PILOT PROJECT

PIEZO-ELECTRIC
AUTOMATIC VEHICLE CLASSIFICATION
SYSTEM

OREGON DEPARTMENT OF TRANSPORTATION
WITH CASTLE ROCK CONSULTANTS
FOR A SHRP LONG TERM
PAVEMENT PERFORMANCE SITE

FINAL REPORT

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by

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INTRODUCTION

Oregon has twelve pavement test sites that are part of the Strategic Highway Research Program (SHRP), Long Term Pavement Performance (LTPP) studies. Part of the data gathering on these sites involves vehicle weight and classification. This pilot project was to help SHRP show others how to specify, procure and install equipment that would provide the necessary data to characterize the sites for the LTPP program.

Castle Rock Consultants (CRC) provided specifications and technical aid for the first phase of this project. After the first phase was completed, CRC produced a paper for SHRP titled, "Piezo-Electric Based Automatic Vehicle Classifier Pilot Project," December, 1989. This report complements the CRC report and discusses the total project from Oregon's perspective.

This report covers procurement of equipment and installation on two pilot sites, one for asphalt concrete (A/C) and the second for Portland cement concrete (PCC). Oregon used the results from this study to write the specifications for contractor installation of the ten remaining sites.

GENERAL REQUIREMENTS

Specifications

The CRC specifications were for materials and installation of automatic-vehicle-classification (AVC). These specifications were modified to produce an equipment procurement specification that directly addressed the AVC pilot projects. This specification is in Appendix 1 and covers materials for use on AVC sites. These sites can also be used for collecting weigh-in-motion (WIM) data.

The installation requirements in the CRC specification were the general guidelines used by the State for installation of the AVC equipment. New specifications were written by Oregon for the ten remaining sites and were based on what has been learned on the pilot projects. Limited copies are available from the Research Unit.

Epoxy for Sensor Installation

Previous experience with sensor installation showed that the epoxy used for sensor installation could be improved. The general properties required of the epoxy for sensor installation in either A/C or PCC pavements were:

- o The exotherm of the epoxy needed to be relatively low so no sensor damage would occur. Also, it is not desirable to have steam generated from the residual moisture in the slots.

- o The epoxy should be moisture insensitive.

- o The epoxy should be flexible enough to move with asphaltic concrete.

- o The epoxy should be thixotropic. (On the first pilot site 3.5% Cabosil was added to the epoxy for body. This resulted in a material that was a little too stiff. The Cabosil was reduced to 2.5% for the second pilot site.)

Epoxy adhesives are normally two component systems, Part A is the epoxy resin and Part B is the hardener or catalyst. For any resin formulation there are a variety of hardeners available. The hardener can be selected to match the prevailing weather conditions.

Packaging is important. One gallon of Part A was in a two gallon container. One quart containers of Part B, the amount required to catalyze one gallon of Part A, were in separate containers. The extra space in the Part A container left room for easy mixing and extra volume for Ottawa sand. Addition of Ottawa sand offers extended control of the exotherm, reduced the amount of epoxy for the job and further control of the rheology.

Material conforming to the above requirements is available as RP - 12 from Revalon Systems, San Jose, California.

Sensors

The original CRC specifications called for 12', Class 2, cable sensors. This type of sensor is adequate for AVC but not suitable for WIM. Class 1 cable sensors are required if the AVC site is going to be periodically used for WIM.

While the project was underway, film sensor technology became available. Two 6' film sensors were obtained so film and cable technology could be evaluated side by side.

Marking Out for the Field Installation

The sensors must be parallel to each other and perpendicular to the traffic. The spacing of the sensors for this project was 8'. A simplified layout procedure is as follows:

1. Measure an 8' length along the edge of the pavement, parallel to the traffic. Mark the end points.

2. From each end point swing a 6' arc nearly perpendicular to the 8' base.

3. Swing a 10' arc, from each end of the base, that intersects the opposite 6' arc.

The end points and the arc intersections satisfy the parallel and perpendicular requirements for the sensors (3-4-5 triangle). Finish the layout using these points as references.

THE ASPHALT CONCRETE PILOT SITE

This site, on I-84, Eastbound, at MP 75.95, is near an automatic traffic recorder (ATR) site (MP 75.93). The intent was to combine the ATR and AVC equipment in a single housing. This permits sharing of utilities and simplifies data collection and comparison.

The problem with the site were the ruts in the travel lane. The ruts were deep enough to possibly damage the sensor during installation. Since there were no other nearby sites in any better condition, a 100' section of the roadway was repaired. The repair consisted of grinding out a 2" deep, 12' wide slot and filling it with new asphalt concrete.

During the roadway repair, a concrete pad was poured for the instrument cabinet foundation. Also, underground conduit for power and sensor cables were placed so everything would be ready when the piezo-electric sensors were installed. The instrument cabinet, a re-fitted signal cabinet, was installed and the electricity brought in.

Slot Preparation

It was difficult to maintain on-line cuts. This was partly due to the transition from the shoulder area to the roadway area. Also, the operator could not see the position of the blade since the saw was a center mount design. Some re-cutting was required.

Re-cutting means that extra epoxy is needed to fill the voids between the sensors and pavement. This results in wasted materials and areas where the exotherm[1] is significantly higher than in other areas.

A combination high pressure water and air jet was used to clean the slots and remove cutting residue from the roadway. Compressed air was used to dry the slots. The pavement temperature was checked and found to be approximately 40° F.

Sensor Installation

During the slot preparation the epoxy was kept in a vehicle that had the heater set to maintain an interior temperature of about 90° F. The epoxy, at the time of mixing, was approximately 80° F, an ideal mixing and placement temperature.

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[1]The exotherm generated when an epoxy sets is a function of the total reacting mass. Detrimentally high temperatures may occur in large mass areas.

Metal holders were used to suspend the sensors in the slots. The holders, 1/8" x 1" steel bar stock, 6" long, were wired perpendicular to the sensors. Weights were used to make the sensors conform to the roadway profile.

Before placement of the epoxy, the slots were heated and dried with propane heaters. The hot air from the heaters was blown into metal hoods that were over the slots.

The first step in mounting the sensors was to "butter" the slots with neat catalyzed resin.

There was free water in one of the slots. The source of the water was unknown, but it was confined to about one foot at the coax cable end of the slot. Just before buttering, the water was absorbed with paper towels and blown with compressed air, a marginally effective procedure.

The epoxy used to place the first sensor had a higher than desirable exotherm. For the rest of the sensors, Ottawa sand was added to the epoxy to reduce the exotherm (about 2/3 the bulk volume of sand to one volume of the neat epoxy).

While the epoxy was hardening, the lead wires were routed to the instrument cabinet. The sensors were checked and Oregon's 19-Class algorithm was loaded into the classifier.

After the epoxy had hardened, a small grinder was used to remove irregularities and make the surface of the epoxy match the roadway.

When the traffic was turned over the sensors, the wave-form from the sensors was examined with a storage oscilloscope. The wave-form from the films had a much cleaner signal than the wave-form from the cables. The raw data reported by the film and cable sensors was the same.

Vehicle Classification

Part of CRC's responsibility at this site was to determine the accuracy of the classifier. First, the speed determination was checked against a radar gun and found to be very good. Next, visual classification of approximately 1,000 vehicles was made and compared with data from the classifier. The results were well below the specification requirement for a minimum compensated accuracy of 90% (61% & 68%). Examination of the Oregon 19-Class algorithms and the raw data showed that the problems were mostly due to the Oregon-supplied algorithms.

The data from the first classification was examined and corrections to the Oregon algorithms were made. To verify the corrected algorithms, a time-stamped video log was made and compared to time-stamped raw data. This resulted in only one additional change to the algorithm. The expected classification accuracy for the algorithms, for Oregon's 19-Classes, is approximately 95%. The raw data capture accuracy was about the same.

It is interesting to note that there were a surprising number of "four-axle vehicles" that were, in reality, two cars. There were also a few "six-axle vehicles" that were three cars. The optimum headway distance to minimize this raw data error was found to be 38'.

The Oregon 19-Class algorithms are in Appendix 2. The correction that made the most significant change in classification accuracy was in the two-axle class. Light two-axle vehicles (cars and pickups) were found to have an axle spacing of 12' or less. Analysis of other data has shown the light vehicles so defined contribute less than 0.002 equivalent single-axle loads (ESAL) per vehicle. Two-axle vehicles with a spacing greater than 12' contribute approximately 0.2 ESAL per vehicle.

After the work on Oregon's 19-Class algorithms was completed, the classifier was set to collect Federal Highway Administration's (FHWA) 13-Class data.

THE PORTLAND CEMENT CONCRETE PILOT SITE

This site is located on I-5, Southbound, at MP 232.35. Both 6' film and 12' cable sensors were installed in the outside travel lane in July, 1990.

The pavement surface at this site was very uniform and flat.

Prior to placing the sensors, a concrete pad was poured for the instrument cabinet foundation. The instrument cabinet and the underground conduit for power and sensor cables were placed so everything would be ready at the time of the installation.

Slot Preparation

The slot cutting was done using two 1/8" thick concrete blades spaced to cut a 2" slot, 2" deep. The two-blade configuration resulted in very neat, straight slots.

Electric chipping hammers were used to remove the concrete to form the slot. This method was quick and effective.

A high pressure water and air jet was used to clean the slots and remove cutting residue from the roadway. The slots were acid etched with 20% hydrochloric acid (muriatic acid) to break the glaze on the sides caused by cutting. The slots were re-cleaned and air dried.

By the time the cutting and cleaning was completed, the temperature was in the high 90's. The roadway temperature was in the low 90's and rising. Consequently, it was decided to leave the slots open until the next day when the morning temperatures would be suitable for using epoxies.

Sensor Installation

The next morning the temperature was in the low 80's with the pavement temperature in the mid 70's.

The slots were re-cleaned using air and water. All four slots were buttered with neat catalyzed resin. As before, metal holders with weights were used to suspend the sensors in the slots. The next batch of resin, for the first 12' sensor, had approximately 1/3 bulk volume of added sand. This resulted in a mixture that was slightly thinner than desirable and the exotherm was on the high side. However, there was no cracking or crazing that is often experienced with an excessive exotherm. For the remaining sensors, 2/3 to 3/4 bulk volume of sand was used.

While the epoxy was hardening, the lead wires were routed to the instrument cabinet.

After the epoxy had hardened, a small grinder was used to remove irregularities and make the surface of the epoxy match the roadway.

When traffic was allowed over the sensors, the wave-form from the sensors was examined with a storage oscilloscope. The wave-form from the cable sensors was similar to the wave-form from the cables installed at the a/c site. No wave-form from either film sensor could be detected. (Note: All the sensors had been checked for proper response before they were installed.)

Replacement of the Film Sensors

Before the film sensors were replaced, a digital multimeter was used to determine the resistance of the dead sensors. The resistance was found to be nearly zero which indicated there may be a near short in the coaxial lead wire.

The short was found in the coaxial cable close to the point that the coaxial lead wire connected to the sensor. The outer metal shield had collapsed, through the interior insulation, onto the core wire. This could only be caused by the heat from the epoxy's exotherm. Normally the insulating material should have handled the heat without problems.

The coaxial cable from the film sensor was examined and found to have a low heat tolerance. The coaxial cable on the cable sensors had a high heat tolerance.

The manufacturer was notified and indicated that they would replace the sensors at no charge if we would send back the failed sensors.

The air temperature was in the high 60's the day the film sensors were replaced. A single saw blade configuration was used to make the removal cuts along the sides of the slots. There was difficulty in staying on line and much more epoxy was required than originally.

An alternate technique for suspending the sensors in the slots was tried. Since the roadway surface was quite flat, two high density, semi-rigid, foam pieces were cut and put in the bottom of the slot to hold the sensors up in place. This method proved to be very effective. It was much easier to finish grind the surface of the epoxy and the amount of grinding was greatly reduced.

Cellular Telephone Installation

Data collection at this site was to be via a cellular telephone link. The installation of the equipment was straight forward. However, it was discovered that not all modems are compatible with cellular equipment. When the proper modem was installed, the unit performed marginally with excessive noise being transmitted.

It appeared that low signal strength was the reason for the excess noise. The original antenna was the quarter-wave model with the instrument cabinet top as the ground plane. The quarter-wave antenna was replaced with a full-wave antenna and a quarter-wave back-plane was added. The back-plane also provided a shield from possible traffic noise. This resulted in much improved transmissions.

Electricity for routine operation was not obtained at the site until September, 1990. At that time the equipment was checked and the site was put into operation collecting FHWA's 13-Class data.

OPERATION AND PERFORMANCE

The Asphalt Concrete Site

The equipment and procedures for manual data collection at this site required the operator to have a basic knowledge of DOS and an understanding of the software. The uniqueness of the equipment, lack of personnel in the area with the necessary skills, and the distance from Salem made data collection unreliable.

Site inspection the following Spring found three of the four sensors operating properly. The asphalt concrete around the cable end of one cable sensor raveled out. The end of the sensor had been broken off by the traffic. Examination of the remains showed that the epoxy adhesion to the asphalt concrete was good. The failure is attributed to the failure of the asphalt concrete.

Classification, using the two remaining film sensors, was satisfactory.

The condition of the asphalt concrete at the site continued to worsen. Rutting was occurring and the sensors were being worn away by the traffic. Data collection was discontinued in the Fall, 1990.

The Portland Sement Concrete Site

Examination of the raw data showed that there were speed differences between the film sensors and the cable sensors. A storage oscilloscope was used to examine the output from the sensors. Figure 1 is a picture of the trace from the leading film sensor and is normal for a five-axle semi.

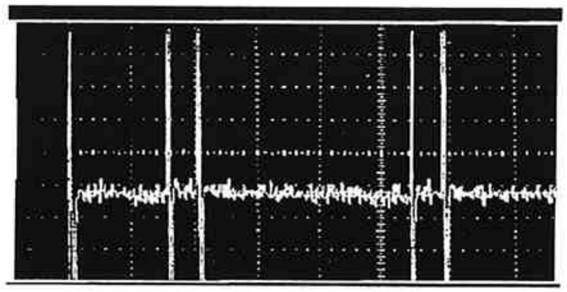

Figure 1

The signal from the trailing film sensor, Figure 2, did not have the nice flat base line that would normally be expected. This anomaly may be the reason that real time data capture is less reliable than the data from the cable piezos.

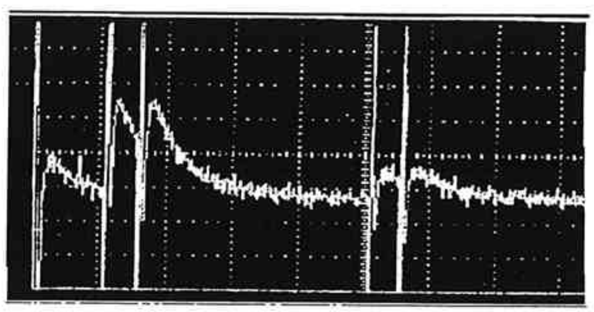

Figure 2

Visual classification data was compared to raw data. Classification accuracy was very similar to the asphalt concrete site.

Data collection using the cellular telephone and vendor supplied software has been satisfactory. In the FHWA 13-Bin mode, the equipment can store about two weeks of data. The time to collect the data using xmodem is less than five minutes.

CONCLUSIONS AND RECOMMENDATIONS

Installation

A "header" and "footer" cut about 1/2" from the ends of the sensors will save material and reduce the local exotherm.

For a single-blade saw a cutting guide for the saw should be developed to eliminate re-cutting. Part of the design for the guide might include a method of slightly elevating one side of the saw. The slot could be cut slightly wedge-shaped with a wider bottom. This would give the finished installation much greater resistance to pull-out or pop-out.

A double-blade saw set to the width of the slot appears to give exceptionally straight cuts.

Select the correct epoxy for the prevailing conditions.

Select sites that have high quality pavements. The premature failure experienced here is not unique since similar failures have been reported by others.

Operations

Analysis of the raw data resulted in several changes to the Oregon 19-Class algorithms. The new algorithm table is in Appendix 2. The new table was tested by comparing the results from the classifier with manual classification from video tape.

The difficulties encountered with data collection at a remote site strongly suggests that a more automated data collection system be considered. A few possibilities are:

1. Change the software to make it less operator dependent. This was discussed with the vendor and it was decided that this would still not be wholly reliable.

2. Design and build a data collection device that, when connected to the classifier, would automatically collect the data and reset the classifier. The vendor has done this and it has been demonstrated to be practical.

3. Install a telephone line and interface the classifier to a modem.

Several modems were investigated. It was found that reliable units are available for about $130.

Telephone line costs are site specific. At this location, no easement was required, and installation would have cost approximately $850. The flat monthly fee would have been about $46.50.

4. Interface to the State microwave system. This at first seemed attractive, but the high up-front cost of the equipment (two transceivers, two terminal node controllers, and hardware interface from the system to the terminal node controllers) eliminated this option.

5. Install a cellular telephone and interface the classifier to the modem. At certain remote locations, this is cost-effective and relatively reliable.

Sampling

Analysis of the raw data identified a problem inherent to AVC and WIM. The volume of data gets so large, so fast, it becomes overwhelming. Examination of the data identified a technique to reduce the volume of data without significant loss of information. A method of significantly reducing the volume (80^{+} %) without significant loss of information is in Appendix 3.

WIM

The major purpose for collecting WIM data is for calculating ESAL values. WIM data has a larger standard deviation than static data. This results in overestimated ESAL values. This problem was investigated and the basis for a solution is in Appendix 4.

APPENDIX 1

SPECIFICATIONS FOR AVC EQUIPMENT

SPECIFICATIONS FOR AVC EQUIPMENT

1. General Requirements

1.1 These specifications cover the supply of piezo-electric automatic vehicle classification (AVC) systems. The terms "AVC," "equipment," and "systems" mean piezo-electric cable or piezo-electric film AVC systems, including all sensors, electronics, interconnections and software.

1.2 The operation of systems supplied under this specification shall be compatible with the requirements of the Strategic Highway Research Program (SHRP).

1.3 Three (3) sets of operator's manuals for each AVC unit shall be submitted with the equipment.

1.4 One (a) maintenance manual shall accompany each unit when delivered. Maintenance manuals shall include schematics, circuit diagrams, parts lists, parts price list, parts lists with cross-reference of all components by manufacturers, and instructions suitable for state technicians to perform services and repairs.

1.5 All software used with the AVC systems shall be clearly documented and provided at no additional cost. Software shall include source code. A software manual, including documentation, shall be provided for each AVC system.

1.6 Any proposed software licensing agreements required by the equipment supplier shall be submitted as part of the bid.

1.7 Acceptance testing of the equipment will be for a minimum of thirty (30) consecutive days of continuous operation.

1.8 If the equipment does not operate according to the specifications during the acceptance testing period, the State will have the option of returning the equipment at vendor's cost.

1.9 The vendor shall provide training for State personnel in operation, maintenance, trouble-shooting, and repairs for the equipment. The bid shall include the vendor's proposed training schedule.

2. Configuration

2.1 The proposed system will be of the type shown in Figure 1.

3. Operating Environment

3.1 The system shall operate in through traffic lanes of interstate and principal highways covering the full range of traffic volumes and truck percentages.

3.2 The piezo sensors shall operate within specification when installed in asphalt concrete, segmented portland cement concrete, and continuously reinforced portland cement concrete pavements. Bidders shall supply independent verification of this fact.

3.3 The electronics shall meet specifications from a temperature of 0 to +160 degrees Fahrenheit, and up to 95 percent relative humidity. The systems shall be capable of withstanding temperatures in the range -40 to +160 Fahrenheit without permanent damage or deterioration.

4. Durability

4.1 The piezo sensors shall have an operating life of at least one (1) year. Failure during that period will require replacement at the vendor's expense.

4.2 The electronics sub-system shall have an operating life of at least two (2) years. Failure during that period will require replacement at the vendor's expense.

5. In-Pavement Sensors

5.1 Piezo cables shall be manufactured by Thermocoax, or approved equal. The cables shall be mounted in accordance with the guidelines in Federal Highway Administration demonstration project FHWA-DP-88-76-006. Other piezo-based technology sensors will be considered. Other mountings may be considered, where the vendor can provide independent evidence of satisfactory operation.

5.2 Active cable length shall be 11'6" in 12' lanes.

5.3 Feeder cables shall be without joints.

5.4 Piezo cable mountings shall be permanently installed, flush with the pavement surface, using epoxy adhesive (Hermetite or similar) along the entire length of each sensor.

6. Data Input and Processing

6.1 The vehicle classification system shall be capable of monitoring signals from two piezo sensors per lane.

6.2 Charge amplifiers, with sealed connectors, shall be provided with time constants between 2 and 4 seconds.

6.3 The signal processing algorithm shall be certified to operate in accordance with a flow-chart supplies by the manufacturer. The flow chart shall indicate and quantify how noise suppression and axle detection is accomplished.

6.4 The vehicle classifier algorithm shall classify in accordance with 19 vehicle classifications used in Oregon's weigh-in-motion systems (See Table 1). Additionally, the algorithm should be flexible and provide output in accordance with FHWA Scheme F (Look-up Table appended as Table 2).

6.5 Provision shall be made for on-site input of all system operating parameters including data processing and system software.

6.6 Diagnostic checks of system operation and performance shall include, as a minimum, checks for low battery power, axle sensor failure, telemetry errors, and condition of module data.

7. Data Storage and Output

7.1 All data output shall be ASCII and RS232-C compatible. External data transmission rates shall include 300/1200 baud. Protocols and handshaking shall be provided for communication to external printers, terminals and IBM-compatible microcomputers. Output shall have "xon/xoff" type protocol.

7.2 An RS232-C port shall be provided for data output at the AVC site.

7.3 Individual vehicle data shall include vehicle number, time, lane, speed, class and axle spacings.

7.4 In the continuous mode of operation, individual vehicle data shall be stored in memory or output in real time.

7.5 In the selection mode, individual vehicle data shall be output or stored in memory for all trucks and buses, or for any selected vehicle class.

7.6 Data storage capacity shall be provided for at least 64K characters.

8. Data Retrieval System

8.1 Provision shall be made for portable data retrieval from the site. Take away memory, portable memory modules, downloading to a dedicated retrieval unit, downloading to a portable microcomputer, or a similar system shall be clearly defined and demonstrated by the manufacturer.

8.2 Whatever data retrieval system is utilized, the eventual data output shall be as specified in Section 7 above.

9. Power and Telemetry

9.1 The system shall be designed for low power consumption and continuous operation. It shall be capable of operating on 110-120 VAC, batteries and a solar panel. Where 110-120 VAC commercial power is utilized, battery back-up shall be provided for 48 hours of continuous operation during supply failures, brown-outs or other supply fluctuations.

9.2 Systems shall include a telemetry sub-system able to receive and transmit data via an auto-answer modem. Provision shall be made for error trapping and re-transmission of data.

9.3 All of the system input parameters shall be capable of being monitored and re-set via the telemetry sub-system.

10. Equipment Cabinet

10.1 Equipment will be housed in an unheated, uncooled, and unsealed roadside cabinet containing power mains, telephone connection, and other electronic equipment. The manufacturer shall provide a case and rack system for the equipment, capable of excluding dust and moisture and preventing accidental damage to components during routine maintenance.

11. Design Requirements

11.1 All electric components shall be of solid state design with high noise immunity utilizing low power, CMOS technology. Logic and data storage components shall be mounted on replaceable plug-in circuit boards. All components shall be firmly mounted and housed so that they will not be damaged by jolts and vibrations encountered in transportation and use. Electronic components shall be fully protected against overloads, power surges and transients.

11.2 Service and delivery of spare parts shall be assured.

12. Performance

12.1 The system shall be capable of a classification accuracy of 90 percent or greater, to allow for compensation or canceling between vehicle categories. This level of accuracy shall be achieved for all vehicle categories contained with the Oregon WIM system, considered either individually or in any combination, provided that the total number of vehicles surveyed in the group exceeds 100 during the period of the accuracy survey.

13. Delivery

13.1 All equipment and software shall be delivered by June 30, 1989.

APPENDIX 2
OREGON 19 CLASS
VEHICLE CLASSIFICATION ALGORITHMS

LOOKUP TABLE FOR AVC
REVISED FEBRUARY 1991
OREGON 19 BIN

All measurements are in feet.

Tandem axle spacing is up to and including 8 feet.
Tridem axle spacing is up to and including 12 feet.

Description	Class	Axles	Algorithm
Light Vehicles (Cars, Vans, Pickups)	1	2	$(A1 - A2) \leq 12$
Light Vehicles with Trailers	2	3 4	$(A1 - A2) \leq 12$, $8 < (A2 - A3) \leq 18$ $(A1 - A2) \leq 12$, $(A2 - A3) > 8$, $(A3 - A4) < 8$
Single Unit	3	2	$12 < (A1 - A2) \leq 20$
Buses	4	2	$(A1 - A2) > 20$
Single Unit	5	3	$7 < (A1 - A2) \leq 20$, $(A2 - A3) \leq 8$
Combinations (2-S1)	6	3	Not Classed Elsewhere
Buses	7	3	$(A1 - A2) > 20$, $(A2 - A3) \leq 8$
Combinations (2-S2, 2-2, 3-S1)	8	4	Not Classed Elsewhere
3-S1 Combination	9	4	$(A1 - A2) > 7$, $(A2 - A3) \leq 8$, $(A3 - A4) > 6$
Single Unit	10	4	$(A1 - A2) > 7$, $(A2 - A3) + (A3 - A4) \leq 12$
3-S2 Semi	11	5	$(A2 - A3) \leq 8$, $(A4 - A5) < 10.5$
2-S1-2 Twins	12	5	$(A2 - A3) \geq 8$, $(A3 - A4) \leq 15$, $(A5 - A5) > 8$
Combinations	13	5	Not Classified Elsewhere
3-S1-2 Combination	14	6	$(A2 - A3) \leq 8$, $(A3 - A4) > 15$, $(A4 - A5) > 15$, $(A5 - A6) > 15$
Combination	15	6	Not Classed Elsewhere
2-S1-2-2 Triples	16	7	$(A2 - A3) > 8$, $(A3 - A4) \leq 15$, $(A4 - A5) > 8$, $(A5 - A6) \leq 15$, $(A6 - A7) > 8$
Combinations	17	7	Not Classed Elsewhere
Combinations	18	8	All
Combinations	19	9+	All

APPENDIX 3

OREGON'S SAMPLING PLAN FOR AVC AND WIM SITES

OREGON SAMPLING PLAN FOR WIM AXLE WEIGHT DATA

One of the major problems in capturing axle weight data is the sheer number of records that must be dealt with. For example, a one week axle sampling at a site with an ADT of 10,000 results in 70,000 records that must be stored, handled and sorted. Of these 70,000 records, say 80% (56,000 records) could eaisly be 2 axle vehicles with an axle spacing of twelve feet or less (light 2 axle vehicles).

The purpose of this plan is to show how the volume of light 2 axle vehicle data may be significantly reduced without loss of information. The problem statement is:

> how can sampling be done to minimize the number of records collected and still maintain the integrity of the information?

The Chapter on "Hypothesis Testing and Interval Estimation" in the text "Statistics for the Social Sciences", by William L. Hays, Published by Holt, Reinhart and Winston, 1973, has a section that applies to the stated problem.

The section "Sample Size and the Accuracy of Estimation of the Mean"
provides a solution as follows. If the sample mean is to lie within $.1\sigma$ of the true mean, at a probability of .99, then:

$$\text{prob.}(\ |M - \mu|\ \leq\ .1\sigma) = .99$$

Since a sampling distribution tends to become normal for large N (56,000 is a large N), the 99% confidence interval would have the limits

$$M - .1\sigma$$

and

$$M + .1\sigma$$

This is the same as

$$.1\sigma = 2.58\sigma_M$$

so that

$$.1\sigma = 2.58 \frac{\sigma}{\sqrt{N}}$$

solving for N

$$N = 665.6$$

Thus, if 666 independent observations are made, the probability that the estimate is wrong by more than $.1\sigma$ is only 1 in 100. Note that the number of observations is independent of the standard deviation.

This sampling criteria, when applied to the light vehicle class, can best be demonstrated by example.

The example above, with an ADT of 10,000 and 70,000 total records and 56,000 light vehicle records would be treated as follows.

The total estimated number of light vehicles is 56,000.

Divide 56,000 (the total number of "light" records) by 666, which is 84.

Record each light vehicles record that is divisible by 84 and discard the rest.

This will result in a sample with very nearly 666 records, which represents the light vehicle class.

The final sample will contain all the heavy vehicle records, ($\approx$14,000) plus the light vehicle sample (666) for a total of $\approx$ 14,666.

The data collection requirements have been reduced by (70,000 - 14,666) $\approx$ 55,334 records or roughly 80%.

When the ESAL contribution of this class of vehicle is considered, this is much more in line with the effort expended for the information gained.

APPENDIX 4

EQUATING WIM AND STATIC WEIGHING DATA

ESAL CORRECTION FOR WIM TO STATIC

Given: 1) The N axle weights, y_i, i = 1 to N, in kips from a WIM site.

2) The standard deviation, σ_s, as determined by a previous static sampling of vehicles over the WIM site.

Definition: The mean of the static weights, $\bar{X}$, is the same as the mean of the WIM weights, Y.

Calculations:

Determine the mean, $\bar{Y}$, and standard deviation, σy, from the WIM axle weight data.

Calculate a "scatter coefficient" S, $S = \sigma_s/\sigma_y$.

Calculate an "intermediate" set, I, $I_i = S \times y_i$, i = 1 to N.

Determine the mean, $\bar{I}$, and standard deviation, σ_i, for the intermediate set. Note that $\sigma_i = \sigma_s$.

Correct the mean of the intermediate set by adding $(\bar{X} - \bar{I})$ to each member of the intermediate set to get the corrected weights y_c, eg:

$$y_{ci} = I_i + (\bar{X} - \bar{I}), \bar{I} = 1 \text{ to } N$$

These corrected weights will yeild the same ΣESAL as if the weights were static.

	STATIC AXLE WEIGHT	STATIC ESALS	WIM AXLE WEIGHT	WIM ESALS	INTER. WEIGHT	AXLE WEIGHT	NEW ESAL
	4	0.038	2	0.002	1.26	3.85	0.033
	5	0.094	5	0.094	3.15	5.74	0.163
	6	0.194	6	0.194	3.77	6.37	0.247
	7	0.360	12	3.110	7.55	10.15	1.589
	8	0.614	8	0.614	5.03	7.63	0.508
	9	0.984	9	0.984	5.66	8.26	0.698
	10	1.500	10	1.500	6.29	8.89	0.936
	8	0.614	8	0.614	5.03	7.63	0.508
	6	0.194	6	0.194	3.77	6.37	0.247
	4	0.038	4	0.038	2.52	5.11	0.102
	5	0.094	2	0.002	1.26	3.85	0.033
	6	0.194	6	0.194	3.77	6.37	0.247
	7	0.360	7	0.360	4.40	7.00	0.360
	6	0.194	12	3.110	7.55	10.15	1.589
	9	0.984	9	0.984	5.66	8.26	0.698
	9	0.984	3	0.012	1.89	4.48	0.061
	8	0.614	5	0.094	3.15	5.74	0.163
	6	0.194	6	0.194	3.77	6.37	0.247
	5	0.094	5	0.094	3.15	5.74	0.163
	7	0.360	11	2.196	6.92	9.52	1.230
	8	0.614	8	0.614	5.03	7.63	0.508
	9	0.984	9	0.984	5.66	8.26	0.698
	10	1.500	10	1.500	6.29	8.89	0.936
	8	0.614	7	0.360	4.40	7.00	0.360
	6	0.194	6	0.194	3.77	6.37	0.247
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	8	0.614	8	0.614	5.03	7.63	0.508
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	10	1.500	10	1.500	6.29	8.89	0.936
	8	0.614	7	0.360	4.40	7.00	0.360
	6	0.194	6	0.194	3.77	6.37	0.247
	6	0.194	6	0.194	3.77	6.37	0.247
MEAN	7		7		4.40	7.00	
STD	1.71		2.72		1.71	1.71	
COUNT	52		52		52	52	
TOTAL ESAL		25.616		36.869			25.639
ERROR >>>				11.2536			0.0233439