent of the total mileage. An additional 60 percent will be between 20 and 59 years of age. Nine percent of the system will fall within its 20 year design life.

This means that we now have a mature primary system and a county system that is beginning to reach a design life. The administration of those systems calls for maintainance and rehabilitation emphasis rather than new construction in this time of declining revenues and buying power. Some 3,000 miles of the original primary pavement are still in place, providing service in an as built condition or serving as part of a composite pavement. Some 3,700 miles of the primary system have been overlaid with asphaltic concrete in an effort to extend their useful life. The last 40 miles of our 780 mile interstate highway in Iowa is under construction while early segments already have surpassed the expectations of their design life in years and traffic loadings. Replacement and major rehabilitation are now our major concern for all parts of the primary road system. Current statistics indicate that we should be replacing at least 160 miles per year to maintain a 60 year cycle recapitalization cycle. We are only able to replace 51 miles per year under the current funding between the years of 1985-1990.

As the focus of the primary road system changed from that of construction to rehabilitation and maintenance, the need for additional tools to be used in programming increased. The importance on this can be seen in the allocation of state highway funds during the period 1985-1990. Construction and modernization account for only 27.5 percent of the budget, while preservation, maintenance and reconstruction account for 64.1 percent. The remaining 8.4 percent is allocated to miscellaneous, operations/administration expenses.

The Department has entered into the development of a Pavement Management Program as a way to cope with the declining revenues and the ageing pavement system. Some of the activities involved with that program include the development of survivor curves, administrative service levels and a rehabilitation matrix. The current survivor curves provided a general knowledge of the behavior of our concrete and asphalt highways in terms of roughness and age. They provided a starting point for more detailed reviews of the pavements prior to making decisions between resurfacing and reconstruction. The curves indicated that Iowa was able to expect 60 year lives from many of our early concrete pavements. The effect and life of resurfacings as viewed by the vehicle operator could also be traced in the curves. The curves are undergoing a modification at this time to account for the effects of the aggregate durability associated with each of the construction projects.

The 10,000 mile primary system has been subdivided into four administrative service levels in an effort to target the funds where they can get the most return for the least investment. Interstate routes form level "A"(734 miles) while level "B"(2,982 miles) represent the remaining major traveled noninterstate routes. Levels "C"(3,146 miles) and "D"(2,935 miles) describe the remaining state routes in decreasing levels of importance. The study dealt only with the rural portion of the system. The results have been used (1) by the Office of Maintenance to establish snow removal policies, and (2) by the Office of Program Management to set target funding levels in relation to the road use taxes generated on the various levels. A third use is being identified in the design of rehabilitation and reconstruction highway projects. Different geometric features are being used in the development of RRRR standards for each of the service levels. Since one of the criteria used in the service level route selection was truck traffic, the pavement design is also being reviewed for possible savings in the various levels.

The physical condition of the primary highway system has traditionally been measured with the aid of a sufficiency analysis annually. The 100 point system identified the relative needs of all highway sections. It is geared primarily to view the needs of the entire right-of-way with emphasis of the need for a paved surface. The analysis also concentrated on satisfying the traffic capacity needs at a high level of service. It's weakness is the lack of adequate detail and emphasis on the pavement condition.

The pavement condition evaluation problem has been addressed in the form of a Rehabilitation Matrix to aid the annual programming process. Physical condition of the pavement is measured by ride, rut depth, cracking occurrence, structural adequacy in terms of deflection, amount of patching and the change in ride over a six year period. A seven point scale has been developed with critical values of each item established from field experience. Each pavement is rated in accordance with the factors that apply and an index value is established to rank all pavement sections regardless of the surface type. Traffic volume and pavement width factors currently in the matrix are being replaced with measures of accumulated 18 kip axle loadings, and maintenance costs, as the information is developed from other records. Currently the matrix values are available only on the rural sections. Municipal extensions must be considered separately using the sufficiency rating only.

The Department currently obtains its truck weight data for the FHWA and internal uses through studies conducted in the odd numbered years. Surveys are conducted at some 20 sites across the state and across the various classifications of roads. All data is collected on summer weekdays and factored through classification studies to represent the various individual road traffic conditions and time of year for variations. Both portable and pit scales are used to gather the data. Weight, size, classification and commodity orgin-destination data are gathered over a 24 hour period on the major classified roads and for 16 hours on the minor classifications. Special case studies were conducted in conjunction with the FHWA cost allocation study to gain data on the effect of weighing vehicles at different times of the day, week, and season. The studies verified the methods being employed by the Department, but also indicated that variations in the truck movements did exist between weekdays and weekends on parts of the system. This type of information can be very helpful in the design of the rural roads.

Design policy guidelines have been established to insure the satisfactory performance of pavements in Iowa. They include:

1. Provide for reasonably uniform pavement support to counteract the effects of:
    a. Frost heaving and frost boils
    b. Inadequate compaction and variable soil types
    c. Inadequate roadway drainage
    d. Differential volume change characteristics of subgrade soils

2. Provide joint designs for rigid pavements that will control warping stresses, afford adequate load transfer and control stresses due to infiltration to counteract the effects of:

a. Variable volume change characteristics
b. Subgrade pumping under conditions of heavy truck traffic

3. Provide mix designs for flexible pavements which will prevent ravelling and other forms of surface deterioration to deal with:
a. Aggregate quality variations
b. Mix design for stabilizing additives
c. Prevention of surface ravelling, etc.

Our design thickness procedures are derived from the following sources and are common to many highway agencies:

1. Theoretical studies of pavement structure behavior.
a. Westergaard and Pickett analysis of rigid slab behavior.
b. Boussinesq equations for deflections due to loads and the Burmister two layer extension of these equations for flexible pavements.

2. Model and full scale tests on which construction and traffic loadings are carefully controlled, such as the Arlington Test Track, the Bates Test Road and the AASHTO Test Road.

3. The performance of normally constructed and maintained pavements subjected to naturally mixed traffic.

Pavement design in Iowa can best be described by considering each of the major surface types separately. The design procedures have been adapted from design those recommended by the Portland Cement Association and/or the AASHTO Committee on Design. The primary design variables considered in the pavement thickness design include:

1. The supporting capacity of the subgrade.

2. The traffic(vehicular volume and weight) that will use the highway.

3. The serviceability expected at the end of a given design period.

4. The road classification which reflects the potential for unpredictable growth and its effect on performance due to normal variations in construction materials.

5. The strength or load carrying capacity of the pavement materials.

Each of the design methods employed begins with traffic information in the form of a "pavement determination estimate"(Figure 1 in the appendix). A computer program utilizes the traffic volume, classification and weight data from the state and federal studies as a sample to develop individual project specific traffic forecasts. The program output includes the daily and 20 year total number of single and tandem axles that can be expected to pass over the project. It also gives the number of 18 kip axle equivalents associated with the given traffic stream for structural numbers(SN) of 3-6 and depth of concrete(D) from 7-10 inches. This information is only as good as the information collected for FHWA and reported back to the states.

Portland cement concrete pavements are designed using the Portland Cement Association method with some minor modifications for use in Iowa. The standard PCA method is modified in the areas of load safety factor and concrete flexural strengths. Different load safety factors are applied to each of the administrative service levels of roads. This is one way of quantifying the amount of risk or reliability of the design. The Department also uses a three year running average of concrete strengths from construction records to develop its design policy values for each of the mix types and service levels. This data is illustrated in Table II of the appendix. The design itself is developed using the influence charts and stress ratio to allowable load repetition charts from the PCA "Thickness Design for Concrete Pavements, 1966" publication. A copy of the worksheet used for the trial depth calculations is included as Figure II in the appendix.

Flexible pavements are designed using the AASHTO Interim Guide and the SN equations. Coefficients used for the various materials are described in Table I of the appendix. Computer programs have been developed to provide the nomograph solutions to trial combinations of materials and thicknesses. This method can also be heavily influenced by the number of 18 kip equivalent axle loads predicted for the design life of the pavement. It is important that the predicted loadings for each situation is as accurate as possible.

Composite pavements that are commonly the result of asphaltic concrete overlays of portland cement concrete are treated in a manner similar to the flexible pavements. Nondestructive testing methods employing the use of the roadrater have been developed to measure the deflections or wave form from a vibrating source. Correlations of that data to the actual pavement thicknesses and strength of materials was developed from work in the FHWA sponsored Long Term Pavement Monitoring Pilot Study. The overlay is designed by comparing the structural number obtained from the nondestructive testing to that calculated from the predicted traffic needs for the next design period. The difference is used in the AASHTO design method to determine an overlay thickness.

In each of the current design methods the major input is the traffic in terms of 18 kip equivalent axle loadings that are predicted over the pavement life. Currently those come from the small sample of vehicles on a particular roadway for one summer day every other year. The update of the AASHTO Interim Guide to Pavement Design addresses the need for increased accuracy in the truck weight and equivalent loading predictions through weigh in motion data collection methods. Agencies should be aware of several items associated with the collection of such data that have an effect on its accuracy.

The site concerns include:
1. Horizontal alignment of the road or skew of the bridge being used. Both have an effect of the performance of the vehicle and the electronic correlation or wheels on the same axle.

2. Maximum bridge span length in the use of bridge systems. A maximum of 65 feet for a single span or series of noncontinuous spans appears to be optimum at this time.

3. Approach roadway conditions must be smooth and free of distress. Any variations will induce dynamic loading effects in the vehicle and create problems in the data accuracy.

4. The site should have reasonable access to public utilities for power to operate the system.

5. The site should also be readily accessible to vehicles for service of the monitoring equipment.

6. Information transmittal modes should be determined to provide a minimum requirement for personnel requirements at the site. Telecommunications is ideal for this operation.

7. Plans must be included for the maintenance of the site and equipment. This decision may influence the brand of equipment purchased due to the other data collection equipment that may be in use by the agency.

The Iowa Department of Transportation is looking forward to using the weigh-in-motion information for several purposes including the pavement design area as follows:

1. Increased sample size of the existing traffic conditions at specific sites and road classifications.

2. Increased accuracy of our traffic axle loading predictions.

3. Improved pavement design inputs for tailoring the pavement to the intended use with greater accuracy.

4. Improved ways of measuring the pavement design performance through monitoring of the actual traffic weights being experienced by the pavements.

5. Weight enforcement monitoring to assure the compliance or record the noncompliance of the traffic using the highways.

The Department is moving toward a programming and project development methodology that emphasizes new quantifiable data such as truck weight information values. It builds on the existing methods and moves the subjectivity to the last point in the decision making process. This type of activity requires greater accuracy in the inputs used in the design to allow the safety factors to be minimized and shifted to the final decision point in the programming process. The process will use the inputs from the highway plan, sufficiency, pavement management, and safety to develop annual programs. Policy decisions regarding the desired level of service to be provided, rehabilitation vs reconstruction criteria, pavement failure risk to be assumed by government, and the special concerns of the public must be addressed. The task of managing our highway systems is becoming more complex, but not impossible. The use of tools such as weigh-in-motion, computers, nondestructive testing, sufficiency, pavement management data, and life cycle costing can provide the administrator with up to date information upon which to make decisions. They will provide the new engineering generation with the ability to make sound transportation rehabilitation and improvement judgements and decisions.

APPENDIX

Figure I - Pavement Determination Example

Figure II- Rigid Design Worksheet

Table I - Flexible Pavement Design Coefficients

Table II - Pavement Design Policy Guides

Figure I

UNION COUNTY PRIMARY PAVEMENT DETERMINATION ESTIMATE # 5242
LOCATION OF PROJECT IS US 169
THE PROGRAM YEAR IS 1985
THE DESIGN YEAR IS 2005
THE TOTAL PROGRAM YEAR TRAFFIC IS 1075
DESIGN YEAR TRUCK TRAFFIC IS 130
DESIGN YEAR P.C. & P.U. IS 1167
TOTAL DESIGN YEAR TRAFFIC IS 1297

TOTAL SECTION LENGTH = 8.75 MILES SECTION DESCRIPTION P.L.

CPUP	SU 2	SU 3	BUSES	RV	TK	TS 3	TS 4	TS 5+	DB	TOTAL
1072	53	3	0	0	6	4	6	37	0	1181

	FLEXIBLE		RIGID	
NO. OF SINGLE AXLES EACH DIRECTION	DAILY	20 YEAR	DAILY	20 YEAR
30,001 - 35,000 (LBS.)	0.00	0.00	0.00	0.00
26,001 - 30,000 (LBS.)	0.00	0.00	0.00	0.00
24,001 - 26,000 (LBS.)	0.02	146.00	0.02	146.00
22,001 - 24,000 (LBS.)	0.05	365.00	0.05	365.00
20,001 - 22,000 (LBS.)	0.08	584.00	0.08	584.00
18,001 - 20,000 (LBS.)	0.43	3139.00	0.43	3139.00
16,001 - 18,000 (LBS.)	1.31	9563.00	1.31	9563.00
12,001 - 16,000 (LBS.)	6.24	45552.00	6.24	45552.00
8,001 - 12,000 (LBS.)	28.45	207685.00	28.45	207685.00
7,001 - 8,000 (LBS.)	5.52	40296.00	5.52	40296.00
3,001 - 7,000 (LBS.)	33.25	242725.00	33.25	242725.00
0 - 3,000 (LBS.)	18.66	136218.00	18.66	136218.00
18K EQUIVALENT SINGLE AXLE LOADS PER DAY, 20 YR				
	SN 3 =	18	D 7 =	[illegible]
	SN 4 =	15	D 8 =	1[illegible]
	SN 5 =	13	D 9 =	13
	SN 6 =	13	D 10 =	13
NO. OF TANDEM AXLES EACH DIRECTION	DAILY	20 YEAR	DAILY	20 YEAR
55,001 - 60,000 (LBS.)	0.00	0.00	0.00	0.00
50,001 - 55,000 (LBS.)	0.00	0.00	0.00	0.00
46,001 - 50,000 (LBS.)	0.01	73.00	0.01	73.00
44,001 - 46,000 (LBS.)	0.03	219.00	0.03	219.00
42,001 - 44,000 (LBS.)	0.06	438.00	0.06	438.00
40,001 - 42,000 (LBS.)	0.15	1095.00	0.15	1095.00
38,001 - 40,000 (LBS.)	0.41	2993.00	0.41	2993.00
36,001 - 38,000 (LBS.)	0.82	5986.00	0.82	5986.00
34,001 - 36,000 (LBS.)	1.74	12702.00	1.74	12702.00
32,001 - 34,000 (LBS.)	3.02	22046.00	3.02	22046.00
30,001 - 32,000 (LBS.)	4.83	35259.00	4.83	35259.00
24,001 - 30,000 (LBS.)	7.32	53436.00	7.32	53436.00
18K EQUIVALENT TANDEM AXLE LOADS PER DAY, 20 YR				
	SN 3 =	18	D 7 =	28
	SN 4 =	17	D 8 =	29
	SN 5 =	17	D 9 =	29
	SN 6 =	16	D 10 =	30

Figure II

4906

(Use with Case I Single & Tandem Axle Design Charts) Bridge Project

Project BRF-169-5(9)--2L-08 1½ Mi. N. of U.S. 30

Type Level B No. of Lanes 2

Subgrade k 100 pci., Subbase None

Combined k ______ pci., Load Safety Factor 1.2 (L.S.F.)

PROCEDURE

T.P.D. = 480

A.D.T. 1,920

1. Fill in Col. 1, 2 and 6, listing axle loads in decreasing order.
2. Assume 1st trial depth. Use 1/2-in. increments.
3. Analyze 1st trial depth by completing columns 3, 4, 5 and 7.
4. Analyze other trial depths, varying M.R.*, slab depth and subbase type.**

BY TJT

DATE 11/83

COUNTY Boone

Trial depth 9½ in. M.R.* 525 psi k 100 pci

CLASS C C.D. Joints

1 Axle Loads kips	2 Axle Loads X L.S.F. kips	3 Stress psi	4 Stress Ratios	5 Allowable Repetition (Table I) No.	6 Expected Repetitions No.	7 Fatigue Resistance Used*** percent
			SINGLE AXLES			
35	42.0	375	.71	1,500		
30	36.0	335	.64	11,000		
26	31.2	295	.56	100,000	365	1
24	28.8	285	.54	180,000	949	1
22	26.4	260	.50	---		2%
20	24.0					
18	21.6					
16	19.2					
14	16.8					
			TANDEM AXLES			
60	72.0	410	.78	210		
55	66.0	385	.73	850		
50	60.0	355	.68	3,500	365	10
46	55.2	325	.62	18,000	1,387	8
44	52.8	315	.60	32,000	3,212	10
42	50.4	305	.58	57,000	7,811	14
40	48.0	290	.55	130,000	22,046	17
38	45.6	275	.52	300,000	43,216	14
36	43.2	265	.50			73%
34	40.8					
32	38.4					
30	36.0					

* M.R. Modulus of Rupture for 3rd pt. loading. 75%

** Cement-treated subbases result in greatly increased combined k values. Use

*** Total fatigue resistance used should not exceed about 125 percent.

SN_3 = .167 S= 2½ 3" Type 'A' A.C.C. Surface Course @ .44 = 1.32

SN_4 = 161 R= 3 10" Type 'B' A.C.C. Base - Class - I = 3.80

SN_5 = .152 SNw = 5.12 - 1.32 = 3.80 11½" A.T.B. Class - I 5.12

[illegible] = [illegible]

XPG515

TABLE I

Component	Coefficient	Minimum Thickness Permitted
Surface Course		
Type A Asphalt Cement Concrete	0.44*	3 (300 tpd)
Type B Asphalt Cement Concrete	0.44*	2 (300 tpd)
Type B Asphalt Cement Concrete Class 2	0.40	
Inverted Penetration	0.20	
Base Course		
Type A Binder Placed as Base	0.40	
Type B Asphalt Cement Concrete Base Class I	0.38	2
Type B Asphalt Cement Concrete Base Class II	0.30	2
Asphalt Treated Base Class I	0.34*	4
Bituminous Treated Aggregate Base	0.23	6
Asphalt Treated Base Class II	0.26	4
Cold-Laid Bituminous Concrete Base	0.23	6
Cement Treated Granular (Aggregate) Base	0.20*	6
Soil-Cement Base	0.15	6
Crushed (Graded) Stone Base ***	0.14*	6
Macadam Stone Base	0.12	6
Portland Cement Concrete Base (New)	0.50	
Old Portland Cement Concrete	0.40**	
Subbase Course		
Soil-Cement Subbase	0.10	6
Soil-Lime Subbase	0.10	6
Granular Subbase	0.10*	4
Soil-Aggregate Subbase	0.05*	4

*Indicates coefficients taken from AASHTO Interim Guide for the Design of Flexible Pavement Structures.

**This value is for reasonably sound existing concrete. Actual value used may be lower, depending on the amount of deterioration that has occurred.

***No current specification.

Table II

POLICY TABLE FOR RIGID CONCRETE PAVEMENTS

ROAD SYSTEM	TYPE OF PAVEMENT	LOAD TRANSFER	SUBBASE	LSF[4]	Flexural Strength Portland Cement Concrete			
					S[3]	Concrete Type		
						A	B	C
SERVICE LEVEL OF HIGHWAY								
LEVEL A	Jointed	Dowels[1]	4"	1.2	1½			430
LEVEL B	Jointed	Dowels[1]	4"[2]	1.2	1½			490
LEVEL C	Jointed	Dowels[1]	4"[2]	1.2	1½			490
LEVEL D	Jointed	Dowels[1]	None	1.1[5] 1.0[6]	1	565		535
SECONDARY & STREETS								
More than 1000 vpd	Jointed	None	None	1.0	1	565	430	535
Less than 1000 vpd	Jointed	None	None	1.0	Mean	635	515	620
OTHER								
Park, Institutional, Etc.	Jointed	None	None	1.0	Mean	635	515	620

1. Dowels at joints 20' C-C are used when truck traffic is greater than 300 vpd (20 yrs) or when a subbase is used.
2. Subbases are used when the projected truck traffic (20 yrs) is greater than 1000 vpd.
3. S-Standard deviations below mean
   1½ Standard deviations below mean gives 93% confidence
   1 Standard deviation below mean gives 84% confidence
4. LSF - Load Safety Factor.
5. Use L.S.F. of 1.2 for all roads South of I-80 and West of I-35.
6. Use L.S.F. of 1.0 below 500 vpd - Level D

MEETING TRAFFIC LOADING DATA NEEDS FOR PAVEMENT ANALYSIS

BY

JOHN P. HALLIN, P.E.
REGIONAL PAVEMENT ENGINEER
FHWA - REGION 10
PORTLAND, OREGON

PREPARED FOR

SECOND NATIONAL CONFERENCE ON
WEIGH-IN-MOTION TECHNOLOGY AND APPLICATIONS
ATLANTA, GEORGIA

MAY 1985

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MEETING TRAFFIC LOADING DATA
NEEDS FOR PAVEMENT ANALYSIS
BY
JOHN P. HALLIN, P.E.

Performance analysis of pavement structural sections requires accurate axle load data. This includes the need to know the number of axle loadings that have passed over an existing pavement to properly assess its performance and estimate remaining life. Forecasts of future loadings are necessary to design economical pavement sections that provide reasonable service lives. Note that it is the knowledge of loadings, not volume, that is important in pavement structural analysis.

In the past the following relationship was used to estimate the total 18 Kip equivalent axle loads (EAL's) expected over the life of a pavement:

Total 18 Kip EAL's = AADT x T x TLF x DF x DL x 365 x Life

Where AADT = average daily traffic volume for all vehicles over the design life.

T = Percent of all commercial trucks as a decimal.

TLF = Truck Load Factor - average 18 Kip EAL's per truck from the current W-4 Table in the Truck Weight Study.

DF = Directional Factor (usually 0.5).

DL = Percent traffic in the design lane as a decimal.

365 = Days per year.

Life = Design life in years.

The percent commercial trucks were based on a classification count made at or near the project site. In many cases the TLF used was an average statewide factor. Little attempt was made to adjust the factor for variations in vehicle classification between the project site and the data used to develop the factor. When using this method, it was assumed that the mix of automobiles and various classifications of trucks remained constant throughout the life of the project. Also, the TLF was assumed to be constant throughout the life of the project. Therefore, the forecast growth in loadings was equal to the projected growth in total vehicle volume.

However, studies of actual traffic volumes and loadings have shown that loadings are increasing at a much greater rate than total vehicle volume. One study of selected sites on the Interstate system in Oregon, Washington, and Montana [1] showed quite dramatically that the above relationship will seriously underestimate truck volumes and 18 Kip EAL's. The analysis of traffic at each site focused on three vehicle groups: total vehicle volume, all trucks (excluding pickups and panels), and 5 axle or greater trucks. The 5 axle or greater truck classification was selected, because on the Interstate system this group generally accounts for 80 percent or more of the 18 Kip equivalent axle load applications. At the sites where truck weight data was available, daily 18 Kip EAL's were calculated.

The traffic data was plotted as shown in Figure 1. The vehicle growth rates were determined for each site by fitting a line to the logarithm of traffic volume and loadings versus the year. The growth rates computed are listed in Table 1. These growth rates are percentage increases from year to year. Estimating traffic at some point in time is identical to estimating the worth of money in the future if the interest rate is known.

The average growth rates were 3.5% for all vehicles, 7.3% for all trucks, 9.7% for trucks 5 axles or greater and 12.1% for 18 Kip EAL's. When reviewing these growth rates, it becomes apparent that the volume of large trucks and load applications are growing at a rate approximately 3.0 to 3.5 times that of total vehicle volume.

The growth rate for load applications is exceeding the rate for growth in truck volume for a number of reasons: 1) There are fewer empty trucks. This is probably the result of deregulation; 2) The mix of truck types is changing with 5 axle or greater trucks becoming a larger part of the truck stream; and 3) Recent legislation has made certain axle configurations possible which result in high 18 Kip EAL's per truck.

The following items are needed to make reliable estimates of future loadings on specific pavement sections:

1. Historical truck volumes by truck type.

2. Base year truck volumes by truck type.

3. 18 Kip EAL factor (Truck Load Factor [TLF]) for each truck type reflecting historical and future loadings.

4. Annual growth rates for each truck type.

5. Lane distribution of loadings.

A well planned data gathering program will be required to develop the above information. The following is a brief discussion of possible roles truck weighing-in-motion (WIM) will play in supplying this data:

Obviously, recently acquired weigh-in-motion equipment will not create historical data. However, it may supply information required to utilize the limited vehicle classification and weight data which is available.

Most historical classification and truck weight data was gathered during 8 or 16 hour periods during the month of June, July, and August. To minimize labor costs, sampling periods were often scheduled during the normal Monday through Friday work week. Review of preliminary data from continuous high speed weigh-in-motion systems in operation in Minnesota [2] and Oregon indicate there is significant variations in truck volumes and weight by day of the week and season of the year. Proper placement of continuous weigh-in-motion/classification systems on the various highway systems could provide the information necessary to develop adjustment factors to normalize short-term data gathered in the past. Figure 2 illustrates the type of weekly data which is available from a continuous weigh-in-motion system.

Continuous weight-in-motion equipment will provide a wealth of base year data. However, economics precludes continuous weigh-in-motion coverage of all highway sections. Therefore, continuous weight-in-motion equipment will have to be placed at statistically selected locations. Its primary function will be to develop seasonal adjustment factors for short-term truck weight data gathered with portable weigh-in-motion equipment. Also, it can be used to develop truck load factors for various highway systems which can be applied to classification counts.

Base year 18 Kip ESAL TLF's can be developed for the various systems and regions in a State using a combination of continuous and portable weigh-in-motion equipment. As previously discussed, continuous weigh-in-motion can be used to develop adjustment factors for historical data. Estimates of future truck load factors will need to be based on projection of historical trends coupled with estimates of probable effects of recent and future truck size and weight legislation.

Estimates of growth rates for each truck type will need to be based on historical data. It will require a number of years before continuous weigh-in-motion or automatic classification equipment will produce meaningful data on classification and weight trends.

Caution must be applied when observing short-term trends which can be developed after weigh-in-motion and automatic classification counting equipment have been in operation two or three years. Figure 3 is a plot of the volume of large trucks, 5 axle or greater, on I-90 in western Montana. This shows the fluctuations which can occur in truck volumes over a short term. While the average long-term growth rate for this location is positive, analysis of the 1978 to 1982 data could be used to show that there is a downward trend in the volume of large trucks.

Continuous high speed weigh-in-motion may provide interesting information concerning the lane distribution of loadings. Preliminary data from Oregon indicates that the historically based distribution of truck volumes between the left and right lane of four lane roadways is fairly accurate. However, the trucks using the right lane are heavier than those using the left lane. This results in a higher distribution of equivalent load applications to the right lane than originally thought.

The proceeding discussion outlined the potential uses and benefits of using WIM data in pavement performance analysis. However, the large number of sections on the highway network make it physically impossible to gather truck weight data on each section. Therefore, it will be necessary to develop a statistically based sampling plan for gathering truck weight and classification data. The data gathered under the plan will provide truck load factors and vehicle volume growth rates which can be applied to classification data gathered by short term classification counts at specific sites.

The Draft Traffic Monitoring Guide [3] proposes the traffic monitoring program outlined in Table 2. This is a statistically based sampling program which uses the HPMS sample. The advantage of using the HPMS sample is that it is readily available and the need to design and implement a new sample design is eliminated. Since the sampling program produces an estimate for an aggregation of elements, special studies will be required to develop loading data for specific projects. These would include vehicle volume counts and special classification counts at the project site.

The monitoring program includes an element for continuous counting. Making some of the ATR stations capable of providing vehicle classification and vehicle weight data would provide needed information on seasonal factors and day-of-week adjustment factors. An adequate number of continuous WIM/automatic classification stations would be necessary to develop factors for each functional class of road by region of the State. Over a period of time these stations would aid in the development of trends in the growth of loads and vehicle volumes by type.

During the past several years there have been an increasing number of reports of premature failures of pavements. In many cases, when these failures were analyzed, it was found the sections had failed prematurely in years but had in fact carried loadings equal to or in excess of the design loadings. The cause of the failures was inadequate traffic load forecasting. A properly designed truck weight and vehicle classification program should greatly improve estimates of load applications for future pavement designs. The sample size required to achieve this program will require the use of WIM and automatic classification equipment.

REFERENCES

1. Hallin, John P., "Traffic Data for Pavement Design," The Workshop in pavement Rehabilitation, Salt Lake City, Utah, September 1984.

2. Dahlin, Curtis and Owen, Frank, "An Analysis of Data Collected at the I-494 Weighing-in-Motion Site," Presented at the Transportation Research Board 63rd Annual Meeting, Washington, D.C., January 1984.

3. "Draft Traffic Monitoring Guide," U. S. Department of Transportation, Federal Highway Administration, Office of Highway Planning, Washington, D.C., July 1984.

4. Hage, Robert J., "Truck Forecasts and Pavement Design," Transportation Research Board 889, Transportation Research Board, Washington, D.C., 1982.

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2. Dahlin, Curtis and Owen, Frank, "An Analysis of Data Collected at the I-494 Weighing-in-Motion Site," Presented at the Transportation Research Board 63rd Annual Meeting, Washington, D.C., January 1984.

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4. Hage, Robert J., "Truck Forecasts and Pavement Design," Transportation Research Board 889, Transportation Research Board, Washington, D.C., 1982.

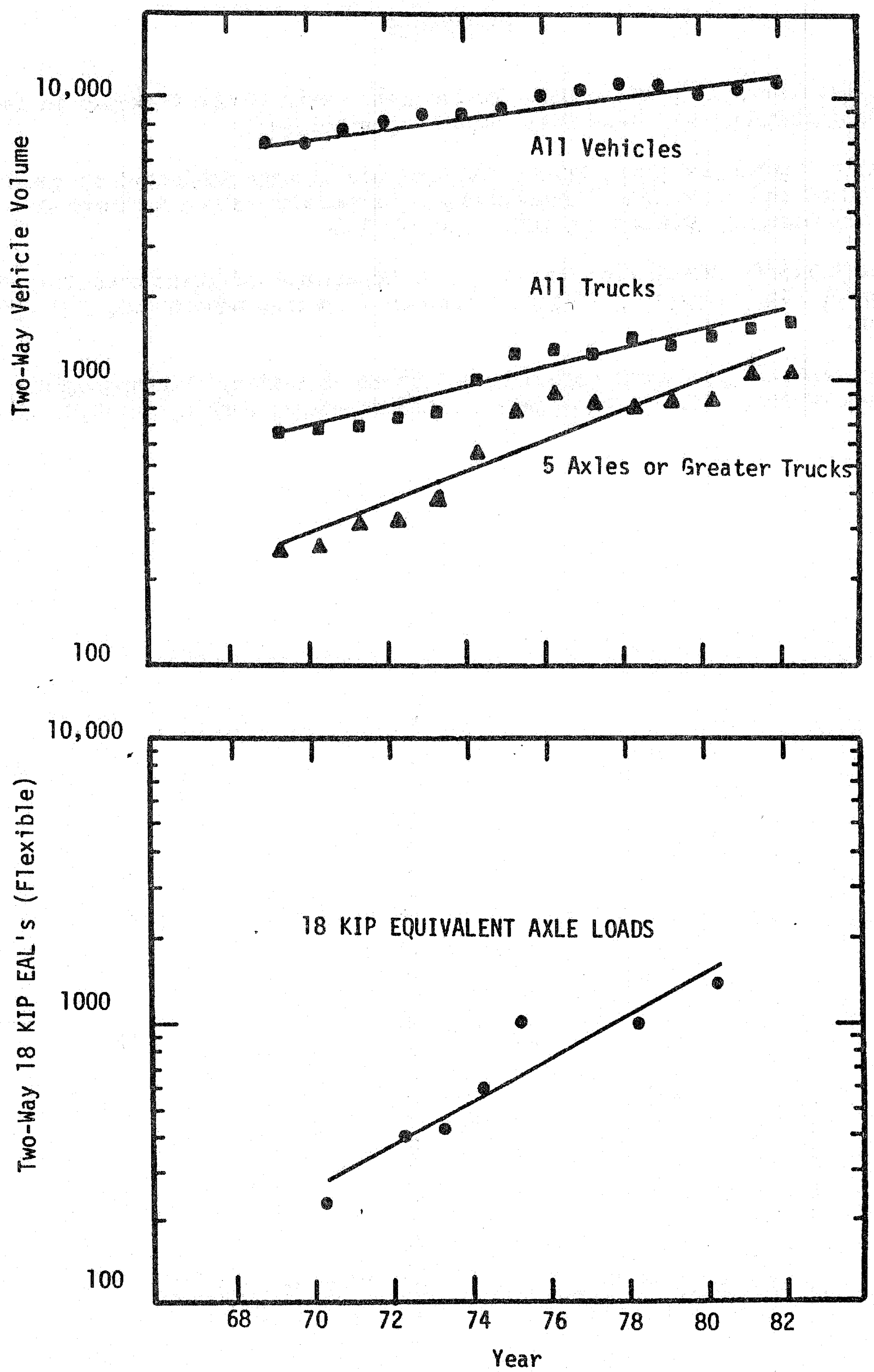


Figure 1. Two-Way Volumes of Vehicles and Axle Load Repetitions on I-90 West of Billings, Montana

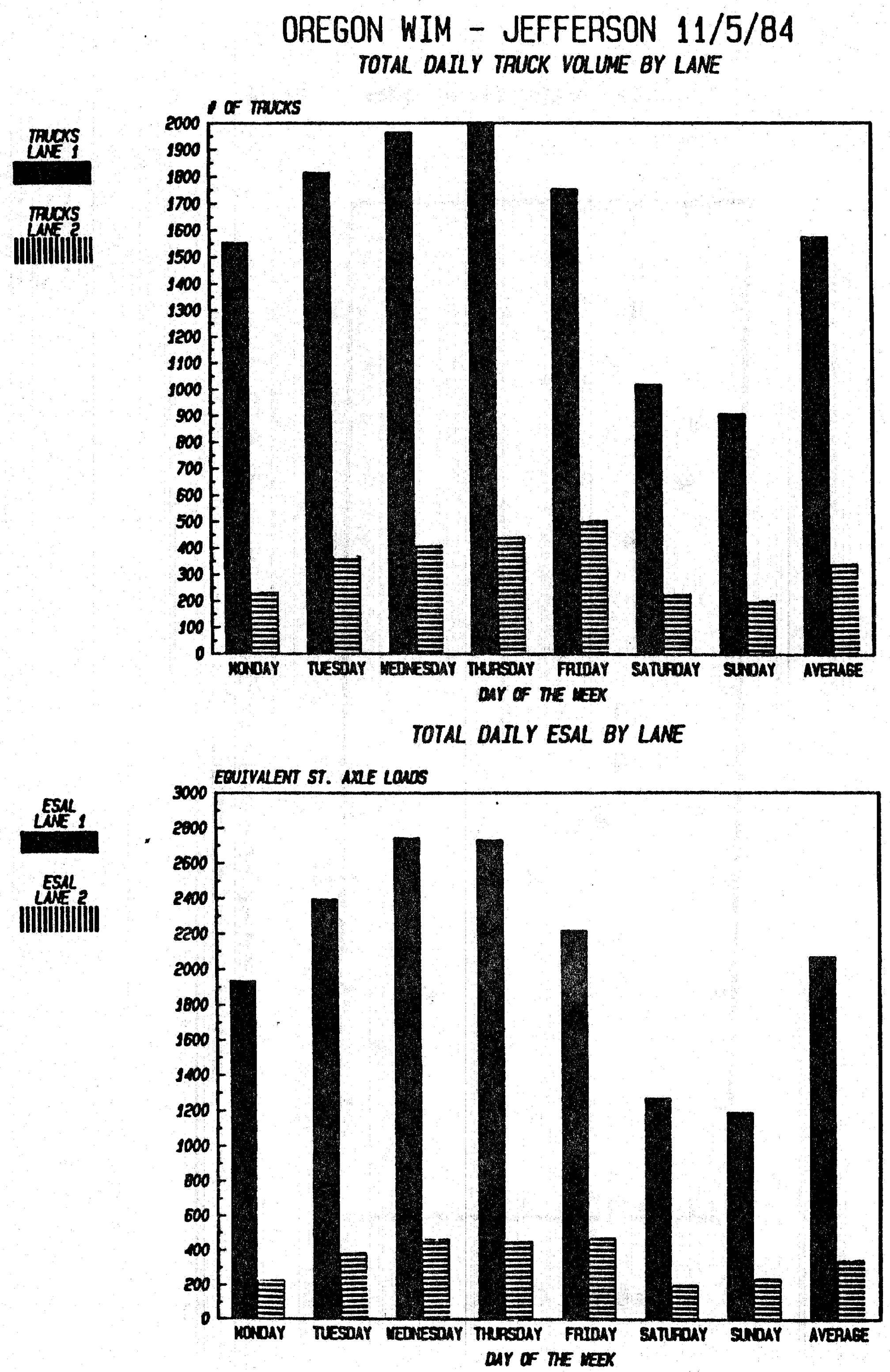


Figure 2. Example of the type of information which can be obtained from a high speed continuous weigh-in-motion system.

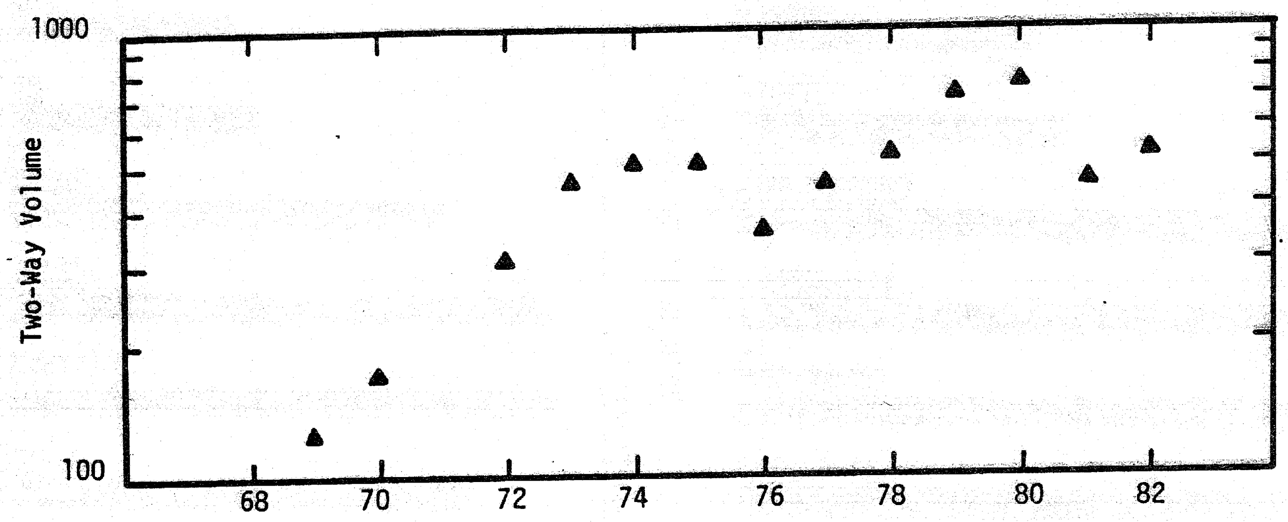


Figure 3. Two-Way Volume of 5 Axles or Greater Trucks on I-90
West of Superior, Montana

TABLE 1
INTERSTATE VEHICLE VOLUME GROWTH RATES
IN THE PACIFIC NORTHWEST

	ANNUAL GROWTH RATES (PERCENT)			
	ALL VEHICLES	ALL TRUCKS	TRUCKS 5 AXLE OR GREATER	18 KIP EAL´s
LOCATION				
MT - I-94, Wilbaux to ND	3.4	5.4	6.3	10.3
MT - I-90, Billings to Laurel	4.0	8.1	13.1	18.9
MT - I-90, Butte	2.6	4.2	9.9	N/A
MT - I-90, Superior West	3.9	9.5	10.4	10.4
WA - I-90, Cle Elum, WA	2.1	N/A	5.6	8.5
WA - I-5, Vancouver to Olympia, WA	3.6	N/A	10.1	13.2
OR - I-5, Ashland, OR	4.1	8.8	11.7	12.6
OR - I-84, Oregon-Idaho Border	4.4	8.0	10.4	11.1
AVERAGE	3.5	7.33	9.69	12.1

TABLE 2
PROPOSED TRAFFIC MONITORING PROGRAM (REF. 3)

ELEMENT	SUBELEMENT	PERIOD	NUMBER	PRODUCTS
1. Continuous	—	365 Days	40 to 60 (Average State)	Seasonality Growth Temporal Distribution
2. HPMS	HPMS Sample	—	HPMS Sample	System Estimates
	Volume	48 Hours	Interstate Sample + 1/3 of Rest Annually (3-year cycle)	System AVMT
	Classification	48 Hours	3-year cycle 300 - 420 Annual 100 - 140	Classified AVMT, Axle Correction factor, Percentage distribution of vehicles
	Weight	48 Hours	3-year cycle - 90 Measurements 30 Interstate 60 Others Annual 10 Interstate 20 Others	System weight + EAL, Vehicle Weight by Classification Category
3. Special (State needs and others)	—	—	At State Discretion	Site specific information, 4R, Truck Routes, Pick-up/Auto Split, Any others

VIII. PLANNING WORKSHOP SESSION

Comparisons

on

Truck Weight Survey

and

WIM Data Collecting

Methods

and

Thoughts on

Future Data Collection

Prepared for

Second National Conference on
Weigh-in-Motion Technology and Applications
Atlanta, Georgia
May 20-May 24, 1985

Bill McCall, Director
Office of Transportation Research
Iowa Department of Transportation
May 13, 1985

Wiley has asked me to discuss Iowa's experience with the Rural Technical Assistance Program Weigh-in-Motion demonstration project and the traditional truck weight survey method of collecting data. Although we've just begun to take data off the weigh-in-motion site last week, I will attempt some observations concerning comparisons between weigh-in-motion and truck survey methods and the results. I may throw in some WAG cost comparisons.

Truck Weight Survey

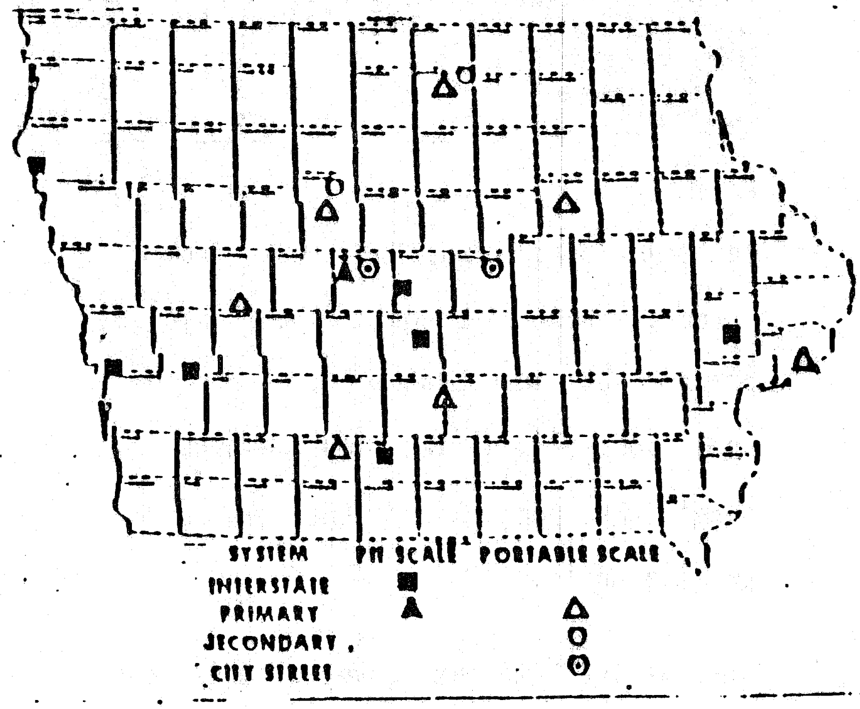
As you know truck survey weight data is currently used primarily for highway planning and highway and bridge design. Iowa collects truck weight data every two years at 19 locations. Permanent weight enforcement scales are used at eight sites and portable scales at 11 sites.

Highway System	Scales Permanent	Portable	Total
Interstate (Rural)	7	-	7
Primary (Rural)	1	5	6
Primary (Urban)	-	2	2
Secondary Rural	-	2	2
Local Urban	-	2	2
Total	8	11	19

Permanent scale equipment varies from three platform electronic type to single platform balanced beam type. Portable scale equipment varies from the older single tire portables to the new low profile units.

Current truck weight survey data is used in the planning, design and preservation of Iowa's highways and bridges. Current and future technology will support automated weight and vehicle classification data usage for not only improved highway and bridge planning but also truck weight enforcement planning and potentially the reduction of motor carrier operating costs. High-speed automatic weight and classification data will not be used, in my opinion in the foreseeable

TRUCK WEIGHT SURVEY LOCATIONS



future, for writing overweight violations.

Truck survey data is gathered every two years during the summer months, on week days with part-time staff. Typical survey crew set up is used for portable weighing. About 17,500 trucks were weighed in the 1983-84 biennium at a cost of about $80,000 or $4.57/truck. An additional $40,000 was spent in 1984 on classification costs, data processing, and analysis.

The advantages of traditional truck weight surveying are:

- o Identify vehicle type
- o Commodity
- o Registration data

Disadvantages are:

- o Limited data collected
- o Biased because of bypass
- o Safety
- o Cost to trucking industry
- o Cost of collecting data

Weigh-in-Motion

The Federal Highway Administration through the Rural Technical Assistance Program provided an opportunity for Iowa to try Weigh-in-Motion. Advantages of WIM are:

- More data collected
- Unbiased data
- Reduce cost to trucking industry
- Reduce cost of collecting data
- Real time information data
- Accuracy
- All season operation
- Speed of vehicle

Disadvantages are:

- Identify body type
- Commodity
- Registration data
- High initial cost

March 7, 1984 the Iowa DOT opened WIM bids from Bridge Weighing Systems, CMI, and

Streeter-Amet. The bids were basically for a system that would provide the following performance levels.

Weight

Axle	Accuracy	% of axles within specified Accuracy
Steering	±15%	67%
Other Single	±10%	80%
Tandem	±10%	85%
Gross	±5%	95%

$$\text{Accuracy\%} = \frac{\text{WIM Weight-Static Weight}}{\text{Static Weight}}$$

Speed ±1MPH

Axle Spacing ±1 foot

Telemetry and compatibility with the IBM PC-XT currently used by the Iowa DOT for polling and processing automatic traffic recorder data.

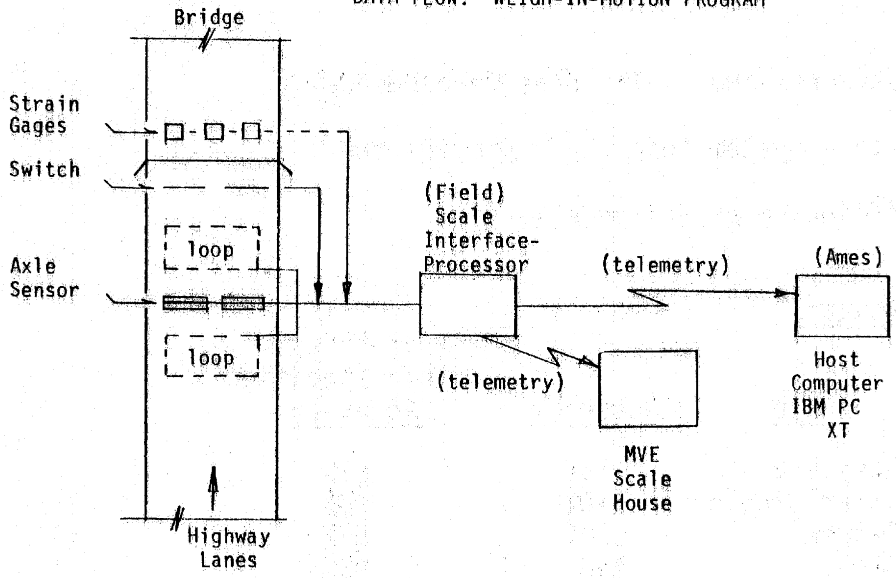
Supporting software that provides for transmitting either raw data or summary information.

The bids were:

Bridge Weighing System-------$95,520

Streeter Amet Division-------$164,427

DATA FLOW: WEIGH-IN-MOTION PROGRAM



<u>Function</u>

- Detects vehicle presence
- Identifies no. of axles
- Identifies time between axles
- Measures axle strains

<u>Function</u>

- Processes the following data on each vehicle:
  . Vehicle I.D.
  . Time of Arrival
  . Lane of Travel
  . Axle Weight
  . Total Wheelbase
  . Gross Weight
  . Vehicle Classification
  . Vehicle Speed
  . 18 KIP EAL
  . Bridge Formula
- Processes above data for computer storage in field with telemetry transfer to Host Computer IBM-PC-XT
- Data format is individual vehicle or summary tables.

<u>Function</u>

- Via telemetry real time display of truck data
- Summary tables from Processor are also available

<u>Function</u>

- Via telemetry, real time or table data. Process and format data for reports and file retention.
- Typical information tables include:
  . Axle configuration and classification
  . Weight distribution by vehicle type
  . Hourly, daily, and weekly variation on vehicles weighed
  . Bridge formula and legal weight violations
  . Scale performance and speed distribution

CMI--------------------------$188,666

The contract payment schedule is:

- o 50% of the bid price upon delivery
- o 30% of the bid price upon certification before the 90 day test period
- o 20% of the bid price after successful completion of the 90 day test period and acceptance by the DOT.

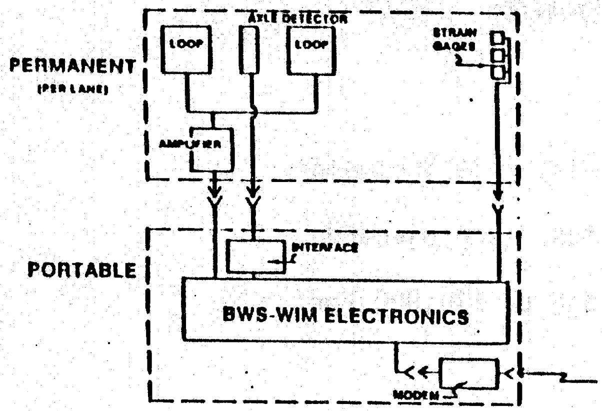
The contract was awarded to low bid Bridge Weighing Systems.

. During the initial phases of system installation, we began to develop what could be considered a first generation "automatic weight and classification system". BWS, International Road Dynamics, Federal Highway Administration and the Iowa DOT agreed to develop a combination semi-portable system that would accommodate both weighing vehicles and using ESAL with a classifier at the same location to predict highway loading.

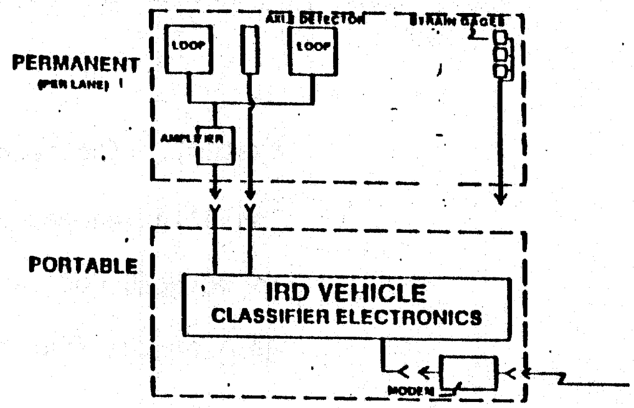
BWS agreed to use the International Road Dynamics loop and axle detector components with their system. As a part of the Rural Technical Assistance Program demonstration project the Iowa DOT purchased an International Road Dynamics classifier and three additional axle detectors. The in-pavement components will be installed at 3 more sites for a total of four locations in the demonstration project. The Bridge Weighing System system will be rotated among these locations to establish 18 Kip EAL by vehicle classifications. The International Road Dynamics classifier will also be rotated among the same four locations and the average 18 Kip EAL for each specific vehicle category will be programmed into the International Road Dynamics classifier. The outcome should be a fairly good prediction of accumulated 18 Kip EAL at the four locations.

I believe this combination of technology may be the first generation of an "automatic weight and classification

PLANNED WEIGH-IN-MOTION SYSTEM COMPONENTS



AUTOMATIC VEHICLE CLASSIFICATION SYSTEM COMPONENTS



SELECTION CRITERIA — WIM BRIDGES

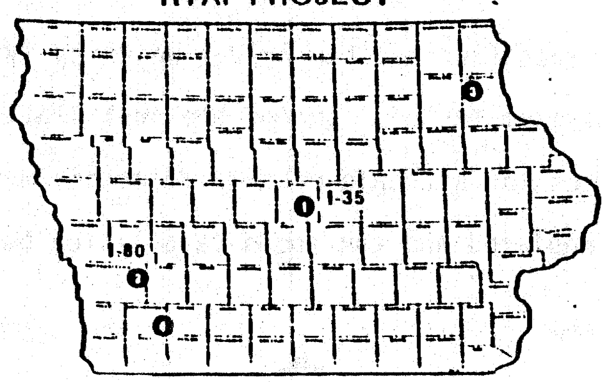
1. SKEW: Maximum 15°. Desirable 5° or less.
2. Span length: Maximum 65'. Desirable 50'.
3. Use simple span. Concrete beam, steel beam or concrete slab.
4. Avoid steel continuous griders.
5. Bridge approach should be smooth and in good condition.

Above criteria was recommended by bridge weighing systems to optimize weight accuracy.

EVALUATION OF IOWA BRIDGES

1. Approx. 2700 total on primary road system.
2. Less than 15% met criteria 1-4.
3. Criteria 5 will further reduce acceptable bridges.
4. Evauation will be used to select 3 additional sites in RTAP program.

WEIGH-IN-MOTION LOCATION RTAP PROJECT



system". The total initial cost including installation and utilities. is projected to be $176,000, an average of $44,000 for each of the four sites.

Now I'll spend just a few minutes bringing you up-to-date on progress installing this first generation system. There were a number of challenges during the installation at the first location. As a matter of introduction, the location is on I-35 northbound between two interchanges on a bridge over an abandoned railroad. It is a pre-stressed concrete bridge 145 ft. x 40 ft., 2^{o} skew and spans of 47'-48'-47'. About two miles down stream and between the interchanges is a Motor Vehicle Enforcement permanent scale.

The loops and axle detector have been installed, the International Road Dynamics classifier and the Bridge Weighing Systems system tested. During the installation testing a couple of axle detectors were replaced and the speed calculation based

B.W.S - WEIGH-IN-MOTION

System: Data Output - Individual Trucks

1. Time of Day & Day of Week
2. Lane of Travel
3. Vehicle I.D. Number
4. Vehicle Type
5. Vehicle Speed
6. Number of Axles
7. Axle Spacing
8. Axle & Gross Weight
9. Weight Violation - Bridge Formula
10. 18 KIP Equivalency Axle Loading

Above data stored on removable hard disk.
Capacity - Approx. 3,000 Trucks.

B.W.S. - WEIGH-IN-MOTION

System: Data Output - Summary Tables

1. Status of WIM operation.
2. Distribution of gross weight - day of week & lane of travel.
3. Vehicle distribution by axle space grouping & day of week.
4. Distribution of single & tandem axles by weight & day of week.
5. Potential overweight trucks - hour of day and day of week.

Above tables developed by B.W.S. Additional summary tables will be prepared as necessary.

AUTOMATIC VEHICLE CLASSIFICATION

System: Data Output - Individual Vehicles

1. Time of Day & Day of Week
2. Lane of Travel
3. Vehicle Type
4. Vehicle Speed
5. Vehicle Length
6. Number of Axles
7. Axle Spacing

Above data stored for approximately 100 individual vehicles. Data then transferred to summary tables.

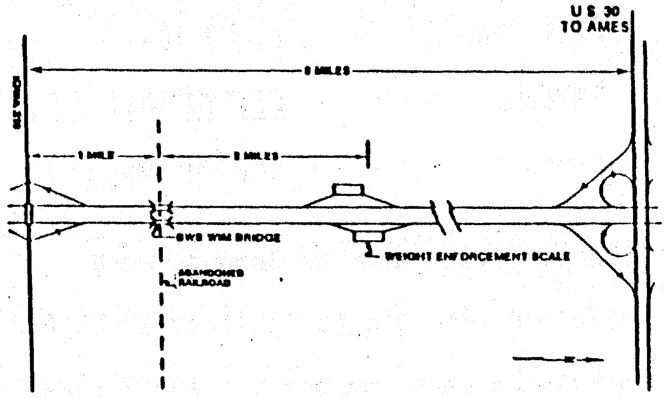
AUTOMATIC VEHICLE CLASSIFICATION

*System: Data Output - Tables**

1. Cumulative number of vehicles and estimated ESAL by lane.
2. Traffic volume by speed range.
3. 24 hour volumes by hour of day and vehicle type.
4. Vehicle length class by vehicle type

*All tables are for each day within the polling period.

SITE VIEW
INTERSTATE 35 WIM BRIDGE
AND WEIGHT ENFORCEMENT SCALE



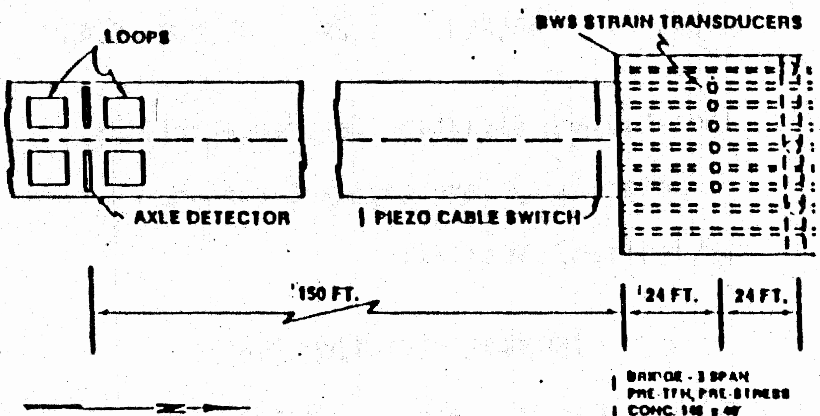
on measurements taken by the loops was found to be beyond acceptable tolerance. In order to obtain an acceptable tolerance on speed calculations a second switch has been placed in the subsystem. Using the same in-pavement subsystem, both classification data using the IRD classification system and weight data using the BWS system have been collected and processed at the bridge site and transmitted to Ames using telemetry. The data has not been verified but looks reasonable.

The Iowa Department of Agriculture certified weights and measures truck passed over the bridge several times. Certified weights were:

Steering	12,000 lbs.
Tandem	33,780 lbs.
Gross	45,780 lbs.

The following average weights were obtained from the agriculture truck for 10 passes in each the outside and inside lane

PLAN VIEW
IOWA WEIGH-IN-MOTION SYSTEM
INTERSTATE 35 — STORY COUNTY



of the bridge.

Axles	Outside Lane	%	Inside Lane	%
Steering	12,600	+5.02%	12,700	+5.8%
Tandem	32,600	-3.4%	32,900	-2.6%
Gross	45,220	-1.2%	45,600	-0.4%

The standard deviation for repeatability of weighing by lane and axle for the agriculture truck is:

STANDARD DEVIATION (tons)

Axle	Outside Lane	Inside Lane
Steering	±0.18	±0.34
Tandem	±0.67	±1.13
Gross	±0.85	±1.46

The data from the agriculture truck will be used to calibrate the bridge. The initial passes of the test truck are within specified tolerances. We believe the system will meet our specifications.

The Iowa system can be accessed at the BWS display.

BWS-WIM SITE -- OUTSIDE LANE

AGRICULTURE TRUCK WIM MEASURES

NUMBER	WEIGHT(IN TONS) SINGLE	TANDEM	GROSS	AXLE SPACING DRIVE	TANDEM
1	12.8	33.4	46.2	15.1	4.2
2	12.8	33.4	46.2	15.1	4.2
3	12.6	32.8	45.4	15.1	4.3
4	12.6	32.8	45.4	15.0	4.2
5	12.4	32.0	44.4	15.1	4.3
6	12.9	33.4	46.3	15.1	4.2
7	12.4	31.8	44.2	15.1	4.2
8	12.6	32.8	45.4	15.1	4.3
9	12.3	31.4	43.7	15.2	4.2
10	12.6	32.4	45.0	15.1	4.2
STANDARD DEVIATION	0.18439	0.67201	0.85182	0.04472	0.04583
AVERAGE	12.60	32.62	45.22	15.10	4.23
CERTIFIED STATIC MEASURES	12.00	33.78	45.78	15.1	4.2

BWS-WIM SITE -- INSIDE LANE

AGRICULTURE TRUCK WIM MEASURES

NUMBER	WEIGHT(IN TONS) SINGLE	TANDEM	GROSS	AXLE SPACING DRIVE	TANDEM
1	13.0	34.0	47.0	15.0	4.2
2	12.7	32.8	45.5	15.0	4.2
3	12.7	33.0	45.7	15.1	4.2
4	13.3	35.0	48.3	15.0	4.4
5	13.1	34.2	47.3	15.1	4.2
6	12.1	31.0	43.1	15.0	4.2
7	12.5	32.2	44.7	14.9	4.3
8	12.4	32.0	44.4	14.9	4.3
9	12.5	32.2	44.7	15.1	4.3
10	12.7	33.0	45.7	15.0	4.2
STANDARD DEVIATION	0.33764	1.12801	1.46506	0.07000	0.06708
AVERAGE	12.70	32.94	45.64	15.01	4.25
CERTIFIED STATIC MEASURES	12.00	33.78	45.78	15.1	4.2

BWS-WIM SITE -- OUTSIDE LANE

AGRICULTURE TRUCK DIFFERENCE FROM STATIC MEASUREMENTS

NUMBER	WEIGHT(IN TONS) SINGLE	TANDEM	GROSS	AXLE SPACING DRIVE	TANDEM
1	0.8	-0.38	0.42	0.0	0.0
2	0.8	-0.38	0.42	0.0	0.0
3	0.6	-0.98	-0.38	0.0	0.1
4	0.6	-0.98	-0.38	-0.1	0.0
5	0.4	-1.78	-1.38	0.0	0.1
6	0.9	-0.38	0.52	0.0	0.0
7	0.4	-1.98	-1.58	0.0	0.0
8	0.6	-0.98	-0.38	0.0	0.1
9	0.3	-2.38	-2.08	0.1	0.0
10	0.6	-1.38	-0.78	0.0	0.0
STANDARD DEVIATION	0.18439	0.67201	0.85182	0.04472	0.04583
AVERAGE	0.60	-1.16	-0.56	0.00	0.03

BWS-WIM SITE -- INSIDE LANE

AGRICULTURE TRUCK DIFFERENCE FROM STATIC MEASUREMENTS

NUMBER	WEIGHT(IN TONS) SINGLE	TANDEM	GROSS	AXLE SPACING DRIVE	TANDEM
1	1	0.22	1.22	-0.1	0.0
2	0.7	-0.98	-0.28	-0.1	0.0
3	0.7	-0.78	-0.08	0.0	0.0
4	1.3	1.22	2.52	-0.1	0.2
5	1.1	0.42	1.52	0.0	0.0
6	0.1	-2.78	-2.68	-0.1	0.0
7	0.5	-1.58	-1.08	-0.2	0.1
8	0.4	-1.78	-1.38	-0.2	0.1
9	0.5	-1.58	-1.08	0.0	0.1
10	0.7	-0.78	-0.08	-0.1	0.0
STANDARD DEVIATION	0.33764	1.12801	1.46506	0.07000	0.06708
AVERAGE	0.70	-0.84	-0.14	-0.09	0.05

Future

Future use of truck weight information will include motor vehicle enforcement planning, weight monitoring and potential support of fleet management information to the motor carrier industry. The key objectives in an automated data collection system are to: reduce bias in the data, increase the number of data collection locations, reduce data collection costs, and provide vehicle information on a timely basis. Current automatic weight and classification system technology can meet these key objectives.

Automatic weight and classification information can be used in analyzing the effectiveness of motor vehicle enforcement strategies. Industry compliance with weight regulations can be more closely estimated. Currently truck survey data indicates about 10% of the vehicles exceed axle or gross legal weight. Motor Vehicle Enforcement Officers find about 2% of the vehicles processed at permanent scales are in violation of legal weights. In roving patrol activities our Motor Vehicle Enforcement Officers find over 25% of the vehicles exceed legal weights. All these figures seem reasonable given the biased data collection environment.

The measure of effectiveness, compliance, is difficult to estimate. A combination of strategically placed automatic weight and classification systems with portable weigh-in-motion systems could identify the magnitude of compliance and noncompliance.

Automatic weight and classification systems located at Long Term Pavement Monitoring sites and correlated with the Highway Monitoring System will provide critically needed support for Pavement and Bridge Management.

Automatic weight and classification system coupled with automatic vehicle identification technology has the potential to lower trucking industry costs by reducing the number of stops a truck makes in each state. The Crescent State Project is leading the nation in encouraging the continued development of supporting technology. NCHRP Panel 3-34, Research Project Title: The Feasibility of A National Heavy Vehicle Monitoring System, has released an RFP that considers institutional issues and the system deployment necessary to support a comprehensive data base that will satisfy both industry and government requirements.

The future of weigh-in-motion lies in low cost and compatibility with existing systems. For example, replacing loop sensors in an automatic traffic recording system with a low cost permanently installed weight sensing subsystem would yield an automated weight and classification system. That plain vanilla approach could be expanded with some whistles, bells and gongs as desired and your checkbook can afford.

Now for some WAG cost comparisons. PLEASE NOTE THAT WE HAVE NOT HAD EITHER THE WIM OR THE ATR SYSTEMS IN OPERATION LONG AND THEREFORE, ACTUAL COST COMPARISONS CAN NOT BE MADE. THE AMOUNTS I WILL TALK ABOUT ARE ONLY IN THE CORRECT ORDER OF MAGNITUDE.

Biennial Truck Survey, 19 loc.---$60K/yr

BWS/IRD System, total initial investment
4 loc.----------$176K.

BWS/IRD System Annual Maint.-est.$10K/yr

ATR Sys. Annual Maint, 106 loc.-est.$30K/yr

Iowa could be spending as much $90K-$100K per year in staff time collecting traffic data at 106 locations and weight data at 19 locations. A starting point might be to cut the annual labor cost in half and improve the information provided to the user.

WEIGHING-IN-MOTION
IN ILLINOIS

Second National Conference on
Weigh-in-Motion Technology and Applications
Atlanta, Georgia
May 20 - 24, 1985

Larry Shoudel

WEIGHING-IN-MOTION IN ILLINOIS

The first high speed weigh-in-motion (WIM) equipment in Illinois is just becoming operational. It is located on the section of pavement near Effingham that carries both Interstate Routes 57 and 70. While a portion of the test weighings have been completed and there have been some data collected, we have not been able to complete any comprehensive analyses. However, we have compiled sample reports to illustrate initial findings. These findings and the comparison testing of selected vehicle dynamic and static weights are encouraging.

In addition to the Effingham site, we are also planning to install WIM equipment this year on Interstate Route 74 near the Indiana State line. This location was initially selected for a permanent weigh station; however, the expense of such an installation and the existance of a pair of weigh stations about 25 miles away in Indiana led to difficulty in justifying the construction of the scales in Illinois. Data from the proposed WIM installation will assist in determining the magnitude of overloading and whether a weigh station should be built at this location.

In addition to the Effingham and Danville sites, we have a test installation on northbound U.S. Route 41 north of Chicago. This site is a joint project with StreeterRichardson (StreeterAmet). It is near their headquarters in Grayslake, and it is used for testing various weighing and classification equipment. We also propose to install permanent WIM facilities on Interstate Route 270 near the Missouri State line and on southbound Interstate Route 94 near Wisconsin. As with the Danville site, the Interstate Route 270 site may be used to determine whether a permanent weigh station is needed.

Following is a summary of the status of WIM projects in Illinois:

LOCATION	EQUIPMENT MANUFACTURER	EQUIPMENT TYPE	INSTALLATION DATE
1. I57/70, Effingham	Streeter Richardson	Permanent In-pavement	Operational May, 1985
2. US 41, Waukegan	Streeter Richardson	Permanent In-pavement	Operational May, 1985
3. I55, Bolingbrook	Streeter Richardson	Weigh Station Sorter	Late 1985
4. I74, Danville	Contract Letting	Permanent In-pavement	June 21, 1985 Letting
5. I270, E. St. Louis	Contract Letting	Permanent In-pavement	FY86 Letting
6. I94, Near Wisconsin	Contract Letting	Permanent In-pavement	FY86 Letting

Although the test installation on U.S. Route 41 near Waukegan was begun first, the Effingham site has been the initial contract project. The contract was awarded to Streeter Richardson in August of 1984 at a bid price of approximately $320,000. The specifications for this project will be generally followed on the Danville installation and the other proposed high speed WIM contracts.

Effingham is located in the southeast part of Illinois. The scale site is on the section that carries both Interstate Routes 57 and 70. It is a four lane section consisting of 10 inches of P.C.C. and a 4 1/2 inch bituminous resurfacing that was added in 1983. The scale is located on a tangent section with a 0 percent grade. The pavement smoothness criteria requires that there be less than 1/8 inch variation in 10 feet.

Traffic volumes for this section consist of a 1984 AADT of 19,900 with 6300 single and multi trailer trucks (31.6%). About 6150 of these have five or more axles. For design purposes, it has been assumed 70 percent of the vehicles are in the two outer lanes.

The specifications require the equipment to have the capability of operating in several different modes. These include the automatic polling and telemetry, truck weight study and selective weight enforcement, remote monitoring, and diagnostic and initial setup modes.

The automatic polling and telemetry mode allows the transmittal of individual truck weight data to the central control unit in Springfield. A standard voice grade telephone line is used for this operation. The central controller is an IBM Model AT personal computer.

While in the truck weight study and enforcement mode, a portable personal computer (Compac) is used on-site to monitor the flow of traffic. Classification is automatically accomplished by the system based upon axle configurations and spacings. A manual override capability allows the operator to enter the classification. The body type can also be entered manually by the operator.

The same operational mode can be used by law enforcement officials to sort out those suspected overweight vehicles for checking on static scales. Due to the heavy graduated fine schedule for being overweight in Illinois, we do not believe the WIM system will be used for directly issuing citations in the foreseeable future. However, since the heavy volume of trucks on this and many other Interstate routes in Illinois preclude weighing all vehicles on semiportable scales, the successful use of high speed WIM equipment as a sorter could be very beneficial.

The remote monitoring mode allows the WIM station to be dialed from the central office in Springfield. The weight of trucks at the scales can then be observed in a realtime mode.

When operating in the diagnostic and initial setup mode the system will be capable of simulating vehicle inputs for self diagnostic testing and calibration. This will also allow the setting of threshold levels, adjusting the clock and performing various diagnostic functions. The display of appropriate error messages and identifying components that have failed will also be part of this mode.

System components were specified in the contract proposal, but adequate latitude was incorporated to allow the various vendors an opportunity to submit a bid. At the Effingham location, inductance loop detectors have been installed in advance of and beyond the scale platforms. Weigh pads have been placed in the wheel paths and off-scale detectors are located between the platforms and on the outside shoulders. Other on-site equipment consists of the scale interface/processor, telephone interface equipment, portable computer and printer. The modem is capable of a transfer rate of 1200 baud.

The specifications require that the scales respond to vehicles traveling at speeds up to 85 miles per hour; however, the accuracy requirements are only applicable to vehicles traveling between 45 and 65 mph. Initial indications are that the high end of this range may be too low since many trucks are exceeding 65 mph.

At the central headquarters, the central unit consists of an IBM model AT personal computer. There is also a printer and a modem for transfer of data to the State mainframe. The transfer of data has thus far been an elusive goal. When achieved, this feature will allow storage and retrieval of the data for future studies.

Static testing and calibration test runs with vehicles of known weight were completed to adjust the equipment. During the calibration test, a three-axle dump truck and a five-axle tractor semitrailer made several repeat runs over the scales.

Initial testing of part of the Effingham system has also been accomplished. Specifications require that no less than 100 trucks be weighed dynamically and statically. The contract requires the two weights be within the following limits:

AXLE	ACCURACY	% of Axles Within Specified Accuracy
Steering	± 15%	67%
Other Single	± 10%	80%
Tandem	± 10%	85%
Gross	± 7%	90%

The testing procedure for eastbound traffic consisted of selecting vehicles for weighing as they approached the WIM site. Vehicle unit numbers, company name and other identifying information were recorded and relayed via radio to State Police officers who directed the selected trucks to the semiportable scales for static weighing. The scales were located beyond the I57/70 split in order to avoid the heavy traffic prevalent on the combined section. On Interstate 57 the scales were located in a rest area and on Interstate 70 they were on the shoulder. The semiportable scale equipment has proven to be very accurate and reliable in providing static weights. However, since they are only technically required to be within 2 percent, it was agreed before testing began that this tolerance could be added to the allowable variation percentages. Initial results have been quite satisfactory for the two lanes that have been tested as illustrated in Attachment 1. Also attached are graphs comparing the individual static and dynamic weights for the vehicles tested.

The system software is designed to provide various reports and summaries. These include the following:

- Batch report - includes the data shown on the realtime display along with the 18 Kip ESAL and other data for individual trucks.

- o Summary report - lists by day of week the number of vehicles detected, trucks, trucks weighed, and trucks overweight; indicates the percent of trucks that were overweight; identifies the type of violation; and the number of trucks not weighed and the reason.

- o Distribution of gross weights by axle configuration - lists the number of vehicles in each of the 13 vehicle classifications in 5,000 pound increments.

- o Distribution of overweight vehicles by hour of day - indicates by direction of travel, and by hour, the number of trucks weighed, the number overweight and the percentage overweight.

- o Distribution of vehicle types by day of week - summarize the volumes of traffic per day in each of the 13 classifications.

- o Distribution of single and tandem axle weights by day of week for buses and greater - lists the single, tandem, and total axle loadings by day of week in 2000-pound increments. It also shows the average axle weights and an 18 Kip ESAL.

- o Distribution of trucks by hour of day - indicates by direction the number of single unit, multi unit and total trucks per hour.

- o Distribution of speeds by vehicle type - summarizes the number of vehicles in each classification group by speed in five-mile-per-hour increments.

Our Office of Planning and Programming currently conducts the FHWA Truck Weight Study weighing every other year. These studies take place at 12 permanent State weigh stations for an eight-hour period on a selected summer weekday. These data are then used for the report to FHWA and are also used to formulate pavement designs and perform other truck-related studies. This biennial study requires approximately 158 man days plus travel time, equipment costs and travel costs.

We rely on the results of the Truck Weight Study to provide data for a variety of purposes, but we are concerned with the reliability of the information. During Federal FY84, there were 5,527,000 vehicles weighed at our 20 Interstate and 11 primary weigh stations. In that same period, there were 60,000 trucks weighed on our 12 sets of semiportable scales. The violation rate at the weigh stations was slightly in excess of one percent. The rate at the semiportable scales was about 10 times higher. Since the element of surprise quickly disappears at the semiportable scale sites, the actual percentage of overloading may be even greater than indicated. Whether or not the higher rate is accurate, it does suggest the heavier trucks may be bypassing the fixed scales, which in turn indicates our Truck Weight Study data is biased. This apparent problem with our current truck weight data collection procedures is a principal factor in our wanting to develop several WIM sites around the State.

In addition to our need for accurate data for determining pavement designs, there are other studies that demand an improved data collection system. When our legislature adopted the 80,000 pound weight law in 1983, one of the provisions included was that we provide the legislature a report on July 1, 1985, and every three years thereafter, which assesses the damage done to public highways by virtue of the increased lengths, widths and weights being authorized. Without a good data base of the type that we hope can be provided by WIM, it is very difficult to identify trends in vehicle size and weight and even more difficult to assess the damage attributable to proposed or enacted legislated changes. By improving our data base, we will also be better able to determine the number of larger, heavier vehicles on the highways and what effect they are having on accident rates. These studies can also be used to analyze the safety record on the State's designated route system for the STAA vehicles.

The extent of and time periods when overloading is being experienced can also be used to establish enforcement schedules and perhaps justify manpower levels. The use of WIM equipment as an enforcement tool is also a possibility.

Information collected at WIM locations can also be useful in analyzing bridge loadings. In some locations where excessive structural deterioration is being experienced, it would be helpful to be aware of the actual loadings taking place. While permanent in-pavement scales can provide general information that could be of use, the portable systems may be preferable in analyzing the stresses on a particular structure.

As previously indicated, we plan to use these data for truck weight studies, enforcement planning, legislative reports and other studies relating to the impact of trucks. We also hope to gain information about the dynamic distribution of weights between axles and the effectiveness of auxiliary axles, especially the lift axles and booster axles that are being utilized more frequently. We also plan to check out the axle distribution on some of the super heavy loads for which permits are being issued. When deciding whether to approve such movements, it is considered essential that the distribution be close to the proposed weights used to analyze the structures being crossed. Having the ability to check dynamic weights will allow us to better control the excessively heavy moves.

There have been a few problems in completing the installation due to availability of equipment and construction delays caused by the weather. We have also been experiencing difficulty in establishing a link between the IBM-AT and the State's mainframe computer. Another concern is whether there will be efforts to miss the scale platforms. We have avoided any enforcement activity during the test weighings and plan to continue this practice until a good data base is established. Even though there has been little publicity about the WIM installation, we understand truck drivers are already aware of its location. The magnitude of off-scale detections will help analyze the extent of evasive action by the drivers.

On the positive side, we are pleased with initial test comparisons between the dynamic and static weights. The installation is in a smooth section of pavement. The platforms are level with the surface and there is no detectable bounce or deflection as vehicles cross the scales. Ensuring continued smoothness at this location will be a high priority.

By the end of 1986, we hope to have five high speed permanent WIM facilities and one weigh station sorting WIM in operation. Efforts are also being made to obtain a portable system during FY86. Preliminary plans are for this to be either the mat type or a bridge weighing system. Data from the permanent facilities and selected portable sites will be used to meet anticipated FHWA requirements that we obtain data at approximately 90 different locations over a three-year period.

Our Office of Planning and Programming has proposed to upgrade 25 of their permanent count stations to classify vehicles and transmit the data by telemetry. The use of portable WIM equipment in conjunction with these stations will help provide an improved data base. The collection of such data will also improve the accuracy of 12-hour manual classification counts when they are expanded to AADT by vehicle type.

In summary, we are beginning to collect data and we believe the equipment is going to provide information that will be extremely useful in pavement and bridge design, enforcement, and planning activities. It should also allow us to better predict the impact of proposed legislative changes in vehicle sizes and weights and evaluate those revisions that become law. We look forward to learning from the experiences other states are having with WIM and what your plans are for future use of this equipment.

Attachment 1

Test Results
HSWIM Vs. Static

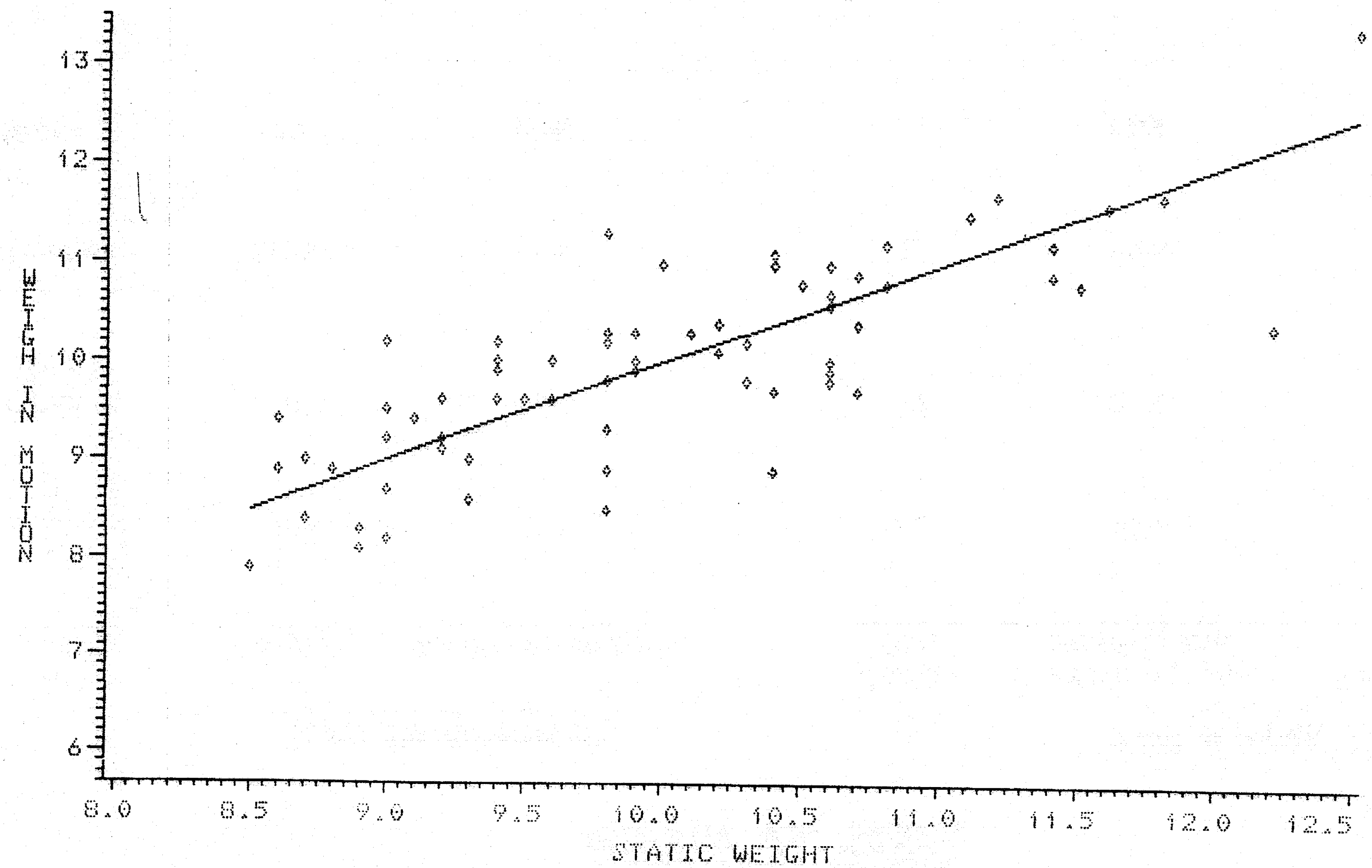
Axle Group	Spec. Requirements		Test Results		
	Accuracy	% within Accuracy	Sample Size	% within Accuracy Requirement	95% Confidence Limit
Steering	±15%	67%	72	99%	±3%
Other Single	±10%	80%	47	81%	±8%
Tandem	±10%	85%	120	89%	±7%
Gross	±7%	90%	72	89%	±7%

Attachment 2

DEPARTMENT OF TRANSPORTATION

WEIGH IN MOTION VERSUS STATIC WEIGHT

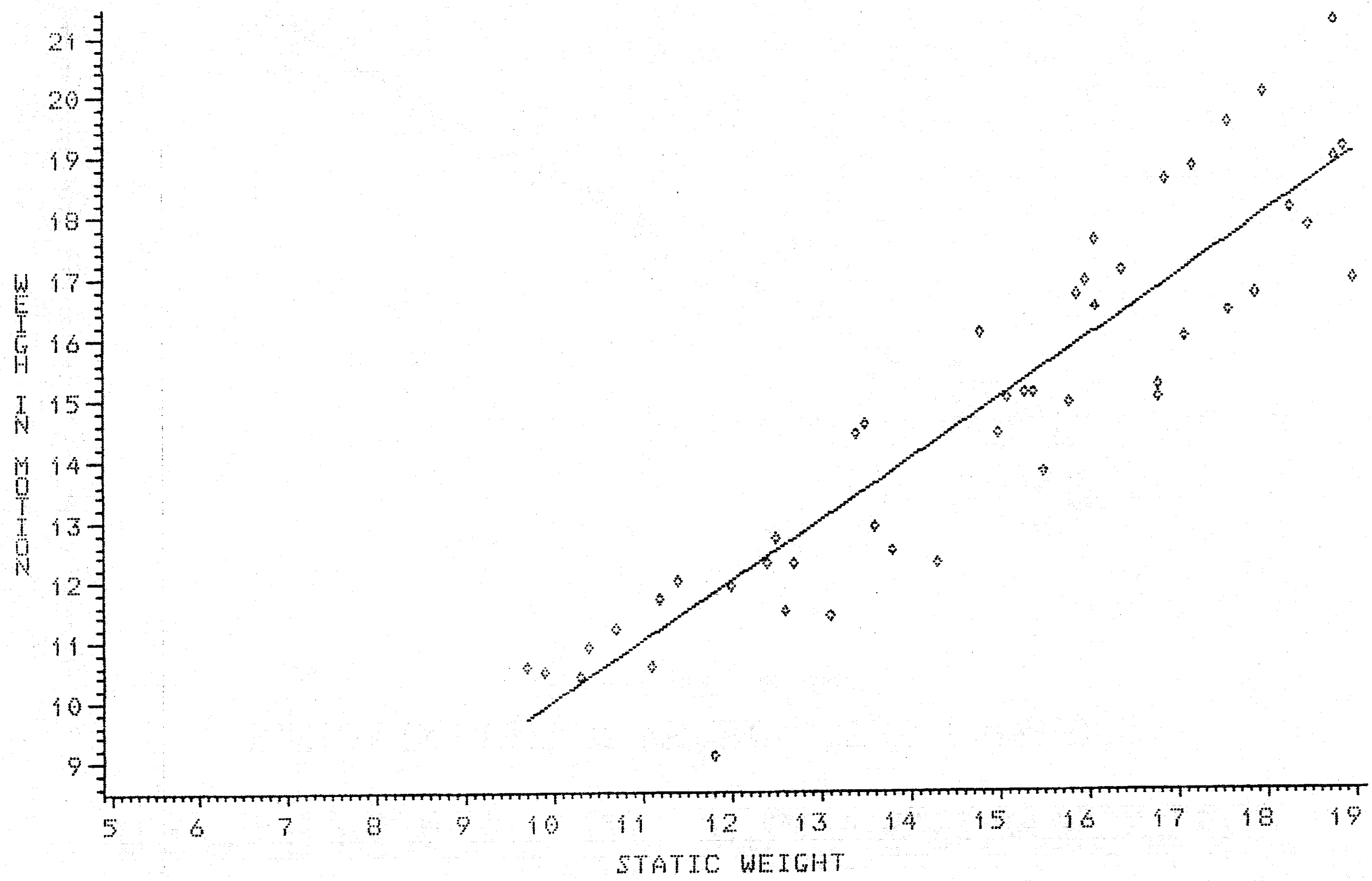
GRAPH=STEERING AXLE



DEPARTMENT OF TRANSPORTATION

WEIGH IN MOTION VERSUS STATIC WEIGHT

GRAPH=OTHER SINGLE AXLES

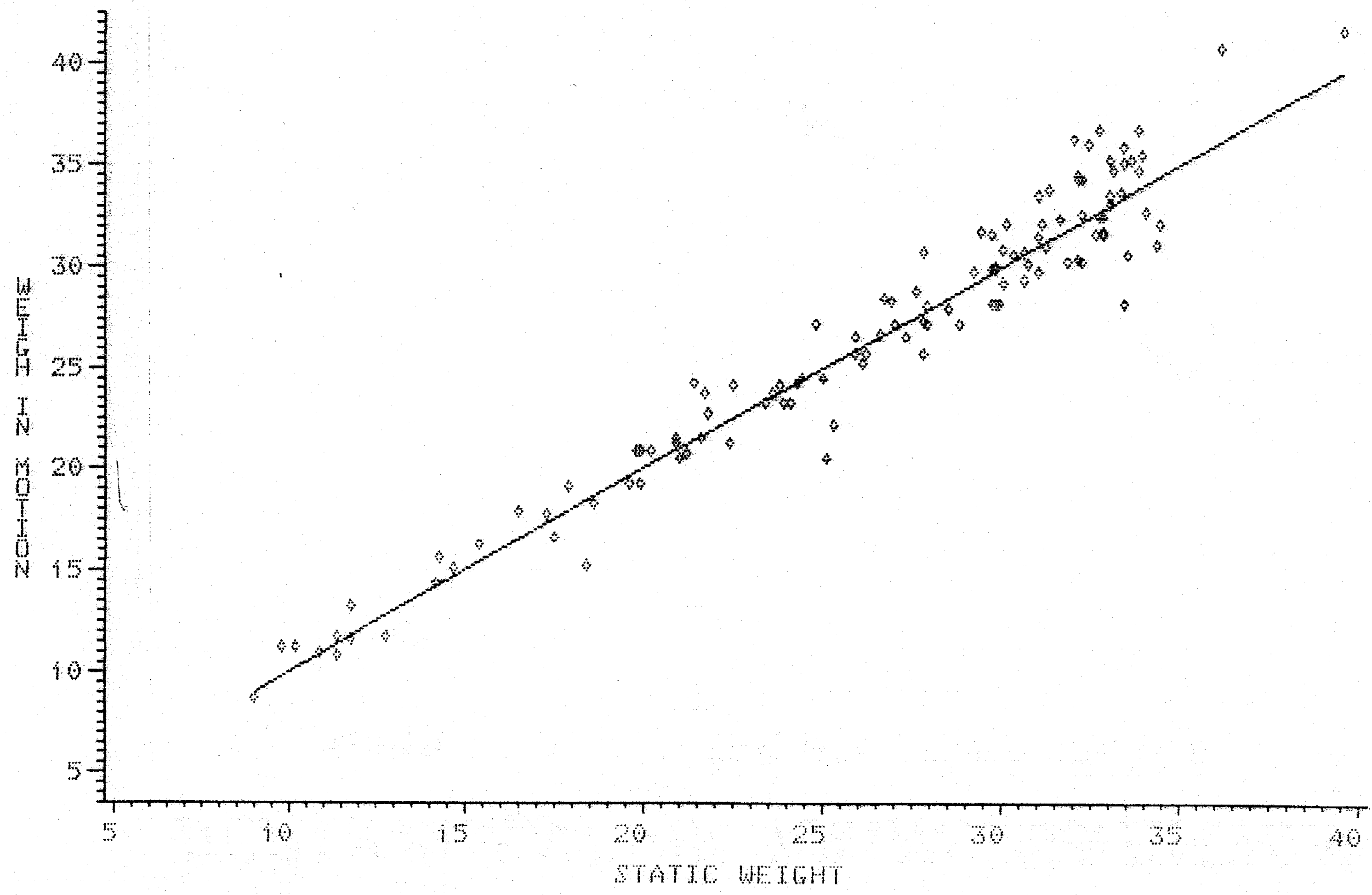


Attachment 4

DEPARTMENT OF TRANSPORTATION

WEIGH IN MOTION VERSUS STATIC WEIGHT

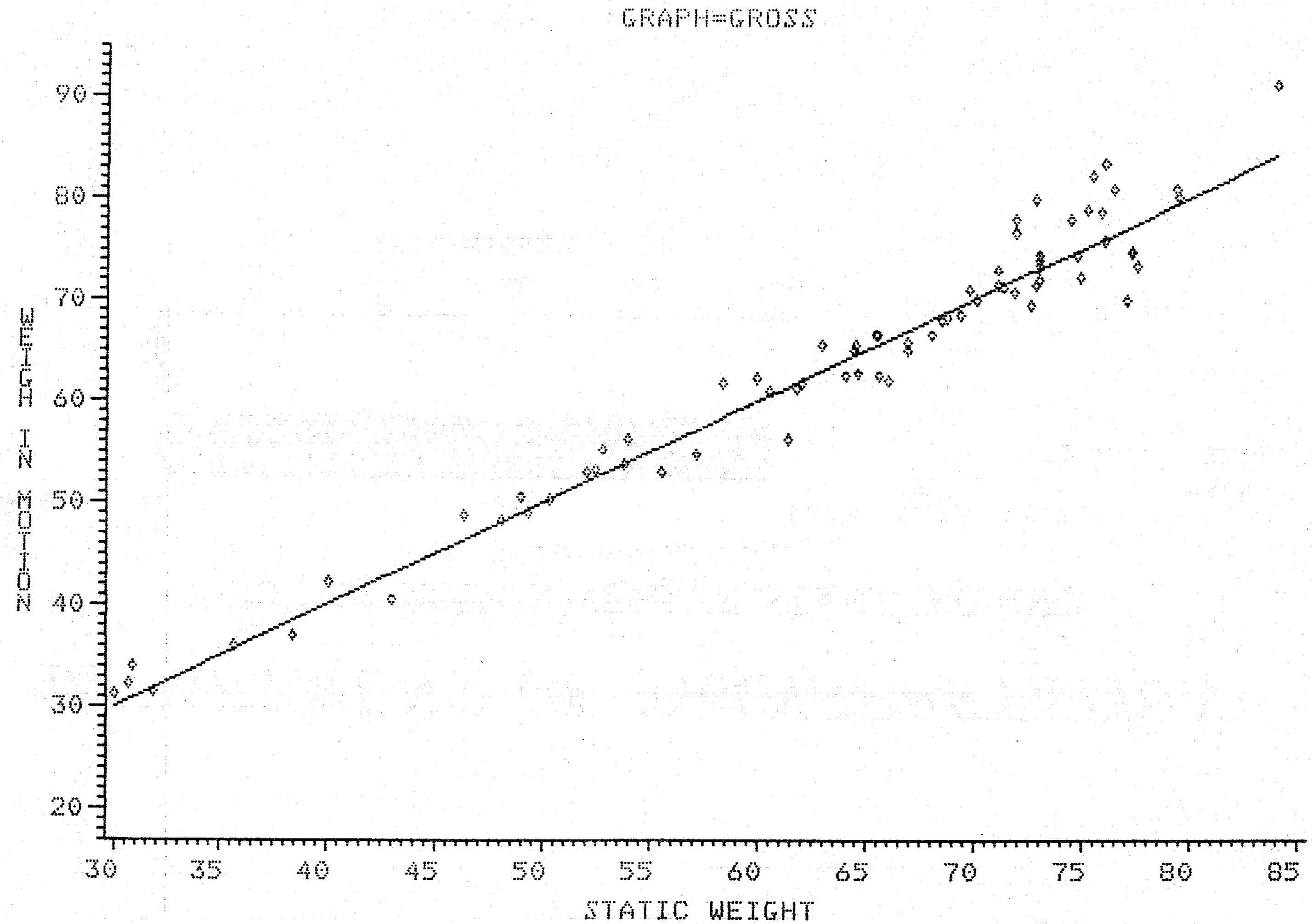
GRAPH=TANDEM AXLES



Attachment 5

DEPARTMENT OF TRANSPORTATION

WEIGH IN MOTION VERSUS STATIC WEIGHT

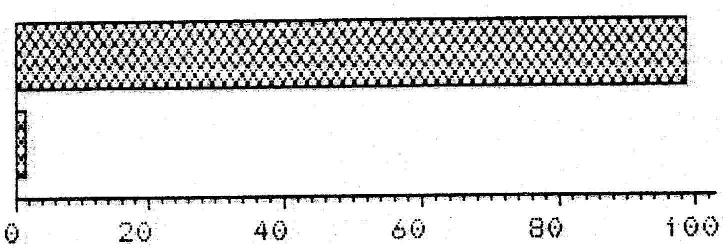


Attachment 6

DEPARTMENT OF TRANSPORTATION

WEIGH IN MOTION VERSUS STATIC WEIGHT

GRAPH=STEERING AXLE



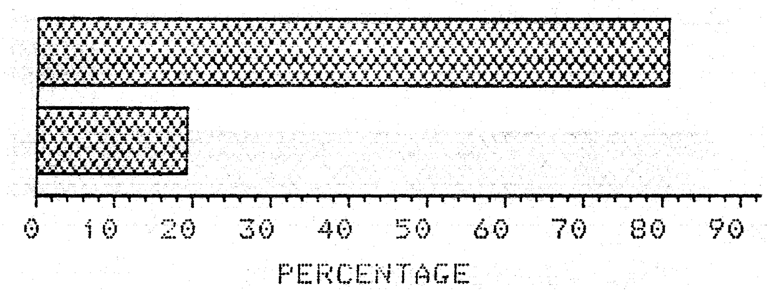
ACCURACY	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
INSIDE	71	71	98.61	98.61
OUTSIDE	1	72	1.39	100.00

Attachment 7

DEPARTMENT OF TRANSPORTATION

WEIGH IN MOTION VERSUS STATIC WEIGHT

GRAPH=OTHER SINGLE AXLES

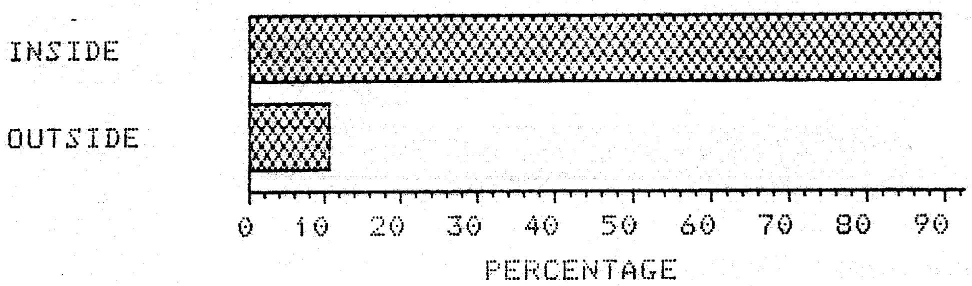


ACCURACY	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
INSIDE	38	38	80.85	80.85
OUTSIDE	9	47	19.15	100.00

DEPARTMENT OF TRANSPORTATION

WEIGH IN MOTION VERSUS STATIC WEIGHT

GRAPH=TANDEM AXLES



ACCURACY	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
INSIDE	107	107	89.17	89.17
OUTSIDE	13	120	10.83	100.00

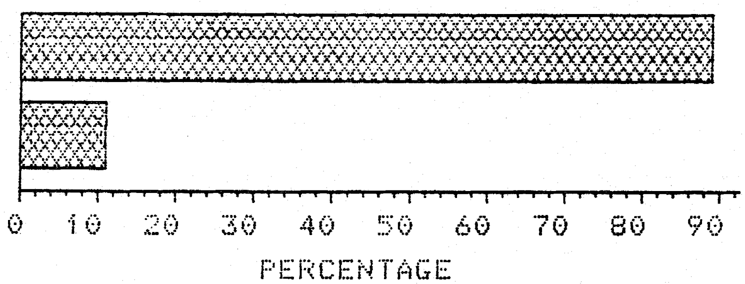
Attachment 8

Attachment 9

DEPARTMENT OF TRANSPORTATION

WEIGH IN MOTION VERSUS STATIC WEIGHT

GRAPH=GROSS



ACCURACY	FREQ	CUM. FREQ	PERCENT	CUM. PERCENT
INSIDE	64	64	88.89	88.89
OUTSIDE	8	72	11.11	100.00

WEIGHING-IN-MOTION
IN
NEW MEXICO

Second National Conference on
Weigh-In-Motion Technology and Applications
Atlanta, Georgia
May 20-24, 1985

Robert Mares

The New Mexico State Highway Department's first WIM System was purchased in April of 1974. The Radian WIM - 1A consisted of a Van (GMC) and Mobil (portable) equipment for field operations, this included complete roadside equipment for 3 permanent sites. After initial testing at these 3 sites an additional 3 sites were selected at strategic areas in the state. This was accomplished in 1975. In 1981, we replaced the Radian WIM - 1A with the second generation Radian WIM - 1E. The second WIM System was placed in a 23' Winnebago Mobil Van to transport the equipment to the permanent sites. The data collected in our Weigh-In-Motion has the following format:

1. State number to conform to FHWA requirements.
2. Highway System, Interstate, Primary etc.
3. Station number.
4. Direction of Travel.
5. Year.
6. Date, year, month, day and the hour.
7. Vehicle type, this code represents the type vehicle being weighed, such as Pick-Ups, 2 axle - 6 tired, 3-2, 3-3 etc., the codes used are the FHWA 6 digit code for trucks.
8. Body type: this is the old 2-digit code that the WIM - Operator on duty will use to identify the type truck going thru the station. I might add that during a weigh session an operator is always on duty and enters the truck data manually into the computer.
9. Gross Weight: This is the gross weight for all axles, we have 5 spaces for axles.
10. Axle Spacing: This field is spaced as follows: A-B, B-C, C-D and D-E.
11. Wheel Base: The length of truck from first axle to last axle.
12. Sequences or serial number.
13. cc - continuation code for longer dimensional trucks.
14. Speed: Speed of Vehicle.
15. Length: Total length of Truck front bumper to back bumper.

16. Calc vehicle type.

The WIM - 1E System stores the data on a diskette unit during the weighing session. The data will be transferred from the floppy disk onto a regular magnetic tape for further processing. The data is then put through 3 edit procedures to ensure that the data is accurate. The first edit is the original edit that was provided to us by the State of Texas when we first initiated WIM in New Mexico. The second edit will test data to conform to FHWA requirements. The third edit was developed by us to further edit the final data. The final process is to load the data on tape, which is then sent to Washington D.C. for processing. FHWA in turn will run the data and supply us with the 'W' Forms for our use. The data gathered from WIM - 1E we find very reliable. We have had our share of downtime with the equipment. The one area that has caused some concern has been the time needed to get equipment repaired. It has presented such problems that a factory representative was sent to New Mexico to solve some of the problems. The WIM equipment is delicate and transporting it from one site to another can become quite unpredictalbe. Tremendous care has to be taken, but like other states we must transport the equipment for long distances, when reaching some of the sites the system would not work. In order to alleviate this problem we have hired an Electronic Technician (expert) who has been able to troubleshoot and repair the WIM System. We find that it is essential to have such an employee on hand, it saves downtime and reduces the repair cost dramatically. In New Mexico we also have a photologging system which is assigned to my Section. The Photolog System is from Techwest in Vancouver, British Columbia. The Electronic Technician is now also repairing this system for us. Looking at the future, we are now in the process of converting our present system and reprogramming the format into our new IBM Personal Computer. I would like to express our gratitude to the State of Oklahoma for the considerable help they have given us in the new conversion. Oklahoma graciously provided us with their programs which have made the conversion possible. We presently are studying the feasibility of replacing the computer in the WIM - 1E with an IBM P.C. This would make the system compatible with our new system. Realizing that truck data has become an important part of not only the construction design of roads, but it also has an important input in the planning functions. WIM and Vehicle Classification are with us today and as more emphases is placed in those areas the technology must keep up with the demand. We the users must work with the producers so that all input will be utilized to improve and produce better and perhaps a more economical WIM System.

STATE OF NEW MEXICO
HIGHWAY DEPARTMENT

BRUCE KING
GOVERNOR

COMMISSION

Louis M. Whitlock
Chairman, Carlsbad

James W. Chaney
Vice-Chairman, Moriarty

Sosimo Padilla
Secretary, Albuquerque

Albert N. Sanchez
Member, Santa Rosa

James T. Martin
Member, Las Cruces

DEPARTMENT

Chief Highway Administrator
J. J. Hewett

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Santa Fe, NM 87503
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AN EQUAL
OPPORTUNITY
EMPLOYER

ESTIMATED COST OF WIM EQUIPMENT, INSTALLATION, AND MAINTENANCE:

Winnebago 23' Motor Home	$18,520
WIM-1E Complete & installed in van	$29,850
Installation of scales in one lane of roadway	
Material - frames, dummy plates, junction box, conduit, wire, epoxy, concrete and miscellaneous materials.	$8,000
Labor - Two Traffic Inventory Personnel and three from local maintenance patrol with necessary equipment.	$900
Transducers - Two at $3,000 each.	$6,000
One operating site	$63,270
Each additional site	$8,900
Maintenance - Approximate annual cost per weigh site .	$400

I recommend four transducers for each six weigh sites due to the length of time required to have transducers repaired.

Joe Wood
October 29, 1981

STATE OF NEW MEXICO
HIGHWAY DEPARTMENT

Cost estimate for weigh-in-motion and telemetry traffic counting/speed monitor site to be installed in project STF-022-2(204).

Transducers		$ 6,000.00
882 IK Installation Kit		9,950.00
Equip. Rental		800.00
Saw with Diamond Blade		
Water Supply		
Air Compressor		
Signs & Cones		
8 Channel Telac		4,000.00
Type 6 Signal Box		400.00
Epoxy-Conduit-Wire-Terminal Strips-Outlets		200.00
Lightning Arrestor		40.00
Coupler		110.00
4 Men - 5 Days @ $15 Hr.		
Salary		2,400.00
Per Diem		880.00
Benefits		240.00
Mileage		450.00
	SUBTOTAL	25,470.00
Contractor will add approx. 30% for profit and overhead		7,630.00
	TOTAL	$33,100.00

VEHICLES WEIGHED IN MOTION — DAY PRINTED JUNE 26,1984

NEW MEXICO STATE HIGHWAY DEPARTMENT PLANNING DIVISION

NEW MEXICO/TEXAS EDIT

ST CODE	HS	STA	D I R	YR	MN	DY	HR	VEH TYPE	BODY TYPE	GROSS	A	B	C	D	E	A-B	B-C	C-D	D-E	WHEEL BASE	SER NO	C	REC COUNT	SPEED	LENGTH	CALC VEH TYPE
								2-AXLE	PICKUP OR PANEL		19	20	0	0	0											
735	01	W04	5	84	06	13	12	200000	11	73	26	47	0	0	0	111	0	0	0	111	202	0	201	49	240	220000
								2-AXLE	PICKUP OR PANEL		7	20	0	0	0											
735	01	W04	5	84	06	13	12	531200	21	903	119	163	151	203	109	105	43	151	92	566	203	1	202	70	676	531200
											F	G	H	I	J	E-F	F-G	G-H	H-I							
											118	0	0	0	0	175	0	0	0		203	9				
								3S1-2	FLAT BED-STAKE-PLATFORM		69	98	114	106	59											
735	01	W04	5	84	06	13	13	200000	11	52	19	33	0	0	0	110	0	0	0	110	204	0	203	61	238	220000
								2-AXLE	PICKUP OR PANEL		8	19	0	0	0											
735	01	W04	5	84	06	13	13	332000	41	319	104	68	75	29	44	131	41	328	37	537	205	0	204	51	658	332000
								3S2	VAN-REF FREIGHT		46	37	46	14	29											
735	01	W04	5	84	06	13	13	332000	41	466	104	112	92	88	90	106	41	247	41	435	206	0	205	67	622	332000
								3S2	VAN-REF FREIGHT		45	44	35	29	29											
735	01	W04	5	84	06	13	13	230000	99	275	116	81	78	0	0	172	43	0	0	215	207	0	206	65	308	230000
								3-AXLE	OTHER		72	53	53	0	0											
735	01	W04	5	84	06	13	13	521200	41	459	80	128	82	85	84	94	200	90	197	581	208	0	207	61	720	521200
								2S1-2	VAN-REF FREIGHT		30	53	33	29	31											
735	01	W04	5	84	06	13	13	332000	41	717	103	243	96	159	116	95	46	300	40	481	209	0	208	60	638	332000
								3S2	VAN-REF FREIGHT		52	131	46	87	73											
735	01	W04	5	84	06	13	13	200000	11	66	32	34	0	0	0	111	0	0	0	111	210	0	209	62	233	220000
								2-AXLE	PICKUP OR PANEL		22	25	0	0	0											
735	01	W04	5	84	06	13	13	332000	41	642	121	180	143	108	90	112	42	233	40	427	211	0	210	61	607	332000
								3S2	VAN-REF FREIGHT		60	91	71	51	49											
735	01	W04	5	84	06	13	13	200000	11	41	23	18	0	0	0	99	0	0	0	99	212	0	211	69	215	220000
								2-AXLE	PICKUP OR PANEL		15	15	0	0	0											
735	01	W04	5	84	06	13	13	200000	11	64	32	32	0	0	0	109	0	0	0	109	213	0	212	72	230	220000
								2-AXLE	PICKUP OR PANEL		26	26	0	0	0											
735	01	W04	5	84	06	13	13	200000	11	88	30	58	0	0	0	111	0	0	0	111	214	0	213	70	231	220000
								2-AXLE	PICKUP OR PANEL		9	21	0	0	0											
735	01	W04	5	84	06	13	13	332000	62	574	71	150	151	93	109	110	43	330	35	518	215	0	214	65	711	332000
								3S2	AUTO OR BOAT TRANSPORT		51	74	79	48	55											
735	01	W04	5	84	06	13	13	332000	41	421	98	94	88	78	63	128	45	348	40	561	216	0	215	61	702	332000
								3S2	VAN-REF FREIGHT		53	60	50	44	41											
735	01	W04	5	84	06	13	13	332000	21	546	128	174	101	79	64	116	40	297	38	491	217	0	216	55	596	332000
								3S2	FLAT BED-STAKE-PLATFORM		64	74	44	28	31											

W-1 Table W-1 gives the type of highway, location, time, date of operation and vehicle types counted and weighed at each station for current and prior year. Type of surface, shoulders and medians, average daily loads are also shown in this table.

W-2 Table W-2 lists information by amount and percentage showing increase or decrease of vehicles counted and weighed compared to previous year's operations:

W-3 Table W-3 determines the average weight of all loaded and empty vehicles. Average loads are also indicated for individual truck type by this table.

W-4 Table W-4 shows the distribution and probable number of single axles, tandem axles, and all axles into certain weight groups, with the 18 kip axle equivalents for trucks weighed, and axles per 1,000 vehicles, weighed.

W-5 Table W-5 shows the distribution and probable number for each vehicle type in various weight groups compared to the previous year.

W-6 Table W-6 shows total weights, axle loads, and axle spacings of trucks and truck combinations weighing in excess of AASHO recommendations and New Mexico State Law.

0= Empty
Col 41 of BPR Format 1= Loaded

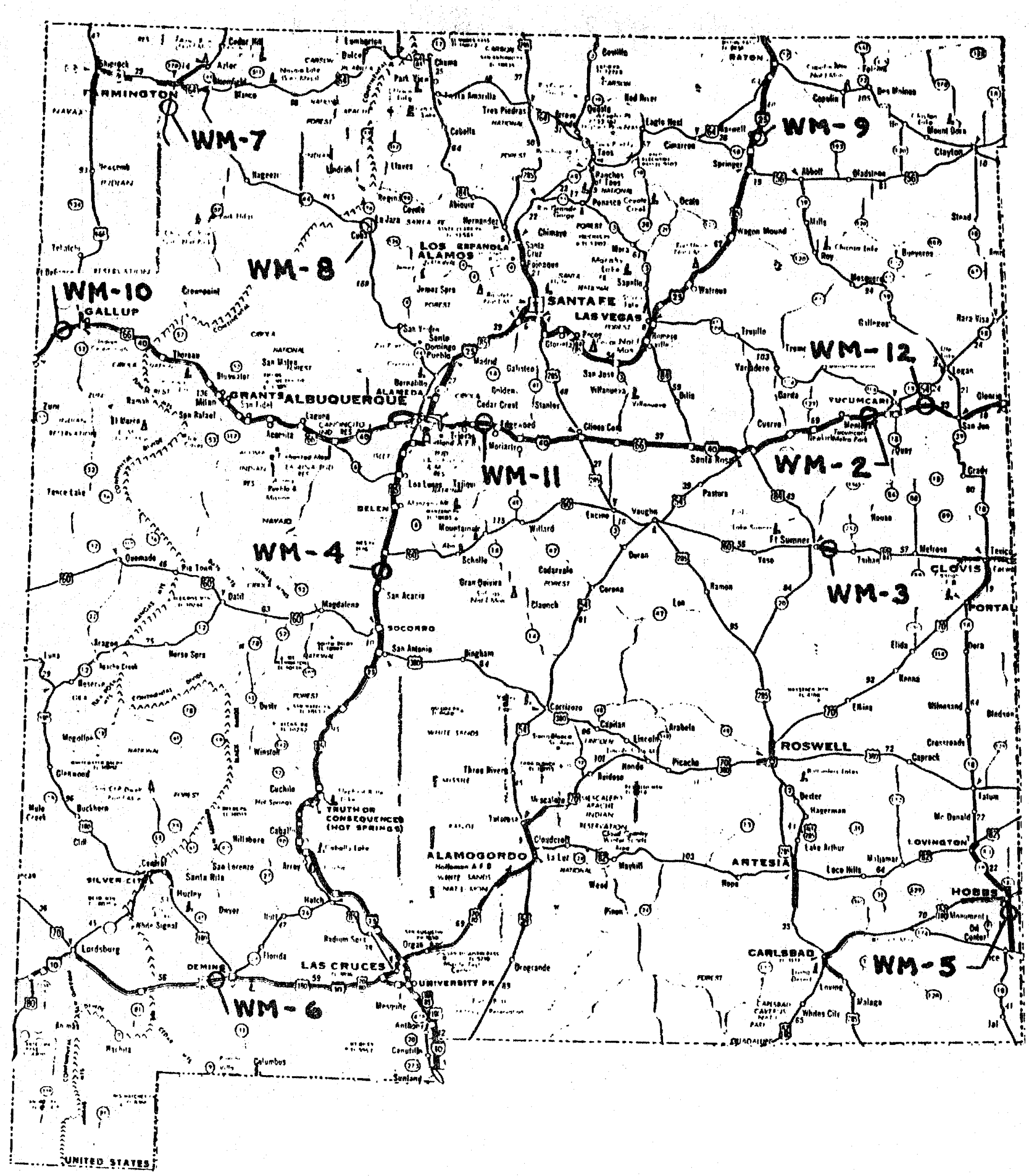
VEHICLE TYPE	CODE	LOADED WEIGHT
PICKUP	200000	5,400
1RT	210000	6,500
2D	220000	15,000
3A	230000	22,500
2S1	321000	25,000
2S2	322000	28,500
2S3	323000	33,500
3S1	331000	28,500
3S2	332000	33,500
3S3	333000	35,500
2-1	421000	25,000
2-2	422000	28,500
2-3	423000	33,500
3-1	431000	28,500
3-2	432000	35,000
3-3	433000	36,000
2S1-2	521200	33,500
2S1-3	521300	36,000
2S2-2	522200	36,000
2S2-3	522300	37,000
3S1-2	531200	36,000
3S1-3	531300	37,000
3S2-2	532200	37,000
	Col. 41 of BPR FORMAT	EMPTY=0
	#7 CARDS	LOADED=1

[illegible]

EQUIVALENCY TABLE FOR VEHICLE TYPES & AXLE SPACINGS

VEHICLE TYPES			AXLE SPACINGS ± 50%						
CODE	SHD	FHWA	A-B	B-C	C-D	D-E	E-F	F-G	G-H
1	2-Axle	220000	12						
2	3-Axle	230000	14	4					
3	2S1	321000	12	28					
	2-1	421000	12	12					
5	2S2	322000	12	28	4				
4	3S1	331000	14	4	28				
	2-2	422000	12	12	20				
	3-1	431000	14	4	12				
6	3S2	332000	14	4	28	4			
	2S1	323000	12	28	4	4			
	2-3	423000	12	12	20	4			
	3-2	432000	14	4	12	20			
7	2S1-2	521200	12	18	8	18			
	3S1	333000	14	4	28	4	4		
	3-3	433000	14	4	12	20	4		
	2S1-3	521300	12	18	8	18	4		
	2S2-2	522200	12	18	4	12	18		
8	3S1-2	531200	14	4	18	12	18		
	2S2-3	522300	12	18	4	12	18	4	
	3S1-3	531300	14	4	18	12	18	4	
9	3S2-2	532200	10	4	22	4	8	18	
	3S2-3	532300	10	4	22	4	8	16	
10	-	-	-	-	-	-	-	-	-

Length:
PU To 11.50 = PU = 200000
PU To 11.50 13.50 = IRT = 210000



APPROXIMATE LOCATIONS OF
WEIGH-IN-MOTION STATIONS, WM

The **FHWA TRAFFIC MONITORING GUIDE** - A Coordinated, Statistically-Based and Cost-Effective Approach for the Collection and Analysis of Traffic Monitoring Data

Stanley Gee
Statewide Transportation Planner
Federal Highway Administration
Region One
Albany, New York

For Presentation at the
Second National Weigh-in-Motion Conference
Atlanta, Georgia
May 20-24, 1985

Introduction

Over the last decade the resources, particularly manpower, devoted to traffic data collection and analysis activities have declined in Region One. Coupled with the increasing number of 4R-type improvements and project data requirements generally taking precedence over ongoing monitoring programs, something had to give. As a result, vehicle classification and truck weighing activities were drastically cut back, and in some States virtually eliminated. Further, traffic counting programs, as historically operated with continuous, control and coverage stations have also been scaled back. What affect does the counting program cutbacks have on the reliability of adjustment factors (major products of the counting program) that are applied to the project counts? What is the impact of not having current classification and truck weight data? And how useful and reliable are the limited amounts of these data that are collected manually for short time periods?

Still, many of our States devote considerable financial resources to volume counting and the other traffic monitoring activities. These programs reflect continuation of past practices which may not fully address current data needs and can be made more efficient by using statistical sampling techniques and by coordinating data collection and analysis.

Background

In an effort to address these issues, the FHWA in 1982 launched a contract research study to develop a statistically based prototype traffic counting program that draws on the sample framework of the Highway Performance Monitoring System (HPMS). The objective of this prototype program was to meet most of the traffic counting

-more-needs of the States while providing the data to meet national needs in a cost-effective and consistent manner. At the same time the program would be flexible enough to meet additional specific needs of each State. Once developed the program was then tested with information provided by five case study States -- Georgia, Kansas, Maine, Ohio and Oregon. The costs and statistical reliability of the existing traffic monitoring programs in the five States were compared with the prototype program.

Documentation of the research study is contained in the final report, Development of a Statewide Traffic Counting Program Based on the Highway Performance Monitoring System - March 1984, prepared by the contractor, Peat, Marwick, Mitchell & Co. The report advocates an integrated three part approach to traffic monitoring consisting of: continuous counting (ATR) stations that are grouped by highway functional classification; the HPMS sample base for the Statewide collection and estimation of volume, vehicle classification and truck weight information; and a special element capturing the needs not met by the previous two elements (e.g., site specific or project traffic data). We believe this three element program provides a cost-effective method to produce highly reliable traffic data. At the very least, a procedure to determine the precision levels of monitoring the data being collected has been introduced. And the opportunity to relate traffic monitoring program costs to data reliability has been established.

Since publication of the Peat, Marwick, Mitchell (PMM) report, we refined and to a degree simplified the prototype program. Last summer the FHWA released for comment the draft Traffic Monitoring Guide which presented major sections of the refined program including the statistical sampling approach, vehicle classification and truck weighing. In February of this year the draft section on volume counting was distributed for comment. The final document is being written. As such, the following paragraphs will outline the monitoring program recommended in the almost final Guide with changes incorporated from the comments received.

FHWA Traffic Monitoring Guide Objectives

The objectives of the Guide and monitoring program recommended in it are to:

Coordinate related monitoring programs that are quite often separately administered;

Streamline data collection activities and eliminate duplication in meeting both State and Federal needs;

Apply statistical sampling procedures to allow assessment of data reliability versus costs;

Increase use of automatic monitoring equipment and computer technology to efficiently collect and analyze the volume of data;

Allow flexibility to handle State needs beyond those specifically addressed in the recommended monitoring program.

Traffic Monitoring Program Structure

The proposed traffic monitoring program is divided into three parts:

1. Continuous Counting (ATR) Element. The classical use of continuous count or ATR data from permanent stations operating 365 days a year to derive seasonal and day of the week adjustment factors for the expansion of short term counts to an annual average daily traffic (AADT) volume remains unchanged. A new simplified approach that involves grouping the continuous counting stations to derive the set of factors is suggested. Subsequent application of this approach to the AADT expansion process would also reduce subjectivity and simplify the procedure for assigning short counts to the proper seasonal factor groups.

2. HPMS (Core) Element. This part is what we consider to be the heart of the recommended monitoring program. This element consists of a sample based procedure for the collection and analysis of Statewide or network level volume, classification and weight data. It relies on the HPMS sample base which offers a standard of consistency and is clearly defined and implemented in every State.

3. Special Needs Element. This element is intended to provide the project or site specific and functionally classified local travel characteristics not directly addressed in the first two elements. Flexibility is afforded for States to maintain important travel monitoring activities to meet other needs. While it appears to be a catch-all category, depending upon individual State needs this could be the most intensive program element for many States.

Major Specific Recommendations

° For computing seasonal factors the continuous counting stations should be aligned by highway functional classification categories. Further review of ATR data should allow aggregation of categories based on similar seasonal variation. We have found that States can generally aggregate up to the following seasonal factor groups: Interstate Rural, Other Rural, Interstate Urban, and Other Urban. Many States will still need to create one or more Recreational factor groups to account for significant seasonal variation. The Recreational factor group will probably be defined by geographical boundaries.

- With the grouping of ATR stations by functional classification the need for control counts is essentially eliminated. Control counting is an intermediate level traffic volume data collection activity employed primarily to provide the information for deciding which seasonal factor group to assign various short counts taken on any point on the highway system. Seasonal factor groups based on functional classification, or based on geographical boundaries for receation groups, can be related directly to highway sections where short counts are taken.

- A uniform monitoring period of 48 hours for volume counting, vehicle classification and truck weighing is recommended. Increasing the typical 24-hour counting period to a' uniform 48 hour period for all monitoring represents a compromise between the need to assure data reliability and the recognition of cost and equipment limitations. Based on national ATR data evaluated during the PMM study significant daily variation in just the number of vehicles were observed. Increasing the monitoring period beyond one day we believe will remove much of the variation attributed to these random occurrences.

- Use a three-year cycle to monitor the total number of volume classification and weighing sample sections that are drawn from the HPMS sample. The monitoring should be spatially and temporarily distributed to the extent possible. The number of sample sections for each type of monitoring is:

Volume - 1/3 number of HPMS sample sections annually (nationally the total sample size varies from a 300+ sections in Delaware, excluding the District of Columbia, to 3800+ sections in Texas).

Classification - 100 HPMS sections monitored annually or 300 sections on a 3-year cycle.

Truck Weight - 30 sessions (10 Interstate, 20 Other Roads) annually or 90 total sessions in 3 years. The actual number of monitoring locations will depend on highway system mileage and amount of travel.

° Rely less on manual methods of data collection and move to modern technology, such as automated vehicle classification systems and weigh-in-motion (WIM) technology, in order to achieve the longer monitoring periods advocated and efficiently handle the resulting higher volume of data being collected.

The Integrated Sample Design

As described earlier, the use of statistical sampling procedures provides the means of developing travel estimates with known levels of accuracy. The integration of data collection and estimation activities serves to produce directly linked estimates while minimizing data collection and avoiding duplication.

By using the existing HPMS sample, the need to introduce and implement a new sample design is removed. The HPMS is the principal reporting system used by FHWA to monitoring highway condition and performance. All States have now implemented the HPMS sample and are reporting data using it.

The HPMS sample base consists of all public roads within a State, except those functionally classified as local. The sample is stratified into three levels: by type of area (rural, small urban and individual or collective urbanized areas); by function classification; and by volume. The sample to be reported is tied to established precision levels (see Appendix F, HPMS Field Manual) using AADT as the characteristic to compute the actual sample size. Although the AADT is one of 75 data items reported, AADT is perhaps the most variable item and, therefore, the reliability of the other characteristics should exceed that of the AADT. The HPMS data base allows the use of simple ratio (universe mileage to total sample mileage in any strata) estimation procedures to derive systemwide estimates aggregable to the State level.

The development of an integrated sample base to estimate specific traffic characteristics tied to the HPMS sample design results in successive subsampling beginning with the HPMS sample, i.e., volume samples are taken from the existing HPMS sample, vehicle classification samples are taken from the volume samples and the truck weights samples are taken from the classification sample. This relationship is illustrated in Exhibit 1.

Exhibit 2 is a table showing the integrated sample design of the Core Element in the recommended traffic monitoring program. The sample size, products or characteristics directly estimable, and the precision of specified products for the individual subelements (volume, vehicle classification and truck weight) are also displayed.

Vehicle Classification Subelement

The number of vehicle classification samples is a function of the specified precision level at which the classification data is desired. Because the sample size required for a stated precision level will differ for each vehicle type, the key vehicle type must first be selected. Exhibit 3 is a graph depicting the relationship of sample size versus precision on the rural Interstate for several vehicle types drawing from the results of the PMM study. The 3S2 tractor semi-trailer (18-wheeler) was chosen as the classification type of importance in determining sample size. We believe a reasonably high precision level for the 3S2 estimate can be achieved without an inordinate number of samples. From 300 measurements taken over a 3-year cycle, the estimated Statewide percentage of 3S2 vehicles in the traffic stream is expected to have a precision of 95-10 (i.e., reliability of ±10 percent with 95 percent confidence). Using the example shown in Exhibit 3, estimates for other vehicle types (autos and 3-axle single unit trucks) will be expected to be more reliable with the same number of samples.

The 100 annual classification measurements will permit computations of the percent distribution of vehicles and the axle correction factors to adjust vehicle counts from pneumatic detection equipment. Linking the vehicle distribution with the annual VMT produced from the volume subelement, estimates of VMT by functional class by vehicle type are attained.

Truck Weight Subelement

An approach similar to the classification subelement was used to determine the truck weight sample. The controlling product from truck weighing that we focused attention on in the determination sample size was equivalent standard axle loadings (ESAL). Because truck weighing is affected by factors not encountered with volume counting and classification, judgement has been applied to ensure a realistic sample size. Some of these factors which also pose problems in quantifying precise reliability levels include costs and locational limitations of equipment, bypassing and the loaded/unloaded weight dichotomy in trucks. Taking these limitations into consideration, two sample sizes based on the ESAL variability of 3S2 vehicles were established. For the Interstate System 30 measurements over a 3-year cycle will give estimates of ESAL for 3S2 trucks with a reliability of ±10 percent at the 95 percent confidence. Exhibit 4 is a graph of the Interstate sample size versus precision relationship based on ESAL variance. Sixty measurements over a 3-year cycle on all other roads will produce estimates in the range of ±20 percent reliability with 95 percent confidence.

By fixing a uniform sample size on ESAL variability for the Interstate stratum, we have obviously ignored the size (mileage and travel) of the Interstate System among States. To compensate, the sampling plan allows collapsing the temporal and spatial considerations of random selection when chossing actual sample sites. For example, a small State like Rhode Island with limited Interstate mileage could potentially design a sampling plan with only two sites that are each monitored five times in a year or a total of 15 times each in the 3-year cycle.

The axle weights that are collected from the truck weight subelement when linked with data from the volume and classification subelements will produce a variety of systemwide weight estimates that may not be currently available or not available with known reliability. Any number of weight characteristics -- total axle load, average axle load, equivalent axle load, average weight, number of overloaded trucks and axles, etc. -- can be directly computed for each classification category. System weight in terms of ton-miles is a simple exercise using the VMT estimates derived from the volume sublement.

Program Implementation

To conduct the monitoring program just described with the sample sizes and monitoring period recommended, automated data collection equipment is obviously necessary. This fact has been explicitly recognized in the Traffic Monitoring Guide. There is no question about the current availability of volume counting equipment. Recently completed evaluations of automatic vehicle classification by the Maine and Kansas DOTs have demonstrated that reasonably accurate classification equipment is on the market. States on this panel and others participating in the Conference have also evaluated and demonstrated the reliability of portable and fixed weigh-in-motion systems. So, the major issue dealing with automatic traffic monitoring equipment left is price. With publication of the final Guide expected this summer and Conferences such as this one, we believe manufacturers will be convinced the market for automatic monitoring equipment is growing. A bigger market should bring about greater price competition and make automated equipment affordable to all States.

Exhibit 1

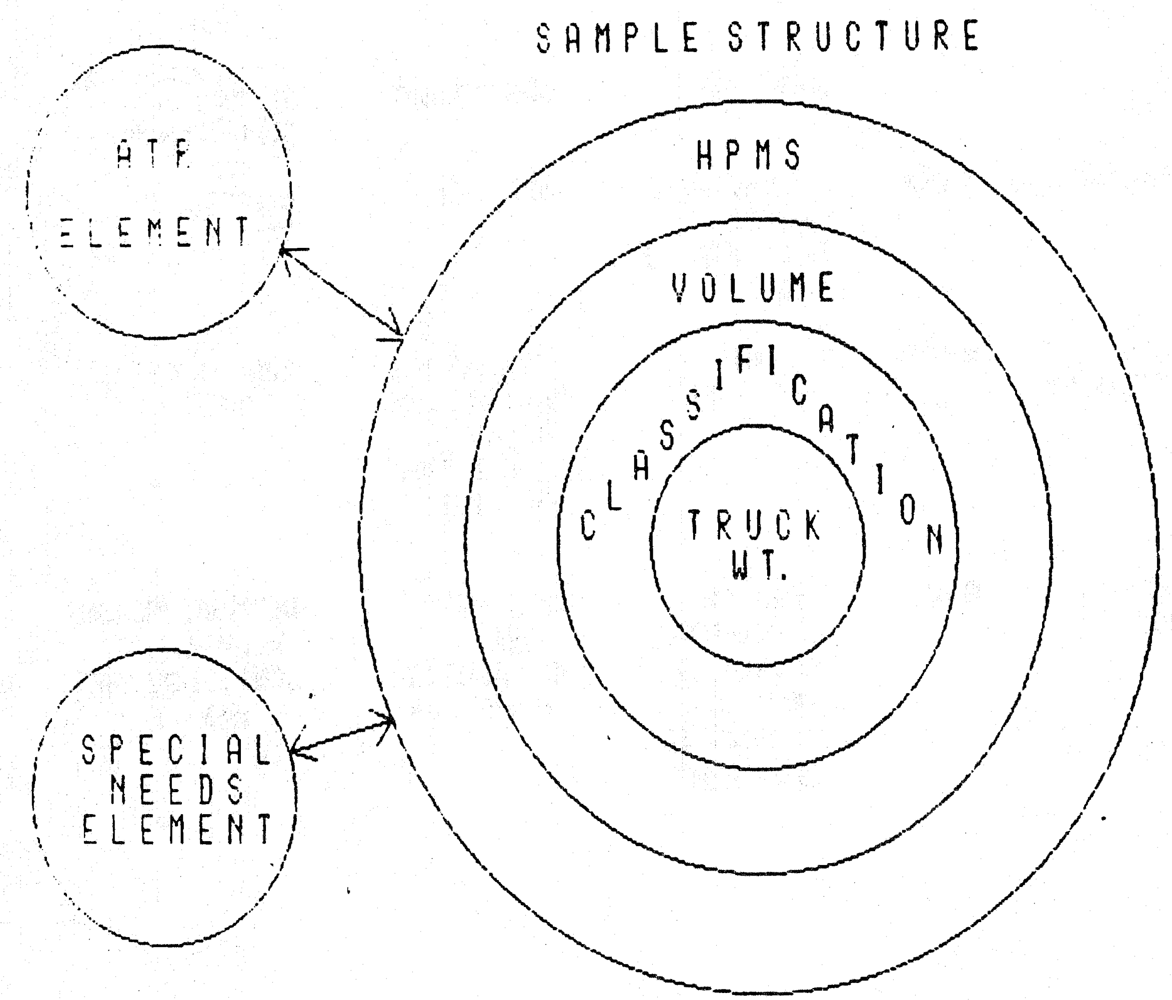

SAMPLE STRUCTURE
ATF
ELEMENT
HPMS
VOLUME
CLASSIFICATION
TRUCK
WT.
SPECIAL
NEEDS
ELEMENT

Exhibit 2

CORE ELEMENT SAMPLE DESIGN

Subelement	Period	Number	Products	Design (Target) Precision
HPMS	-	HPMS SAMPLE	SYSTEM ESTIMATES	STRATUM AADT SEE HPMS MANUAL
TRAFFIC VOLUME	48 HOURS	1/3 HPMS SAMPLE ANNUALLY FULL SAMPLE 3-YR CYCLE	SYSTEM AVMT	ANNUAL VMT 95-5
VEHICLE CLASSIFICATION	48 HOURS	100 ANNUALLY 300 3-YR CYCLE	CLASSIFIED AVMT AXLE CORRECTION FACTORS % DISTRIBUTION OF VEHICLES	STATEWIDE % 3S2'S 95-10(3-YR)
TRUCK WEIGHT	48 HOURS	ANNUAL - 30 10 INTERSTATE 20 OTHER RDS 3-YR CYCLE - 90 30 INTERSTATE 60 OTHER RDS	SYSTEM WEIGHT & ESAL VEHICLE WEIGHT BY CLASS. CAT.	INTERSTATE 3S2 ESAL 95-10(3-YR) OTHER RDS 3S2 ESAL 95-20(3-YR)

Exhibit 3

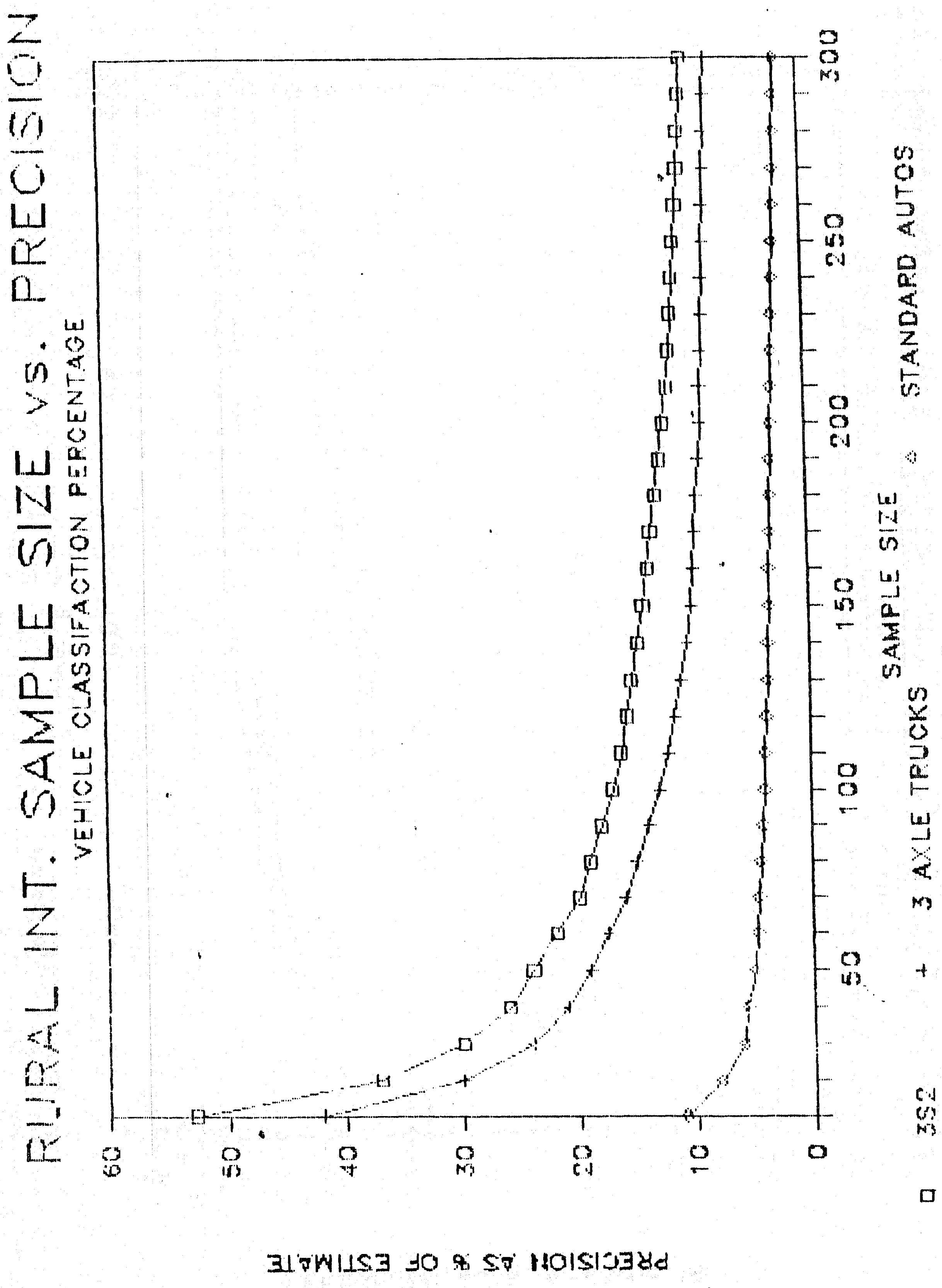
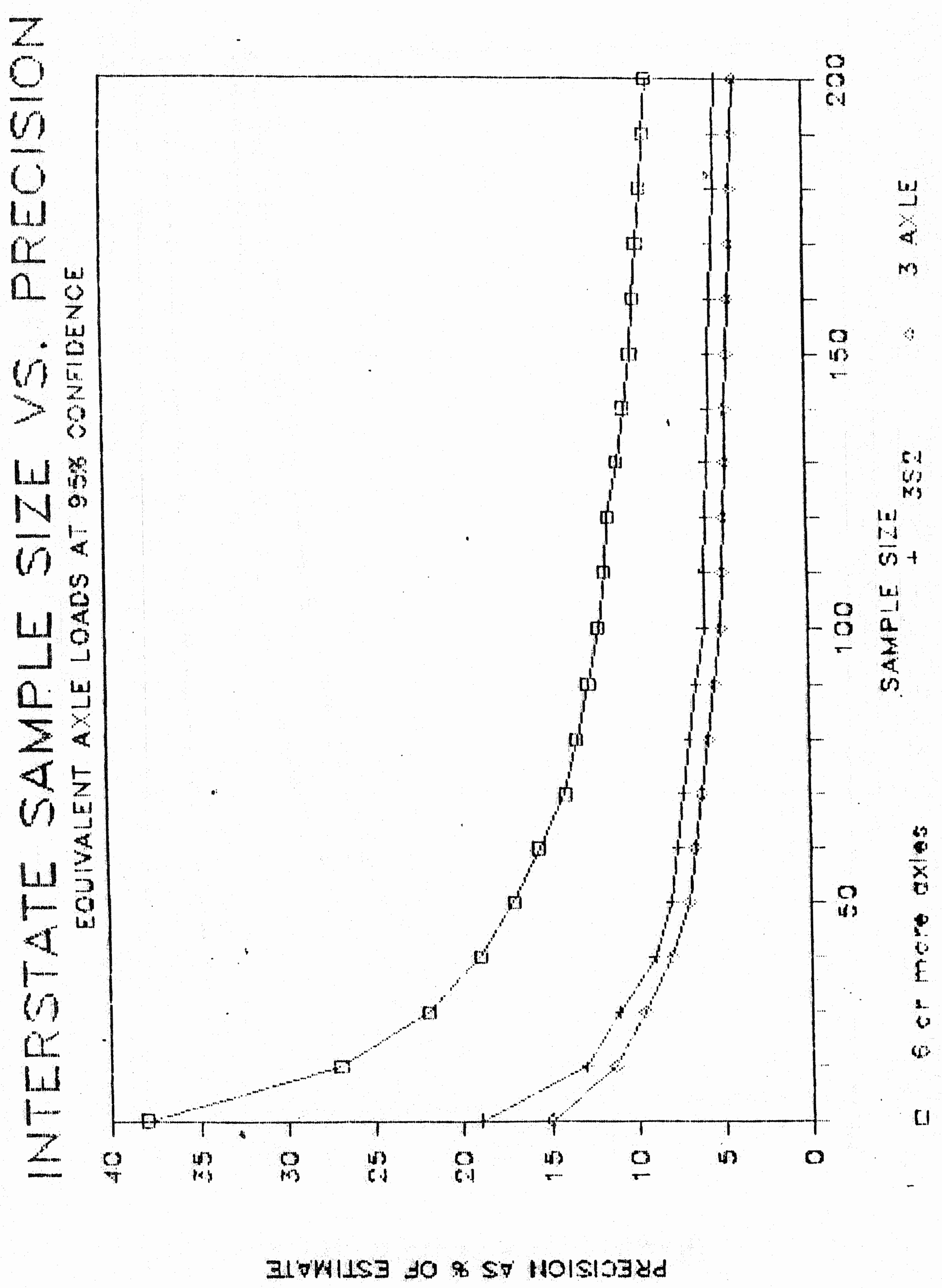

RURAL INT. SAMPLE SIZE VS. PRECISION
VEHICLE CLASSIFACTION PERCENTAGE
PRECISION AS % OF ESTIMATE
SAMPLE SIZE
0
10
20
30
40
50
60
50
100
150
200
250
300
□ 3S2
+ 3 AXLE TRUCKS
◇ STANDARD AUTOS

Exhibit 4



INTERSTATE SAMPLE SIZE VS. PRECISION
EQUIVALENT AXLE LOADS AT 95% CONFIDENCE
PRECISION AS % OF ESTIMATE
0
5
10
15
20
25
30
35
40
SAMPLE SIZE
50
100
150
200
6 or more axles
3S2
3 AXLE

CHARACTERISTICS OF WISCONSIN'S TRUCK WEIGHT STUDY AND BRIDGE WEIGH-IN-MOTION SYSTEM

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CHARACTERISTICS OF WISCONSIN'S TRUCK WEIGHT STUDY AND BRIDGE WEIGH-IN-MOTION SYSTEM

For the past two years The Wisconsin Department of Transportation (WisDOT) has participated in FHWA's "Demonstration of Coordinated Weight Monitoring and Enforcement Program Using Weigh-In-Motion (WIM) Equipment" as part of the Rural Technical Assistance Program. The Departments Division of Planning and Budget has directed the project from its inception while the Division of State Patrol, responsible for Motor Carrier enforcement, has played a key role in several operational aspects associated with the WIM system. The demonstration project has allowed WisDOT to test the overall performance of the Bridge WIM equipment as well as develop an entirely new comprehensive and representative truck weight data base.

TRUCK WEIGHT STUDY BACKGROUND

In the past, truck weight data was collected as a means of determining pavement loadings which in turn could be used in highway design requirements and estimates of pavement life. The Division's Traffic Data Unit collected planning information at 14 permanent and 3 portable weighing stations located on the rural interstate and state trunk highway systems. Certain situations required portable scales to be used in conjunction with permanent roadside locations to determine vehicle weights and related data in the opposite lane of traffic. In all, data was collected for a time period of 16 to 24 hours on a summer weekday at each station. Because of the importance and constantly changing nature of this data and information, a survey of truck weights, vehicle classifications and origin/destination details among other items was required for submittal to FHWA every two years. From this survey the FHWA was able to develop a basis from which it could determine truck weight trends and revise estimates of equivalent axle loadings for various truck classifications. Much of this factual material was then used in design and maintenance computations.

During the previous two years the Division's Traffic Data Unit collected truck weight data using the BWIM system at 19 bi-directional sampling stations. These stations were located on several distinct highway jurisdictions and functional road classes such as rural and urban interstates and state trunks, as well as principal and minor arterials. Survey operations at seven of the stations were expanded to include nights, weekends and the four separate seasons of the year. Knowledge of temporal and seasonal variations in truck travel allows for the development of more accurate estimates of average annual loads which is valuable for users such as motor carrier enforcement. The overall consensus is that the increase in stations has vastly improved statewide coverage of the Truck Weight Study and as a result a more representative and valid sample of trucking information is available which provides significant data on a number of highway corridors.

TRUCK WEIGHT STUDY SAMPLING PLAN

The sampling plan developed in Wisconsin provides procedures used by WisDOT for determining the number and locations of sampling stations for its Truck Weight Study. The programs purpose is to collect representative trucking characteristic data for use in pavement design, highway cost allocation, motor carrier enforcement and other planning and research activities. Previous weight studies produced data of limited value due to inadequate road type and geographic coverage. In addition, stations were selected without any statistical guidelines for sampling. Utilizing new weighing-in-motion technologies and emphasizing the collection of basic weight data permits a more random selection of weigh stations and a more comprehensive sample of truck traffic. The sampling plan developed relies heavily upon user needs and statistical criteria to help ensure a valid and meaningful sample.

Using data from a recent Highway Performance Monitoring System Wisconsin Truck Weight Case Study, the number of required stations was calculated on the basis of the average variability of truck weights in the State. These stations were distributed across recommended road types in proportion to the size of the total population of truck vehicle miles of travel on each road type. Stations by road type were then assigned to counties using a weighted random numbers procedure while criteria was presented for selecting corridors and sites where stations should be established. This kind of sampling approach generates more representative and comprehensive data that better describes general as well as specific characteristics of the overall truck population throughout the State.

PREVIOUS CONSIDERATIONS

Obtaining accurate information on truck weight presents a problem no matter what type of system is chosen to conduct the survey. One of the main problems of prior years is the fact that costs of collecting truck weight data were high which limited the amount of data that could be collected. Until the advent of the BWIM system several other factors which follow have contributed to or caused inaccuracies in the data that was collected.

Overweight vehicles avoided weigh scales which skewed the information by creating a lack of representative data on heavy trucks and in turn diminished the quality of the data collected;

Costs of the manpower necessary to operate a station as well as the overall costs of purchasing and maintaining scales made it prohibitive to expand vehicle weighing programs;

Small numbers of locations where weigh stations exist statewide did not represent either a random or a representative sample of traffic on the state highway system;

Considerations necessary for weigh station crew safety as well as safety of the travelling public, turnaround space and scale accuracy limited the number of sites suitable for the existing portable scales.

The enforcement of weight laws causes overweight trucks to take evasive action such as using bypass routes to avoid any operating weigh station or waiting at a truck stop until the scale facility closes. The result of this avoidance is weight data which under reports the heaviest trucks and consequently causes average survey weight to fall below the actual average weight.

With the use of the Bridge WIM system, many of these drawbacks could potentially be eliminated. The basic concept of the BWIM scale is that it has the capability to unobtrusively weigh vehicles without forcing them to stop. Weigh-In-Motion is not only an entirely new and innovative means of collecting representative and qualified TWS data but it can also increase the efficiency of existing scale houses while obtaining "missing" data not previously available through the use of static scales.

BRIDGE WIM SYSTEM FUNCTIONAL CHARACTERISTICS

For planning purposes, the BWIM system can be set up on concrete and steel girdered bridges that are accessible from underneath. The skew angle (where roadway and bridge meet) should be less than 40° and the length of the bridge span should be between 30'-90'. The system itself consists of sets of strain gauges which are placed on the support beams of bridges. The electronic gauges are attached by wires to an elaborate computer system housed in a van which is parked and hidden underneath the bridge if possible. The computer uses strain measurements from the bridge and input from tapeswitch axle sensors on the roadway to classify and weigh each passing truck.

Calibration Procedure

Before operations can take place, an influence line of the bridge must be created. A mathematical process which calculates vehicle weights uses the influence line for the bending moment (flex) in the bridge girders at the location of the strain transducers. In addition, each bridge must then be properly calibrated with the use of a weighted test truck. A test vehicle (county dump truck) with a known weight of 40,000 or more pounds is required to cross the BWIM location a minimum of six times in each lane. These crossings are essential to assure proper weighting factors and samples are calculated in the BWIM computer program disk for each lane of traffic. The entire process requires approximately two or more hours depending upon the distance involved for each test truck crossing.

Set Up And Take Down

To fully set up and take down the equipment requires approximately one hour depending upon circumstances unique to each bridge site. Once, installed, features such as the tapeswitch coverings on the roadway and strain gauge connections under the bridge can remain in place if the possibility of vandalism is remote. This eliminates a portion of the time needed to set up and take down while allowing extended data collection periods. One complete set of electronic BWIM equipment is all that is needed to move from one bridge site to another. This holds overall operating costs to a minimum, especially when compared to some of the other WIM system operations which are, for practical purposes, permanent and require one complete system for each site investigated. Of course, two people who are well trained in all areas of the system are also required for on-site operations. The complete bridge WIM system including all necessary computer and electronic equipment along with a van to house the apparatus costs in the neighborhood of $120,000.

ACCURACY TESTS OF THE BWIM SYSTEM

In addition to collecting Truck Weight Study data at several locations in Wisconsin, efforts of the Bridge WIM System's crew concentrated on conducting accuracy tests of the WIM System's vehicle weight categories. Bridge WIM operations were set up and accuracy test comparisons were performed at four separate locations throughout the state in an attempt to determine the precision of the system's weight measurement capabilities. Vehicles were randomly selected for weighing on the bridge WIM and then weighed at permanent scale sites for comparison purposes. The entire operation required patience and coordination between the WIM crew operators and the enforcement officers at each scale site. Sites were selected based upon their close proximity to permanent weighing facilities and also to provide a representative sample of various types of bridge configurations. Each of the bridge sites selected represent either prestressed concrete or steel deck girder configurations along with varying skew angles and span lengths.

From a statistical standpoint, accuracy measurements were presented in a manner which confirmed that the standard deviation range or variance in weights was least accurate for steering axles while gross weights proved to be the most accurate. Results were also presented to ascertain whether the bridge WIM system consistently weighs high or low at different locations or among certain axle groupings. As proven in the analysis, the drive axles were consistently weighed low while in most cases the trailer axles were weighed higher than their actual weight. At most sites gross weight was underweighed on lighter weight vehicles and over weighed on heavier vehicles. A detailed analysis of these and several other procedures and methods of analyzing the accuracy test results is contained in a final Evaluation of The Bridge Weigh-In-Motion System Report which our Department recently developed.

During the course of the RTAP project, another series of special verification tests was conducted to assess the capabilities of the bridge WIM system's classification, axle spacing and speed categories. These sections were individually examined and then compared to each specific examples actual occurrence. Throughout all of this groups comparison tests, near precise results were recorded.

Enforcement experiments which were conducted with the cooperation of the Division of State Patrol included comparing "abnormal" truck data, when enforcement personnel are present or near Bridge WIM operations, to "normal" truck data, when no enforcement personnel are in the general area. Results of this type of analysis are based upon potential overload percentages at each location. Other activities involved conducting operations in conjunction with enforcement where known seasonal overloads exist and comparing the results. The majority of this analysis has shown the existence of a moderate percentage of potential overweight vehicles with some situations having a comparatively high concentration. Without reducing the current range of error, however, pinpointing individual overweight trucks becomes very difficult. Again details of these testing procedures are contained in the evaluation report.

SUMMARY

To summarize, I've included several of the specific advantages and limitations of the BWIM system.

Main advantages of the BWIM System are:

- The weighing device including the set of strain gauges is invisible to the motorist and the entire system is unobtrusive for the most part;

- The system can be moved from girdered bridge to girdered bridge without difficulty making it one of the most portable operations on the market;

- Depending upon the location selected for data collection, essentially no site construction is required to install the system;

- The system requires only two people to operate and classify, and only one person is necessary for monitoring the apparatus in its automatic mode capacity;

- By pressing the correct commodity description into the key pad, a listing of all the vehicle transport types recorded at any given station location is made available.

- The system provides a great deal of flexibility, both from the standpoint of increasing highway system coverage throughout a large geographic distribution as well as increasing efficiency in the rate of collecting data in comparison to previous methods.

Primary limitations of the BWIM System are:

- The system can only be used on concrete and steel girdered bridges, rendering several other bridge configurations in Wisconsin inadequate for its use;

- The bridge girders underneath the structure must be accessible to the crew members measuring and setting the strain gauges;

- When two or more trucks are travelling on the bridge at one time the system is not able to properly record any of the vehicles's weights;

- The system must be properly calibrated for each bridge which requires obtaining a measured weight calibration truck and compensation for its use;

- The system's electronic components must be located very near the bridge which creates concern when selecting a site both suitable and unobtrusive for the van;

- Unless speeds of vehicles can be slowed and approach pavements smoothed, problems of individual axle as well as gross weight inaccuracies will continue;

- Individual axle errors are randomly distributed on heavier loads, resulting in data which is acceptable for many planning purposes such as computing average loads of a specific station location or highway system category but is not accurate enough for the enforcement of truck weight laws.

In the past, Truck Weight Study data and information was compiled at specified locations throughout the state, leaving serious questions and concerns as to its validity in representing all vehicular travel patterns and occurrences. Futhermore, a considerable amount of time and manpower was required to organize and conduct various activities relative to the study's operational procedures. The outcome or final tabulation was nevertheless as accurate as could be expected. Because of its portability, the BWIM now allows for the collection of truck samples which are entirely representative of any given area of the state for a portion of the original overall cost. The accuracy level associated with those same truck weight samples at any given location however, can only be a collective estimate based upon all random test samples.

INTEGRATION OF TRUCK WEIGHING PROGRAMS

Prepared for

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INTEGRATION OF TRUCK WEIGHING PROGRAMS

Truck weighing has been conducted in the U.S. for many years for a variety of purposes, including: pavement and bridge design, monitoring, and research; size and weight enforcement; planning; and the formulation and administration of policy, legislation, and regulations. To date, most truck weight data used for these functions were obtained and analyzed through the cooperative efforts of the States and the FHWA in the Truck Weight Study within the framework of the Highway Planning and Research Program. However, recent developments in three major areas - Traffic Monitoring, the Strategic Highway Research Program (SHRP), and Size and Weight Enforcement - contain needs for significantly increased levels of truck weight data collection activity. It is important that the needs in each of these programs be addressed in a coordinated manner through some level of integration.

Traffic Monitoring

The Federal Highway Administration (FHWA) recently issued a draft version of its new Traffic Monitoring Guide. When completed, this publication may be one of the most important transportation documents of this decade. By clearly defining the relationships among traffic counting, vehicle classification, and truck weighing in systematic terms, the FHWA has provided the States with a tool which will enable them to improve both the assessment of current traffic conditions and the projection of future traffic conditions on their highways. The States will also be able to design their traffic monitoring with a reasonable understanding of the quality of data which will be obtained from a given level of effort.

The questions of how many samples of these quantities should be made, how often they should be taken, and how to obtain the samples are addressed in the

Traffic Monitoring Guide by presenting procedures which are based on the following concepts:

1. Statistical reliability is directly related to the variability of the quantity being measured.
2. Variability may be reduced by careful stratification.
3. The sample size required to achieve a given level of confidence is reduced by decreasing the variability of the quantity being measured.

Based on a statistical analysis of data files acquired by the Truck Weight Study, the FHWA concluded that a minimum (default value) of 30 truck weighing sessions of 48 hours duration are needed each year in each State. These weighing operations would be conducted at 30 different sites a second and third year, resulting in 90 truck weighing sessions over a three year period. This procedure would allow an estimate of the average equivalent single axle load value for the most frequently occurring large truck, the 3S2 (18 wheeler), on the Interstate system within ±10% with 95% confidence. States which do not wish to use the FHWA default values for the number of stations are provided with statistical procedures for designing their own programs based upon their own data files.

The 50 States, by following the FHWA minimum recommendations, would have a total of 1500 48-hour truck weighing sessions annually. This number is in contrast to the current level of 600 Truck Weight Study sessions annually, most of which are for less than 24 hours of weighing. The FHWA has recognized that a change in the magnitude of truck weighing suggested by the recommendations in the Traffic Monitoring Guide will require the use of weigh-in-motion (WIM) equipment to automate the process.

Pavement Monitoring

A concurrent effort by the States and FHWA is the Strategic Highway Research Program (SHRP), which will contain several areas of study, including an ambitious Long Term Pavement Performance Monitoring (LTPPM) component. Truck weighing is a critical element of LTPPM, since it is necessary to develop mathematical relationships between pavement performance and the characteristics of applied axle loads. It has been estimated that as many as 4,000 highway sections will be required to meet the data needs of SHRP. By application of the statistical design procedures given in the Traffic Monitoring Guide to produce ±10% accurate estimates of ESAL for 3S2 trucks on each unique LTPPM highway section (rather than for a system of roadways), it is apparent that the data collection at these sites must be much more intensive than is needed for the triennial Truck Weight Study. A minimum of one 48-hour truck weighing session at each LTPPM site each year is desireable. This need will undoubtedly require the use of WIM equipment for satisfaction.

Enforcement

Increased interest by the General Accounting Office and the Congress, as well as the FHWA and the States, has led to increased emphasis on providing tools for: improving the efficiency and effectiveness of truck weight enforcement; assessing the magnitude of the problem of overweight trucks; and determining whether enforcement efforts are having the desired effects. WIM equipment clearly has a place in this effort, since it is the only technology available for quickly processing large numbers of trucks and for unobtrusively sampling the weight characteristics of truck in the traffic stream without warning the operators of overloaded vehicles that they should divert to other routes.

Integration of Truck Weighing Programs

Each of these programs (Traffic Monitoring Truck Weight Study, LTPPM, and Enforcement) require a level of effort for truck weighing which is an order of magnitude greater than current activity. Under current manpower and funding constraints, such an occurrence seems unlikely for any single program taken individually. In this context, the FHWA and the States have initiated several programs, including the Rural Transportation Assistance Program's (RTAP) Demonstration of Coordinated Weight Monitoring and Enforcement Using WIM Equipment, the Crescent Demonstration Project, and other State, FHWA, and National Cooperative Highway Research Program (NCHRP) research. Attention to this issue is also being given within the data collection design activities for the LTPPM tasks included in SHRP. However, even the estimated $150 million projected for SHRP over the next five years may be inadequate for intensive truck weighing on each of up to 4,000 sections. It is therefore important to consider ways for integrating existing and planned truck weighing activities, both static and dynamic, to ensure that data are collected in a manner which is usable for the full range of traffic monitoring, pavement monitoring, and enforcement functions.

Opportunities for Integration

One way to acomplish this objective is to design truck weighing operations for compatibility with all three functions. For example, if WIM equipment is used in a "binning" mode, in which axle and gross weights are totalled by categories and by time period, it would be beneficial to include a violator default feature, by which individual overweight vehicles are identified and their axle weights and spacings stored in memory. In this way, every WIM truck weight study could also serve an enforcement assessment function. Similarly, WIM equipment used for enforcement assessment should include features which allow data storage in a form which is useable for either traffic or pavement monitoring applications. This is not meant to imply that all data will be useful among programs, but the capability to interchange information should be present.

Static truck weighing enforcement operations are another potential source of data which has not been exploited to a significant degree. However, these operations are not generally effective for either enforcement or truck weight data collection for more than one hour, due to the problem of scale avoidance. Data taken from such operations may be biased in that the heaviest vehicles would not be adequately represented. However, there are many continuously operated static scale locations which are impossible to avoid. These facilities can be, but rarely are, used to provide detailed data on the truck traffic stream. These sites should be given careful consideration for the installation of WIM sorter scales which weigh all truck traffic and record the data. Alternatively, data collection circuitry can be added to store the weight data acquired by the static scale automatically for later analysis.

The design of the systems of Truck Weight Study, LTPPM, and Enforcement assessment locations is a third possible area of integration. The problem with this idea is that each of these efforts is based on different objectives. The Truck Weight Study locations were originally selected based on allocating a minimum number of sites to each of several functional classification systems. In addition, these weighing locations were placed to provide some geographical representation within most States. The recent implementation of the Highway Performance Monitoring System (HPMS) took into account the locations of these historical truck weighing locations in the sense that the States attempted to locate HPMS panel sections in the vicinity of Truck Weight Study locations whenever possible. The draft Traffic Monitoring Guide further encourages the relocation of Truck Weight Study sites to provide a better data base for the HPMS program. The highway sections to be selected for LTPPM will probably <u>not</u> be identical to those within the HPMS unless a conscious effort is made to ensure compatibility.

Assuming that 500 truck weighing locations can be used for both Traffic Monitoring and LTPPM, a total of 5,000 sites may be needed annually to support these two programs. Enforcement assessment truck weighing can be done at a subset of these 5,000 sites. Innovative applications of available technology are required if these data needs are to be satisfied to any reasonable extent.

Application of Technology

Automatic vehicle classification (AVC) in combination with portable WIM devices is one obvious solution. The AVC units can be either installed permanently in the roadway and in a cabinet in a manner similar to automatic traffic recorders (ATR's) or deployed using temporary surface-mounted sensors as are temporary counters. Units are available which use a variety of sensor technologies, including inductive loops, pneumatic tubes, and triboelectric or piezoelectric cables.

Portable WIM equipment is now available from at least two vendors which use a surface-mounted capacitive weighmat. This weight sensor can be installed in less than 30 minutes and has acceptable levels of accuracy. The cost of a portable capacitive weighmat-based system is approximately $50,000. The cost of each capacitive weighmat alone is about $10,000. Recent work in the development of a low-cost truck weighing system for the FHWA by Cunagin, et al, now offers the possibility of a much more intensive truck weight data collection effort. When the prototype system is delivered to the FHWA in the fall of 1985, it will have the following features:

1. The weight sensor will be a strip version of the capacitive weighmat. The dimensions of the strip are 6" long by 6'wide by 3/8" thick.

2. The total system cost will be $5,000, including both the data acquisition electronics and one strip sensor. The cost of the capacitive strip sensor should be less than $1,000.

3. The device can be installed and removed by one man, exclusive of the need for work zone traffic control.

4. It will have an accuracy of ± 10% at the 90% confidence level for heavy axles.

Several vendors of other WIM equipment have indicated that they intend to market a version of the FHWA low-cost weight sensor during 1986.

Another possible approach to obtaining the data needed for traffic monitoring, LTPPM, and enforcement use is the installation of permanently installed traffic data collection sites which use both AVC and WIM devices. In this configuration, surface-mounted weight sensors are not suitable since they do not have the required durability. For this application, a wide variety of weight sensors are available and have been marketed for a long time. Unfortunately, this equipment typically costs in excess of $75,000 per installation so that the cost of widespread application of this equipment would be prohibitive. Low-cost permanently installed weight sensors are now being investigated for use in the U.S. One technology under consideration is piezoelectric cable. This device has been used extensively in France and West Germany and in a research environment in England. The cost of permanently installing the sensors for both AVC and WIM will be about $500 per lane using this technology. Another possibility for low-cost permanently installed weight sensors is embedding the FHWA low-cost WIM sensor within the pavement rather than mounting it temporarily on the surface. Although this approach has not yet been tried, it is a reasonable option for further investigation.

Bridge weighing offers another reasonable alternative for acquiring truck weight information on the scale needed for expanded traffic monitoring, LTPPM, and enforcement programs. This technology uses strain gauge transducers fixed to the longitudinal support beams of bridges to provide input to an algorithm which solves a set of simultaneous equations to compute axle weights. This equipment can be used in conjunction with axle sensors on the highway surface to provide the traffic data needed for each data requirement. However, bridge weighing systems can be used only on certain types of bridges and may have difficulty determining the individual axle weights on tandem axles as well as the weight of the steering axle. Nevertheless, bridge weighing technology potentially offers one additional tool which can be used in acquiring the vast amount of traffic data which are needed for the revised and new truck weighing functions.

CONCLUSION

The emerging needs for expanded truck weight data collection activity in the areas of Traffic Monitoring, LTPPM, and Size and Weight Enforcement can and should be addressed. WIM technology is a powerful tool which can be used effectively to meet these needs. However, it is important that the truck weight data collection activities for these purposes be coordinated and integrated to ensure that available resources are effectively utilized.

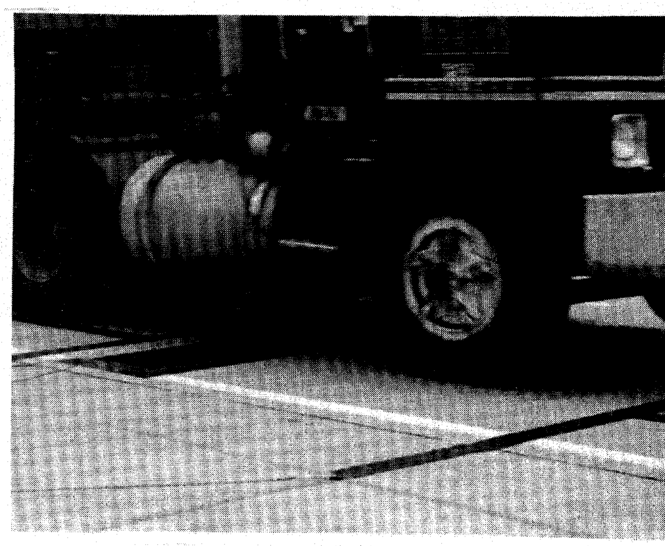
IX. FIELD TRIP & WIM SYSTEMS GENERAL INFORMATION

Conference participants were able to observe during the field trip the operation of 5 different weigh-in-motion systems.

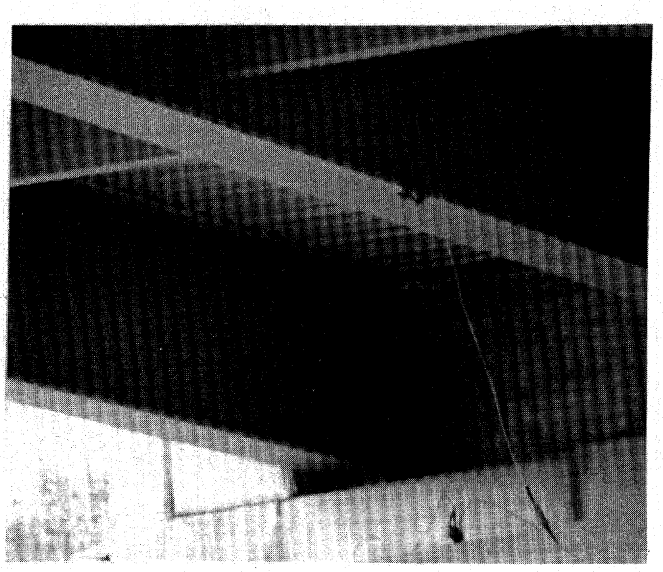
These included:
1) Bridge Weighing Systems, Inc.
2) Golden River Corp.
3) Siemens-Allis, Inc.
4) Streeter-Richardson, permanent
5) Streeter-Richardson, portable

A field demonstration of a CMI-Dearborn, Inc. classifier was conducted. A tour of Georgia DOT's newest permanent truck weigh station in operation in Carroll County on I-20 WBL just east of the Bremen exit was also made.

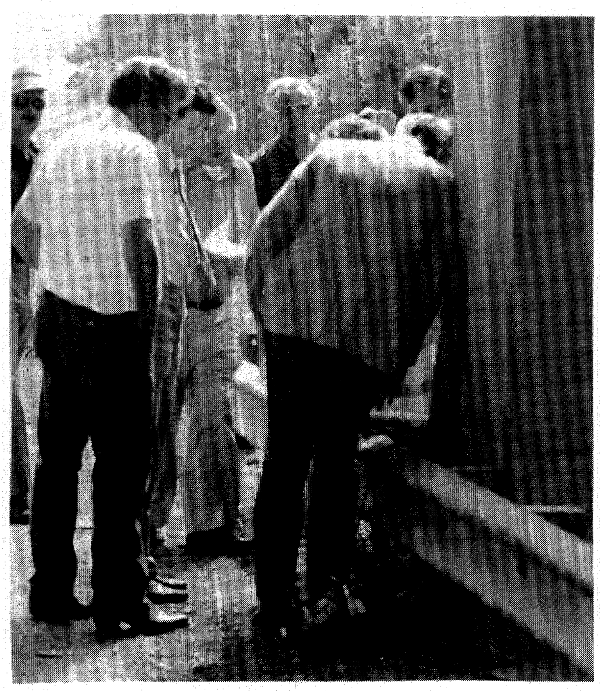
General information on several WIM systems represented at the conference is offered for the reader's reference. This brief information serves to complement discussion of the systems in the proceedings. This general information does not imply endorsement by either the Federal Highway Administration or the Georgia Department of Transportation of any particular product.

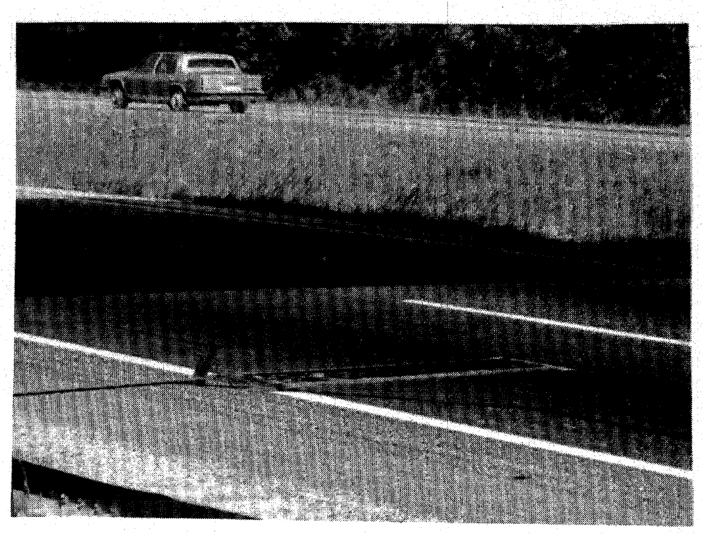


Streeter-Richardson



Bridge Weighing Systems





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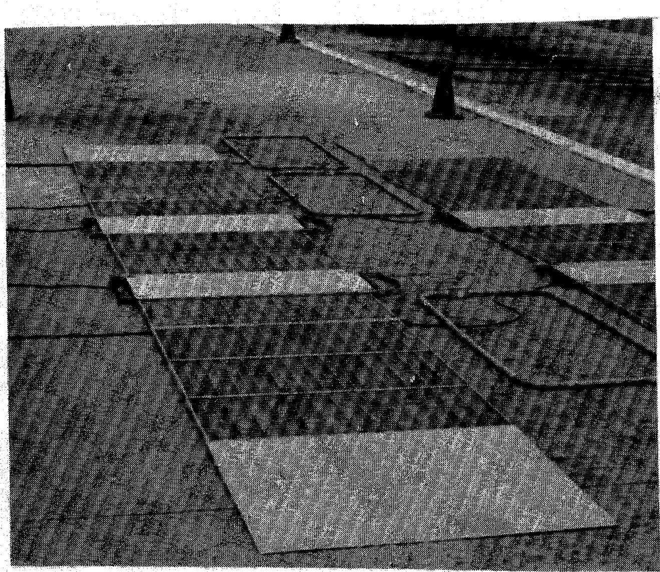
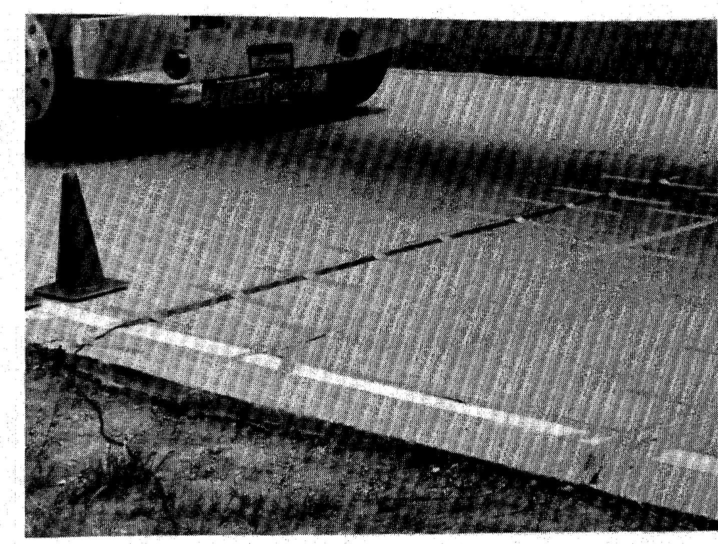
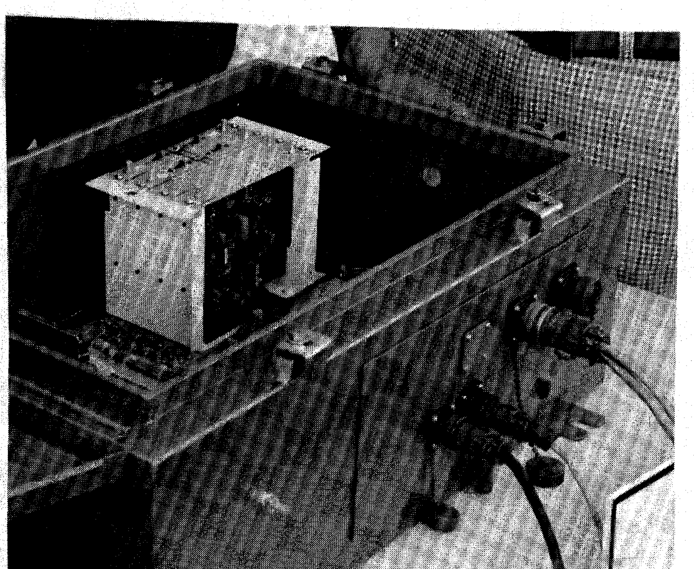


Siemens-Allis



CMI Dearborn classifer



BRIDGE WEIGHING SYSTEMS, INC.

Concept

The portable Fast Weigh system was the first system introduced by Bridge Weighing Systems, Inc. It is now just one of the options available for utilizing the BWS Weigh-in-Motion technology. The concept utilizes existing highway bridges as equivalent static scales. The high speed weighing combines strain transducers easily attached to bridge girders and tapeswitches, roadtubes, or permanently installed axle detectors. Data is transmitted to a microprocessor housed in a van in a discrete position, usually under the bridge. Traffic is neither slowed nor diverted and drivers are unaware of the weight measurement operations in progress. No special platforms, scales, off-road ramps or booths are necessary.

Choices Now Available

- Portable FAST WEIGH System — Offers mobility to easily weigh trucks on many different routes.
- Semi-Portable FIXED WEIGH System — Offers an unmanned system for continuous weight data collection. Can easily be moved to new sites.
- Mobile ENFORCE WEIGH System — For accurate screening of overweight vehicles to assist enforcement operations.
- Semi-Portable SORT WEIGH System — Provides sorting capabilities at static weigh-stations. Can be moved from station to station.
- BWS Data Gathering Services — To assist transportation agencies and consultants, and provide truck weight data and/or highway bridge testing.

Operation

The BWS Fast Weigh system is quickly set-up and intended as a manned operation to survey truck weights on a highway route - **the system is intended to be portable.** On an initial visit to a test site a calibration vehicle is needed to fix a conversion factor. On subsequent visits, this calibration is not needed and set-up time is typically less than one hour. The Fast Weigh system can be disconnected and prepared for removal to a new site in less than one-half hour. All equipment is designed to fit in even a small van and will run on a small portable generator. Transducers are easily attached without needing special equipment.

Features of the Bridge Weigh-in-Motion System

- Uses existing highway bridges as scales
- Multi-lane capability
- No special construction, ramps or platforms required
- Monitoring of trucks is carried out at highway speeds
- Quick set-up with minimum or no traffic disruptions (depending on system options)
- Can operate without detection by drivers of weighing operation
- No data bias due to "lost" trucks
- Wide variety of bridge types used including steel and concrete girders
- In use at more than 200 sites worldwide
- Simple training programs available from BWS
- Testing, installation and data processing services available from BWS
- Axle weights are determined and summed to obtain gross weight
- Portable operation
- Two lane standard capability
- Summary tables available from system without main-frame computer
- Can run on portable generator
- Quick and easy installation at new site
- Optional observer to record visual vehicle classification data
- Automatic vehicle classification and weight calculation

Installation

- One strain transducer on each longitudinal load carrying girder attached by C-clamps or lead anchors
- Roadtubes or tapeswitches attached to road surface
- Optional piezoelectric cables can be permanently installed at often used sites
- Instrument van houses equipment

Equipment

- Micro-computer with hard disk drive
- Generator
- Strain transducers
- Software
- Signal Conditioning Center

Accuracy

- Speed ± 1%
- Classification 98% correctly classified
- Gross weight ± 5% for 95% of vehicles at highway speed
- Tandem weights ± 10% for 90% of vehicles at highway speed

Fast Weigh is just one of the options now available for application of the bridge weighing technology. All options use the Bridge Weigh-in-Motion concept which do not require any special construction and provide unbiased weight data since drivers are unaware of the weighing operation. The applications of the portable FAST WEIGH system include the following:

1) Situations where many major and bypass routes must be surveyed. This requires portability which is the unique feature of FAST WEIGH.

2) Sites in which relatively short weighing period of one to five days will adequately describe truck patterns. (The BWS FIXED WEIGH, an unmanned system, is available for users requiring longer recording periods.)

3) Sites needing repeated visits to obtain daily, weekly, or seasonal variation. FAST WEIGH may be used at night or in all types of weather.

4) Enforcement screening - FAST WEIGH weight data will appear on the CRT display within one second of a truck crossing the instrumented span. This information may be radioed to enforcement officers who can stop the vehicle and issue a citation using portable scales. (Users needing only the enforcement capability may wish to consider the BWS ENFORCE WEIGH system. This system is intended for permanent installation of transducers and exceptionally quick set-up and disconnect times.)

5) Bridge loading and evaluation - FAST WEIGH output can also provide information for determining load and stress levels for bridge evaluation. In addition, a data gathering service is available from BWS to assist highway agencies and consultants to gather and interpret such data.

System Output:

- Accurate truck weight data
- Individual truck and summary tables
- 18-kip equivalents for pavement life
- Truck planning information
- Real-time weight processing for enforcement screening
- Speed and Classification information
- Bridge Loading Violations
- Bridge loading and behavior - optional for assisting in bridge strength evaluation

For further information contact:

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Phone: (216) 831-6131
Telex: 985662

BRIDGE WEIGHING SYSTEMS, INC.

FIXED WEIGH FEATURES

System Description

FIXED WEIGH is a semi-portable system designed to operate in an unmanned, unattended mode collecting axle and gross weight data twenty-four hours a day. As with the Fast Weigh System, bridges are used as equivalent static scales.

The FIXED WEIGH System is easily moved from site to prepared site. Less than six hours is required to take the system down and to set it back up at a new site (travel time excluded).

Unlike most stand-alone WIM systems, data is retained on each individual vehicle weighed in a 24-hour period. Only then is the data summarized in tabular form.

Only the best in-pavement WIM system offers accuracies comparable to bridge WIM system accuracies. However, initial costs, installation costs, as well as maintenance costs are far lower with FIXED WEIGH than with in-pavement systems.

Site Preparation

The FIXED WEIGH system is easily moved from site to site. Each site is prepared by installing loop detectors and axle sensors embedded in the pavement, a NEMA type 12 water and dust tight enclosure, and 115 volt AC electric power. A telephone line is necessary if modem communications are desired.

'Off Scale Vehicles'

In some states truck drivers have begun to recognize weighing devices installed in or on top of the highway pavement and have learned to avoid weighing by simply changing their lateral position within the lane. Since the FIXED WEIGH System uses the response of the entire bridge to weigh the vehicle, such avoidance attempts are fruitless.

System Rotates Between Sites

Ideally, the FIXED WEIGH System is rotated around several (3 or 4) sites on a periodic basis. While the FIXED WEIGH System is collecting classification and weight data at one site, vehicle classifiers can be installed at each remaining site to collect classification data. Thus, the weight data can be extended to periods when only classification data was collected.

FIXED WEIGH becomes extremely cost-effective with such a sampling plan.

ENFORCE WEIGH FEATURES

System Description

The ENFORCE WEIGH System is a portable, compact system designed to operate from a patrol sedan on the roadside. Approaching vehicles see only an officer with radar and are unaware of the weighing operation. The output gives the officer "probable cause" to pull over and statically weigh the vehicle.

Bridges Permanently Instrumented

Several bridges can be instrumented at strategic locations around the state. Upon arrival at the site, the officer will connect the system to the bridge instrumentation and initialize the computer program.

Nothing Applied To Pavement Surface

Vehicle velocities are obtained via radar while the computer calculates the axle spacings from the measured strain record. Tapeswitches or roadtubes are not needed.

Training

Only two to three hours of training are needed to operate the system. Additional training is available, enabling state personnel to instrument and calibrate new sites.

No Avoidance Possible

Any vehicle proceeding along the route can not avoid the scale. Shifting lateral position within a lane will not cause the vehicle to be missed as with pads placed on the pavement.

Output

Vehicle weights are output within seconds of the vehicle crossing the bridge. Certain violation calculations are done and the relative degree of likelihood of the vehicle being overweight is displayed.

Quick Set-Up, Quick Disconnect

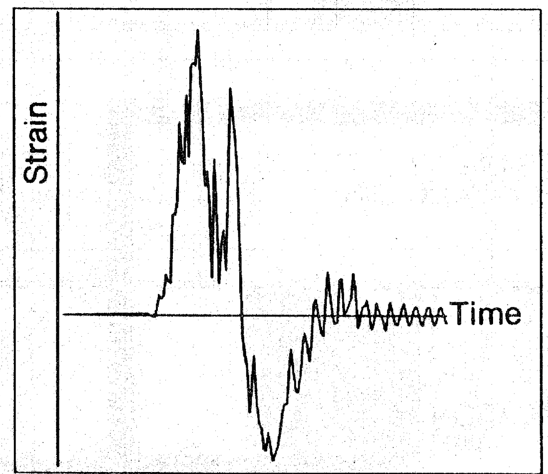
Set-up involves unlocking the system control box and attaching one cable. The system instrumentation is then readied for weighing and the computer program initialized. System set-up will take 5 to 10 minutes from arrival until weighing is begun. The system allows for quick disconnect, approximately 30 seconds.

TRUCK ID: 34 LANE 1 SPEED: 59.9 MPH TYPE: 3S-2 TIME 958

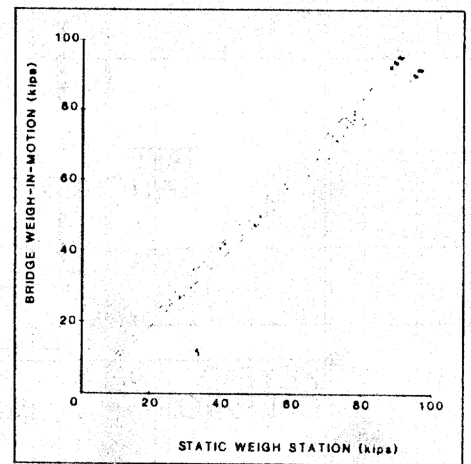
SPACING		12.1	4.3	28.6	4.7
AXLE WEIGHTS	9.8	17.9	17.9	10.2	10.2

TOTAL WEIGHT 66.2

18 KIP EQUIVALENT: RIGID 2.63 FLEXIBLE 1.65



The Bridge Weigh-in-Motion System can collect and save complete bridge strain records for later analysis.



Gross weight measured by the BWS system is accurate within ± 5% for 95% of vehicles measured

BRIDGE WEIGH-IN-MOTION USERS

Idaho Transportation Department
P.O. Box 7129
Boise, Idaho 83707
Mr. John Hamrick

Iowa Department of Transportation
800 Lincoln Way
Ames, Iowa 50010
Mr. Robert Studer

Kansas Department of Transportation
Bureau of Transportation Planning
State Office Building
Topeka, Kansas 66612
Mr. Dennis Slimmer

Maryland Department of Transportation
Bureau of Highway Statistics
P.O. Box 717
Baltimore, Maryland 21203
Mr. Thomas Neukam

Ohio Department of Transportation
Bureau of Technical Services
P.O. Box 899
Columbus, Ohio 43216
Mr. Tony Manch

Oregon Department of Transportation
Economic Services and Planning
325 13th Street, N.E.
Salem, Pregon 97310
Mr. Milan Krukar

Utah Department of Transportation
Department of Materials and Research
4501 South 2700 W.
Salt Lake City, Utah 84119
Mr. Robert Todd

Wisconsin Department of Transportation
Division of Planning and Budget
P.O. Box 7913
Madison, Wisconsin 53707
Mr. Lang Spicer

Federal Highway Administration
HRS-11
6300 Georgetown Pike
McLean, Virginia 22101
Mr. Harold Bosch

Department of Main Roads
309 Castlevagh Street
Sydney, New South Wales 2000
Australia
Dr. Gavin Donald

Deliveries expected by January 1986:

New South Wales, Australia
United Kingdom
Sweden
United States (3)

State or Federally funded research projects underway:

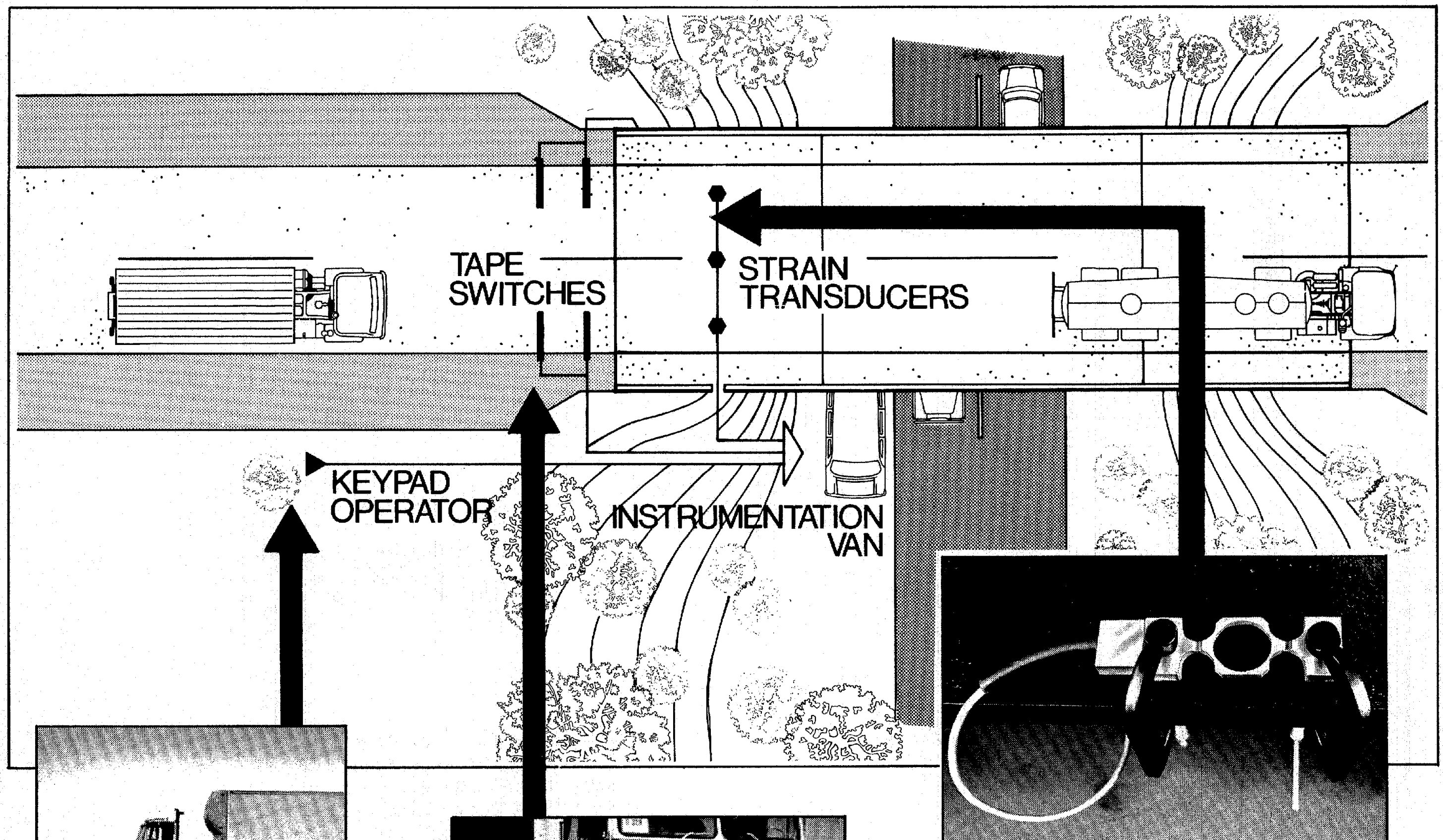
Develop criteria for using WIM data for rating and evaluating bridges.

Extend bridge WIM system to cover four lanes, two lanes in each direction.

Develop bridge WIM for a four lane urban interstate with high traffic density.

Typical Installation

BRIDGE WEIGHING SYSTEMS, INC.



A standard van can be equipped with a complete Weigh-in-Motion system.

[illegible]

CMI-DYNAMICS, INC. *WEIGHT MONITORING SYSTEMS*

1. High Speed Data Collection. Here the scale is mounted flush in the highway surface and we generate a weight, dimension and speed record for each vehicle passing through the system. The information generated is used by highway designers, planners and research departments.

2. High Speed Sorting. In this application, the scale is placed in the entry ramp of a weigh station. Its purpose is to screen those vehicles that are obviously legal and allow them to proceed back onto the highway without stopping. Marginal or overweight vehicles are automatically directed to a static scale for enforcement weighing.

3. Low Speed WIM. Current application for this system is truck terminal check weighing. Accuracy is 0.5% and we are hoping that future applications will include truck weight enforcement. The State of North Carolina is currently testing a system and will be compiling data for N.B.S..

Weight-in-Motion Data Collection System

The CMI Dearborn WIM System is the outcome of many years of development to create a practical, reliable and economical weight monitoring system that can withstand extremely harsh environmental conditions and to monitor heavy traffic at highway speeds.

The CMI WIM System has been applied to both high and low speed sorting and also as a tool for accurate data collection.

In the data collection mode of operation, the CMI WIM System monitors the entire population traversing a preselected roadsite.

A record is produced for each vehicle listing the time, date, vehicle type, 18kip equivalency, speed, gross weight, axle spacing and individual axle weight. The information is stored for later retrieval in a series of tables which can be designed to suit local requirements.

Combination systems providing the sorting and data collection functions are also available.

SYSTEMS ACCURACY

WIM Systems involve weighing axles at normal highway speeds. Three major factors that affect system performance are:

1. Approach roughness.
2. Vehicle balance.
3. Dynamic response of the weighing system.

If the roadway approach roughness is less than one eighth inch under a 10-foot straightedge, accuracies of plus or minus 5 percent can be expected at normal highway speed. Axle spacing is plus or minus 2 inches.

SCALE

Vehicle weight is determined by two scales, one for each side of the vehicle. The weight will be considered correct only when both scales are activated. The scales are completely sealed to prevent the intrusion of salt, water, and dirt, etc. The seal protects all mechanical components including the load cell/transducer assembly. Each unit is installed in a prefabricated frame mounted flush with the roadway surface.

Each side of the scale is monitored by trouble free off-scale detectors which deliver an error signal if the vehicle crosses the system improperly. These devices are also sealed against water intrusion and, like the scale, are able to withstand scraping during ice and snow removal.

WIM SYSTEM ADVANTAGES

The CMI Dearborn WIM System provides accurate axle load information for monitoring performance of existing pavements.

It provides information and indicates trends for predicting future truck volumes and axle loads.

It provides accurate data for assessing bridge structural performance.

The CMI WIM System is completely automatic, requiring no operating personnel. It will report on a predetermined schedule via telephone modem or on demand. The system has a self-diagnostic feature which is capable of access by telephone.

SYSTEM ELECTRONICS

The electronics of the Data Collection System consist of an interface and a microprocessor plus a statistics computer. The system is connected by telephone to a host computer or terminal. The statistics computer utilizes a cassette tape cartridge for data storage. The electronics package can fit into a standard traffic control box which should be supplied with a simple heater for wintertime operation.

VEHICLE CLASSIFICATION

Moving vehicles are classified into as many as 20 categories ranging from cars to trucks with nine or more axles. Loop detectors are used to determine presence and speed, and the time delay between axle weighings determines axle spacings.

OPERATING ENVIRONMENT

-50 degrees F to +140 degrees F.

POWER REQUIREMENTS

The WIM System operates on 110 Volts AC/60Hz. Power surge and lightning protection is provided for the electronic components. The system will automatically restart following a power outage without loss of previously collected data.

820 Lafayette Rd.
Hampton, NH 03842
(603) 926-1200 Telex: 750684

```
Wed May 11 11:37 Lane 2
Type: 8    18-K ESAL Rigid:2.093    Flexible:1.233
Speed: 63 mi/hr:
Weight: 65754 lbs.
      0....:...10....:...20....:...30....:...40....:...50 feet
  0            0   0                           0   0
 8548        14761                           16336     lbs
                 10241                           15868
```

CMI-DEARBORN, INC.

Weigh-in-Motion Sorting System

The CMI Dearborn WIM System is the outcome of many years of development to create a practical, reliable and economical weight monitoring system that can withstand extremely harsh environmental conditions and to monitor heavy traffic at highway speeds.

The WIM System has been applied to both high and low speed sorting and also as a tool for accurate data collection.

In the sorting mode of operation, the WIM System is generally located in the conventional weigh station entry ramp. Each vehicle is checked for compliance with bridge formula, axle, and gross vehicle weight limits. Suspect vehicles are automatically directed to the re-weigh scale for further weighing.

Combination systems providing the sorting and data collection functions are also available.

WIM SORTING SYSTEM ADVANTAGES

1. 100 percent screening of all trucks entering the weigh station.
2. Improves weigh station efficiency.
3. Vastly reduces manual weighing.
4. Cost effective: reduces manpower requirements.
5. Gives a complete vehicle record.
6. Identifies specific bridge formula violations
7. Provides a printout of specific violations.
8. Energy savings: majority of trucks merely have to slow down.
9. Improved trucking industry relationship.
10. A single CMI WIM installation has weighed and classified 468,000 trucks (1.5 million axles) in one year with 100 percent availability.

POWER REQUIREMENTS

The system operates on 110 Volt AC/60Hz. Power surge and lightning protection is provided for the electronic components. The system will automatically re-start following a power outage without loss of previously collected data.

OPERATING ENVIRONMENT

-50 degrees F to +140 degrees F.

SCALE

Vehicle weight is determined by two scales, one for each wheel path. The weight will be considered correct only when both scales are activated. The scales are environmentally sealed to prevent the intrusion of salt, water and dirt, etc. The seal protects all mechanical components including the load cell/transducer assembly. Each unit is installed in a prefabricated frame mounted flush with the roadway surface.

Each side of the scale is monitored by trouble free off-scale detectors which deliver an error signal if the vehicle crosses the system improperly. These devices are sealed and, like the scale, are able to withstand scraping during snow and ice removal. Improperly weighed vehicles are automatically directed to the re-weigh station.

VEHICLE CLASSIFICATION

The system will classify vehicles with up to nine or more axles. Loop detectors are used to determine presence and speed, and the time delay between axle weighings determines axle spacings.

SYSTEM ELECTRONICS

The WIM Sorting System electronics consist of an interface and a pre-programmed microprocessor. Output is transmitted to the scale house where it is displayed on a CRT screen, printer, or both.

In conjunction with signals from loops, it gives a complete vehicle weight record including time, date, speed, axle spacing, individual axle weights, gross vehicle weight and bridge formula compliance. Output control signals are used to direct traffic either back onto the highway or to the re weigh scale. Acceptance threshold may be adjusted manually at the console, or the system can be programmed to automatically increase violation limits during peak traffic periods.

The WIM System is equipped with self diagnostics which can be accessed through the computer keyboard or remotely via telphone data link. It is also equipped with a unique calibration monitor which continuously checks overall system accuracy.

If required, the CMI Dearborn WIM Sorting System can be supplied with a statistics computer which will provide overall truck traffic data on a daily or weekly basis. All systems are equipped with telemetry.

OPERATING SPEED RANGE:

5 to 60 MPH

DYNAMIC WEIGHING SYSTEM ACCURACY:

Plus or minus five percent at prescribed speed.

INFORMATION PRESENTED:

1. Individual axle weights.
2. Group weights (tandems, etc.).
3. Gross vehicle weight.
4. Bridge formula violation.
5. Axle count or vehicle identification.
6. Axle spacing.
7. Vehicle count.
8. Date and time.

DISPLAY:

CRT screen of sufficient capacity to display and store data on four or five vehicles. Display also identifies overweight axles, axle combinations, GVW and bridge violations.

PRINTED RECORD:

Will operate automatically when system detects a violation. All data on the suspect vehicle will be recorded including specific violation.

BRIDGE FORMULA:

The system is programmed to detect and signal bridge formula violations on vehicles with five or more axles. It will also identify the particular axle group in violation, thus reducing the manpower required for weighing.

WEIGHT LIMITS:

The system is programmed to detect and signal the following violations:

a. Steering axle limit.
b. Single load bearing axle limit.
c. Tandem axle limit.
d. Triple axle limit.
e. GVW limit.

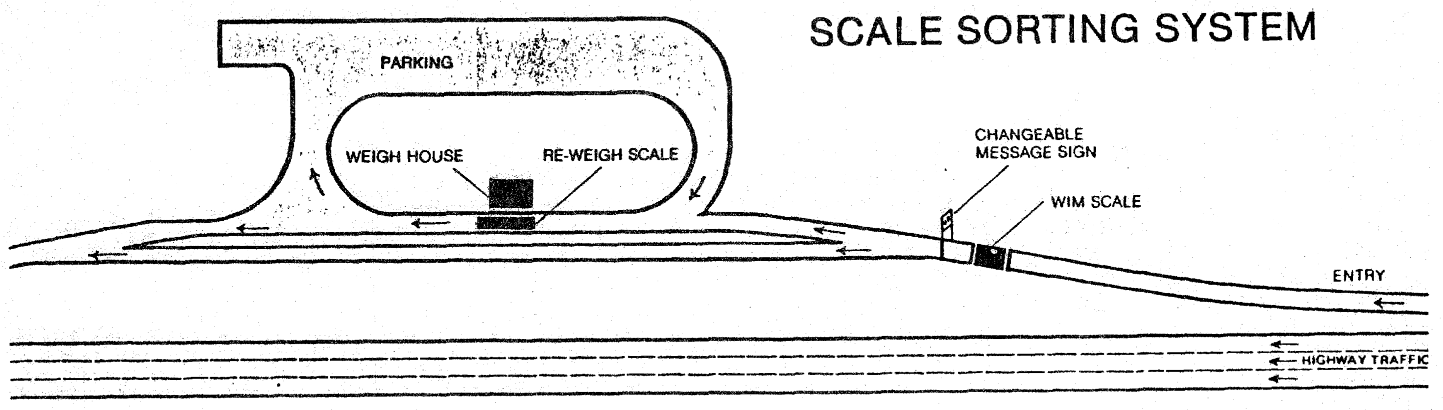
AUTOMATIC CONTROL:

1. Actual weight, GVW or bridge formula violations will signal overhead sign.
2. Improper traverse of scale platform will signal overhead sign.
3. Signal for overhead sign cancellation once vehicle has passed.
4. Signal to warn of violator evasion.
5. System has means to detect backup condition between dynamic and static scales.
6. System will automatically reset to normal violation limit when backup condition is removed.

PROGRAMMING:

The electronic computer equipment is easily modified to suit local requirements.

SCALE SORTING SYSTEM



CMI / WEIGHWRITE

The versatile **WEIGHWRITE** Dynamic Axle Weigher will weigh any type of road vehicle, regardless of length or number of axles.

Each axle is weighed whilst the vehicle is in motion at 2.5 mph and summated manually or automatically to produce a gross vehicle weight.

Standard User Features.

★ Prints individual axle weights.
★ Time and Date print – full calendar, battery backed.
★ Personalized name and address header on print-out.
★ Sequentially numbered weight print – battery backed.
★ Automatic "Zero" and "Calibration".
★ Alpha-numeric Display – prompts operator in use of system.
★ Dedicated keys for specific functions, Gross, Tare, etc.
★ 96 Character Alpha-numeric print-out on single or duplicate stationery.
★ Management Modes with coded security access.
★ Wide range of options.

Optional User Features.

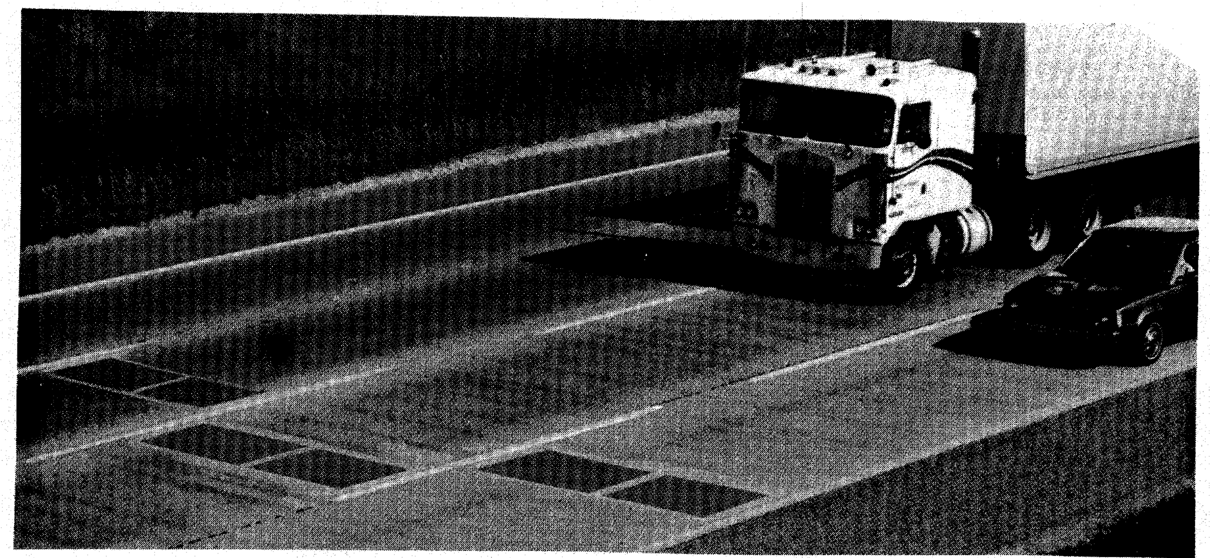
★ "Communications 1" – Provides communication with Large Scale Displays, Vehicle I.D. Equipment, Remote Printers, Traffic Light Systems.
★ "Communications 2" – Provides all the functions within "Communications 1" – along with communication with personal and mainframe computers, and modems.
★ Expandable Memory
★ Extensive Reporting Facility.
★ Expanding Software Library

MODEL ADS4

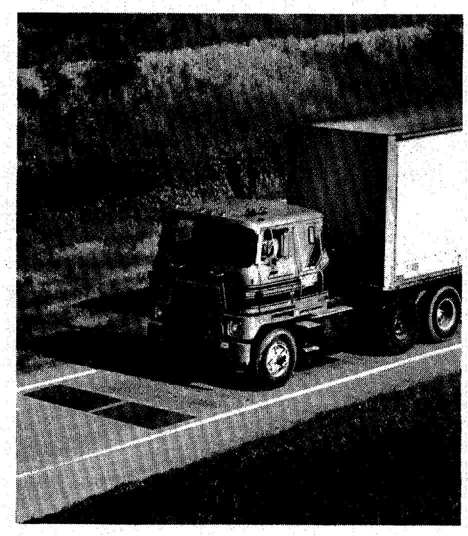
CAPACITY OF WEIGHBEAM	15000Kg (33000lbs) PER AXLE
MAXIMUM LOAD OF WEIGHBEAM	20000Kg (44000lbs) PER AXLE
ACCURACY OF INDICATED AXLE LOAD	± 50Kg (110lbs) PER AXLE
OPERATING SPEED	0 TO 4km/h (2.5 mph)
OPERATING TEMPERATURE RANGE	
LOAD INDICATOR	0°C TO + 50°C (+32°F + 122°F)
LOAD CELLS	-10°C TO + 70°C (+23°F + 158°F)
SPECIAL LOAD CELLS	-30°C TO + 50°C (-42°F + 122°F)
WEIGHBEAM PLATFORM WEIGHING AREA	3.04M × 0.76M (10ft × 2ft 6in)
POWER REQUIREMENTS	240V 50/60 Hz 120VA 115V 50/60 Hz 120VA

VEHICLE I.D.	VEHICLE 5
ADDRESS HEADER	CARRYMORE TRANSPORT LTD. MILES AWAY ROAD ANYTOWN.
DATE & TIME	2/FEBRUARY/1985 11:34
SEQUENTIAL NO.	TICKET No. 47
ZERO CONDITION	ZER ... 0000
CALIBRATION NUMBER	CAL ... 1100
AXLE WEIGHTS	AXLE 1 4.28 TONNES AXLE 2 7.86 TONNES AXLE 3 6.13 TONNES AXLE 4 6.13 TONNES
GROSS WEIGHT	TOTAL WEIGHT 24.40 TONNES

CMI-DEARBORN, INC.



Data Collection System



Sorting System

WEIGHWRITE

<u>CMI-Dynamics, Inc. Users</u>

Minnesota DOT	(4) Multi lane data collection systems.
Maine DOT	(2) Multi lane data collection systems.
Oregon DOT	(1) Multi lane data collection system with AVI.
Oregon DOT	(2) Weigh station sorting systems with AVI.
Florida DOT	(4) Weigh station sorting systems.
Caltrans	(1) Weigh station sorting system.
Wisconsin	(1) Weigh station sorting system. (2 WIMs)
North Carolina	(1) Low speed enforcement system.
Michigan	(1) Low speed commercial system.
Ontario MTC	(4) Weigh station sorting systems.
Quebec MTC	(1) High speed (main line) sorting system.
New Brunswick MTC	(3) Low speed commercial systems.
Saskatchewan MTC	(2) Data collection systems.
Alberta MTC	(1) Multi lane data collection system.
Alberta MTC	(1) Weigh station sorting system.
Alberta MTC	(1) Low speed commercial system.

GOLDEN RIVER

Weighman Portable Weight Classification System

Golden River Corporation, 7672 Standish Place, Rockville, Maryland 20855, U S A Telephone (301) 340 6800

Designed for the environment
Evolved from systems developed to operate reliably in extremes of climate throughout the world, Weighman is a rugged, battery powered microprocessor-based system built to withstand prolonged use in the field

A totally portable system
At 8kg (18lbs) and 30kg (66lbs) respectively, Weighman and the pressure sensitive weight mat are easily moved from site to site. This and rapid installation (typically 1 hour) combine to bring flexibility and scope in information gathering capabilities.

Classification versatility
For each vehicle passing the site the Weighman determines axle weight, gross weight, FHWA Scheme F class, FHWA Bridge Formula compliance, speed, length and arrival time. This data can be stored by the Weighman on an individual vehicle basis Other storage options are available which allow the user to classify vehicles into groups before storing the data. This classification can be based on vehicle class, gross weight or axle weight.

Unmanned operation and telemetry
Weighman can be left on-site unattended. Automatically stored data can be collected at any time with the Golden River Retriever This unit is also used to alter detection parameters and to monitor correct functioning of the installation – a single Retriever typically servicing 3 to 5 Weighman systems. For fully automatic or remote data retrieval, Weighman can be linked direct to the telephone network' and information passed directly to a central office for future evaluation.

Manned sites
For immediate assessment of data, hard copy is available on-site using a printer linked direct to the Weighman An alarm signal is provided to draw attention to vehicles exceeding the FHWA Bridge Formula, introducing the possibility of control and enforcement

Built in compatibility
Weighman can be used in a stand alone situation but is also compatible with other detection, retrieval and output devices produced by Golden River and can therefore be incorporated into most complex traffic pattern evaluation systems and is able to transmit pre-formatted data direct to computerised systems

Basic installation
A basic weight detection site comprises a Weighman, 2 road loops and a pressure sensitive weight mat The weight mat is surface mounted between the loops and all are linked by cables to connectors on the front panel of the Weighman Weighman can be housed in a roadside cabinet or simply chained to a suitable anchorage point The unit is inconspicuous and extremely robust

Essential additional equipment
Weighman requires the addition of a Retriever to provide data collection and user programming, a battery charger/interface and a printer or similar data analysis provision for the production of hard copy

The Weighman is programmed from the Golden River Retriever, a portable, battery powered programmer/reader unit, connected to the Weighman recorder either directly on site or remotely using modems and the telephone network.

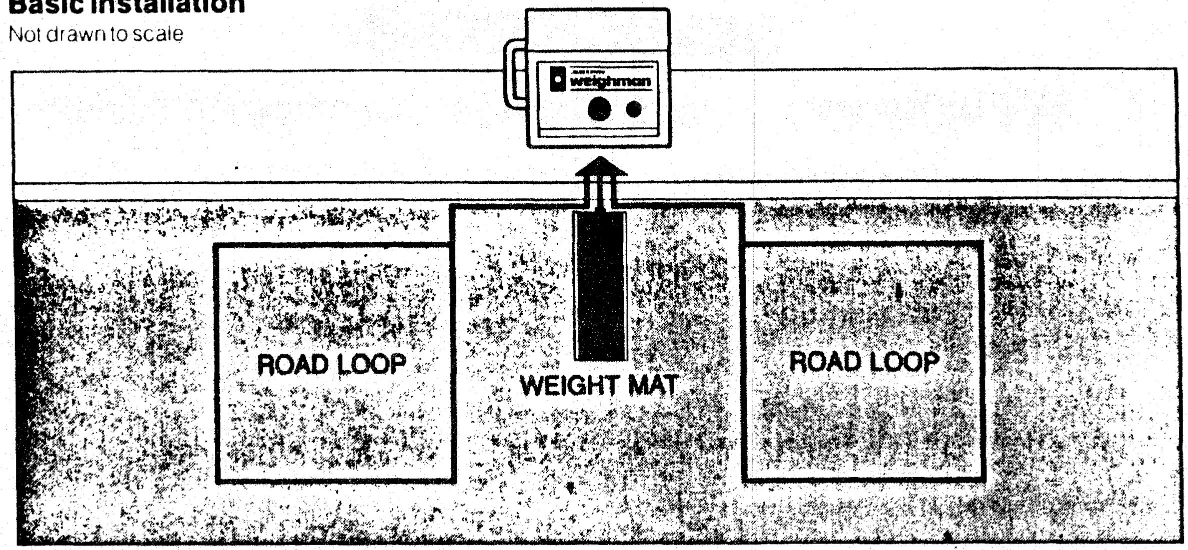
The system requires two loops for full vehicle sensing and classification. These loops can be either temporary or cut into the pavement at permanent sites.

The Weighman has a full range of capability. Maximum gross weight is 100 tons, more than double the allowable limits in the U.S. The system will record axle weights and spacings for 13 axles per vehicle.

Tests of the Weighman indicate that when the system is properly installed and calibrated, the user can expect gross weights measured by the Weighman to be typically within 10% of static gross weights.

Basic installation

Not drawn to scale



Specification

Count Interval	5 minutes to 24 hours (31 programmable intervals)
Maximum Count	4000 per bin per recording
Memory Size	44K bytes standard
Expansion	Memory capacity expandable to 256K
Preset Start	Starts recordings at programmable time and date
Accuracy	Weight: ± 10% ± 0.25 tons Speed: <60mph ± 2.5mph Length: Typical ± 19" (480mm) ± 3.3%
Battery	Sealed lead acid 6V 10Ah
Battery Life	Typically 10 days between 24 hour recharge cycle
Status	Self test output
Battery Status	Direct Weighman voltage reading on Retriever
Clock	24 hour Real Time Clock, ± 2 mins/month
Calendar	FULL YYMMDD calendar, with leap years
Identification	8 digit number, user assigned
Classification Parameters	1) Gross weights, axle weights, FHWA Scheme F Class, FHWA Bridge Formula compliance, speed, length, arrival time 2) 13 classes, 12 weight bins for each of 4 axle types 3) 13 classes and 12 gross weight ranges 4) 13 classes only 5) 12 gross weight ranges 6) 12 axle weight ranges
Telecommunications	Facility for direct telephone modem connection between Weighman and Retriever
Loop Detectors	2 multiplexed, self-tuning detectors
Loop Inductance	40μH to 200μH
Drift	Automatic compensation
Sensors	One weight mat, two road loops
Sensor Connection	12 metre cable between mat and logger
Temperature	Weighman: −40°C to +80°C (−40°F to 175°F) Weight mat: 0°C to +80°C (32°F to 175°F) (Weight mat not designed for use in snow/ice conditions)

A basic Weighman system typically comprises

One GR0349 Weighman Logger 44K standard or
One GR0381 Weighman Logger 128K
One GR0352 Weight mat
One GR0351 Oscillator and cable

One GR0306 Connector with tails
One GR0323 Loop connector
Six GR0238 Surface loop kits (12 lays)
Three GR0350 Mat fixing kits (12 lays)

Supplementary equipment/consumables

GR0521	Extra 32K memory module for Weighman (factory fitted)
GR0357	Retriever 128K memory
GR0304	Charger for Weighman or Retriever
GR0308	Charger/interface for Weighman or Retriever
GR0452	Printer
GR0350	Spare mat fixings kit (12 lays)
GR0351	Spare oscillator module for mat
GR0352	Spare mat
GR0238	Spare surface loop kit (2 lays)

GOLDEN RIVER

Data Presentation

Configuration	Data
28	12 Axle Weight Bins
43	3 Axle Weight Categories by 13 Vehicle Class Types
44	12 Gross Weight Bins by 13 Vehicle Class Types
45	13 Vehicle Classes
46	12 Gross Weight Bins
47	Detail Record by Vehicle - All Data Elements

SAMPLE OUTPUT:

CONFIGURATION 47

A PER VEHICLE DETAILED REPORT

```
*BEGIN 47 01 03500000 0 6.4 0 0188 030
*SEQ   DATE     TIME      SPD CL C LENG  VEH.TY  TOT   AXLE1 AXLE2 AXLE3 AXLE4 AXLE5 AXLE6 AXLE7 AXLE8 AXLE9 AXL10 AXL11 AXL12 AXL13
*AXLE SEPARATION                                 TOTAL        1-2   2-3   3-4   4-5   5-6   6-7   7-8   8-9   9-10 10-11 11-12 12-13

02511 85/05/03 10:10:32.3 056 03 C 017.0         005640 02820 02820
02511                                             010.8       010.8

02512 85/05/03 10:10:33.2 056 09 N 053.8         084224 08648 19364 18236 19928 18048
02512                                             050.0       014.4 004.3 027.5 004.0

02517 85/05/03 10:10:59.6 059 09 C 055.1         025756 05828 06580 05452 04512 03384
02517                                             053.8       012.5 004.3 032.7 004.2

02518 85/05/03 10:11:06.1 060 09 C 049.8         028012 06392 08272 04136 05640 03572
02518                                             046.3       013.5 004.3 024.6 004.0
```

WEIGHMAN USERS

State of Colorado
Department of Highways
4201 East Arkansas Avenue
Denver, Colorado 80222

ATTN: C. Peterson (303-757-9488)

State of Alaska
Department of Transportation
Mail Stop 2500
Pouch Z
Juneau, Alaska 99811

ATTN: Karen Morehouse (907-465-2777)

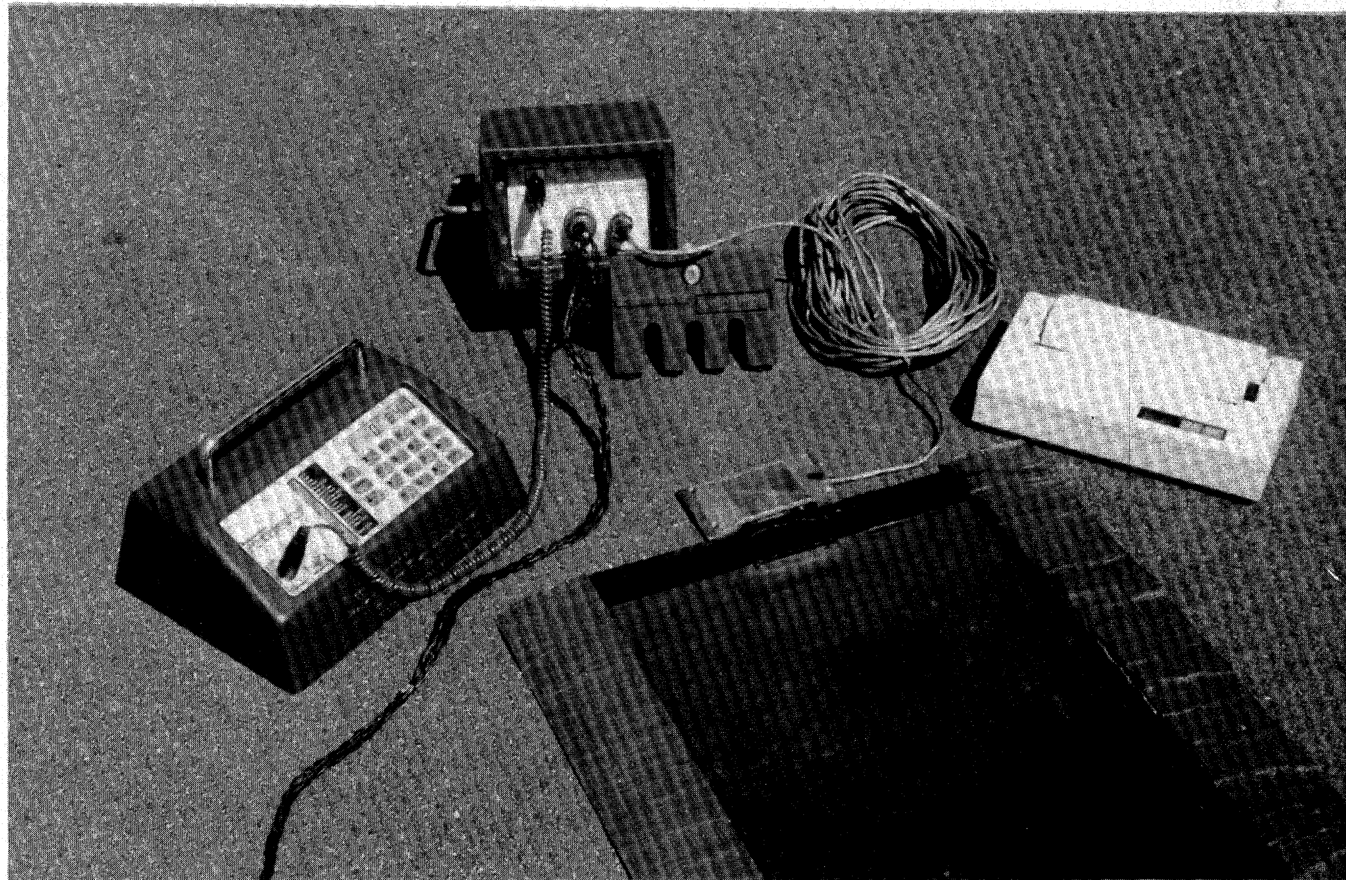
State of Florida
Department of Transportation
605 Suwannee Street
Burns Building
Tallahassee, Florida 32301

ATTN: Rick Reel (904-488-4318)

State of Missouri
Department of Highways & Transportation
100 West Capitol Avenue
Jefferson City, Missouri

ATTN: Allen Heckman (314-751-4688)

GOLDEN RIVER



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RADIAN
CORPORATION

WIM
WEIGH-IN-MOTION SYSTEM

WIM-1E®...Weighing Vehicles in Motion

WIM SYSTEM...Accuracy, Speed, Safety and Savings in Highway Weighing Operations

Radian's WIM System is an advanced microcomputer Weigh-in-Motion System which automatically weighs vehicles moving at highway speeds. Traffic safety as well as agency operator safety is realized because vehicles are not stopped to be weighed and dimensioned. In addition, simultaneous multiple lane weighing further reduces safety hazards as vehicles are not required to change lanes to be weighed.

WIM SYSTEM Applications

Ease of installation and operational adaptability are important features of the WIM System. Where permanent installations are not practical, the WIM System can be moved from one location to another with a minimum set-up time (30 minutes for a two-man crew). The WIM System's microprocessor design permits it to be adapted to various operational requirements.

WIM-1E® ENFORCEMENT SYSTEM

The enclosed diagram shows a WIM-1E® System in a weight law enforcement configuration. In this configuration, the WIM-1E® can automatically perform axle and gross weight law enforcement, conduct traffic control operations, compute fines and provide printouts from data stored on flexible diskette.

All vehicles except passenger cars are directed into the weigh station or can be sorted with in-highway scales and message signs. Vehicle detectors placed in the main highway lanes identify vehicles attempting to avoid the weigh station. The sorting scale, buried in the ramp lane, weighs each vehicle passing over it at speeds up to 45 mph (72 km/h). The vehicle is classified by the WIM processor according to single or tandem axle configuration. Vehicle weight is computed to within ±5 percent statistical accuracy at this point. The weight information is compared to legal axle and gross limits, including Bridge Formula weights. Preventing further delay, an overhead traffic signal directs legal vehicles to return to the main highway. Potentially overweight vehicles are directed to a precision, low-speed scale. Alarms alert the system operator if a vehicle takes the wrong direction.

WIM SYSTEM ENFORCEABLE ACCURACY

Vehicles pass over the low-speed, precision scales at a maximum speed of 10 mph (16 km/h), and weights are computed to within ±1 percent statistical accuracy. A second traffic signal directs overweight vehicles to a parking facility, while vehicles within legal limits are directed back to the main highway. The WIM-1E® can automatically compute fines and accept operator-entered vehicle data.

Vehicle Information acquired by WIM SYSTEM

TYPE	RANGE
SYSTEM MEASURED	
1 Wheel Weight	0 19,842 lbs (0 9t)
2 Axle Weight	0 39 684 lbs (0 18t)
3 Gross Weight	Sum of Axle Weights
4 Vehicle Speed	5-80 MPH (8-129 Km/h)
5 Axle Count	2-15
6 Axle Spacing	2-40 Ft (0 6-12 2 Meters)
7 Vehicle Length	10-120 Ft (3 1-21 3 Meters)
8 Time of Day	0 24 Hrs
9 Calendar Time	Day, Month, Year
OPERATOR SUPPLIED	
10 Visual Vehicle Classification	Code 10 Axle configurations
11 Visual Vehicle Identification	10 Digits Alphanumeric
12 Other Identification Data	7 Digits Site Location Operator Etc

WIM SYSTEM Operation Features

Standard

- Weight of vehicles in motion at speeds up to 80 mph (129 km/h)
- Weight of up to four traffic lanes simultaneously
- Weight of wheels (single or dual) to detect imbalanced loads
- Automatic compensation when wheel weights differ by more than 50 percent
- Automatic compensation when one wheel load transducer fails
- Programmable weight threshold
- Interchangeable wheel load scales in all applications
- Scale component no heavier than 140 pounds (64 kilograms)
- Wheel load chassis removeable from roadbed without special equipment for mobile applications
- Automatic vehicle classification (based on axle spacing)
- Automatic scale balance and re-zero
- Automatic self-tuning loop detectors
- Automatic self-test diagnostics and reporting
- Total traffic count in up to four lanes--independent of weighing
- Speed classification in up to four lanes--independent of weighing
- Data storage on IBM compatible flexible diskette
- Operator input via keyboard
- Battery-powered date and time-of-day clock
- Lightning protection

WIM SYSTEM Component Characteristics

Transducer (Standard)

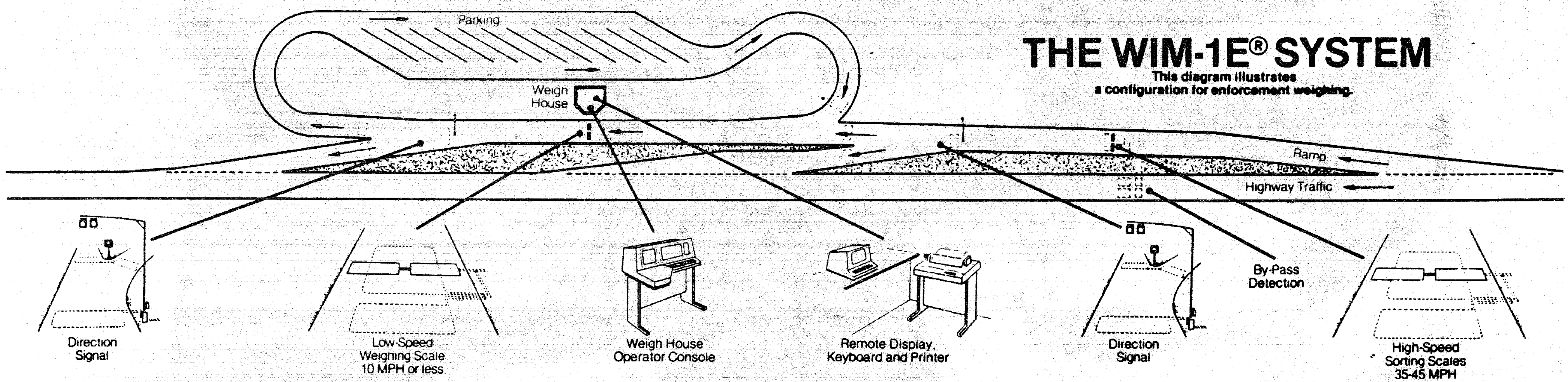
- Rainhart Model 882, triangular-articulated plate design (patented by Dr. Clyde E. Lee)
- Two transducers per lane (weighing application)
- Four lanes maximum simultaneous weighing
- Transducer Weight — No component heavier than 140 lbs. (64 kilograms)
- Weighing Capacity — 19,842 lbs. (9000 kilograms)/transducer (standard); higher capacity available as an option
- Vehicle Speed — High-speed transducer--60 mph (96 km/h) ±10% statistical accuracy
Mid-speed transducer--40 mph (64 km/h) ±5% statistical accuracy
Low-speed transducer--10 mph (16 km/h) ±1% statistical accuracy

WIM SYSTEM Users

Alabama, Florida, Georgia, Louisiana, Mississippi
Nevada, New Mexico, Texas, Virginia, Wyoming

THE WIM-1E® SYSTEM

This diagram illustrates a configuration for enforcement weighing.



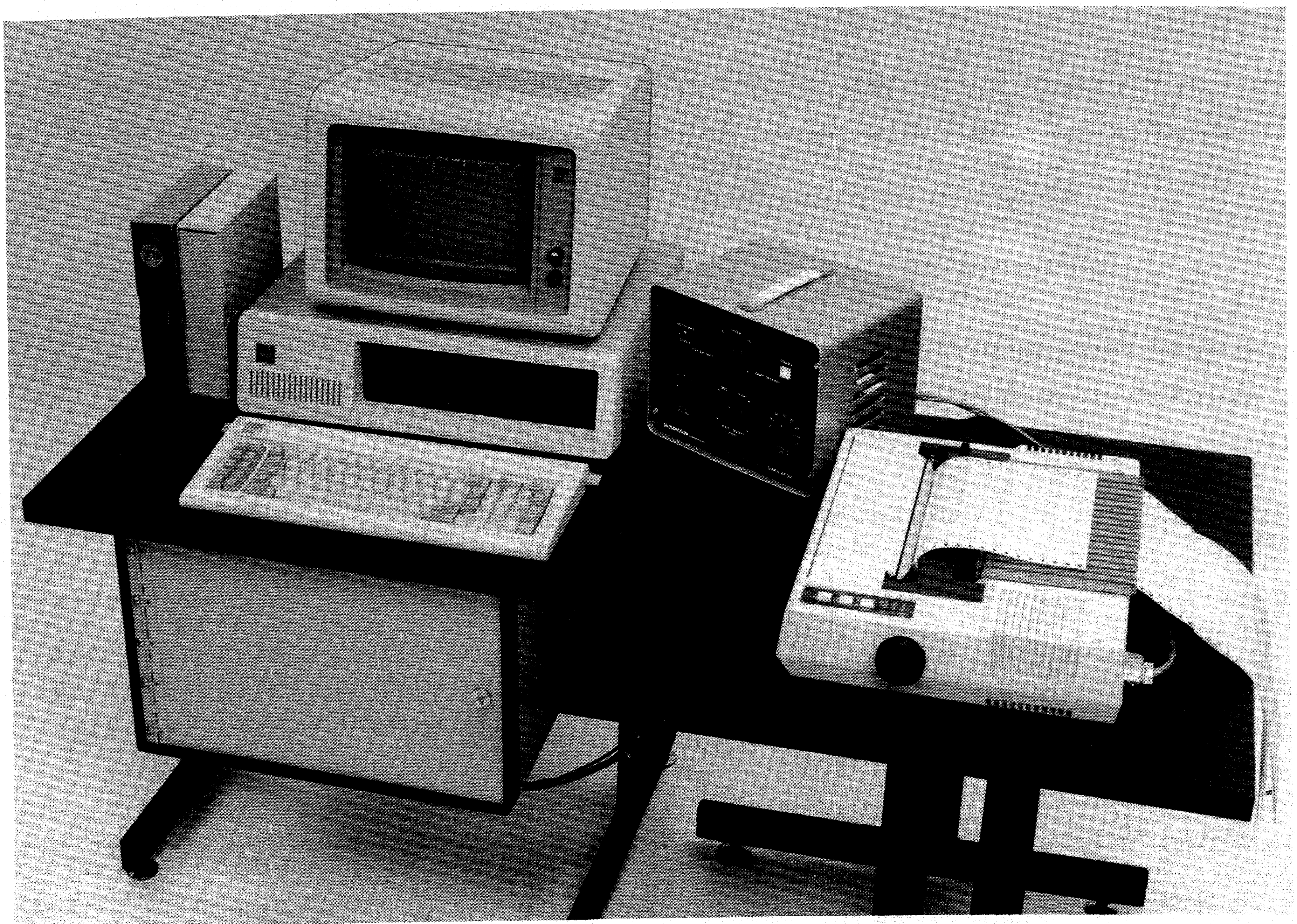
WIM-1E® System consists of Operator's Console, Flexible Diskette, CRT/Keyboard Display, Keyboard/Printer, Loop Detectors, Junction Box and Inductance Loops, Transducers, Directional Signal Controls

<u>System</u>

- Selectable weight threshold
- Measurement axle spacing and vehicle length
- Unattended or operator-controlled operation
- High reliability, low maintenance
- Mobile or fixed operation capability
- Easy expansion to meet future needs
- Remote data transmission capability

Related WIM Products

- WIM-1D® Mobile/Fixed Statistical and Enforcement
- WIM-1RM® Remote Mobile/Fixed Statistical and Enforcement with remote data telemetry
- WIM-1SR® Mobile/Fixed Statistical and Enforcement ruggedized for harsh environments
- WIM-1T® Fixed Toll Weight Applications
- TC-100 Miniature Battery-Operated Traffic Counter
- VCS-1005 Weight Vehicle Classifier
- VCS-2000 Axle Configuration Vehicle Classifier
- Special Traffic Control and Monitoring Systems



RADIAN CORPORATION

Siemens weighing-in-motion... Portable, Mobile and Stationary Systems.

Siemens, an international leader in advanced products and systems for a wide variety of industrial and commercial applications offers a series of Weighing-in-Motion (WIM) systems specifically designed for dynamic measurement of truck traffic. Available in **portable, mobile and stationary** configurations for use as statistical systems for highway planning; screening systems for enforcement weighing; and as measuring systems for toll collection and bridge protection, Siemens WIM systems:

- Analyze emerging trends in traffic... affording highway maintenance and planning departments the vital information and statistics they need for today—and tomorrow.
- Provide law enforcement agencies with accurage long- and short-term data for identification of load violators and proper assessment of penalties.
- Ensure maximum useful life of roadways and bridges through controlled design life...maintaining maximum highway safety while protecting the taxpayers' highway investment.

Siemens WIM systems provide reliable performance across the applications spectrum to include high-speed, moderate-speed and low-speed measurement situations, as your requirements dictate. Modular in design for maximum flexibility...and system expandability, every member of our WIM system family offers you these important benefits:

- Increased vehicle throughput.
- Increased speed of operation, through dynamic, in-motion capabilities, reducing air pollution, fuel consumption and truck driver time.
- Increased safety...dynamic measurement keeps traffic moving. No more hazardous highway backups.
- Increased deterrent...accurate, high-volume screening and spot-checking discourages repeat offenders.
- Increased enforcement...eliminates weigh-station "by-passing" and facilitates proper assessment of penalties.

States presently using SIEMENS-ALLIS Weigh-In-Motion equipment

California	Planning and weighstation screening
Delaware	Weighstation screening
Massachusetts	Portable enforcement screening
Pennsylvania	Weighstation screening, portable screening
Washington	Planning

For further information please contact:

Mr. Vincent Cipriano
Project Manager
Weigh-In-Motion Systems
Siemens-Allis, Inc.
1 Computer Drive
Cherry Hill, NJ 08034
(609) 424-9210

WIM 100 System

Designed for use in statistics gathering (highway planning), toll collection and traffic data counting applications, the WIM 100 System offers the convenience of 2-week unattended operation. Powered by two 12 volt batteries, the system records, on magnetic tape, the following data:

- Axle count
- Axle load classification
- Vehicle count
- Hourly data recording

WIM 200 System

Designed for statistics gathering in highway planning applications, and as a measurement system in toll collection and bridge protection applications.

The WIM 200 System provides CRT display magnetic data recording and hardcopy printout of data including:

- Axle load classification
- Gross weight classification
- Vehicle count
- Vehicle classification
- Vehicle length
- Vehicle classification

WIM 300 System

The WIM 300 System is a portable screening system for enforcement weighing applications, affording accurate dynamic measurement of up to 175 trucks per hour. Low-profile, environmentally-rugged weigh pads are used for measurement of wheel load, axle load and gross weight, which are indicated on an LCD visual display featuring hand-held remote controlled operation. Overweights automatically trigger a distinct, audible alarm and provide a hard copy print-out.

The WIM 300 System records and displays the following data:

- Wheel load
- Axle load
- Overload detection
- Gross weight
- Vehicle count

WIM 400 System

For applications requiring the ultimate in screening capabilities for enforcement weighing, or statistics gathering for highway planning agencies, the WIM 400 System . . . for use in mobile (van-based) or stationary (scale house) configurations.

Major elements of the WIM 400 System central control unit includes:

- Siemens microcomputer
- Siemens WIM 400 System software
- Siemens Alphanumeric keyboard
- Siemens Magnetic Card Reader
- Siemens CRT video monitor
- Siemens PT 88 dot matrix printer

The WIM 400 System provides CRT display magnetic data recording and hardcopy printout of the following data:

- Wheel load
- Single/multiple axle load
- Axle spacing
- Gross weight
- Axle and Gross Weight
- Manipulation detection
- Vehicle classification
- Vehicle length
- Vehicle load imbalance
- Vehicle speed
- Penalty form printout
- Date/time/vehicle identification

SIEMENS-ALLIS

WIM 400 System

(TYPICAL PRINT-OUT GENERATED BY A VIOLATION).

DATE: 01/28/85 TIME: 16:44:59 W.I.M.-STATION NO: 14

MEAS-NO: 25864 CLASS: 53 SPEED: 18.3MPH LENGTH: 51.7FT

AXLE	LEFT	RIGHT	WEIGHT	ALLOW.	SPACE	OWT.	ERR.
A1	6.39	6.32	12.7	20.0			
A2	8.73	8.72	17.5	18.0	15.0		
A3	9.13	9.16	18.3	18.0	5.8	0.3	
2-3	17.86	17.88	35.8	36.0	***		
A4	8.23	8.06	16.3	22.4	21.3		
A5	8.47	8.48	16.9	22.4	8.2		
4-5	16.60	16.54	33.2	44.8	***		
2-5	BRIDGE FORM.		69.0	65.5	35	3.5	

GROSS WEIGHT : 81590 LBS OVERLOAD : 1590 LBS

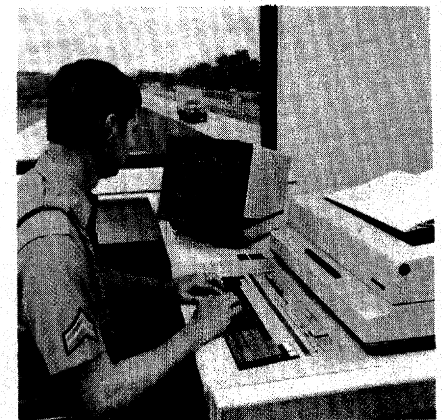
* **The combination of axle #2 and axle #5 exceeded the bridge gross weight formula by 3500 pounds. Other combinations of axles may also exceed the formula but axle #2 and axle #5 is the worse case condition on this vehicle.**

DATA AND ACCURACY REQUIREMENTS FOR WEIGH-IN-MOTION SYSTEMS

Measurement	Range	Resolution	Error $\bar{x}$	Error s	n	Speed,mph	Sensor	Signal
Single Axle Weight	40 k lbs.	100 pounds	± 4%	7%	30	3 - 9.9	Wheel Scales	DC analog
					40	10 - 19.9		
	+50% Overload Capacity				160	20 - 29.9		
					160	30 - 29.9		
					40	40 - 49.9		
					400	All Speeds		
Tandem Axle Weight	80 k lbs.	100 pounds	± 4%	5%	20	10 - 19.9	Wheel Scales	DC analog
					80	20 - 29.9		
					80	30 - 39.9		
	+50% Overload Capacity				20	40 - 49.9		
					200	All Speeds		
Gross Weight	No Limit	100 pounds	± 4%	4%	20	10 - 19.9	Wheel Scales	DC analog
					80	20 - 29.9		
					80	30 - 39.9		
					20	40 - 49.9		
					200	All Speeds		
Vehicle Presence	Yes or No	-	-	-	-	-	Detection Loops	Logic Signal
Vehicle Speed	5 - 70 mph	0.1 mph	±0.2mph	0.5mph	200	-	Wheel Scales	Computed
* Axle Spacing	70 ft.	0.1 ft.	±0.2ft	0.3ft.	200	-	Wheel Scales	Computed
Axle Count	2 - 13	1	-	-	-	-	Wheel Scales	DC analog
Time, Date	24 Hour Clock Day,Month,Year	1 sec						Logic

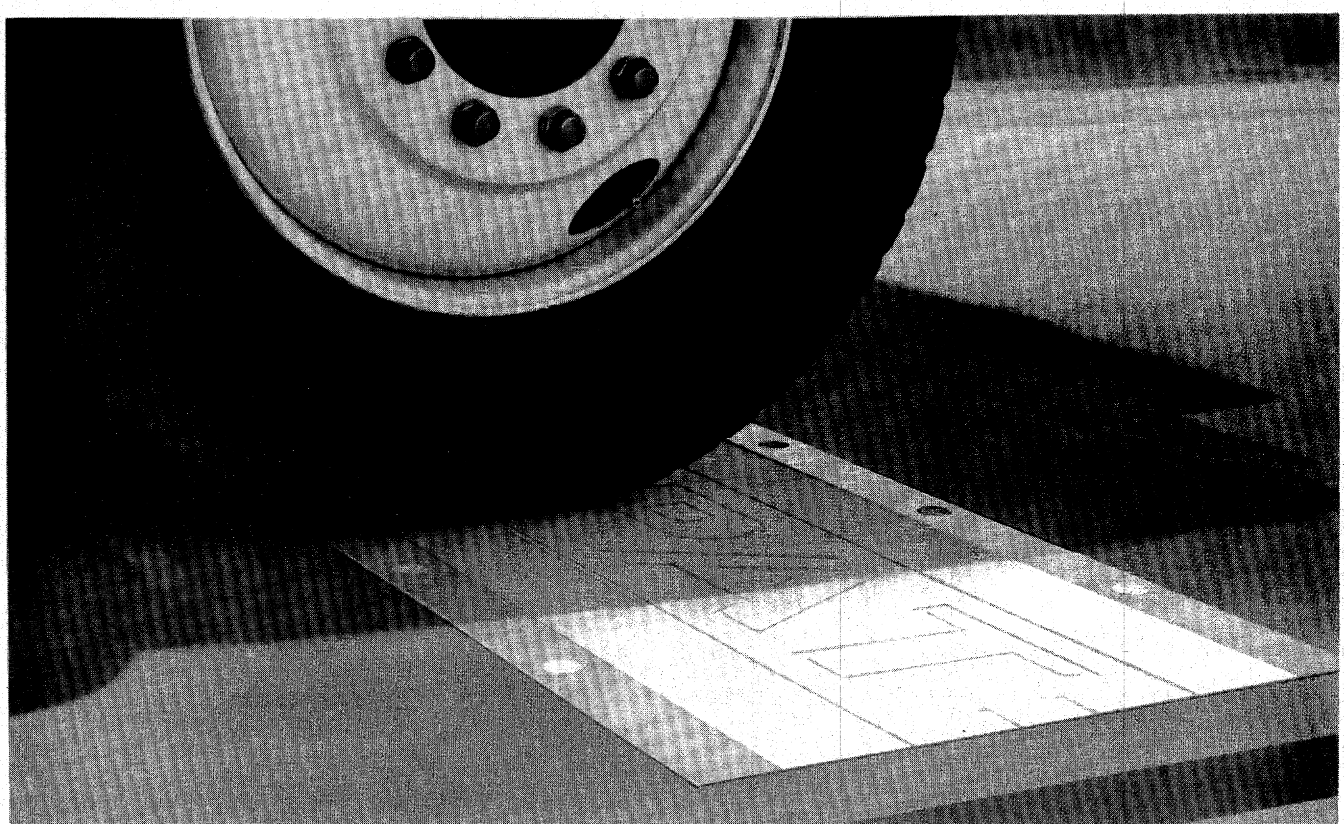
NOTES: $\bar{x}$: Average Error, s:Standard Deviation, n:Minimum Sample Size for Calculating $\bar{x}$ and s,Kips=1000 lbs

** Axle spacing accuracy is directly related to maintaining a constant vehicle speed through the WIM scale.*



WIM - 400 Computer system, installed at the Delaware Weighstation.

Portable WIM 300 system weighpads installed in roadway cut-out. When not in use dummy grids are installed.



Permanently installed WIM system weighpad. Low cost - low profile installation, only 2 inch deep cut out required.

Streeter Richardson
Mangood Corporation

MODELS 5150 XT & XTP

Weighing In Motion at Highway Speeds

The 5150 XT Systems consist of:

RollWEIGH® 5150 Instrumentation:

- a microcomputer Control Unit
- a Scale Interface Processor Unit
- a page Printer

Weight Sensing Specifications:

For Permanent Applications:

Weighing Plate:

Size: 64″ (162.5 cm) L
× 19.9″ (50.5 cm) W
× .94″ (2.4 cm) D
(2 required per lane)
Loops and axle sensors are used to detect vehicle presence and measure axle spacings.

For Portable Applications:

Weighing Mat(s):

Size: 20″ (510 mm) W
× 71″ (1800 mm) L
× .31″ (8 mm) H
connecting cables.
Loops are used to detect vehicle presence.

- The Model 5150 XT can be used attended or unattended at a fixed site for data collection.
- The Model 5150 XTP can be used for data collection as a portable unit or for enforcement screening.

The 5150 automatically weighs and records for each vehicle:

- sequential vehicle number
- time/date
- lane
- axle weights
- axle spacings
- total wheelbase
- vehicle classification (user programmable)
- vehicle speed
- gross weight
- potential violations including Bridge Formula

System Features

Individual vehicle data is saved for further processing by a host computer. Data can be transferred via modem communication, or via 5¼″ floppy disk which is fully compatible with IBM PC microcomputers. A software package is available for statistical analysis of the truck data.

Vehicle classifications are user programmable, allowing additional subcategories to the standard FHWA 13 channel vehicle classifications, or all new categories should the standards change. In addition, the user can select which vehicle categories are to be displayed, printed, and stored. All other traffic is counted by classification in hourly intervals.

Operation

The system weighs trucks in motion as they move across a weigh in motion scale with RollWEIGH 5150 instrumentation. Individual axle weights, spacings, axle group weights, and gross weights are computed and compared against preset values. If the vehicle is over those values, it is noted on the vehicle record, and flashed in reverse video on the screen.

Operation: Traffic flows at normal highway speeds. All data is displayed and collected automatically—attended or unattended.

Features & Benefits:

- Versatility allows storage on a disc or tape.
- This reliable, solid-state microprocessor design assures accurate collection and classification of all information.
- These sites can also be equipped with a Model 505 XT Telac Weigh In Motion Field Recorder. Automatic calling by a Central Controller transfers data daily.

```
           ** REALTIME PRINTOUT OF 5150 DATA **

**********************************************************
STATION: 002    LOCATION: I-57/I-70 Effingham, Illinois
----------------------------------------------------------
2330     59 mph   Lane: 1   08:46   11-14-1985
Class: 5A-ST      Total      1       2       3       4       5
Weight (kips)      63.5     9.7    15.1    14.5    12.0    12.2
Spacings (ft)      55.6        14.0     4.3    32.5     4.8
----------------------------------------------------------
```

Streeter Richardson
Mangood Corporation

MODEL 5150 SS

Weighing In Motion on any Static Scale

Use any static scale as a weigh in motion system with a StreeterAmet 5150 SS system. Move trucks through your weigh stations faster:

- Weigh all trucks in motion as they drive over the static scale.
- Excess gross or axle weights are identified.
- Reweigh identified violators statically for citations...without traffic back-ups!
- Available with a portable platform.

This system provides:

- Low cost weigh in motion
- Reduced delays at weigh stations
- State of the art microprocessor design
- Modular construction for ease of maintenance

The 5150 SS Weigh In Motion System consists of:

RollWEIGH® 5150 Instrumentation:
- a microcomputer Control Unit
- a Scale Interface Processor Unit
- a page Printer
- a static/motion selector switch (switches load cell input)

Weighbridge Specifications:

Use this system with a new or existing weighbridge. Multi-platforms arrangements use one of the platforms. Calibration handles differences in weighbridge sizes. Loops and axle sensors are used to detect vehicle presence and measure axle spacings.

Operation

The system weighs trucks in motion as they move across a static scale with RollWEIGH 5150 instrumentation. Individual axle weights, spacings, axle group weights, and gross weights are computed and compared against preset values. If the vehicle is over those values, it is directed to the "run around" road to return to the scale to be reweighed statically, using certifiable static weighing equipment meeting NBS H-44 requirements.

Weighing In Motion on any Static Scale

Application: Weigh In Motion on your new or existing static scale. Just add the Model 5150 SS instrumentation package.

Operation: All traffic moves across the static scale. Only trucks with excess axle or gross weights are reweighed statically.

Features & Benefits:
- Using the Model 5150 SS with existing scales reduces or eliminates weigh station delays.
- Only violators are stopped for weighing.
- You can get the advantages of weighing in motion at a very low cost.

The 5150 automatically weighs and records for each vehicle:

- sequential vehicle number
- time/date
- lane
- axle weights*
- axle spacings
- total wheelbase
- vehicle classification (user programmable)
- vehicle speed
- gross weight
- potential violations

*Using methods protected by the following patents:
US Patent #4,258,809; Canadian Patent #1093106. Other patents pending.

System Features

Individual vehicle data is saved for further processing by a host computer. Data can be transferred via modem communication, or via 5¼" floppy disk which is fully compatible with IBM PC microcomputers. A software package is available for statistical analysis of the truck data.

Vehicle classifications are user programmable, allowing additional subcategories to the standard FHWA 13 channel vehicle classifications, or all new categories should the standards change. In addition, the user can select which vehicle categories are to be displayed, printed, and stored. All other traffic is counted by classification in hourly intervals.

Streeter Richardson
Mangood Corporation

MODEL 5150 SE
Weighing In Motion Combining Screening & Enforcement

Traffic back-ups associated with busy port of entry scales can be eliminated with the use of the StreeterAmet Model 5150 SE Package. Combined with any configuration of static scale, this system screens *all* truck traffic.

- All trucks proceed on the by-pass lane at 30 to 40 mph.
- Trucks with excess axle, tandem, or gross weights, and those overspeed or off scale are directed to the static scale.
- Identified violators are reweighed and citations issued.
- Overcrowded weigh stations become a thing of the past!

Combine this Weigh In Motion System with any static enforcement scale. The 5150 SE Weigh In Motion System consists of:

- a microcomputer Control Unit
- a Scale Interface Processor Unit
- a page Printer
- a weigh plate system, or a low profile platform system
- other sensors as required

Operation

The system weighs trucks in motion as they move across a weigh in motion scale with RollWEIGH 5150 instrumentation. Individual axle weights, spacings, axle group weights, and gross weights are computed and compared against preset values. If the vehicle is over those values, it is directed to the static scale to be reweighed statically, using certifiable static weighing equipment, meeting NBS H-44 requirements.

The 5150 automatically weighs and records for each vehicle:

- sequential vehicle number
- time/date
- lane
- axle weights
- axle spacings
- total wheelbase
- vehicle classification (user programmable)
- vehicle speed
- gross weight
- potential violations

Weighing In Motion Combining Screening & Enforcement

Application: The most effective system available for high traffic port of entry locations. The 5150 SE offers maximum traffic flow using a combination screening and enforcement system.

Operation: All traffic is screened in the bypass lane. Indicated violators are directed to the static scale and reweighed—without any traffic interruption!

Features & Benefits:

- This high speed electronic system screens ALL truck traffic.
- Automatic operation eliminates weigh station delays and shutdowns.
- All violators are identified because you screen all traffic.

System Features

Individual vehicle data is saved for further processing by a host computer. Data can be transferred via modem communication, or via 5¼" floppy disk which is fully compatible with IBM PC microcomputers. A software package is available for statistical analysis of the truck data.

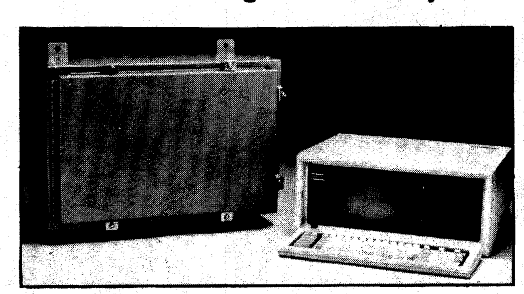
Vehicle classifications are user programmable, allowing additional subcategories to the standard FHWA 13 channel vehicle classifications, or all new categories should the standards change. In addition, the user can select which vehicle categories are to be displayed, printed, and stored. All other traffic is counted by classification in hourly intervals.

Streeter Richardson
Mangood Corporation

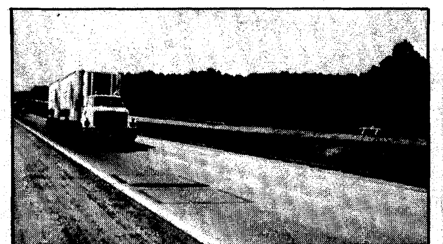
Streeter Richardson Division
155 Wicks Street • Grayslake, IL 60030
Tel: 312/223-4801 • Telex: 6871111

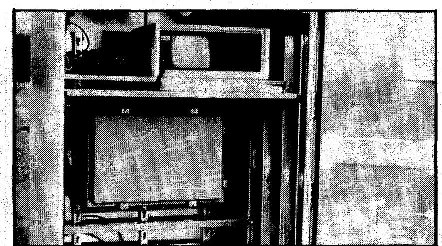
For additional information
call toll-free
800-323-9441

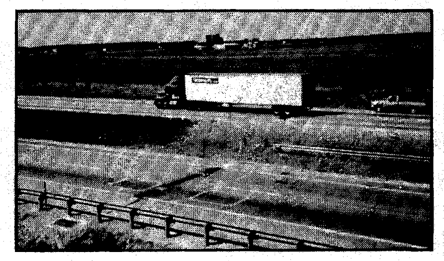
The 5150 SE Weigh in Motion System



RollWEIGH Instrumentation Package







Above—At a permanent site, the data can be transferred via a modem or by disk.

Top Left—The mat and temporary loops are easy to install.

Left—Permanent sites allow gathering of data unattended.

The 5150 XT System

DATA DISPLAY
(A typical CRT Screen Readout)

Vehicle Identification ①

Speed Across In Motion Scale ②

Total Vehicle Weight ③

Total Vehicle Length ④

Number of Axles on Vehicle ⑤

"*" Indicates Overweight Condition ⑥
(Automatically Directed to Static Scale)

Individual Axle Weights ⑦

Indicates Excessive Speed for Accuracy ⑧
(Automatically Directed to Static Scale)

Tandem Weights (Accumulated Weight of Any ⑨
2 Axles Less Than 6' Apart)

Spacing Between Axles ⑩

"B" Indicates All Traffic to Bypass. ⑪
"S" Indicates All Traffic to Static Scale

"S" Indicates Overspeed or Underspeed ⑫
"O" Indicates Off Scale and "*" Indicates Overweight

```
⑪
B—STATION: I-94E   OPERATOR: 123   TIME: 23:59   DATE: 3-16-84—
①              ②                ③                    ④                ⑤
0001 SPEED:     25.0 TOTAL WT.:     198.0  TOTAL LENGTH: 94.5 NO. AXLES: 11
     WEIGHTS:      18.0  18.0  18.0  18.0  18.0  18.0  18.0  18.0  18.0  18.0  18.0
     TAN WTS:            36.0        36.0        36.0        36.0        36.0
     SPACING:         10.0  3.9  14.0  3.9  17.5  3.9  14.3  3.9  13.2  3.9

0002 SPEED:     31.2 TOTAL WT.:      60.0  TOTAL LENGTH: 56.0 NO. AXLES: 5
     WEIGHTS:      7.7  13.7  13.1  12.6  12.9
⑫OS  TAN WTS:            26.8       25.5
⑧    SPACING:         10.0  4.0  32.0  4.0
                                       ⑥
0003 SPEED:     10.2 TOTAL WT.:     200.1* TOTAL LENGTH: 67.8 NO. AXLES: 8
⑦    WEIGHTS:      20.0  50.1*  40.7*  18.0  18.0  18.0  17.1  18.2
*    TAN WTS:            90.8*       36.0          35.3
     SPACING:         10.0  3.8  14.3  3.7  10.4  15.7  3.9

0004 SPEED:      6.4 TOTAL WT.:      17.2  TOTAL LENGTH: 23.6 NO. AXLES: 3
     WEIGHTS:      1.8   8.2   8.2
⑨    TAN WTS:            16.4
⑩    SPACING:         14.0  3.6
```

X. CONFERENCE ATTENDEES

2ND NATIONAL W.I.M. CONFERENCE
ATTENDANCE REPORT
ATLANTA, GEORGIA

NAME		ADDRESS		
ADAMS	TOM	1100 CIRCLE 75 PKWY SUITE 945 LOCKHEED-GETEX	ATLANTA	GEORGIA 30339
ALDRIDGE	WRIGHT	801 BROADWAY FHWA	NASHVILLE	TENNESSEE 37203
ALTOBELLI	DANATO	1720 PEACHTREE RD,NW,SUITE 300 FHWA	ATLANTA	GEORGIA 30034
ATTARAN	DR. KAZEM	1120 N ST CALIFORNIA D.O.T.	SACRAMENTO	CALIFORNIA 95807
BALL	ROBERT	2540 EXEC CTR,W SUITE 208 FLORDIA D.O.T.	TALLAHASSE	FLORIDA 32301
BARNUM	LEO	1221 E. BROAD ST. DEPT OF HWYS & TRANS	RICHMOND	VIRGINIA 23219
BARRETT	DEAN	P.O. BOX 5051 TX STATE DEPT/HWYS & PUBLIC TRANS	AUSTIN	TEXAS 78763
BARROWS	WILLIAM	2300 SOUTH DIRKSEN PKWY ILLINOIS D.O.T.	SPRINGFIELD	ILLINOIS 62764
BATSON	DON	8501 MO-PAC BLVD RADIAN CORP	AUSTIN	TEXAS 78766
BEDARD	RICHARD	155 WICKS STREET STREETER AMET	GRAYSLAKE	ILLINOIS 60030
BEEZLEY	GENE	155 WICKS STREET STREETER RICHARDSON	GRAYSLAKE	ILLINOIS 60030
BELL	CHRIS	1800 S W WHITESIDE DR CRC	CONALLIS	OREGON 97333
BELZ	ALBERT	STATE OFFICE BUILDING MAINE D.O.T.	AUGUSTA	MAINE 04333
BERGAN	ARTHUR	735 EMERALD WAY U. OF SASKATCHEWAN	SASKATOON CANADA	SASKATCHEWAN S7J 4E3
BERGERON	ROCH	200 EAST DORCHESTER D.O.T. OF QUEBEC	QUEBEC CITY	QUEBEC G1K 5Z1
BIGGS	ELMER	1614 FED. BLDG,31 HOPKINS PLZ FHWA,REGION 3	BALTIMORE	MARYLAND 21201
BIRD	ROBERT	ROOM 207,STATE OFFICE BLDG DEPT. MOTOR VEHICLE ENF.	FRANKFORT	KENTUCKY 40622
BISHOP	HENRY	STATE OFFICE BLDG RHODE ISLAND D.O.T.	PROVIDENCE	RHODE ISLAND 02903
BLACKWOOD	A.	1900 WASHINGTON STREET,EAST WEST VIRGINIA DEPT OF HWYS	CHARLESTON	WEST VIRGINIA 25305
BOSCH	HAROLD	6300 GEORGETOWN PIKE FHWA-HNR-10	MCLEAN	VIRGINIA 22101
BOTELHO	FRANK	400 7TH ST.S.W. FHWA	WASHINGTON	D.C. 20590
BOWLIN	PAUL	1409 COLISEUM BLVD ALABAMA D.O.T.	MONTGOMERY	ALABAMA 36130
BOWMAN	GROVER	1720 PEACHTREE RD,NW,SUITE 300 FHWA	ATLANTA	GEORGIA 30367
BREITWIESER	JOHN	575 N PENNSYLVANIA ST,RM 254 FHWA	INDIANAPOLIS	INDIANA 46204

BREWER	DAVID	4423 EMERY INDUSTRIAL PKWY BRIDGE WEIGHING SYSTEMS,INC.	WARRENSVLE HGHT	OHIO 44128
BROWN	JACK	605 SUWANNEE ST;MS 36 FLORDIA D.O.T.	TALLAHASSEE	FLORIDA 32301
BYRD	L.	444 N CAPITOL ST., NW, SUITE 343 AASHTO	WASHINGTON	D.C. 20001
CABLE	JAMES	800 LINCOLNWAY IOWA D.O.T.	AMES	IOWA 50010
CAMERON	DONALD	P. O. BOX 10147 FHWA	LANGSING	MICHIGAN 48901
CANADY	RICHARD	2330 S DIRKSEN PKWY,RM 9 ILLINOIS D.O.T	SPRINGFIELD	ILLINOIS 62764
CANDY	DICK	155 WICKS ST STREETER-RICHARDSON	GRAYSLAKE	ILLINOIS 60030
CANTWELL	TOM	P.O. BOX 7192 WISCONSIN STATE PATROL	MADISON	WISCONSIN 53702
CHADICK	JOHN	PO BOX 430 DELAWARE STATE POLICE	DOVER	DELAWARE 19903
CHANEY	ROBERT	4501 SO 2700 WEST UTAH D.O.T.	SALT LAKE CITY	UTAH 84119
CHAPMAN	STEVEN	8000 CALANDER RD GENERAL ELECTRODYNAMOCS	ARLINGTON	TEXAS 76017
CHARLES	JAMES	300 N. CLIPPERT MICHIGAN STATE POLICE,M.C.D.	LANSING	MICHIGAN 48913
CHEATHAM	JAMES	18209 DIXIE HWY FHWA, REGION 5	HOMEWOOD	ILLINOIS 60430
CHRIST	JAMES	144 CREEK RD PENNSYLVANIA D.O.T.	CAMP HILL	PA 17120
CIPRIANO	VINCENT	1 COMPUTER DRIVE SIEMENS-ALLIS	CHERRY HILL	NEW JERSEY 08034
COFFINBARGAR	WILLIAM	31 LANSING DR. ILLINOIS D.O.T.	SPRINGFIELD	ILLINOIS 62703
CORBIN	A.	P.O. BOX 191 SOUTH CAROLINA HIGHWAY PATROL	COLUMBIA	SOUTH CAROLINA 29202
COVILLE	PATRICK	RUE DELLA PASSERELLE THERMOCOAX ET CIE	SURESNES	FRANCE 78150
CUNAGIN	WILEY	1110 BERKELEY STREET TEXAS TRANSP. INSTITUTE	COLLEGE STATION	TEXAS 77840
DAMMINGER	GARY	1 COMPUTER DRIVE SIEMENS-ALLIS	CHERRY HILL	NEW JERSEY 08034
DAVIES	JEFFERY	820 LAFAYETTE ROAD CMI-DEARBORN, INC.	HAMPTON	NEW HAMPSHIRE 03842
DAVIES	DR. PETER	1800 SW WHITESIDE DR CRC CORPORATION	CORVALLIS	OREGON 97333
DAVIS	DICK	8000 CALANDAR RD GENERAL ELECTRODYNAMICS	ARLINGTON	TEXAS 76017
DAVIS	DAVID	1199 MILBORO RD TN D.O.T.	NASHVILLE	TENNEESSE 37217

DEGRAFTENREID	DON	301 S. PARK,DRAWER 10056 FHWA	HELENA	MONTANA 59626
DODSON	KENNETH	707 N CALVERT ST,RM 206 MARYLAND D.O.T.	BALTIMORE	MARYLAND 21202
DUKE	CARL	1227 WALNUT STREET STREETER AMET	ALLENTOWN	PENNSYLVANIA 18102
DUMMERMUTH	HEINZ	OESTLICHE RHEINBRUECKENSTR.50 SIEMENS AG	KARLSRUHE 21	GERMANY D-7500
EASTEP	LES	2300 S DIRKSEN PKWY ILLINOIS D.O.T.	SPRINGFIELD	ILLINOIS 62764
EDWARDS	FRED	1720 PEACHTREE RD,NW,SUITE 300 FHWA	ATLANTA	GEORGIA 30367
ETTLINGER	TONY	7672 STANDISH PLACE GOLDEN RIVER CORP.	ROCKVILLE	MARYLAND 20855
EVANS	DAVID	KING'S WORTHY SARASOTA AUTOMAT	WINCHESTER	UNITED KINGDOM SO23 7QA
EVANS	LOREN	1720 PEACHTREE ROAD USDA FOREST SERVICE	ATLANTA	GEORGIA 30334
EVERT	KENNETH	BOX14030 2960 STATE,RM102 OREGON D.O.T.	SALEM	OREGON 93710
FARROW	CYRIL	28 WIGANTHORPE ELECTROMATIC	PIETERMARITZB'G	SOUTH AFRICA 3201
FULLER	ROBERT	DIV. HQ,7068 NEW JERSEY STATE POLICE	W. TRENTON	NEW JERSEY
FURIATE	DAVID	660 E. MAIN STREET OHIO STATE HWY PATROL	COLUMBUS	OHIO 43205
GALLEGOS	EDWIN	AV REPUBLICA #476,OFICINA 302	QUITO	ECUADOR
GASSNER	SIEGFRIED	HERTZSTR. 32-34 PAT	7507 ETTLINGEN	W GERMANY
GEE	STANLEY	LEO O'BRIEN F.O.B. 7TH FLR. FEDERAL HIGHWAY ADMINISTRATION	ALBANY	NEW YORK 12207
GOMES	GERCI	RUA SAO JOSE,90 GR 1904 CIM-SANEAMENTO E INSTRUMENTAL LTDA	RIO DE JANEIRO	RIO DE JANEIRO 20010
GOODMAN	PHILLIP	1100 CIRCLE 75 PKWY SUITE 945 LOCKHEED-GETEX	ATLANTA	GEORGIA 30339
GOSS	CURTIS	4000 GREENMOUNTAIN TX STATE DEPT/HWYS & PUBLIC TRANS	AUSTIN	TEXAS 78759
GRIFFIN	LARRY	306 E. KAY OKLAHOMA D.O.T.	MIDWEST CITY	OKLAHOMA
GRIFFITHS	PETER	POLO GROUNDS IND. EST MANGOOD LIMITED	PONTYPOOL	GWENT U-K NP4 OYS
GRIMES	RONNIE	AL HWY DEPT-STATE PLANNING ALABAMA HWY DEPT	MONTGOMERY	ALABAMA 36130
GROVES	CLYDE	155 WICKS STREET STREETER RICHARDSON	GRAYSLAKE	ILLINOIS 60030
HALLIN	JOHN	708 S.W. 3RD AVE FHWA	PORTLAND	OREGON 97204

HAMRICK	JOHN	P.O. BOX 7129 IDAHO D.O.T.	BOISE	IDAHO 83707
HARRIS	L (BUCK)	602 KING ST MONTANA D.O.T.	EAST HELENA	MONTANA 59635
HART	LAWRENCE	P.O. BOX 4533 RAINHART COMPANY	AUSTIN	TEXAS 78765
HAWKINS	NEIL	201 MORE HALL, FX-10 UNIVERSITY OF WASHINGTON	SEATTLE	WASHINGTON 98195
HENION	LOYD	325 13TH,NE,EXECUTIVE HOUSE OREGON D.O.T.	SALEM	OREGON
HERBSTER	KEITH	BOX 94759 NEBRASKA D.O.T.	LINCOLN	NEBRASKA 68509
HICKMAN	ROBERT	555 ZANG ST.,ROOM 400 FHWA	LAKEWOOD	COLORADO 80228
HOLMAN	FRANK	1409 COLISEUM BLVD ALABAMA HWY DEPT	MONTGOMERY	ALABAMA 36130
HOPPER	BEN	P. O. BOX 25201 N.C. DIV. OF MOTOR VEHICLES	RALEIGH	NORTH CAROLINA 27611
HUDZINA	EDWARD	415 UNION ST PENNSYLVANIA D.O.T.	TAYLOR	PENNSYLVANIA 18517
HUFT	DAVID	700 EAST BRADLEY SOUTH DAKOTA D.O.T.	PIERRE	SOUTH DAKOTA
HURLEY	RICHARD	FAIRBANKS WEIGHING DIV FAIRBANKS SCALES	ST. JOHNSBURY	VERMONT 05819
JACKS	MARSHALL	400 7TH ST. S.W.,ROOM 3401 FHWA	WASHINGTON	D.C. 20590
JACKSON	JAMES	817 AIRVIEW DR MISSOURI D.O.T.	JEFFERSON CITY	MISSOURI 65101
JACKSON	PHILLIP	P.O. BOX 270 MISSOURI D.O.T.	JEFFERSON CITY	MISSOURI 65102
JACOBSEN	FLOYD	126 EAST ASH ILLINOIS D.O.T.	SPRINGFIELD	ILLINOIS 62764
JACOBSON	DENNIS	600 E. BLVD AVE. NORTH DAKOTA HWY DEPT	BISMARCK	NORTH DAKOTA 58505-0178
JOHNSON	DOUGLAS	1920 L. STREET, N.W. ASSOC. OF AMERICAN R.R.	WASHINGTON	D.C. 20036
JOHNSON	BERNARD	155 WICK STREET STREETER AMET	GRAYSLAKE	ILLINOIS 60030
JONES	DENNIS	826 FEDERAL BUILDING FHWA-TX DIVISION	AUSTIN	TEXAS 78701
JUBA	FREDERICK	TRANS & SAFETY BLDG,RM 1013A PENNSYLVANIA D.O.T.	HARRISBURG	PENNSYLVANIA 17120
KENT	PERRY	400 7th STREET, S.W. (HHP-44) FEDERAL HIGHWAY ADMINISTRATION	WASHINGTON	D.C. 20590
KENT	GEFFOREY	SIMPSON RD G K INSTRUMENTS LTD.	MILTON KEYNES	UNITED KINGDOM MK1 1LN
KOGLIN	TOM	P.O. BOX 1149 NEW MEXICO D.O.T.	SANTA FE	NEW MEXICO 87504-1149

KRAMER	DOUGLAS	3311 W STATE ST IDAHO D.O.T.	BOISE	IDAHO 83731
KRUKAR	MILAN	325 13TH NE;EXECUTIVE HOUSE OREGON STATE HWY DIV	SALEM	OREGON 97310
LAI	MIKE	14TH FLOOR,215 GARRY ST. MANITOBA HWYS & TRANSP	WINNIPEG CANADA	MANITOBA R3C321
LAMBERT	LOUIS	BOX 30030 MICHIGAN D.O.T.	LANSING	MICHIGAN 48909
LEATHERS	REX	400 7TH ST. S.W. RM 3212 FHWA	WASHINGTON	D.C. 20590
LEE	CLYDE	DEPT CIVIL ENGR,ECJ 4.2 UNIVERSITY OF TEXAS AT AUSTIN	AUSTIN	TEXAS 78712
LILL	RICHARD	2200 MILL RD AMERICAN TRUCKING ASSOCIATION	ALEXANDRIA	VIRGINIA 22314
LOFROOS	WILLIAM	C/O FLORDIA D.O.T. FLORDIA D.O.T.	TALLAHASSE	FLORDIA 32301
LONG	JIMMY	819 TAYLOR STREET FHWA	FT. WORTH	TEXAS 76102
LOWE	JOHN	4999-98 AVE,TWIN ATRIA BLDG ALBERTA TRANSPORTATION	EDMONTON CANADA	ALBERTA T6B 2X3
MAKI	KEITH	1263 SOUTH STEWART ST NEVADA D.O.T.	CARSON CITY	NEVADA 89712
MARES	ROBERT	P.O. BOX 1149 NEW MEXICO HWY DEPT	SANTA FE	NEW MEXICO 87504-1149
MARTINEZ	RICHARD	24 WOLCOTT HILL ROAD CONNECTICUT D.O.T.	WETHERSFIELD	CONNECTICUT 06109
MCCALL	BILL	800 LINCOLN WAY IOWA D.O.T.	AMES	IOWA 50010
MCDADE	JONATHAN	HTO-31,400 7TH ST,SW FHWA	WASHINGTON	D.C. 20590
MCELHANEY	DAVE	400 7TH ST,S.W. FHWA-HHP 40	WASHINGTON	D.C. 20590
MCGIBONEY	CHARLES	143 MORNINGWOOD DR FHWA	LEXINGTON	SOUTH CAROLINA 29072
MCLEROY	CHARLES	819 TAYLOR ST FHWA	FT. WORTH	TEXAS 76102
MEARS	STEVE	SIMPSON RD,FERRY STRATFORD G K INSTRUMENTS LTD.	MILTON KENT	UNITED KINGDOM MK8 9DJ
MELTON	CLARENCE	P.O. BOX 1850 MISSISSIPPI D.O.T.	JACKSON	MISSISSIPPI 39215
MILNER	DON	P.O. BOX 1850 MISSISSIPPI D.O.T.	JACKSON	MISSISSIPPI 39215
MINOR	HOWARD	155 WICKS STREET STREETER RICHARDSON	GRAYSLAKE	ILLINOIS 60030
MOORE	ROBIN	OLD CROYTNGHAM RD	CROWTHORNE	UNITED KINGDOM R63 6AU
MOREHOUSE	KAREN	POUCH Z, MS 2500 D.O.T.	JUNEAU	ALASKA 99811

MORI	KENNETH	1120 N. STREET CALIFORNIA D.O.T.	SACRAMENTO	CALIFORNIA 95814
MORRIS	A.	P.O. BOX 191 SOUTH CAROLINA HIGHWAY PATROL	COLUMBIA	SOUTH CAROLINA 29202
NEELY	GERALD	P.O. BOX 15123 NEELY ENTERPRISES,INC	AUSTIN	TEXAS 78761
NELSON	DAVID	6301 ROCKHILL ROAD FHWA	KANSAS CITY	MISSOURI 64141
NEUKAM	JOHN	707 N. CALVERT ST. MARYLAND STATE HWY ADM	BALTIMORE	MARYLAND 21203
OCONNELL	WALTER	7672 STANDISH PLACE GOLDEN RIVER CORPORATION	ROCKVILLE	MARYLAND 20855
OPPERMANN	MARY	P.O. BOX 25201 NORTH CAROLINA D.O.T	RALEIGH	NORTH CAROLINA 27611
ORNI	YOAV	12 LINCOLN ST. CARCOM	HAIFA	ISRAEL 34369
ORR	DONALD	8501 MO-PAC RADIAN CORP.	AUSTIN	TEXAS 78766
OVERBAY	DEBRA	700 EAST BRADLEY SD D.O.T.,RESEARCH PROG.	PIERRE	SOUTH DAKOTA 57501
PENDLETON	JOHN	4501 S. 2700 W. UTAH HIGHWAY PATROL	SALT LAKE CITY	UTAH 84119
PRICE	GLEN	SUITE 200,1720 PTREE RD,NW FHWA	ATLANTA	GEORGIA 30367
RAMBO	RAY	2300 S. DIRKSEN PKWY ILLINOIS D.O.T.	SPRINGFIELD	ILLINOIS 62764
RAUHUT	BRENT	10214 I.H. 35 NORTH BRENT RAUHUT ENGINEERING	AUSTIN	TEXAS 78753
REED	HARRY	206 S 17TH AVE 300B ARIZONA D.O.T.	PHOENIX	ARIZONA 85007
REEL	RICHARD	605 SUWANNEE ST FLORDIA D.O.T.	MAIL-STATION 27	FLORIDA 32301
REILLY	DAVID	550 EGAN ST,SUITE 300 FHWA	CHARLESTON	WEST VIRGINIA 25301
REITZ	DANIEL	P.O. BOX 600 GENERAL RAILWAY SIGNAL	ROCHESTER	NEW YORK 14692
RIEDL	GREG	155 WICKS STREET STREETER RICHARDSON	GRAYSLAKE	ILLINOIS 30060
ROBERT	MARC	200 DORCHESTER,SOUTH,3F QUEBEC - D.O.T.	QUEBEC CANADA	PROV. OF QUEBEC G1K5Z1
ROBERTS	WAYMON	ROOM 706 A J BLDG TENNESSEE DEPT OF PUBLIC SAFTEY	NASHVILLE	TENNESSEE 37219
RODRIGUEZ	ROBERT	11TH & BRAZOS TX DEPT OF HWYS & PUBLIC TRANS	AUSTIN	TEXAS 78701
SAUNDERS	ROGER	200 N E 21ST OKLAHOMA D.O.T.	OKLAHOMA CITY	OKLAHOMA 73105
SAVAGE	PAT	400 7TH ST,S.W. FHWA-HHP-14	WASHINGTON	D.C. 20590

SAYNE	RICHARD	KINGSTON PACK ST DEPT OF SAFETY	KNOXVILLE	TENNESSEE 37920
SCHMITT	LOUIS	206 SOUTH 17TH AVE 300B ARIZONA D.O.T.	PHOENIX	ARIZONA 85007
SCHOENHARD	LARRY	700 BROADWAY EAST SOUTH DAKOTA D.O.T.	PIERRE	SOUTH DAKOTA 57501
SHOUDEL	LARRY	2300 S. DIRKSEN, RM 117 ILLINOIS D.O.T.	SPRINGFIELD	ILLINOIS 62764
SHRYOCK	DUDLEY	419 ANN ST KENTUCKY D.O.T.	FRANKFORT	KENTUCKY 40622
SHULLER	E.	NCDOT - DIV OF HWYS D.O.T.	RALEIGH	NORTH CAROLINA 27611
SILVERSMITH	PAUL	DRAWER A CONN D.O.T.	WETHERSFIELD	CONNECTICUT 06109
SIMMS	PAUL	P.O. BOX 2261 ARK HWY & TRANSP DEPT	LITTLE ROCK	ARKANSAS 72203
SMITH	SUSAN	155 WICKS STREET STREETER RICHARDSON	GRAYSLAKE	ILLINOIS 60030
SMITH	EDWARD	1409 COLISEUM BLVD ALABAMA HWY DEPARTMENT	MONTGOMERY	ALABAMA 36445
SNYDER	RICHARD	4423 EMERY INDUSTRIAL PARKWAY BRIDGE WEIGHING SYSTEMS INC	WARRENSV'LE HGT	OHIO 44128
SOMMERVILLE	FRASER	1800 SW WHITESIDE DR CRC CORPORATION	CORVALLIS	OREGON 97333
SOUTHGATE	HERBERT	UNIVERSITY OF KENTUCKY UNIVERSITY OF KENTUCKY	LEXINGTON	KENTUCKY 40506-0043
SPICER	LANG	P.O.BOX7913,4802 SHEBOYGAN AV WISCONSIN D.O.T.	MADISON	WISCONSIN 53707-7915
STARTZ	CLARENCE	STATE OFFICE BLDG.8TH FLOOR KANSAS D.O.T.	TOPEKA	KANSAS 66612
STEEN	DONALD A	230 DUFFY AVE AMPEREX ELECTRONIC CORP	HICKSVILLE	NEW YORK 11802
STEHR	RICHARD	TRANSPORTATION BLDG,ROOM 820 MINNESOTA D.O.T.	ST. PAUL	MINNESOTA 53155
STEMITZ	JAMES	1500 N. WASHINGTON BLVD SARASOTA AUTOMATION	SARASOTA	FLORIDA 33577
STUTZENBERGER	WILLIAM	419 ANN ST. KENTUCKY D.O.T.	FRANKFORT	KENTUCKY 40622
SULLIVAN	WILLIAM	BOX 1850 MISS. STATE HWY. DEPT.	JACKSON	MISSISSIPPI 39205-1850
SWEITZER	GORDON	5268 NW 2ND MOTOR VEHICLE DIV	DES MOINES	IOWA 50313
TIDWELL	JOHN	PO BOX 26806 FHWA	RALEIGH	NORTH CAROLINA 27611
TODD	ROBERT	4501 SOUTH 2700 WEST UTAH D.O.T.	SALT LAKE CITY	UTAH 84119-5998
TROMP	CORY	5353 WILCOX CMI-DEARBORN INC	MONTAGUE	MICHIGAN 49437

TWEEDIE	RONALD	1220 WASHINGTON AVE NEW YORK D.O.T.	ALBANY	NEW YORK 12232
VAN BERKEL	JOHN	1120 N STREET CALTRANS	SACREMENTO	CALIFORNIA 95814
WARPOOLE	RICHARD	SUITE 100,JAMES K POLK BLDG TENNESSEE D.O.T.	NASHVILLE	TENNESSEE 37219
WEEKS	M	1500 N.W. SHINGTON BLVD SARASOTA AUTOMAT	SARASOTA	FLORIDA 33577
WELTER	NICK	BORSIGSTR. 3 SIEMENS-ALLIS	OESTLICHE R.50	W GERMANY D-7512
WILBER	CURT	155 WICKS STREET STREETER RICHARDSON	GRAYSLAKE	ILLINOIS 60030
WILDER	ROBERT	500 PIEDMONT AVE, N.E. GA. MOTOR TRUCKING ASSOCIATION	ATLANTA	GEORGIA 30308
WILLIAMS	DAVID	1100 CIRCLE 75 PKWY SUTE 945 LOCKHEED-GETEX	MARRETTIA	GEORGIA
WOOD	EDWIN	211 MAIN ST,ROOM 1100 FHWA	SAN FRANCISCO	CALIFORNIA 94105
WYMAN	JOHN	P.O. BOX 4970 MAINE D.O.T.	PITTSFIELD	MAINE 04967
YOUNG	RICHARD	1 COMPUTER DRIVE SIEMENS-ALLIS INC.	CHERRY HILL	NEW JERSEY 08034
ZEPP	MURRAY	1201 REISTERTOWN RD. M.D. STATE POLICE HQ	PIKESVILLE	MARYLAND 21208
ZUIEBACK	JOEL	7018 OWENSMOUTH AVE,#204 SPARTA,INC.	CANOGA PARK	CALIFORNIA 91303

CONFERENCE HOSTS, GEORGIA DEPARTMENT OF TRANSPORTATION

BRYANT, L.	2 CAPITOL SQ, ATLANTA, GA 30334
CHILDERS, ALLAN	2 CAPITOL SQ, ATLANTA, GA 30334
COPELAND, KEN	940 VIRGINIA AVE, HAPEVILLE, GA 30354
DEAVER, RICK	15 KENNEDY DR, FOREST PARK, GA 30050
HANEY, ERNEST	25 KENNEDY DR, FOREST PARK, GA 30050
MORELAND, THOMAS	2 CAPITOL SQ, ATLANTA, GA 30334
MOTES, JESSE	5025 NEW PEACHTREE RD, CHAMBLEE, GA 30341
PEARCE, LAMAR	940 VIRGINIA AVE, HAPEVILLE, GA 30354
SELF, HAROLD	940 VIRGINIA AVE, HAPEVILLE, GA 30354
WILLIAMS, JACK	5025 NEW PEACHTREE RD, CHAMBLEE, GA 30354
WILLIAMS, VIRGINIA	940 VIRGINIA AVE, HAPEVILLE, GA 30354

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