MICHIGAN'S SYSTEM FOR WEIGHING, DIMENSIONING, AND CLASSIFYING VEHICLES IN MOTION

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ABSTRACT: The history of Michigan's system for rapid weighing, dimensioning, and classification of vehicles in motion is presented. The system in its present state of development, is described in detail. System calibration and accuracy are outlined. It is concluded that feasibility and accuracy of such installations has been demonstrated, and various modifications and improvements are suggested for future systems.

KEY WORDS: vehicle classification, weighing equipment, weight measurements, dimensional measurements, weight indicators, electronic devices, traffic actuated detectors.

MICHIGAN'S SYSTEM FOR WEIGHING, DIMENSIONING, AND CLASSIFYING VEHICLES IN MOTION

Michigan first became interested in the possibilities of dynamic vehicle weighing in 1952, and a research project was initiated. Its goal was to determine the accomplishments of others to that date, to keep abreast of subsequent progress primarily through the literature, and to begin low-key experimentation. In other words, to start a process of self-education, and to begin considering possible experimental contributions that Michigan might make to this potentially valuable work area.

In 1952-53, experiments were conducted with so-called "electronic loadometer plates" (see Appendix), which were nothing more than curved steel or aluminum plates with a strain gage network placed on their concave underside. As a vehicle axle passed slowly over the convex surface of the plates they would deflect downward causing tensile strain in the undersurface. This strain was sensed and averaged by the strain gage network, and then converted to weight by means of strain-load calibration curves. These plates were used in at least one field study (1) and performed quite well for slow-moving axles. However, they were about 1 in. high, thus elevating the axle being weighed. To correct the error resulting from this elevation it was necessary to place plates so that axles adjacent to those being weighed were also elevated. As this approach to the weighing problem did not appear too promising, it was abondoned and little or no additional work was done by Michigan until 1958.

In early 1958, plans and specifications were completed for a proposed experimental strain gage load cell-type scale. It was installed in an approach ramp to the Department's Fowlerville weigh station during the winter of 1958-59. During 1959 and early 1960, experiments were performed with this installation to investigate static and dynamic accuracies, effects of axle type and vehicle speed on accuracy, load cell placement, platform restraints, platform hold-down configurations, magnitude of hold-down forces, platform configuration and stiffness, etc.

As a consequence of the results of this work, the Department decided to proceed with a more extensive system. In July 1960, a proposal was completed and submitted to the Bureau of Public Roads for consideration under the Highway Planning and Research Program, as a cooperative project for development of one complete dynamic vehicle weighing system. At the Bureau's suggestion, this proposal included provisions for measuring moving vehicles as well as weighing them.

Upon approval by the Bureau, the proposal was circulated to a number of companies engaged in electronic systems work, inviting them to submit performance proposals. In the fall of 1960, the proposal submitted by Epsco, Incorporated, of Cambridge, Massachusetts, was accepted and they were awarded a contract for a feasibility study to indicate the probable success of a complete weight and dimension system. In March 1961, Epsco reported their study's results. Their conclusion, supported by experimental data, was that the proposed system was fully feasible. Consequently, a second contract was awarded to Epsco in July 1961, covering a complete on-site measuring and weighing system.

Because the Bureau still had some doubts concerning the degree of success attainable by the proposed system, they limited the scope of this second contract to a so-called "breadboard system." They reasoned that full operation and accuracy should be demonstrated before installing a complete system that would have to include an on-site computer, printout equipment, closed circuit television, control and operation consoles, etc. This limited contract was completed and reported out by Epsco in March 1964. The results were disappointing, in that target accuracies were not achieved and physical plant condition and much of its design were marginal at best.

To rectify the physical plant deficiencies and attain what were considered reasonable goals, "Post Part A" was proposed by the Department, to be performed by the Department. This proposal was approved by the Bureau in September 1963, and began shortly thereafter. Its purpose was improvement--in the areas of accuracy, reliability, durability, and safety--of an already existing measurement system. Post Part A was completed in February 1965, with a greatly improved, much more accurate system. On the basis of the Post Part A results, the Bureau approved continued progress on the project. This was furthered by the Department's preparation of complete specifications for Part B. This phase included replacement of most of the breadboard components; a completely new, redesigned dimension system; and all other components necessary to a fully automatic system.

The contract for Part B was awarded to Philco Corporation in December 1964, work began in March 1965, and was completed in February 1966. The system as completed is described in detail later in this paper.

At the completion of Part B, the Department initiated the final phase of the program--Part C. This phase is of 16 months duration and is programmed for completion by July 1, 1967. It is to consist of a period of research operation of the system, to study and improve its functioning by making minor revisions, developing operational procedures, and exploring all possibilities for obtaining useful data from the system.

Unfortunately, shortly after the inception of Part C, the system received a severe lightning strike. System damage was extensive, involving nearly all major system units and requiring replacement of hundreds of components throughout the system (especially in the digital computer). This repair work is now nearing completion and an extensive lightning protection net has been added to prevent a recurrence.

SYSTEM DESCRIPTION

With the following system, a complete qualitative and quantitative description of the traffic traversing the instrumented area can be obtained. All or any portion of the following information can be accumulated for any desired period:

For Cars:

Total Number*
Speed*

For Trucks:

Total Number*
Speed*
Height*
Width*
Length*
Axle Spacings*
Axle Weights*
Gross Weight*
Vehicle Type
Location of Spread Tandems
Loading
Fuel Type
Vehicle Class
Auto Carrier

Of these information items, those followed by an asterisk can be obtained automatically, and the balance semi-automatically.

The system is located on I 94 near Grass Lake, about 14 miles east of Jackson. The system's physical configuration and components are illustrated in Figure 1. The components include the following items:

1. Four electronic scales for dynamic weighing of truck axles.
2. An infrared source and sensor array for dimensioning of trucks.
3. Ultra-sonic transceivers surveying both westbound lanes of the expressway to determine classification (car or truck) and speed of all traffic.
4. A digital computer, digital magnetic tape unit, and teleprinter.

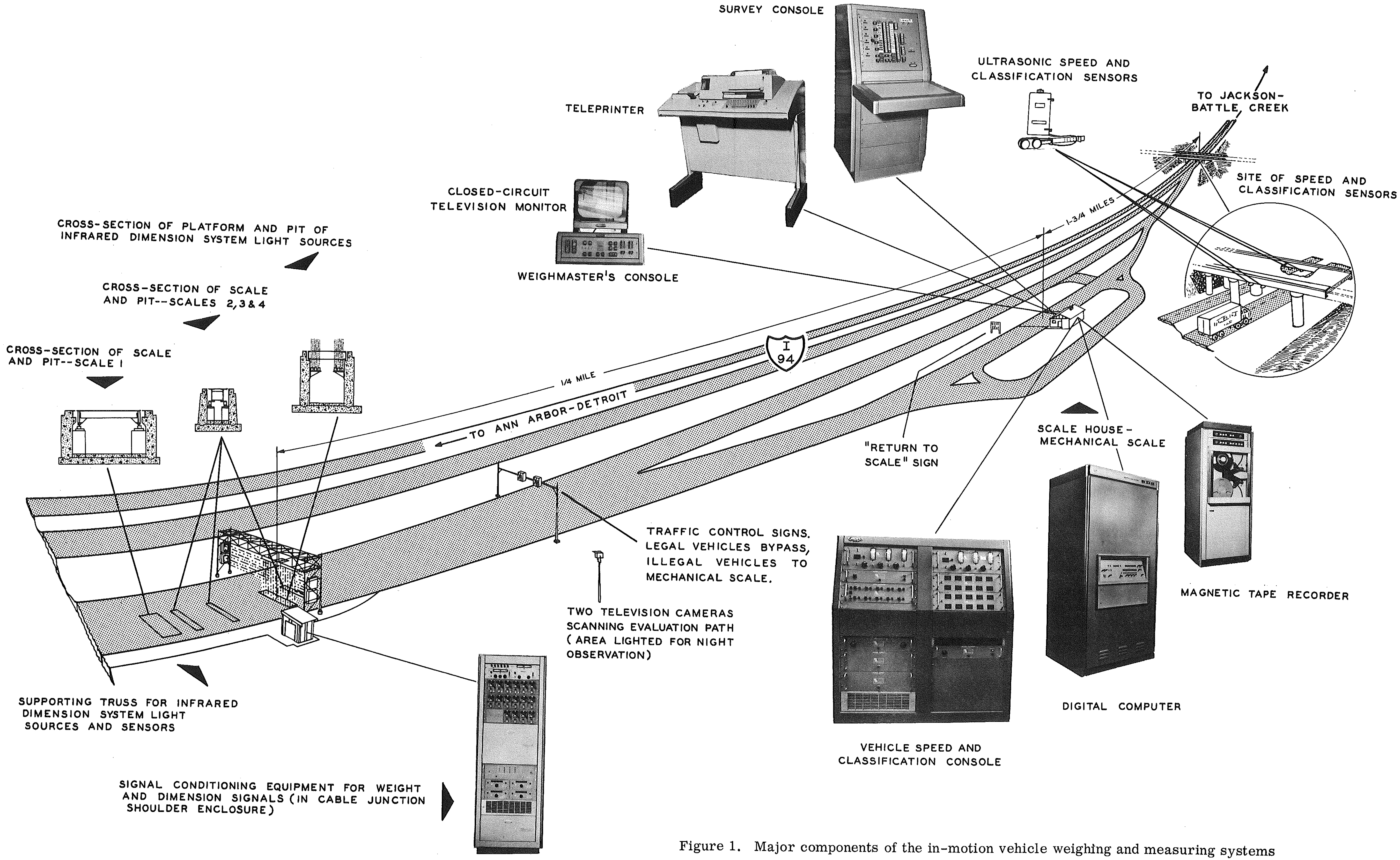


Figure 1. Major components of the in-motion vehicle weighing and measuring systems

5. Pre-processing or signal conditioning electronic equipment to prepare all weight, dimension, and road switch signals for the computer.

6. A survey console permitting manual input of data onto magnetic tape for off-site analysis.

7. A weighmaster's console controlling and operating the weight and dimension subsystems.

8. A television system allowing the weighmaster to observe the evaluation path.

9. A speed and classification console that calculates, records, and displays speed and classification data.

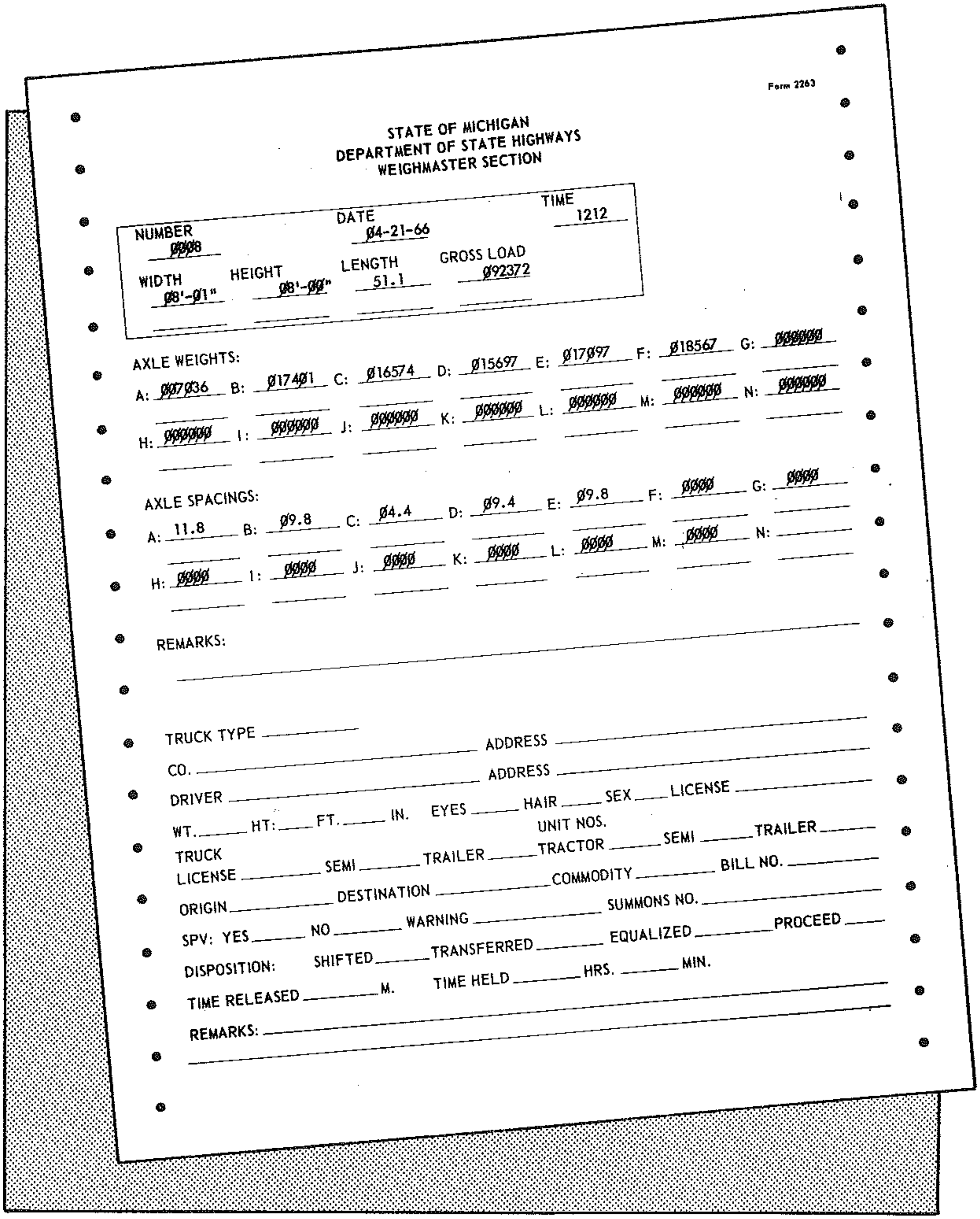
System Functions

The system is designed for operation of the weighing, dimensioning, and speed-classification subsystems either separately or together.

The system's weighing function is accomplished by four 12-ft wide electronic scales centered at intervals of 10, 20, and 40 ft along the evaluation path. The first scale encountered is 9-ft long and is used to weigh single, tandem, and tridem axles. The three remaining scales are each 3-ft long and are used to determine single-axle weights. A pair of road switches installed in the surface of each scale platform provides signals for determining the total number of axles, axle spacings, vehicle speed, and also to assist in obtaining the weight per axle. In addition, one switch is located ahead of the first scale to start the entire measurement process.

The system's dimension measurement function is accomplished by an infrared beam array located between the third and fourth scales. This array consists of 13 horizontal beams to measure truck height and 72 vertical beams to measure truck width. The 10 center vertical beams perform a dual purpose, determining vehicle length as well as width.

When a truck passes through the weight and dimension evaluation path, the computer makes a real time computation to determine which lane the truck will take. The computer is programmed so that oversize or overweight trucks are directed to stop at the scale house for static measurements, while legal trucks are directed to take the bypass. When a violation occurs, a hard copy printout (Fig. 2) is produced by the teleprinter by the time the violator reaches the mechanical scale. In addition, a hard copy printout can be obtained on any other truck by pushing a button provided on the weighmaster's console.



Form 2263

STATE OF MICHIGAN
DEPARTMENT OF STATE HIGHWAYS
WEIGHMASTER SECTION

NUMBER 0008
DATE 04-21-66
TIME 1212
WIDTH 08'-01"
HEIGHT 08'-00"
LENGTH 51.1
GROSS LOAD 092372

AXLE WEIGHTS:
A: 007036 B: 017401 C: 016574 D: 015697 E: 017097 F: 018567 G: 000000
H: 000000 I: 000000 J: 000000 K: 000000 L: 000000 M: 000000 N: 000000

AXLE SPACINGS:
A: 11.8 B: 09.8 C: 04.4 D: 09.4 E: 09.8 F: 0000 G: 0000
H: 0000 I: 0000 J: 0000 K: 0000 L: 0000 M: 0000 N:

REMARKS:

TRUCK TYPE
CO. ADDRESS
DRIVER ADDRESS
WT. HT: FT. IN. EYES HAIR SEX LICENSE
UNIT NOS.
TRUCK TRACTOR SEMI TRAILER
LICENSE SEMI TRAILER
ORIGIN DESTINATION COMMODITY BILL NO.
SPV: YES NO WARNING SUMMONS NO.
DISPOSITION: SHIFTED TRANSFERRED EQUALIZED PROCEED
TIME RELEASED M. TIME HELD HRS. MIN.
REMARKS:

Figure 2. Facsimile of typical hard-copy printout on trucks traversing evaluation path.

The vehicle speed and classification sensors are located at an overpass approximately 1-3/4 miles beyond the weight and dimension subsystems. They include one speed transceiver and one vehicle height transceiver mounted over each of the two westbound lanes of the expressway. Signals from these detectors are transmitted through buried cables back to their own console at the weighing and dimensioning site.

System Modes

The subsystems, which collect and automatically process data to determine axle weights, axle counts, and heights, widths, and lengths of vehicles in motion, are designed for use in four modes:

1. Normal (or Automatic) Mode, in which dynamic vehicle data are processed and control signals generated that automatically route traffic either onto the static (mechanical) scale or back into the main traffic stream. Computer decisions are displayed on the weighmaster's console so that he may over-ride the computer and summon vehicles to the scale house if he wishes. In this mode, a hard copy record is typed out for all vehicles found to be illegal.

2. Raw Data Transfer Mode, in which raw data from the sensors are encoded and transferred directly to magnetic tape with the truck serial number (assigned by the computer), time, and date.

3. Survey Standby Mode, a transition mode inhibiting data collection. This allows all dynamic data taken during survey operation to be complemented by manually collected data on the same record.

4. Traffic Survey Mode, in which dynamic vehicle data and appropriate truck serial numbers are recorded on magnetic tape. At the scale house, data are input manually to the survey console and then automatically transferred to magnetic tape under the same serial number to indicate axle configuration, load condition, fuel type, etc. , as provided by the survey console. To assist in control and in entering of manual data, a closed circuit television display of the dynamic scale area is presented on a monitor on the weighmaster's console.

SYSTEM CALIBRATION AND ACCURACY

The lightning strike to which the system was subjected occurred shortly after initial full-scale Part B operation began. Consequently, the system calibration and accuracy program was not completed, and has not been completed at this writing. However, two extensive calibration and accuracy determinations were performed earlier in the study and should still be valid. If there is any change it is expected that earlier accuracies will be improved, due to improvements in signal conditioning and processing equipment. The calibration and accuracy work described here is that performed during the early phases of Part B.

Weight Calibration and Accuracy

Tests performed to determine dynamic weighing characteristics and accuracy of the four scales utilized two special State Highway Department test vehicles and approximately 250 trucks from the traffic stream normally traversing the scale installation. Single-axle loads of these 250 vehicles ranged from 4 to 19 kips, and tandem-axle loads from 8 to 32 kips. Most trucks traveled over the scales at 20 to 50 mph.

For purposes of these tests it was decided to take weights on single axles and 4-ft tandem axles only, excluding steering axles, tridems, walking beams, and any other special types presenting difficulties in static weighing such as air suspension axles and liquid carriers.

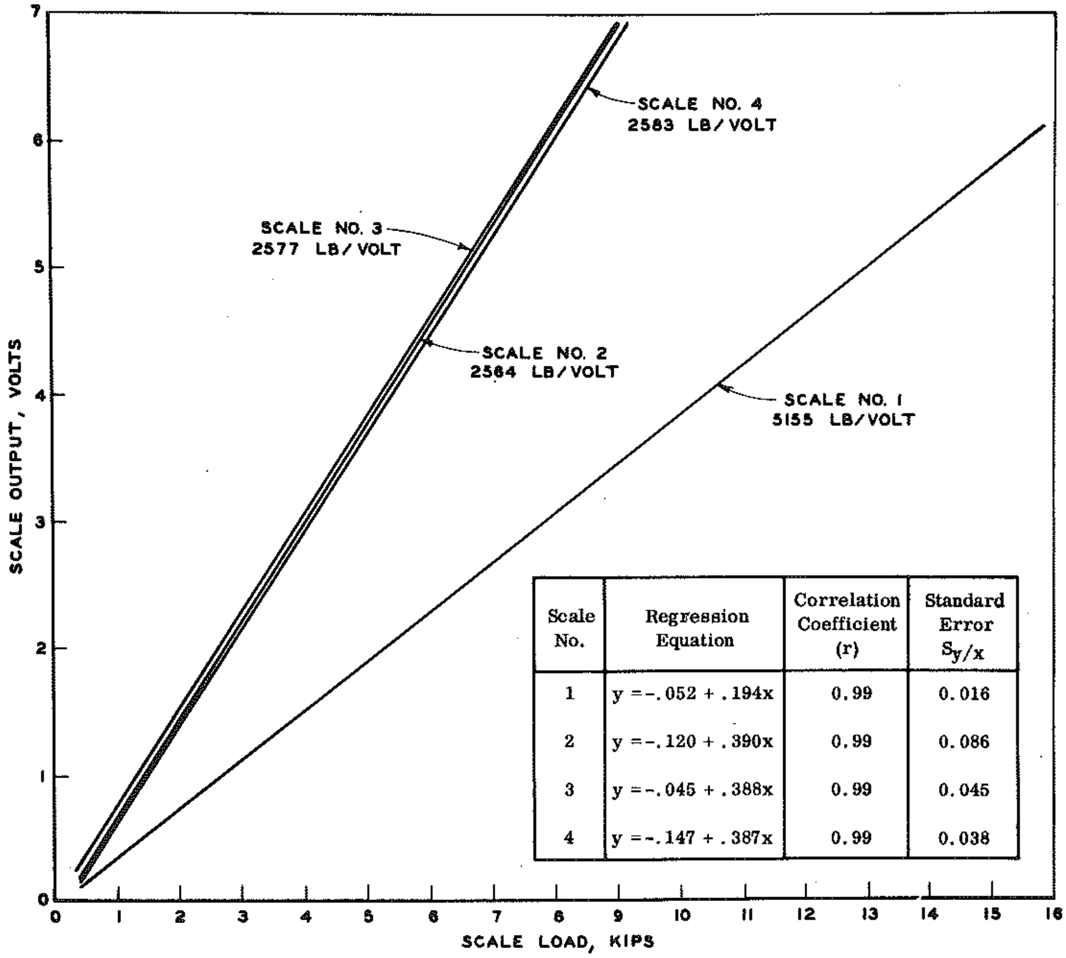
Calibrations were established for all scales prior to testing as follows:

1. The 16 load cell power supply outputs were adjusted, using a digital voltmeter to an indicated accuracy of ± 0.01 v (i.e., 4.99 to 5.01 v for the cells of Scale No. 1, and 9.99 to 10.01 v for the cells of Scales 2, 3, and 4).

2. The tare voltage output of each cell was balanced to 250 μv resulting in a combined scale output (four cells) of 1 mv. This voltage was then amplified by a factor of 1000 to give a tare voltage signal of 1.0 v. The purpose of this tare voltage was to preclude the possibility of the scale signal going negative when the platform was vibrating.

3. To complete calibration, the relationship between applied load and scale voltage output was determined by stopping axles on the electronic scale platforms, making precise recordings of the resulting scale output voltages, and then statically weighing these axles on the mechanical scales. The resulting relationships are shown in Figure 3.

Test procedure consisted of selecting a vehicle as it approached the system, recording its normal speed passage over the scales, and then stopping it at the mechanical scale for careful static weighing. Utilizing this procedure, some 140 single axles and a similar number of tandems were measured.



Scale No.	Regression Equation	Correlation Coefficient (r)	Standard Error $S_{y/x}$
1	y =-.052 + .194x	0.99	0.016
2	y =-.120 + .390x	0.99	0.086
3	y =-.045 + .388x	0.99	0.045
4	y =-.147 + .387x	0.99	0.038

Figure 3. Electronic scale calibrations.

In addition to the tests just described, it was felt that the system's repetition ability should be evaluated. To this end, the two Department trucks, one with a near legal limit single axle (16.25 kips) and the other with a near legal limit tandem axle (31.85 kips), each made 20 recorded runs across the scales at a controlled speed of approximately 35 mph.

Two methods of analysis were used in determining the system's accuracy. The first consisted simply of combining the four individual scale weights into one average. These average electronic weights were then paired with their corresponding mechanical scale static weights in a simple regression analysis, to produce a regression equation and standard error of estimate of the relationship between electronic and static weights.

It was desired to present accuracy ranges at the high confidence level of 99 percent (meaning that 99 out of 100 samples will fall within the specified range). The accuracy ranges specified here represent 2.58 standard errors (assuming data to be normally distributed). In other words, the product of one standard error and 2.58 establishes the limits about the regression line within which 99 percent of all test samples will occur.

The second analytical method was somewhat different, and represents an apparently successful attempt to improve system precision by computing individual scale weighing coefficients on the basis of a large number of axles. Then, using the coefficients so determined, individual vehicle axle weights may be predicted on the basis of the electronic scale outputs. This constitutes a "multiple regression" and requires solution of an equation of the form $Y = aX_1 + bX_2 + cX_3 + dX_4 + e$, where $X_1 \ldots X_4$ represent electronic weights for a given axle on Scales 1 through 4, respectively, and the coefficients a, b, c, and d control the magnitude of each scale's contribution to the final computed and reported weight of this axle. The equation's constant e represents and corrects for any apparent fixed bias in the combined scale system.

The coefficient computed for a given scale is a measure of that scale's reliability in predicting static axle weights, i.e., the output of a scale with a high coefficient, even though possibly biased toward high or low weights, is characterized by a consistent (low scatter) relationship with static weight. A low coefficient indicates a much less reliable relationship (large scatter) between electronic and static weights. Therefore, in the final calculation of any given axle's weight, the indicated electronic weights from the scale(s) found most reliable are heavily weighted and those from less reliable scales are less heavily weighted in proportion to their reliability.

The specified system accuracies based on the multiple regression method are then determined in the same manner as in the first method. The Y values resulting from solution of the multiple regression equation are paired with their static values, and a simple two-variable linear regression analysis is performed. This produces the straight-line equation of the relationship, the standard error of estimate, and with proper conversion (2.58 standard errors) the system accuracy at the 99-percent confidence level.

The scatter plots of Figures 4 and 5 appear to indicate that further accuracy refinement might be realized by separating the weights into bands and analyzing them on that basis. To determine the effects of such an approach, single- and tandem-axle weights were both separated into three ranges, spanning the full range from zero to the maximum load encountered. Results of this work are given in Tables 1 and 2.

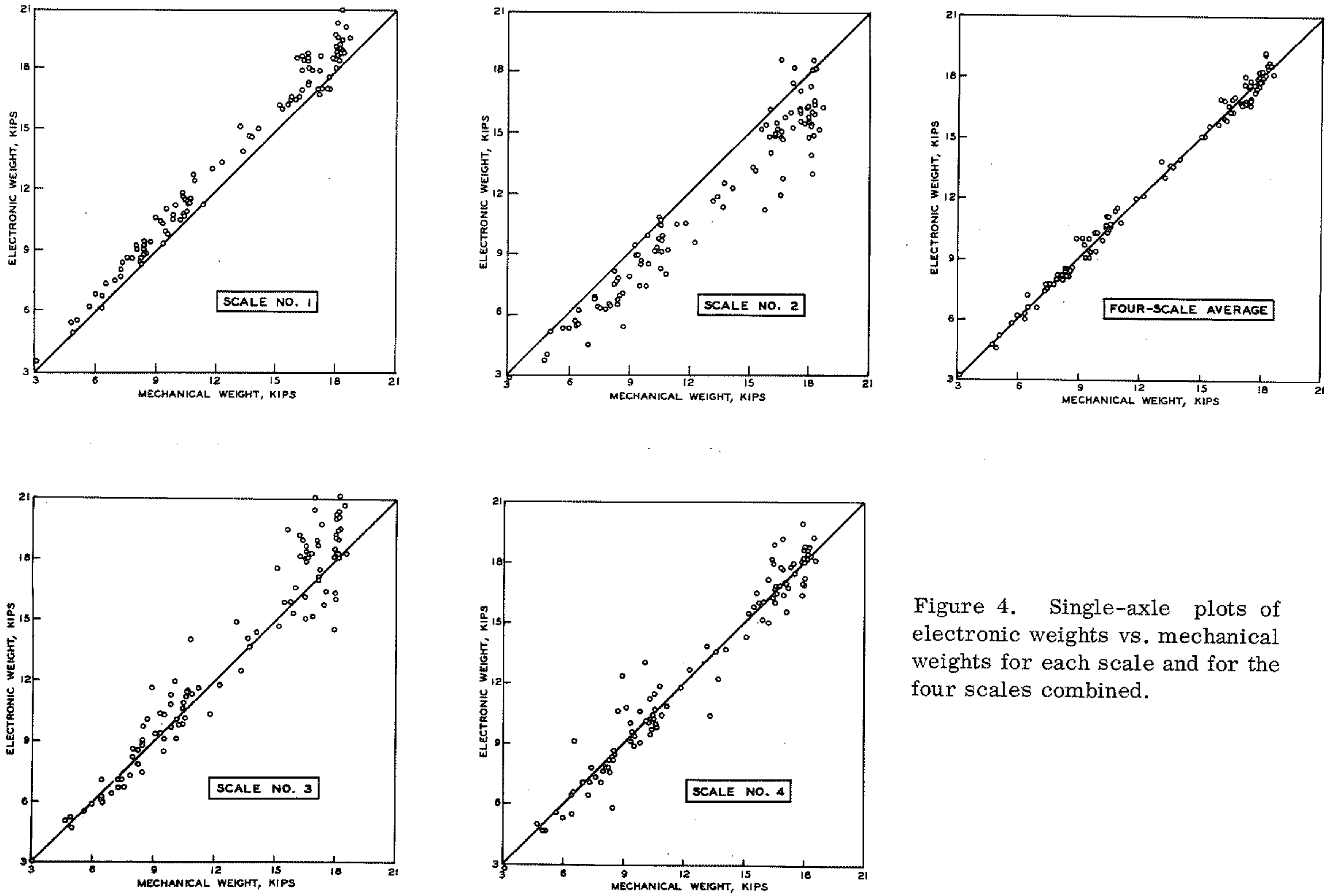


Figure 4. Single-axle plots of electronic weights vs. mechanical weights for each scale and for the four scales combined.

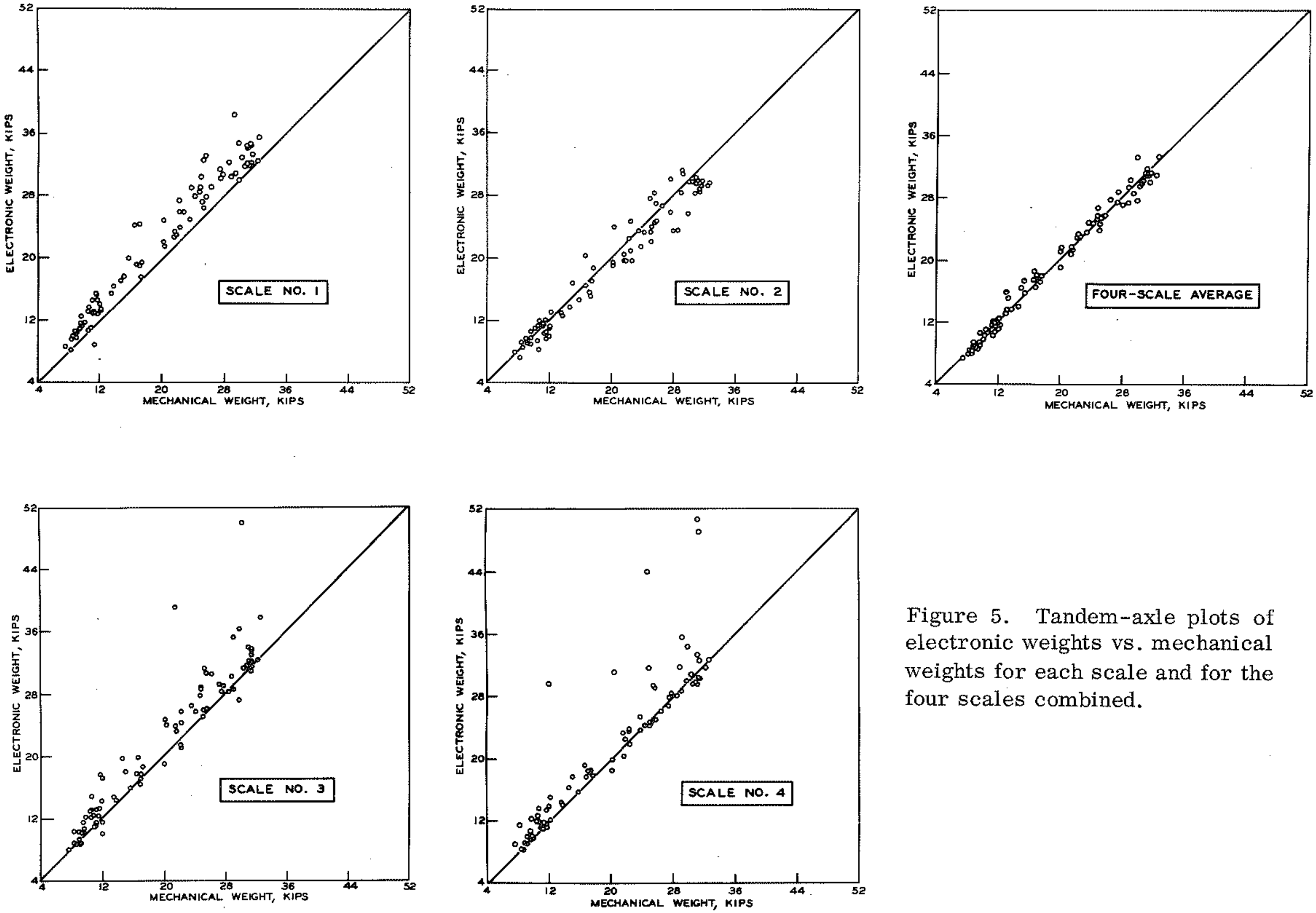


Figure 5. Tandem-axle plots of electronic weights vs. mechanical weights for each scale and for the four scales combined.

TABLE 1
ERROR COMPARISONS
Two Methods of Computing Weight: Unweighted Arithmetic Mean and Multiple Regression

	Axle Load Range	Unweighted Arithmetic Mean	Multiple Regression
Single Axles	0 to 9 kips	---	760 lb
	9 to 16 kips	---	920 lb
	16 kips and over	1420 lb	940 lb
	Full Range (all axles combined)	1210 lb (or 6.7% of 18 kips)	950 lb (or 5.3% of 18 kips)
	Special Group: 25 heavy single axles from traffic stream	1410 lb (or 7.8% of 18 kips)	810 lb (or 4.5% of 18 kips)
	Special Group: 18 repetitions of one 16.26-kip single axle (Department truck)	796 lb (or 4.4% of 18 kips)	0 lb
Tandem Axles	0 to 16 kips	---	1370 lb
	16 to 24 kips	---	1900 lb
	24 kips and over	---	2300 lb
	Full Range (all axles combined)	2260 lb (or 7.0% of 32 kips)	2200 lb (or 6.9% of 32 kips)
	Special Group: 23 heavy tandem axles from traffic stream	2080 lb (or 6.5% of 32 kips)	1264 lb (or 4.0% of 32 kips)
	Special Group: 19 repetitions of one 31.85-kip tandem axle (Department truck)	1190 lb (or 3.7% of 32 kips)	0 lb

TABLE 2
MULTIPLE REGRESSION SCALE COEFFICIENTS
OF THE EQUATION $\underline{y = aX_1 + bX_2 + cX_3 + dX_4 + e}$
AND ESTIMATED STANDARD ERRORS $\underline{S}$ OF THESE COEFFICIENTS

Scale No.	Constants and Their Standard Errors*	Single Axles				Tandem Axles			
		0-9 kips	9-16 kips	>16 kips	Full Range	0-16 kips	16-24 kips	>24 kips	Full Range
1	a	0.65	0.63	0.38	0.60	0.23	0.17	0.27	0.25
	S	0.10	0.12	0.07	0.05	0.06	0.06	0.09	0.04
2	b	0.20	0.30	0.13	0.23	0.19	0.42	0.14	0.21
	S	0.09	0.07	0.04	0.03	0.06	0.10	0.08	0.05
3	c	0.14	0.03	-0.02	0.03	0.36	0.42	0.13	0.34
	S	0.09	0.07	0.04	0.03	0.06	0.10	0.09	0.05
4	d	-0.05	0.04	0.19	0.13	0.03	-0.05	0.36	0.21
	S	0.06	0.09	0.06	0.04	0.06	0.12	0.09	0.06
	e	110	-270	5500	-60	1300	100	-500	-960
	S	300	400	1200	120	400	1500	1700	230

* $\underline{a}$, $\underline{b}$, $\underline{c}$, $\underline{d}$ = coefficients
$\underline{S}$ = standard errors
$\underline{e}$ = bias constants

Table 1 gives results of the multiple regression analysis, the weight band analysis, and application of both these analytical methods to a select group of very heavy single and tandem axles (near or over legal limit in each case), plus the results of a series of repetitions of two particular axles, one single and one tandem.

The multiple regression analysis can be seen to result in significant accuracy improvement in every instance of its use, indicating its superiority as a method of analysis for this study. The relative merit of weight band separation is somewhat less conclusive in the single-axle analysis, except for the 0- to 9- kip range where there is significant improvement. In the tandem-axle analysis, considerably more improvement appears throughout the whole range, except for the higher error of the over-24-kip band as opposed to the full range error. Results of this weight band analysis, although not too conclusive, are sufficiently encouraging to indicate the value of exploring the matter further.

The next category of Table 1 to be considered concerns the two groups of near-legal-limit axles. These groups were examined because of the nature of the accuracies specified for Part B of this study, where the allowable error specified for both single and tandem axles is given as a percentage of the maximum legal load. Very good accuracy can be seen to have been achieved for both single and tandem axles, and again the efficacy of multiple regression analysis is demonstrated.

The final tabulation of Table 1 presents results of the repetitive tests with the two Department vehicles. In this area, predictably, are found the lowest errors of any test grouping, and the effects of multiple regression analysis are most dramatically demonstrated, there being zero error for the 37 dynamic weighings at the 100-percent confidence level.

In Table 2 the multiple regression equation coefficients of the weight band analysis are presented and the value of one standard error of each coefficient is included. The purpose of this chart is threefold: 1) it defines the magnitude of the contribution of each scale for each weight band and the axle type used, 2) by means of the coefficient standard errors it presents a measure of the reliability of each coefficient, and 3) it gives the magnitude of the system (four-scale) bias, in pounds, for each weight band, and a measure of the certainty of this fixed bias by virtue of its standard error. This table also points out the influence or lack of influence of different scales in different weight bands. Contributions of a given scale may vary markedly for different weight bands or different axle types. Large variations of fixed bias occur in different weight bands and for different axle types.

Dimensional Accuracy

The dimensional accuracy obtainable by the infrared array is limited by the 1-in. interval spacing of the sensors. In addition, height and width measurements are adversely affected by vehicle bounce, flapping tarps, etc. which tend to bias height readings to the high side, and by vehicle "crab," a very common vehicle characteristic which tends to bias width readings to the high side. These tendencies are predictable and have been substantiated for both height and width by past tests.

Vehicle length and axle spacing both depend upon timing procedures and knowledge of vehicle velocity. The velocity of each axle of any given vehicle traversing the system is determined by timing its passage between two road switches of known separation. Thus, it is possible to determine a vehicle's velocity and rate of acceleration or deceleration, and thereby arrive at an average velocity.

Axle spacing then becomes a direct function of the elapsed time between actuations of a road switch by adjacent axles and the known velocity. Vehicle length is a similar determination, except that it is a function of elapsed time between vertical infrared beam interruption and restoration and the known vehicle velocity. All of these timing procedures and computations are performed by the computer, with the accuracy of the computations primarily dependent upon a uniform vehicle velocity, or a uniformly changing velocity.

Dimensional accuracies have not been determined since the lightning damage to the system. Those determined prior to that incident are not applicable because sensor spacing has recently been reduced and the entire dimensional hardware system replaced. Expectations are that the system will be much more accurate because of the significant improvements in hardware and in physical configuration.

The only accuracy from the earlier tests that should still be applicable is axle spacing. At the time of the determination this was ± 0.14 ft (99-percent probability).

Speed and Classification Accuracy

The ultra-sonic doppler-type equipment used for vehicle speed and classification determinations is the type made by the General Railway Signal Co. It has been used by traffic engineers for many years and has known and proven capabilities and limitations. The accuracy study performed indicated a speed measurement accuracy of ± 7.0 mph (again at the 99-percent confidence level).

Vehicle classification--car or truck--determined by this equipment is a function of vehicle height. The system calls any vehicle over 6.5 ft high a truck, and any less than this height, a car. In a monitored 600-vehicle sample there were no errors if three pickup trucks can be classified with cars.

Survey Data Accuracy

The accuracy of information recorded in the survey mode depends upon the experience and ability of the console operator. The six vehicle variables (Vehicle Type, Location of Spread Tandems, Loading, Fuel Type, Vehicle Class, and Auto Carrier) must be recognized by the operator as a vehicle traverses his field of view and then he must depress the correct switches on the console keyboard. If the information is correctly perceived and input to the console, there should be no errors in automatic transfer of data to magnetic tape.

OBSERVATIONS AND CONCLUSIONS

The most valuable result of any experimental prototype system, such as that reported here, is in the proof of system feasibility and in the instruction it gives concerning possible future systems. This project has proved that usable, acceptable accuracy is entirely feasible for in-motion vehicle weighing and measuring systems. It has pointed up the need for various modifications and improvements in future systems:

1. The large, expensive scale pit-platform configurations employed in this study could be greatly simplified in future systems. Scales such as the Lee (2) low-profile or similar types are indicated. Also, the number of scales required could be reduced. The results of this study show that the fourth scale is adding very little to system accuracy, and therefore three would probably prove adequate.

2. The present infrared-beam-type dimension system performs its function quite well. However, winter conditions often limit its use. Large or dense snowflakes can interrupt the beams. Snow on the platform, either falling there or tracked by trucks, can also cause beam interruption. Avoiding such problems and obtaining a truly all-weather system will be difficult but possible. Future systems should consider other types of dimension sensing such as ultra-sonic, image matching, etc.

3. It will be desirable that any future dimension and scale systems be as unobtrusive as possible. A completely hidden or disguised system would be most effective. In addition, a system located directly in the traffic stream

rather than on adjacent ramps would be highly desirable if the resulting traffic control problems can be resolved.

4. Possibly the most useful and efficient future system would be fully portable, thereby giving time and location flexibility to the enforcement and survey groups utilizing such equipment.

5. Experience has shown that it would be advantageous to completely separate weight and dimension functions in future systems. Most breakdowns encountered to date have resulted from minor dimension system malfunctions. However, with the system as presently constituted, these minor dimension measurement problems can also invalidate weighing results.

6. A very serious problem area in the present system, which has not yet been resolved, is that of road switches. This system requires twelve such units and to date the longest lived switch installed lasted about three months. An all solid-state type of switch is now on order. However, there is no assurance that this unit will solve the problem. The best approach in future systems would be to attempt a design that does not require any type of surface switch.

7. Future systems could easily be designed to eliminate any need for closed-circuit television or site lighting, both of which are expensive. Also, any future network of systems could be designed to share a central computer, further decreasing necessary on-site equipment and as a consequence reducing cost.

In summary, it can be stated that Michigan's dynamic vehicle weighing and measuring system is a success. It has the ability to weigh and measure trucks traveling at highway speeds, and to do so with acceptable, usable accuracies. It is true, as with any complex prototype system, that some components now lag behind the "state of the art." Also, the system has weak areas. However, it is to uncover such problem areas that prototypes are designed and fabricated.

The important accomplishment is proving that such installations are feasible and practical. Future workers can approach the problem from the standpoints of improvement and refinement.

It is not difficult to forsee the time when later generation descendants of this system are widespread throughout our road network, making it possible to acquire continuous, current, nationwide traffic information and thus improve highway design, highway traffic legislation, and traffic control and enforcement.

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NOTE

APPENDIX

ELECTRONIC LOADOMETER PLATES

The loadometer plate is composed of a sheet of armor-plate steel 30-1/8 by 24-3/16 by 1/2 in. thick. A strip of 1-in. channel iron is welded underneath each of the short sides at the edge, and a strip of rubber (24-3/16 by 9/16 by 5/8 in.) of 60-68 Durometer hardness is cemented into the groove of the channel to give the plate a base that will seat itself upon a rough surface such as concrete.

Ten A-7, SR-4 strain gages (120 ohm) are mounted on the under or concave side of the plate at the points indicated in Figure A1. Gages 1, 2, 7, and 8 are wired in series, and Gages 3, 4, 5, and 6 are wired in series. These two series circuits are then wired in parallel, giving a resultant resistance of 240 ohms. The two temperature compensating gages are mounted upon unstrained cantilevers and wired in series, thus also giving 240 ohms.

The plates were calibrated in the laboratory and at the weigh station near Fowlerville on US 16. In the laboratory, the loads were applied by a hydraulic press, and distributed over an area of approximately 40 sq in. It was also necessary to calibrate at the weigh station because of the possibility of differences in the area of load application, which in the case of dual truck tires may be as much as 150 sq in. In the laboratory the loads were applied from 0 to 14,000 lb in 1,000-lb increments in the four positions, as follows:

1. At junction of transverse and longitudinal centerline.
2. On transverse centerline and 4 in. off longitudinal centerline.
3. On longitudinal centerline and 4 in. off transverse centerline.
4. At a point 4 in. off transverse centerline and 4 in. off longitudinal centerline.

It was found that for any of these positions the results were very nearly linear and very good repetition could be obtained.

The maximum range of deviation over the four positions was approximately 7 percent. It was found that in practice it is quite easy to center the wheel loads on the transverse centerline, and in the case of dual tires, symmetrically with respect to the longitudinal centerlines. Therefore, it was concluded that this centering of the loads would eliminate the deviation due to calibration positions 3 and 4, and consequently reduce the range of deviation to approximately 2.2 percent. However, the readings obtained from the weigh station indicated that a correction curve for single axles and another for tandem axles were necessary. This correction was necessitated by the elevating effect of the plates. This elevating effect was partially compensated for in the case of tandem axles, by wooden plates 3/4-in. thick, which were placed under the axle adjacent to the one being weighed. Calibration curves for Plates 1 and 2 are shown in Figure A2.

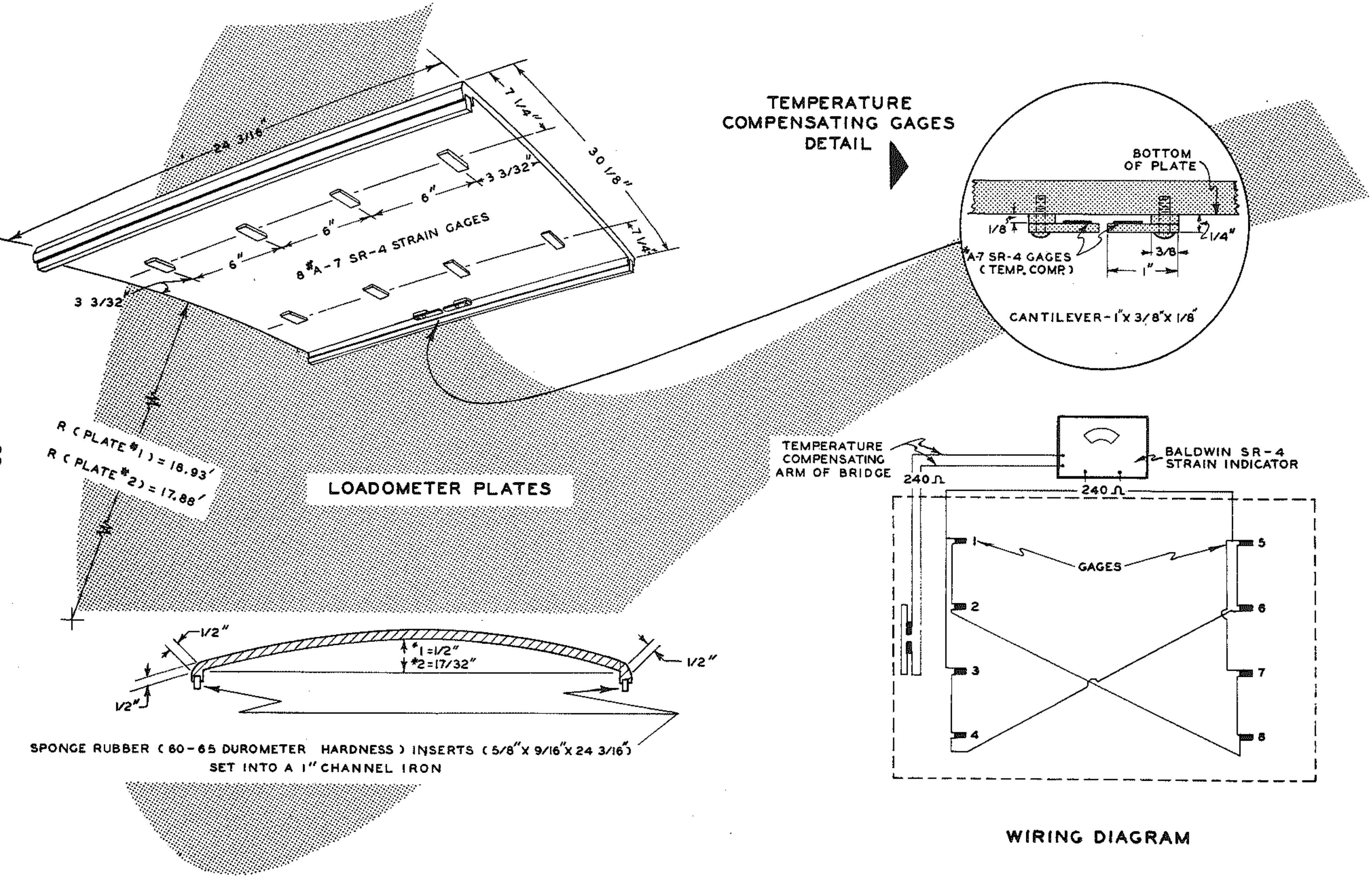

Figure A1. Details of electronic loadometer plates.

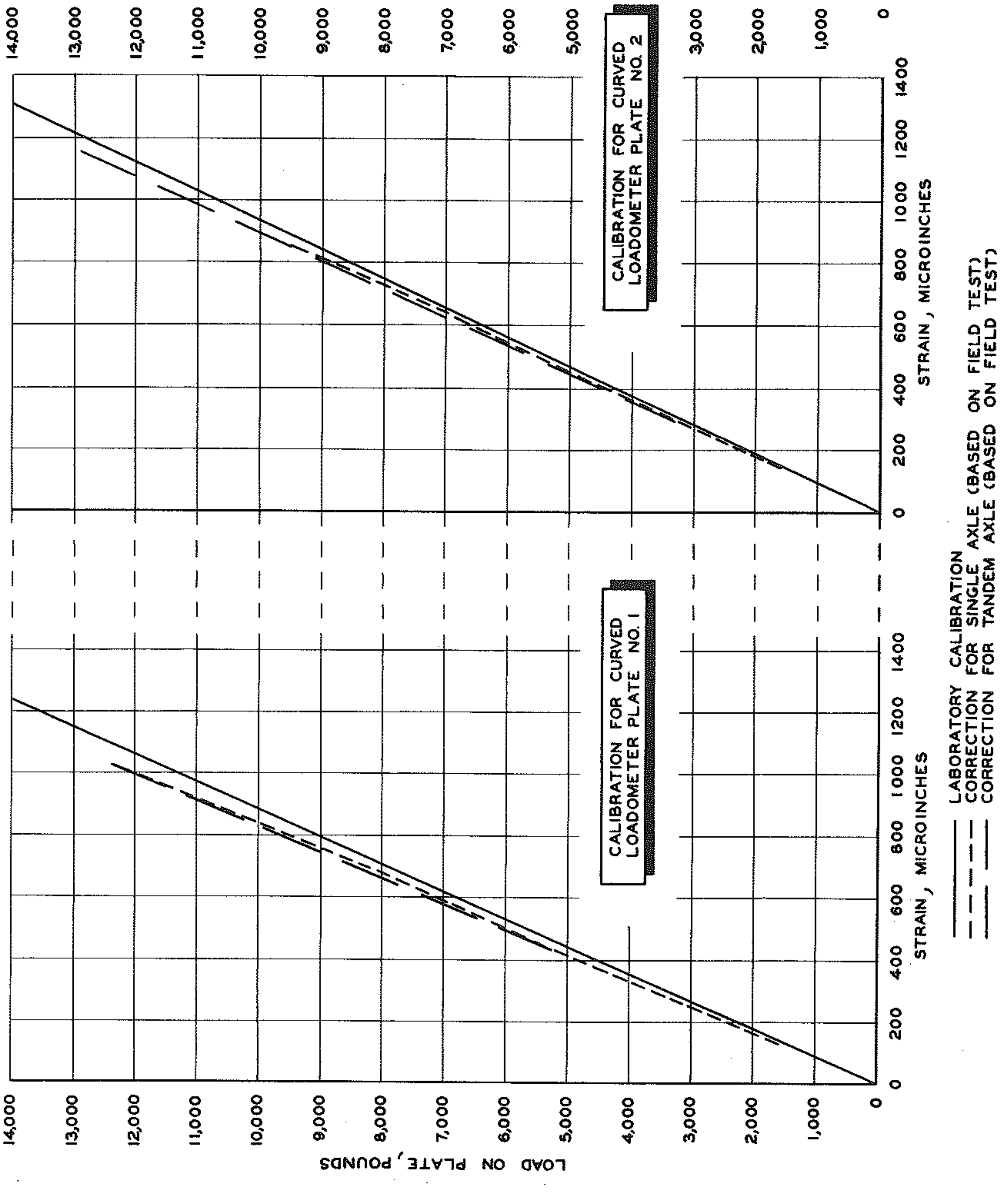

Figure A2. Calibration of electronic loadometer plates.