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Wiley D. Cunagin and Saïd O. Majdi

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16. Abstract

Truck weight data are required for pavement and bridge design, truck size and weight enforcement, and the development of administrative policy and legislation. The efficient collection and analysis of these data require that truck weighing-in-motion (WIM) equipment be used. Unfortunately, the high cost of these devices (greater that $50,000 per unit) has prohibited the large scale implementation of WIM technology. Lower cost WIM systems systems are also necessary to provide new or expanded data required by both the Long Term Pavement Performance (LTPP) monitoring element of the Strategic Highway Research Program (SHRP) and implementation of the provisions of the recently issued Federal Highway Administration (FHWA) Traffic Monitoring (TM) Guide.

Several possible technologies exist for low cost WIM systems. One of these, piezoelectric cable, was investigated in a research effort jointly sponsored by the States of Iowa and Minnesota and FHWA and in other work in the State of Washington and several European countries. A second approach is an inexpensive capacitive weighmat WIM sensor and associated electronics developed for FHWA. A third alternative is a reduced cost configuration of the bending plate WIM transducer manufactured and distributed by the PAT Equipment Corporation. Each of these was evaluated in this study to determine its usefulness in providing effective truck weighing devices at a cost that would allow widespread implementation of in-motion truck weighing programs in Texas.

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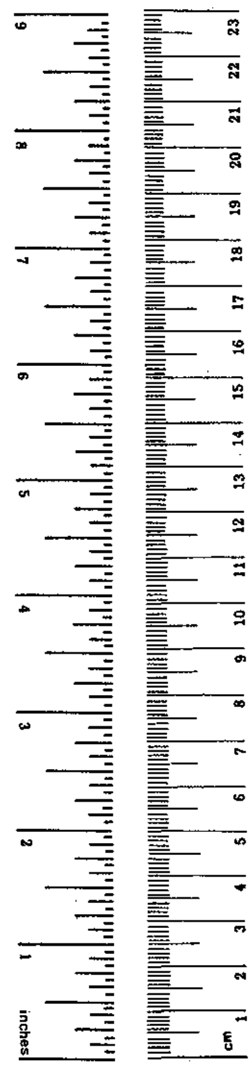
METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

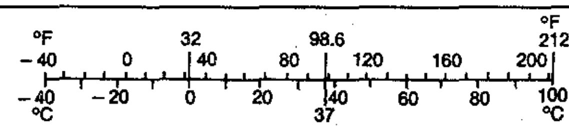
NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectores (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



These factors conform to the requirement of FHWA Order 5190.1A.

* SI is the symbol for the International System of Measurements

EVALUATION OF LOW COST WIM ALTERNATIVES

by

Wiley D. Cunagin

and

Saïd O. Majdi

Research Report 1140-1F
Research Study 2-10-86-1140
"Evaluation of Low Cost WIM Alternatives"

Sponsored by

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IMPLEMENTATION

This report includes a review of available low cost WIM technologies and an assessment of their likelihood of successful implementation in a large scale program of truck weighing in Texas. A work program for implementing such a program is also included.

DISCLAIMER

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CHAPTER 1. INTRODUCTION

Truck weight data are required for pavement and bridge design, truck size and weight enforcement, and the development of administrative policy and legislation. The efficient collection and analysis of these data require that truck weighing-in-motion (WIM) equipment be used. Unfortunately, the high cost of these devices (greater than $50,000 per unit) has prohibited the large scale implementation of WIM technology. Lower cost WIM systems are also necessary to provide new or expanded data required by both the Long Term Pavement Performance (LTPP) monitoring element of the Strategic Highway Research Program (SHRP) and implementation of the provisions of the Federal Highway Administration (FHWA) Traffic Monitoring (TM) Guide.

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OBJECTIVE OF STUDY

The objective of this study was to determine the feasibility of using low cost WIM technology in large scale truck weighing programs. This research emphasized the feasibility of deploying low cost WIM equipment in the field with little or no additional development.

REPORT ORGANIZATION

Chapter 2 describes the work conducted and results obtained in the identification and assessment of technologies available for use in low cost WIM systems. This included a literature and product review, a review of user needs and available technology, and a feasibility analysis of those technologies that were identified as having possible application to low cost WIM installations.

Chapter 3 describes the effort to redesign and fabricate a low cost WIM system based on capacitance-based technology similar to that designed and prepared under a recently completed FHWA contract.

Chapter 4 describes the laboratory and field testing conducted and results obtained in the active evaluation of those technologies that were identified as candidates for use in the low cost WIM system. These included the selection of the appropriate technologies, conduct of laboratory and field tests, and analysis of the laboratory and field data.

Chapter 5 describes the effort to automate the low cost WIM systems identified and tested previously. One of the low cost WIM systems was then modified and evaluated.

CHAPTER 2. TECHNOLOGY ASSESSMENT

The first stage of the study was devoted to the assessment of technology currently available for use in low cost WIM systems. The first task in this effort was the conduct of a literature and product review. WIM user needs and available technology were then reviewed. The third task was a feasibility analysis of the technologies that were identified in the previous tasks. The work carried out and results obtained under each of these activities are described in the following sections.

LITERATURE AND PRODUCT REVIEW

A detailed search of available literature and product information was conducted through the use of several sources, including: an automated literature search via the National Technical Information System (NTIS); a microcomputer data base of reference materials created and maintained within the Texas Transportation Institute (TTI) Traffic Monitoring Program; discussions with experts on WIM technology both inside and outside of vendor organizations; and additional discussions with experts in the areas of sensor technology that have not yet been successfully applied to WIM systems.

The automated literature search was accomplished using key words to retrieve listings of relevant publications. These documents were obtained for evaluation to determine if they contained information that would be useful in this research. The TTI data base is an implementation that uses the dBASE III Plus software package and contains more than 1,000 entries. The WIM experts associated with vendors included Mr. Bernard Johnson of Howe Richardson, Mr. Gerald Neely (formerly with the Radian Corporation), Mr. Jeff Davies of CMI Dynamics, Mr. Siegfried Gassner of the PAT Equipment Corporation, and Mr. Richard Snyder of Bridge Weighing Systems. The discussions with experts in areas of sensor technology included detailed contacts with Mr. Perry Kent of FHWA and with representatives of the Pennwalt Corporation, the major U.S. supplier of piezoelectric film.

REVIEW OF USER NEEDS

Meetings were held with Mr. Jon Underwood and Mr. Curtis Goss of D-10 and Mr. Perry Kent of FHWA to discuss user needs for low cost WIM systems. The needs for truck weight data arise principally from the following programs:

1. Truck weight studies required by the FHWA Traffic Monitoring Guide
2. Truck weight data required to support the LTPP monitoring effort within SHRP
3. Site-specific truck weight data needed to make design calculations for pavements and bridges.

The FHWA Traffic Monitoring (TM) Guide stipulates that the State should acquire at least 48 hours of truck weight data at 30 locations each year. Of these, ten (10) should be Interstate sites. In each of the following two years, 30 additional locations will be surveyed, resulting in a total of 90 locations over a three year cycle.

The truck weight data collection aspect of the SHRP LTPP is still under review. However, it is clear that accurate estimates of the weight distributions of the trucks traversing each SHRP LTPP highway section are necessary if this important research is to be successful. These truck weight data, with additional environmental and materials characterization information, provide the "cause" portion of the cause-and-effect relationships that are under study. It is certain that the truck weight input to the performance of the SHRP LTPP highway sections is a critical element of this program.

Recent research conducted for the Department has indicated that the truck weight characteristics for even the same vehicle types vary significantly among sites. This includes those highway sections that otherwise have similar functional characteristics. It is therefore imperative that a sample of truck weight data be collected on every highway section for which it is important that an adequate design be accomplished. This will allow the unique truck weight characteristics of each highway section to be measured.

ASSESSMENT OF AVAILABLE TECHNOLOGY

The information about available technology identified and obtained in the literature search and product review was analyzed to determine the applicability of each technology to low cost WIM systems. The following discussion describes the results of this work.

Commercially Available WIM Systems

The WIM systems currently available in the U.S. are described in the subsequent sections in the context of the following general classes of WIM sensor technology.

1. Strain gauge load cells
2. Hydraulic load cells
3. Bending plates with strain gauges
4. Capacitive weighmats
5. Strain gauges attached to bridge beams
6. Piezoelectric cable
7. Piezoelectric film

Applicability of Commercial Systems to Low Cost WIM

There were two major issues that were judged to determine the applicability of commercially available WIM technology to low cost WIM applications. The first was associated with the appropriateness of the general class of WIM sensor. The second issue is the applicability and cost of specific WIM transducers within each general class that was determined to be appropriate.

In evaluating whether WIM systems are appropriate and applicable to low cost configurations, it is reasonable to characterize them according to their portability, operating speed, accuracy, and cost. Portability falls into three categories: portable, semiportable, and permanent. Operating speeds were defined in this research as low (less than 10 mph), moderate (10 to 50 mph), and high (greater than 50 mph). Accuracy is expressed in this study as the standard deviation of the percent difference between the axle, axle group, and gross vehicle weights obtained with the WIM system and the same weights measured on a static scale, where each percent difference is defined according to the following equation.

$$PD = \frac{\text{WIM Weight - Static Weight}}{\text{Static Weight}} * 100$$

Accuracy for gross weights was defined in this research to be within the following categories: high (less than 4%), moderate (4 to 8%), and low (greater than 8%). Cost includes the initial capital cost and the installation, operating, and maintenance costs. Each of the types of WIM systems is discussed in the following paragraphs in the context of its attributes of portability, operating speed, accuracy, and cost.

Strain Gauge Load Cells

Three firms offer WIM systems that use bearing plates resting on load cells. The Radian Corporation WIM system currently used by the Department is an application of this technology. It consists of a relatively shallow, light weight sensor assembly that is installed in a steel frame that has been permanently placed in the road surface. This equipment was developed at the University of Texas by Dr. Clyde Lee. This device has an overall depth of about 2 inches (in.). The weighing surface of each sensor assembly is 4′6" wide by 20" in the direction of travel and is segmented into six triangular loadplates to reduce rocking in what was originally three square plates. One of these sensor assemblies is normally placed in each wheel path.

The Radian WIM system is semiportable. It cannot be installed and left permanently because the WIM transducer is not sufficiently durable. This device can operate in all three speed ranges. Its accuracy is moderate at all speeds. The question of cost is moot since the Radian equipment is no longer offered or supported by the manufacturer.

Howe Richardson also markets a system that is based on bearing plates with load cells. This WIM system uses one rectangular bearing platform for each sensor assembly. Load cells are located at each corner and at the center of each lateral edge of the 12′ wide transducer. The weighing platform is split in the center. The weight sensor in this system is more massive than in the Radian scale. A greater mass with basically the same operating principal makes it less likely that this transducer can stop oscillating before another set of tires has mounted the weighing surface. This ringing effect is due to the low natural frequency of the assembly and is very difficult to overcome. Since the mass is fixed, a higher natural frequency can only be attained with higher spring constants. That is, the spring action must be made stiffer. This, however, results in relatively smaller deflections and a consequent loss of sensitivity. As a consequence of these factors, Howe Richardson recommends the use of its load cell WIM system only at speeds less than 50 mph (i.e., at low and moderate speeds). This version of the Howe Richardson WIM system is 26" long.

The Howe Richardson load cell WIM system is intended for permanent installation and cannot be used in a portable mode. The accuracy is moderate at both low and moderate speeds. The initial equipment cost for a 4-lane installation is approximately $185,000.

The Weighwrite ADS-4 low speed WIM system consists of one load cell in each corner of a steel platform that measures 10' by 2'6" by 8" deep. Installation requires an excavation of approximately 24" depth to allow for placement of a concrete foundation that contains a drainage pipe and supports the steel frame. This WIM system is much more massive than the Howe Richardson load cell system. It is intended only for speeds less than 2.5 mph.

The Weighwrite load cell WIM system is permanently installed. The accuracy level is high at low speed. The initial capital cost for this device is approximately $20,000.

Hydraulic Load Cells

Only the CMI Dynamics WIM system (formerly manufactured and marketed by International Road Dynamics, IRD) uses hydraulic load cell technology. It is the most massive on the U.S. market. It, like the Howe Richardson and Weighwrite load cell WIM systems, requires the assistance of mechanized equipment, such as a front end loader, to place in the excavation prepared for it. The CMI Dynamics WIM transducer consists of a single oil-filled piston that acts as a load cell. Trucks cross a single steel platform, 5'4" wide by 21" long by 9" deep, and the load is transferred to the load cell by lever arms. One transducer is placed in each wheelpath.

The CMI Dynamics WIM system is permanently installed. It cannot be moved easily to another site. This device operates at all three speed levels. Its accuracy is moderate at all levels. The cost for this equipment is approximately $200,000 for a four lane site.

Bending Plates with Strain Gauges

Bending plate systems are offered by both Howe Richardson and PAT Equipment Corporation. In this sensor technology, strain gauges are bonded to the underside of steel plates so that the strain measured is proportional to the load applied to them. This technology has been shown to have several advantages. The first is that it has a low mass. It therefore avoids the problem of low natural frequency that may preclude the use of more massive WIM transducers at higher speeds. These sensors also have no moving parts, so there is very little to wear out. The transducers can be sealed against environmental effects, thereby improving the reliability of the system. The State of California tested the PAT Equipment Corporation bending plate system extensively and concluded it has significant advantages for high speed weighing activities.

The PAT Equipment Corporation bending plate WIM system is semiportable; the transducers can be moved among sites but the procedure is awkward and this is not normally done. It operates at all speed ranges at a moderate level of accuracy. The cost is approximately $185,000 for the equipment for a four lane site.

The Howe Richardson bending plate WIM system is also semiportable but it is not advisable to move the transducers among different sites. It operates at all speed ranges. Accuracy levels have been reported between low and moderate. The cost is about $185,000 for a four lane site.

Capacitive Weighmats

Portable capacitive weighmat systems are now offered by Howe Richardson, Golden River, and PAT Equipment Corporation. The weight sensor used by each of these vendors is a capacitive weighmat marketed by the Electromatic Company of South Africa. This device is 6′ wide by 20" long by 3/8" thick. It consists of three sheets of steel maintained in approximately parallel position by a rubber dielectric. The instrumentation treats the weighmat as a variable three-plate capacitor within a tuned circuit. Compression of the sensor by a wheel load causes a change in the oscillating frequency of the tuned circuit. The magnitude of this frequency shift is interpreted as a weight by microprocessor-based circuitry in the WIM electronics.

Each of the three vendors has taken a unique approach to this WIM system. Golden River, which originally manufactured only traffic counters, constructed its weighmat interface board by modifying its inductive loop board. Howe Richardson adapted its fixed weighing site technology to the capacitive weighmat. This difference in starting point probably accounts for the fact that the Golden River device is battery powered while the Howe Richardson equipment needs an electrical generator to produce power. The PAT Equipment Corporation capacitive weighmat system is basically an adaptation of their bending plate electronics interface.

All of the three capacitive weighmat WIM systems are portable but the Golden River product is the most portable since it includes a battery-powered roadside unit that is designed to work without human intervention. The PAT Equipment Corporation unit can also function using battery power. The Howe Richardson product requires alternating current (a.c.) power from either a commercial source or a portable generator. The capacitive weighmat sensor should not be used at speeds less than 20 mph. At speeds greater than 20 mph, the Golden River product has had accuracies in the low and moderate categories. The PAT Equipment Corporation and Howe Richardson capacitive weighmat WIM systems have given results with moderate levels of accuracy.

The cost of the capacitive weighmat WIM systems is approximately $35,000 each.

Strain Gauges Attached to Bridge Beams

The only commercially available WIM system that uses strain gauges attached to bridge beams is offered by Bridge Weighing Systems. The Bridge Weighing Systems device was first developed at Case Western Reserve University in research sponsored by FHWA. The active weight sensing device is a strain transducer that is clamped (for portable installations) or permanently fixed to the longitudinal support beams of a highway bridge. Temporary or permanent axle sensors are placed on the road surface of the approach to the bridge to assist in the classification of vehicle types and to acquire speed data.

An optional manual input is provided for detailed manual classification information. Data are recorded in a dedicated microcomputer equipped with the required electronic data acquisition subsystems. Mobile versions of this WIM system usually have the instrumentation installed in a van that can be parked under the bridge. Permanently installed versions of the system have an instrumentation cabinet.

Accuracy of this equipment can be affected by a number of factors. The first of these is the horizontal alignment of the roadway approach and the skew of the bridge. These can affect the performance of vehicles and thereby the axle weight readings. Single spans cannot exceed 65 feet in length, but noncontinuous spans can be used. As with all WIM systems, the roadway approach to the WIM location must be smooth and free of distress.

Bridge WIM systems are the least detectable of all of the WIM devices. The equipment is very reliable and requires little maintenance. It can be operated unattended. Some users have reported difficulty in weighing multiple trucks on the same span. This problem may preclude its use for many applications unless it can be shown that algorithms under development to address it are successful.

Bridge WIM systems are available in either permanent or portable modes. These systems operate within all three operating speed ranges at a moderate accuracy level. The cost is approximately $100,000 for a four lane site.

Piezoelectric Cable

Piezoelectric cable has been used in research and highway applications in France since 1972. It has more recently received attention in the United Kingdom and in the U.S. Originally developed to sense vibrations in nuclear power plants (hence the trade name Vibracoax), this device consists of a copper central conductor and an outer copper sheath (3 mm in diameter) with a piezoelectric powder as its dielectric. When a force or a pressure is applied to the cable, electrical charges of opposite polarity are attracted to the surfaces of the copper conductors. This phenomenon occurs only when the force is changing. When it is constant, the accumulated electrical potential drops exponentially.

When used as a WIM transducer, the cable is usually mounted in a steel or aluminum channel in a potting material as indicated in Figure 1. Several efforts have been carried out in this country to evaluate this technology for wider use. These activities have received a great deal of attention due to the expected lower cost of such installations. In the States of Oregon and Washington, the piezoelectric device offered by the French government was installed and evaluated. Another piezoelectric cable system, developed for the Transport and Road Research Laboratory (TRRL), was tried in Iowa and Minnesota. A third system, marketed by CMI Dynamics for the British Weigh-write company, has also been offered. At a recent meeting of Organization for Economic Cooperation and Development (OECD) persons at the TRRL facilities, the Weighwrite system performed significantly better than either the TRRL equipment or the French system. Other countries have also investigated piezo-electric cable technology but have not yet produced systems available in this country.

Piezo cable WIM systems are permanently installed. They function in all operating speed ranges at a low level of accuracy. The cost has been advertised as $15,000 for one lane.

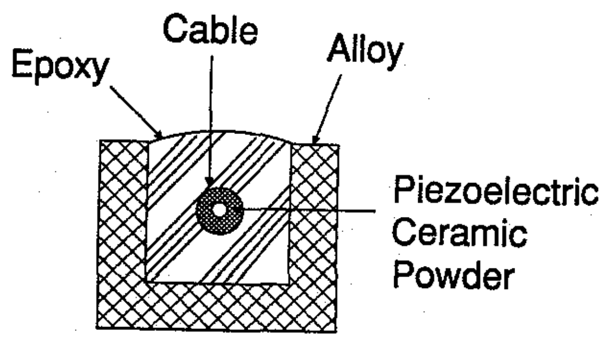

Figure 1. Aluminum Channel Configuration for Piezoelectric Cable.

Piezoelectric Film

The most recent development in WIM transducer technology is a class of devices based on piezoelectric film. These transducers may have significant advantages over the currently available WIM sensors, including a much lower unit cost and a very high signal-to-noise ratio. The four configurations now under production are shown in Figures 2 through 5. The new piezoelectric film sensors include: one that is packaged in a form similar to the piezoelectric cable devices that have been installed in Iowa and Minnesota (Figure 2); a portable piezoelectric film weighmat (Figure 3); and a thin strip piezoelectric film sensor that is appropriate for either installation in a shallow excavation in concrete (Figure 4) or placement as a temporary sensor on the surface of the highway (Figure 5). All of these devices are under development by the Pennwalt Corporation and will be commercially available in the near future.

Piezo film WIM transducers are available in both portable, shown in Figures 3 and 5, and permanent (Figures 2 and 4) configurations. All forms of piezoelectric film transducers function in all of the operating speed ranges. The accuracy of these devices has not been tested in the field but preliminary indications are that moderate levels can be achieved. Although complete system costs are not yet available, the piezoelectric film WIM transducer costs approximately $500 for the same transducer that is sold for $1,200 in the piezoelectric cable device.

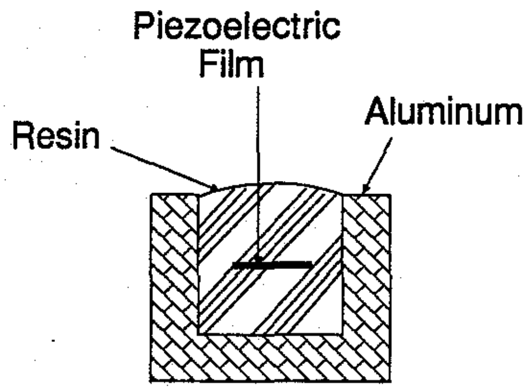

Figure 2. Aluminum Channel Configuration for Piezoelectric Film

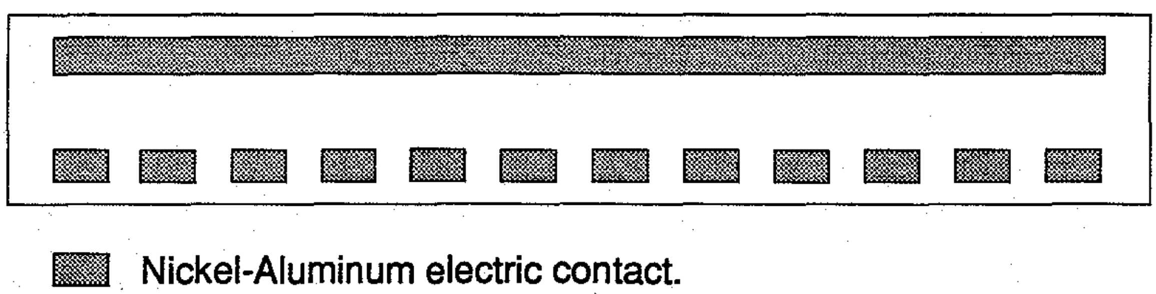

Figure 3. Portable Weighmat Configuration for Piezoelectric Film

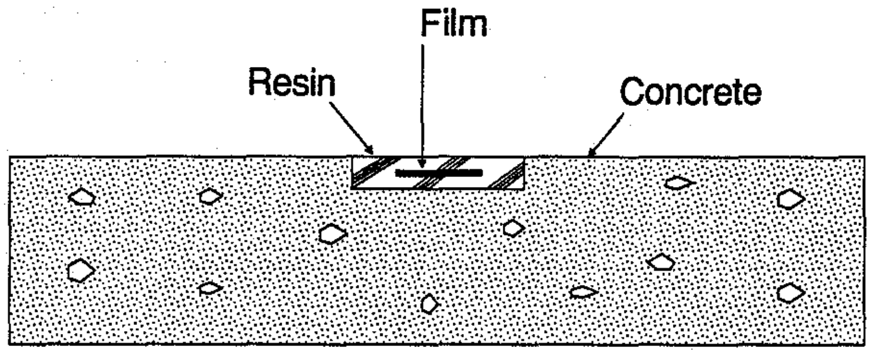

Figure 4. Shallow Strip Configuration for Piezoelectric Film

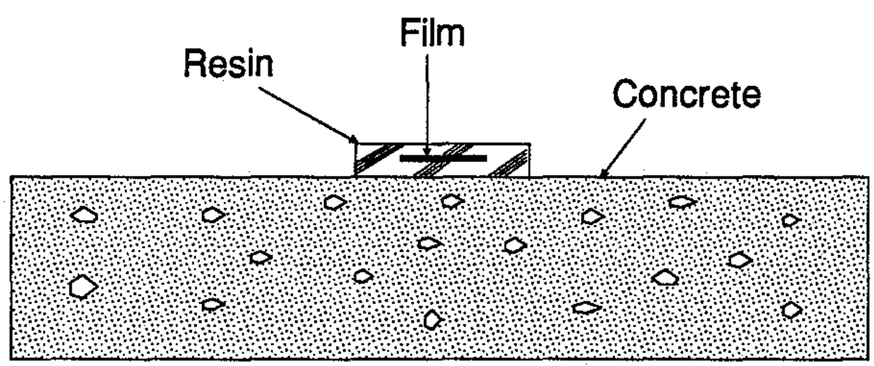

Figure 5. Temporary Strip Configuration for Piezoelectric Film

FEASIBILITY ANALYSIS

Based on the information acquired and consideration of the Department's needs, the feasibility of employing specific commercially available WIM products and/or technologies in low cost configurations in a large scale WIM program was evaluated. The costs and time requirements for both the development and implementation of promising approaches were included.

The Department's needs fall into two general areas. The first is for a permanently installed (i.e., unmanned) WIM site accessible via phone lines for transfer of data. The second need is for a lower cost and/or more durable portable WIM transducer. Both of these applications require data accuracy at least comparable to that obtained currently using the Department's Radian semiportable and Howe Richardson portable WIM systems.

As indicated in the previous discussion, the following general classes of WIM sensor technology were considered for possible use in a low cost, automated, WIM system configuration that could be implemented on a large scale.

1. Strain gauge load cells
2. Hydraulic load cells
3. Bending plates with strain gauges
4. Capacitive weighmats
5. Strain gauges attached to bridge beams
6. Piezoelectric cable
7. Piezoelectric film

The criteria that were considered included portability, operating speed, accuracy, cost, and likelihood of success in both the short term and longer term. Permanent and portable WIM applications are discussed separately in the following paragraphs.

Permanent Configurations

Of those listed above, the WIM technologies that lend themselves to permanent applications included the following:

1. Strain gauge load cells
2. Hydraulic load cells
3. Bending plates with strain gauges

4. Strain gauges attached to bridge beams
5. Piezoelectric cable
6. Piezoelectric film

The strain gauge load cell WIM systems discussed previously included products offered by the Radian Corporation, Howe Richardson, and Weighwrite. The Radian Corporation system uses a transducer that is not durable enough to be left in place for long periods of time. It is therefore not appropriate for permanent unmanned applications. The Howe Richardson strain gauge load cell transducer is not recommended by the vendor for use at speeds greater than 50 mph. Since most of the applications for which WIM equipment is needed are located on sections of rural highway, this transducer was determined not to be feasible for use in a low cost, automated, permanently installed WIM system. Likewise, the Weighwrite device operates at only low speeds and is therefore not appropriate.

The hydraulic load cell device requires extensive site preparation, resulting in high installation costs. It is therefore not appropriate for this application.

The bending plates with strain gauges were determined to be appropriate for this application. It operates in all speed ranges with a moderate to high level of accuracy. However, the cost of the traditional configuration for this equipment is too high for large scale implementation. The cost for a four lane site with the configuration shown in Figure 6 is $185,000. This includes two bending plate transducers in steel frames in each lane and the associated cabling and electronics. The cost can be reduced significantly by making one or more of the following modifications.

1. Reduce the number of lanes from four to one.
2. Reduce the number of transducers to one per lane.
3. Use reduced cost electronics.

The lower cost configuration shown in Figure 7 will reduce the cost for one site to $8,500 for the sensor installation plus the cost of the electronics. At present the electronics unit costs approximately $30,000. It is possible that this could be reduced to result in a low total system price.

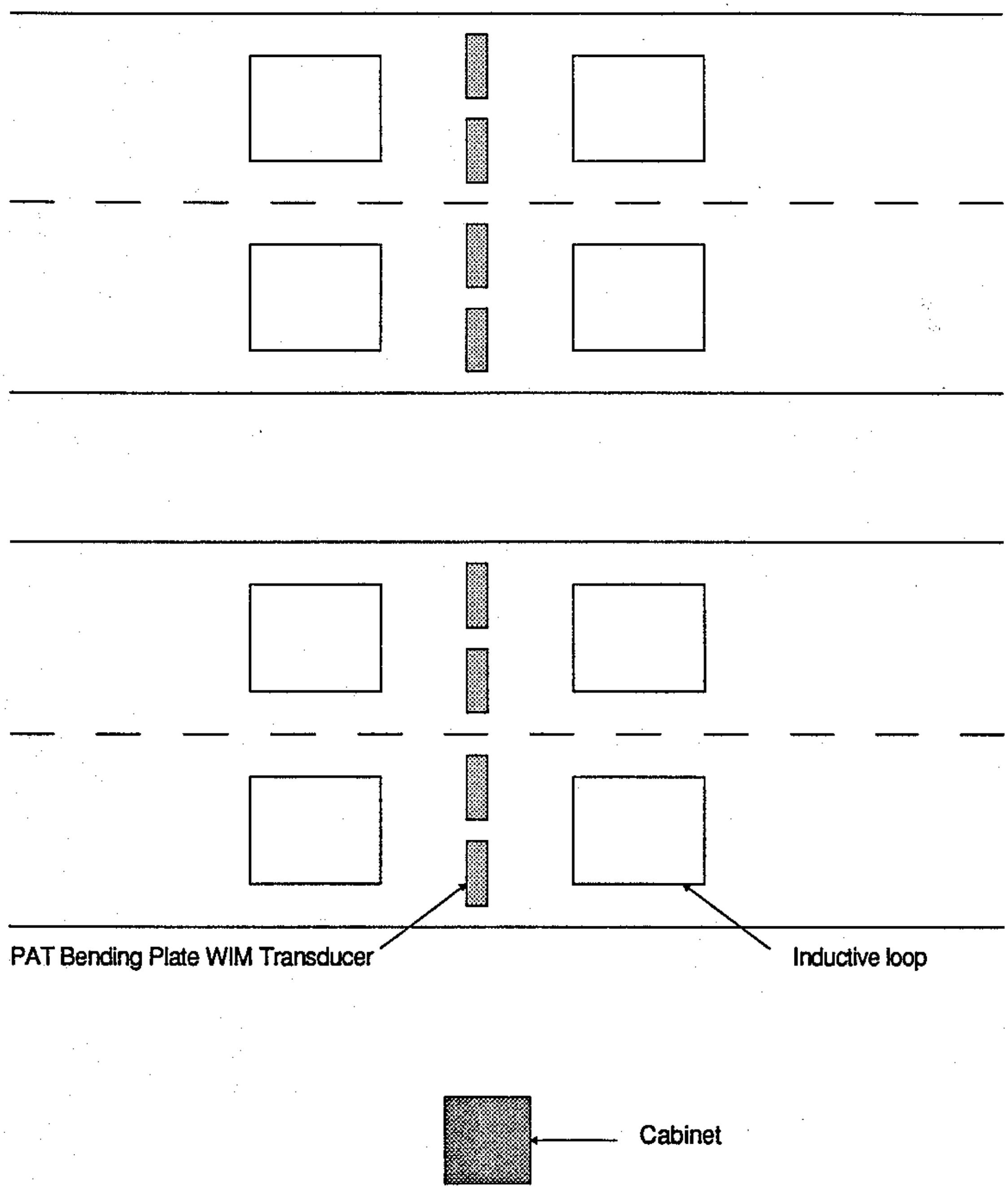

Figure 6. Four lane configuration of bending plate WIM system.

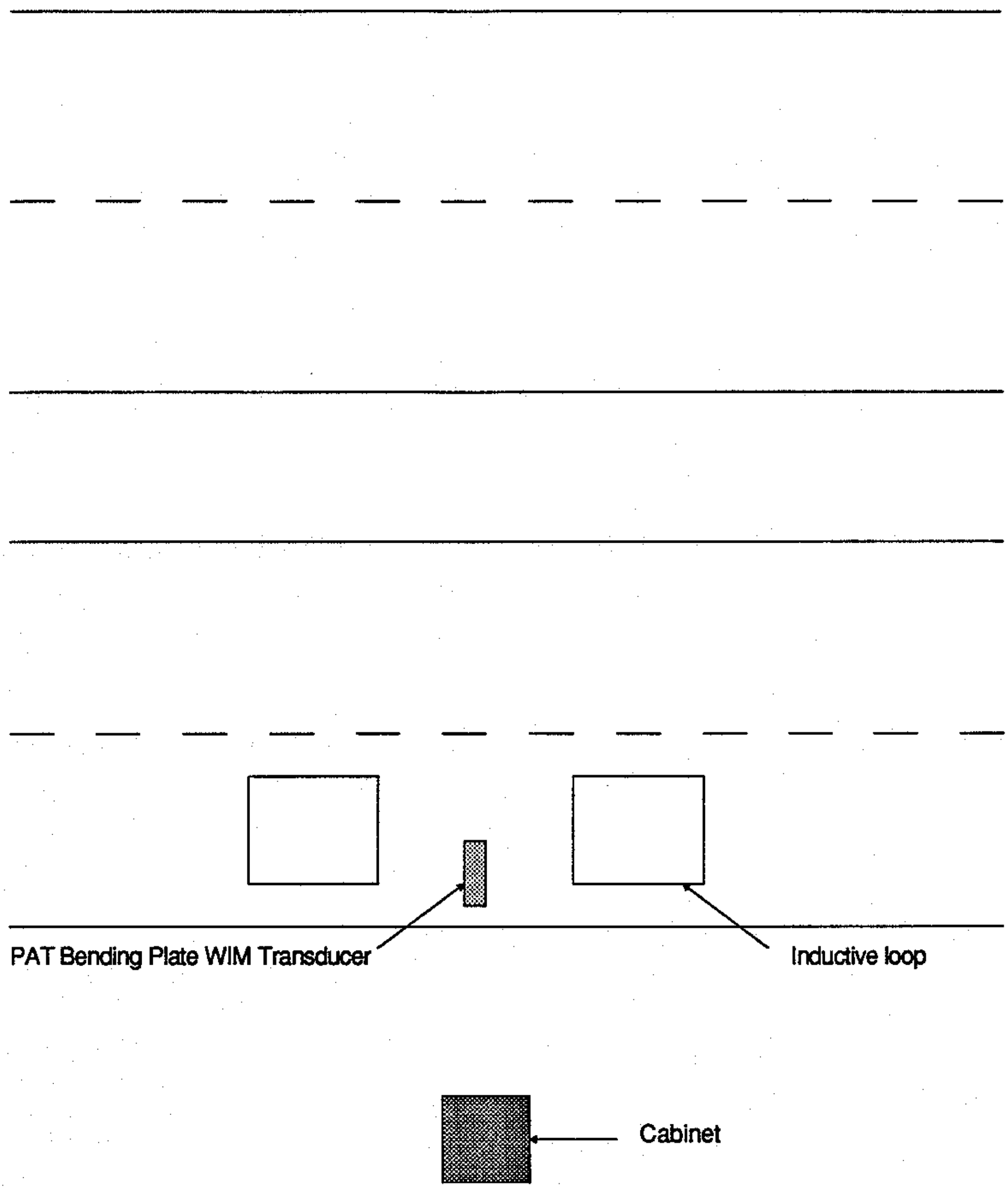

Figure 7. Reduced cost configuration of bending plate WIM system.

A low cost WIM system that uses strain gauges attached to bridge beams is under development under National Cooperative Highway Research Program (NCHRP) Project 3-36, in which a system with a target price of $10,000 is nearing completion. This device was not available for this study.

Piezoelectric cable technology is now being offered in at least three commercially available low cost WIM systems and has been studied in other research and therefore was specifically excluded from this study. Piezoelectric film technology was not available as a permanent WIM transducer during this study.

Portable Configurations

The WIM technologies that are candidates for portable applications included the following:

1. Capacitive weighmat
2. Strain gauges attached to bridge beams
3. Piezoelectric cable
4. Piezoelectric film

The capacitive weighmat is a technology that has been successfully used as a low cost WIM device for several years. There are two possibilities for reducing the cost of the capacitive weighmat WIM systems. The first is to reduce the cost of the WIM transducer. This has been accomplished under an FHWA-sponsored study that resulted in a user-constructed (rather than purchased from a vendor) capacitive weighmat. However, this transducer is much less durable than the manufactured transducer. Producing the WIM transducers is also a labor-intensive effort.

The other option for reducing the cost of capacitive weighmat WIM systems is to reduce the cost of the electronics. This was also done in the FHWA study with better results than were obtained for the capacitive weighmat. The electronics designed and produced under the FHWA project are available to all State agencies. It can be fabricated for approximately $3,000. This device was determined to be appropriate for further consideration under this study.

As indicated in the previous section, a low cost version of the strain gauges attached to bridge beams is under development in NCHRP Project 3-36. This device was not considered further in this study. Similarly, the piezo-electric cable and film technologies were not considered in this study for the same reasons described in the previous section.

CHAPTER 3. FABRICATION OF LOW COST WIM SYSTEM

TTI developed an improved version of the low cost capacitive weighmat WIM system previously developed for FHWA. This upgrade of the FHWA system included the substitution of a state-of-the-art 8052 microprocessor in place of the 6502 used in the first prototype. It also was constructed on smaller STD circuit boards. The device was tested at the Texas A&M Research Annex and under the field and laboratory testing program.

The functional diagram for the redesigned WIM system is shown in Figure 8 and the block diagram is shown in Figure 9.

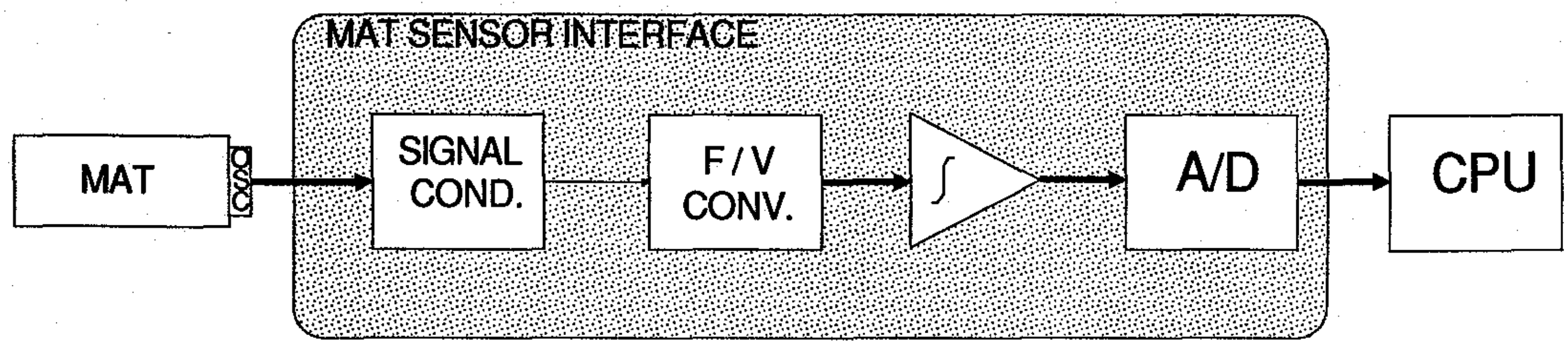

Figure 8. Functional Diagram for Capacitive Weighmat System

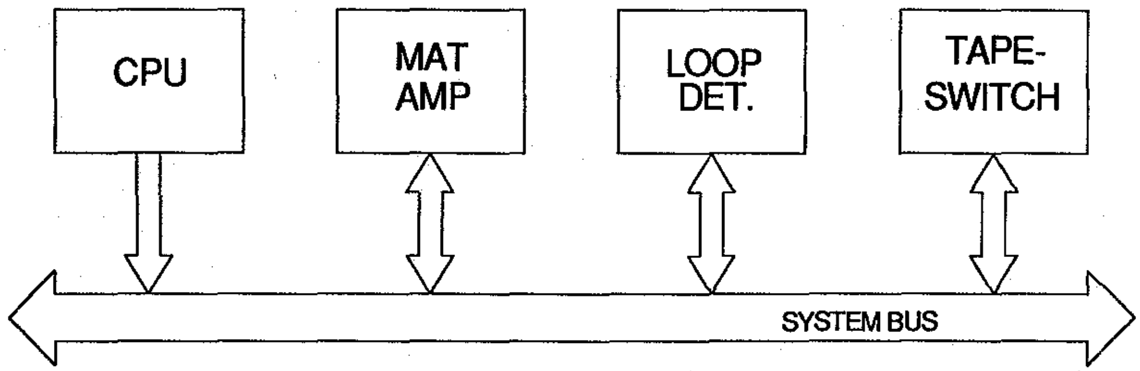

Figure 9. Block Diagram for Capacitive Weighmat System

CHAPTER 4. EVALUATION OF LOW COST TECHNOLOGIES

SELECTION OF WIM SYSTEMS

In accordance with the results of the feasibility analysis, the following commercially available WIM systems/technologies that could potentially be used in a low cost configuration were obtained for evaluation.

1. PAT Corporation bending plate WIM transducer
2. Redesigned low cost capacitive weighmat WIM system.

In addition, a Howe Richardson Model 241W low cost portable capacitive weighmat WIM system was ordered but not received for use in this study.

The PAT WIM equipment was installed on IH-35, south of Austin. The data collection electronics for the PAT WIM system was obtained on loan from the vendor.

During the course of the study, it was decided that piezoelectric film technology had advanced sufficiently so that it would be useful to include them in the laboratory testing portion of this study.

LABORATORY TESTS

Laboratory tests were conducted for the selected alternative low cost WIM systems. These included the use of environmental chambers, automatic loading, and test track procedures. These tests were used to establish the performance characteristics of the low cost WIM options under controlled conditions. These characteristics included sensor sensitivity, uniformity, and susceptibility to temperature and humidity.

Test setups were designed and constructed for testing the PAT bending plate WIM transducer, the capacitive weighmat, and on fabrication of piezoelectric film into a potential WIM sensor. Each test setup included a support structure to allow simulation of the pavement under the device.

Loading tests were carried out using a platen with an area of 40 square inches that was applied to the surface of each WIM sensor. The loads applied were varied from 1,000 to 10,000 pounds in increments of 1,000 pounds. The platen was applied at five evenly spaced locations along the lateral dimension of the sensor, as well as at three longitudinal points in line with the lateral locations, as indicated in Figure 10. In evaluating the response to variable loading, the platen was placed at each of the five points on the longitudinal center of the sensor.

These tests were carried out over a range of temperature and humidity conditions to determine the effects of those factors on sensor performance.

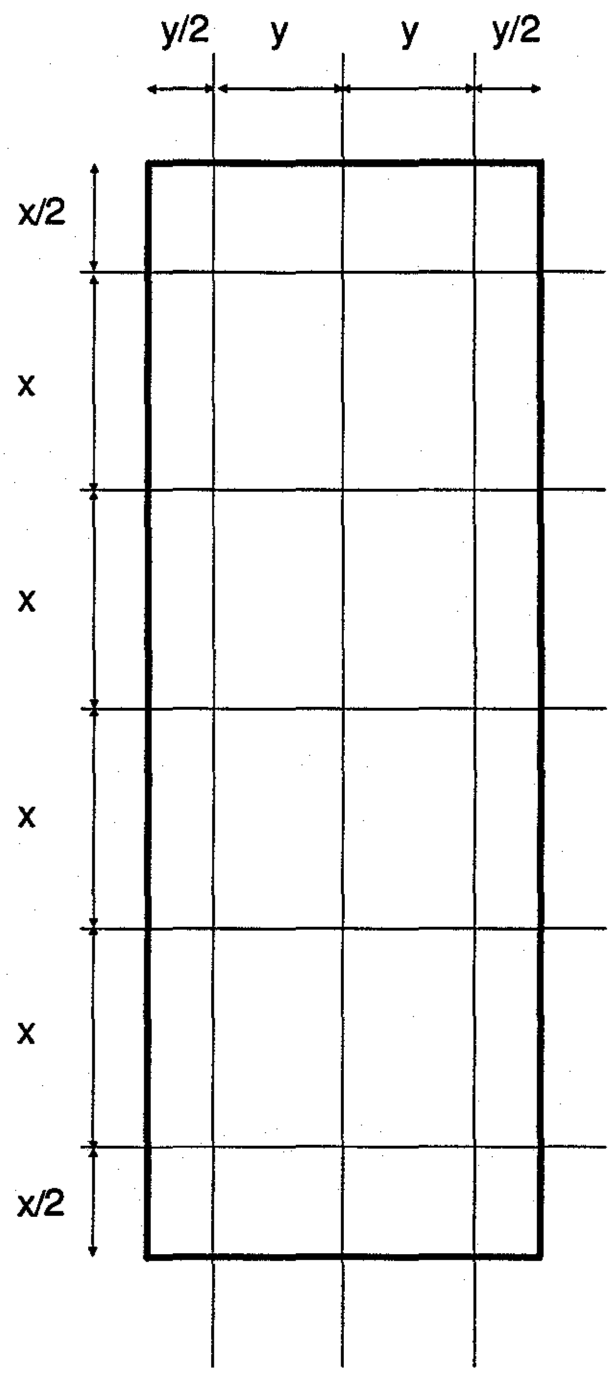

Figure 10. Platen Placement for Uniformity Testing

ANALYSIS OF LABORATORY TEST DATA

TTI analyzed the data acquired in the laboratory tests to determine the detailed performance characteristics of the alternative low cost WIM systems under laboratory conditions. The results of this analysis are summarized in the following paragraphs.

Figures 11, 12, and 13 present the results for the PAT bending plate sensor at low, high, and room temperatures, respectively. Testing point 1 is located nearest to the cables leading to the roadside electronics. The L,C, and R notations indicate the left, center, and right longitudinal locations when seen from the end of the sensor to which cables are attached. The output in millivolts is the output of the sensor itself in response to the load. Figure 14 shows the output in response to the variable loading.

Figures 15 through 18 give corresponding results obtained for the capacitive weighmat. Figure 19 gives a similar plot for the piezoelectric film device.

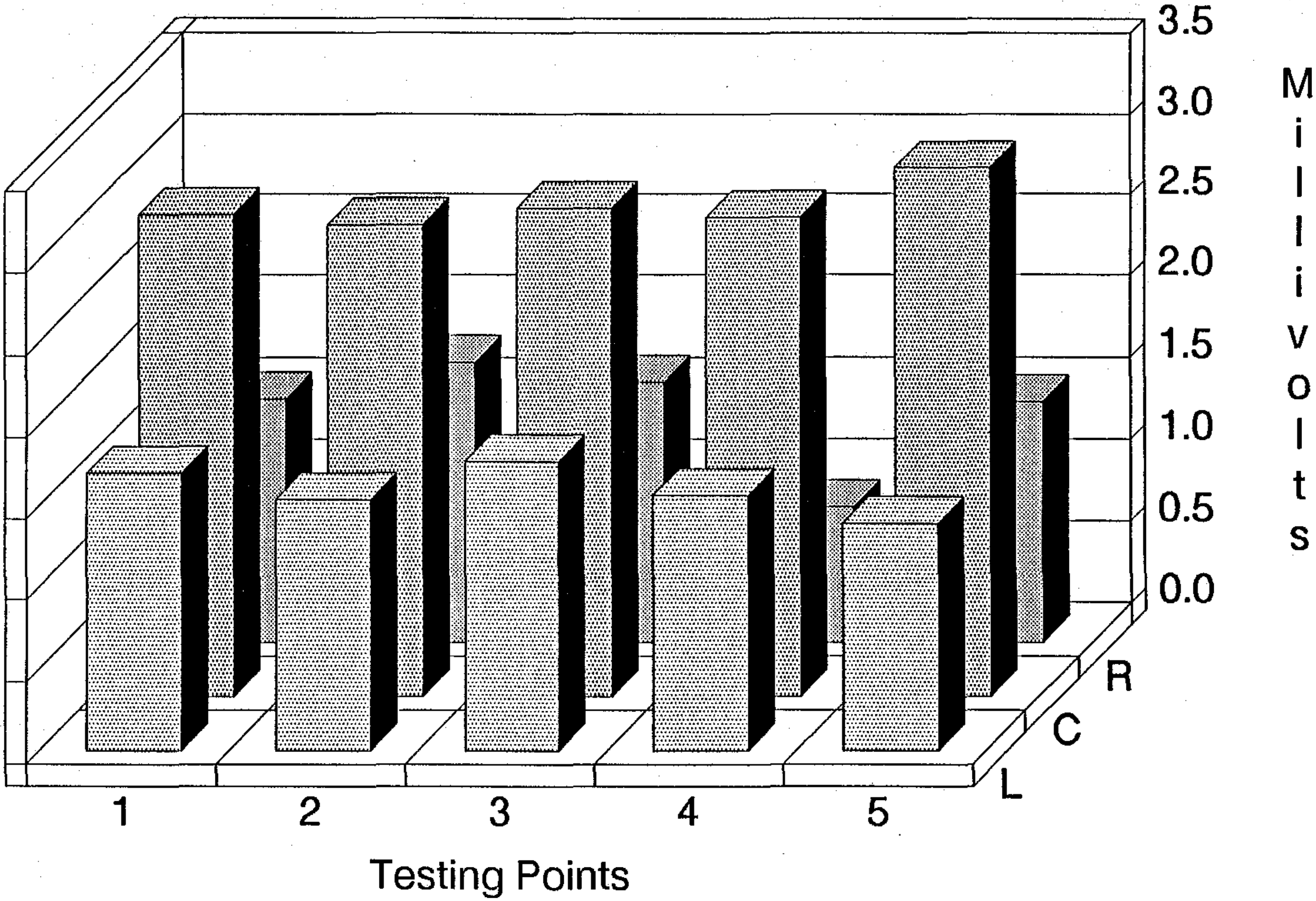

Figure 11. PAT Bending Plate Outputs at Low Temperature

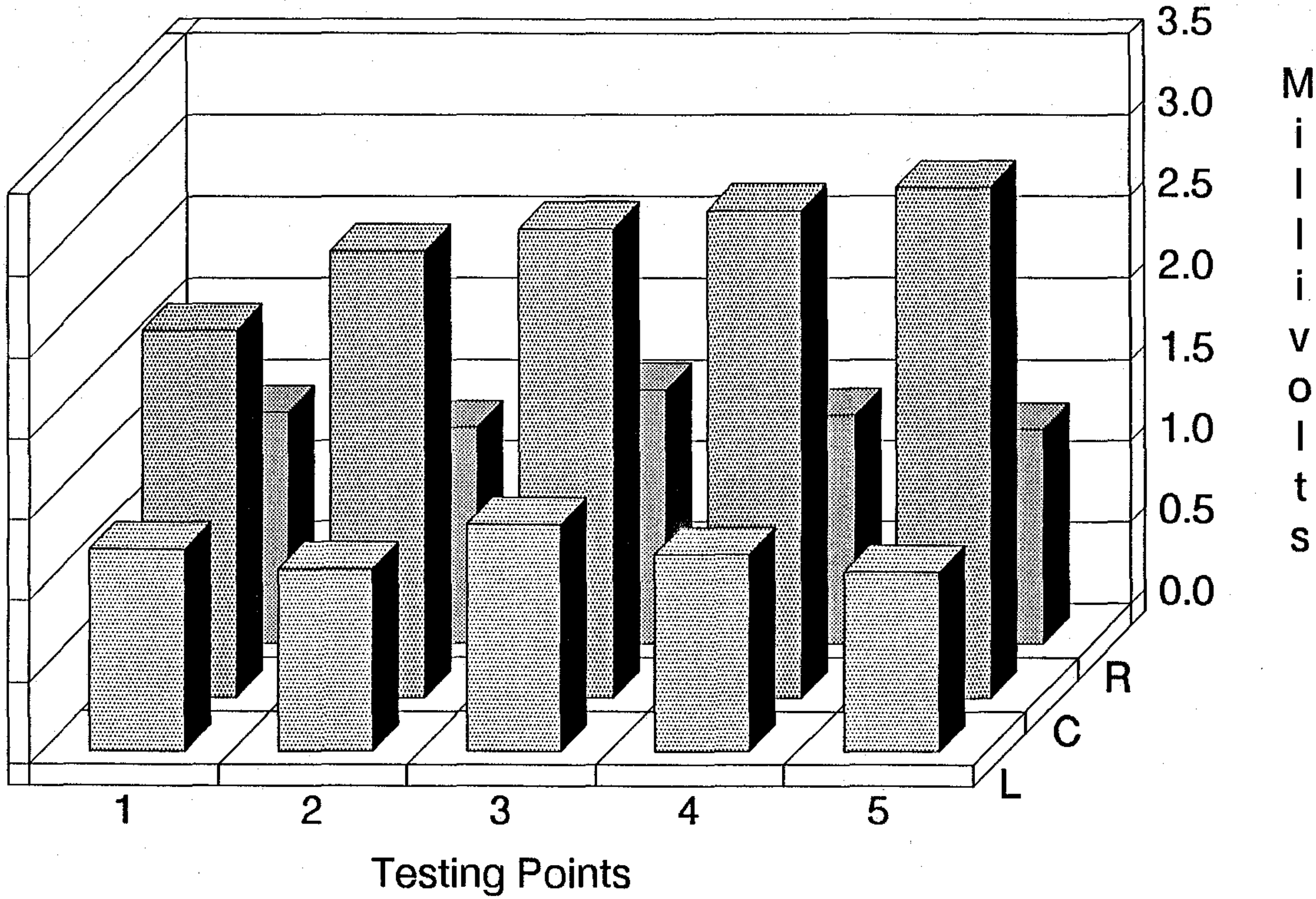

Figure 12. PAT Bending Plate Outputs at High Temperature

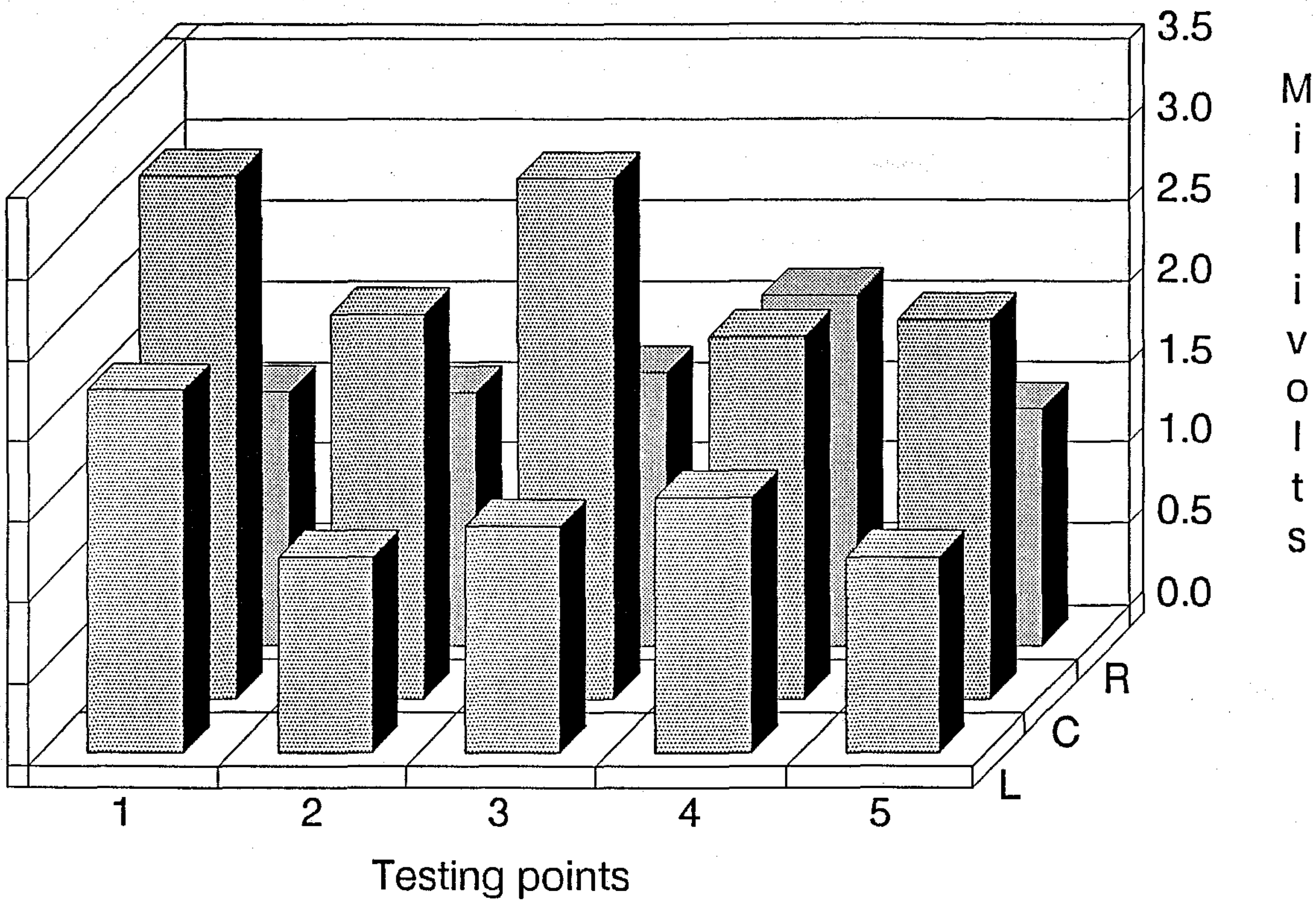

Figure 13. PAT Bending Plate Outputs at Room Temperature

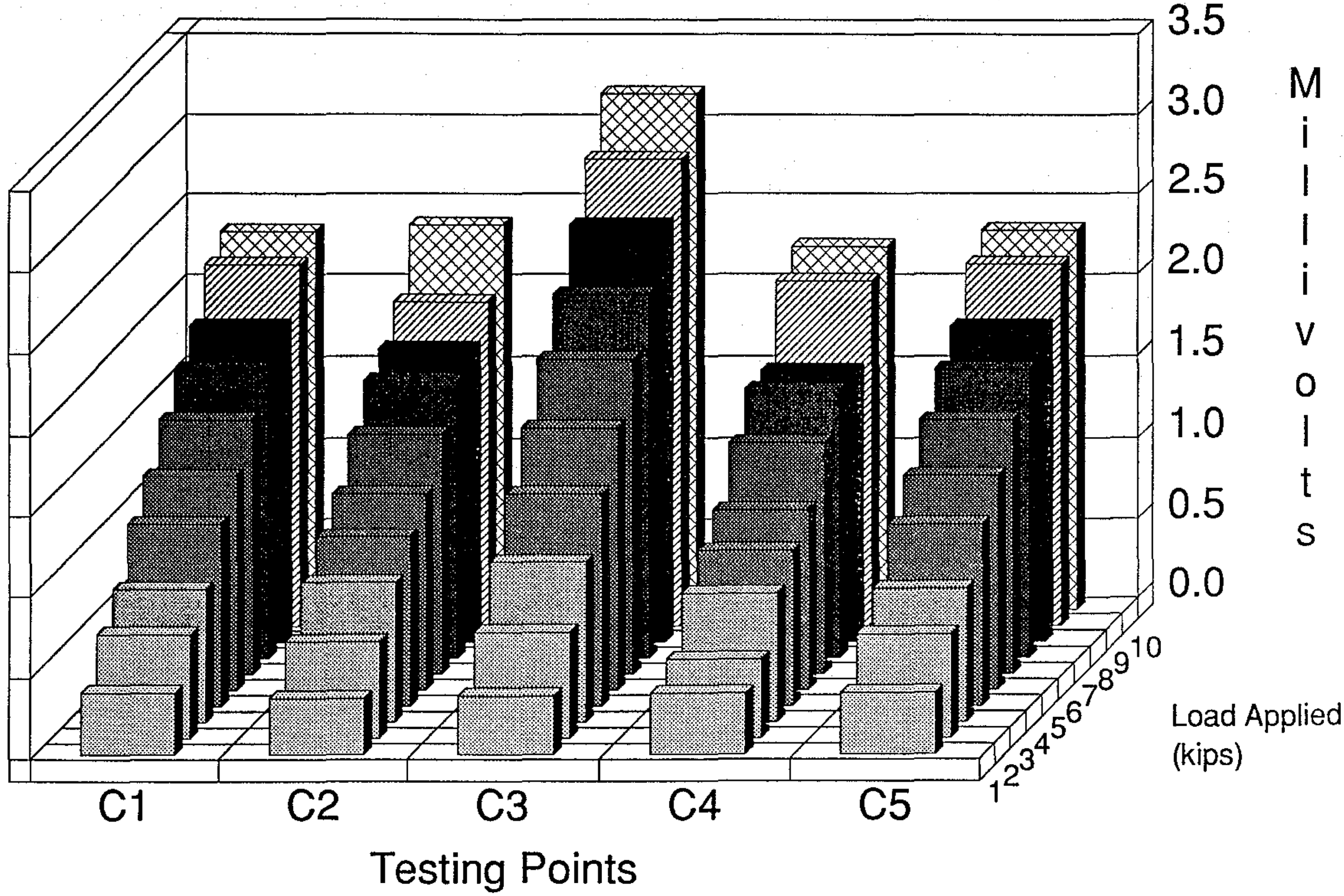

Figure 14. PAT Bending Plate Output Response to Variable Loads at Room Temperature

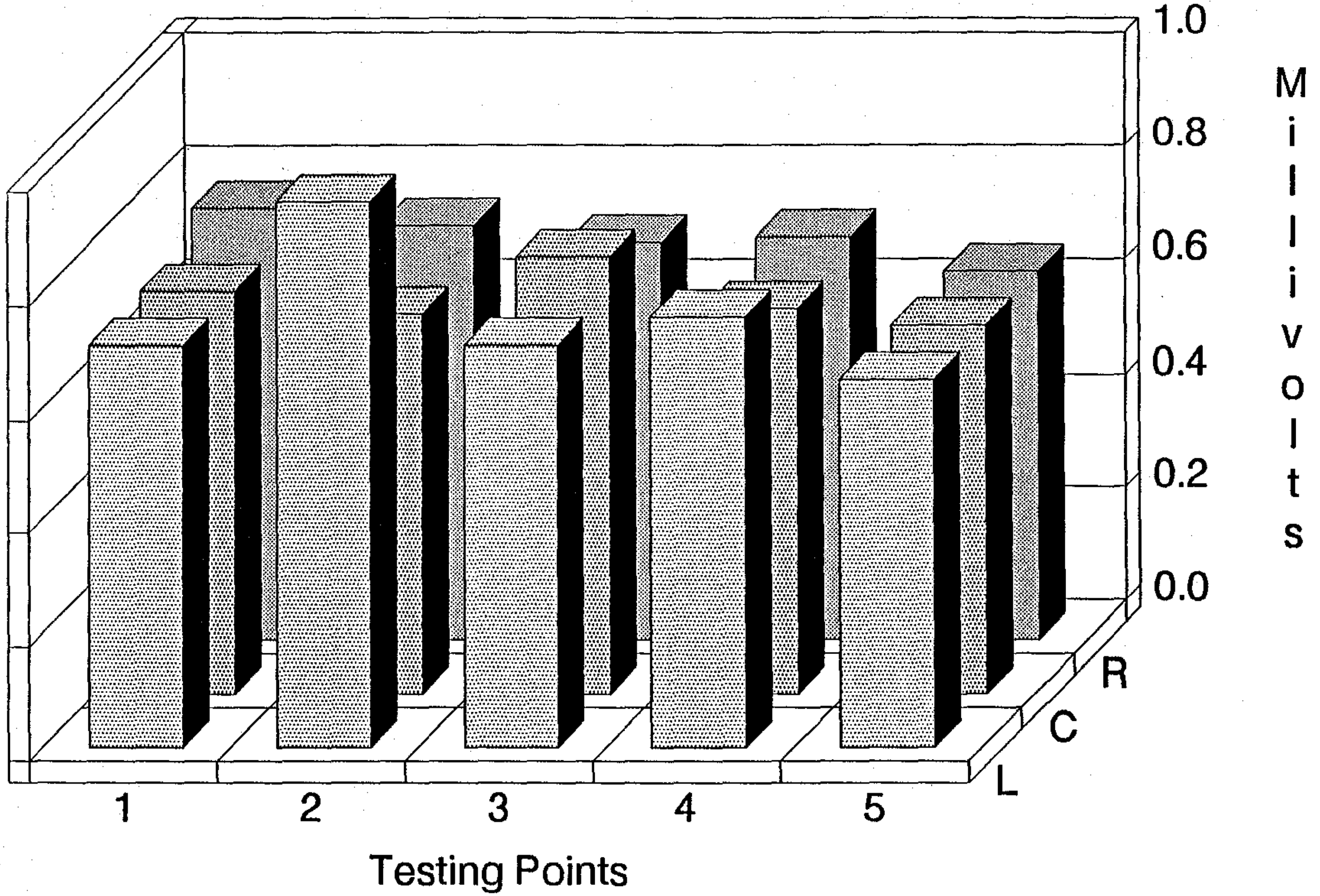

Figure 15. Capacitive Weighmat Outputs at Low Temperature

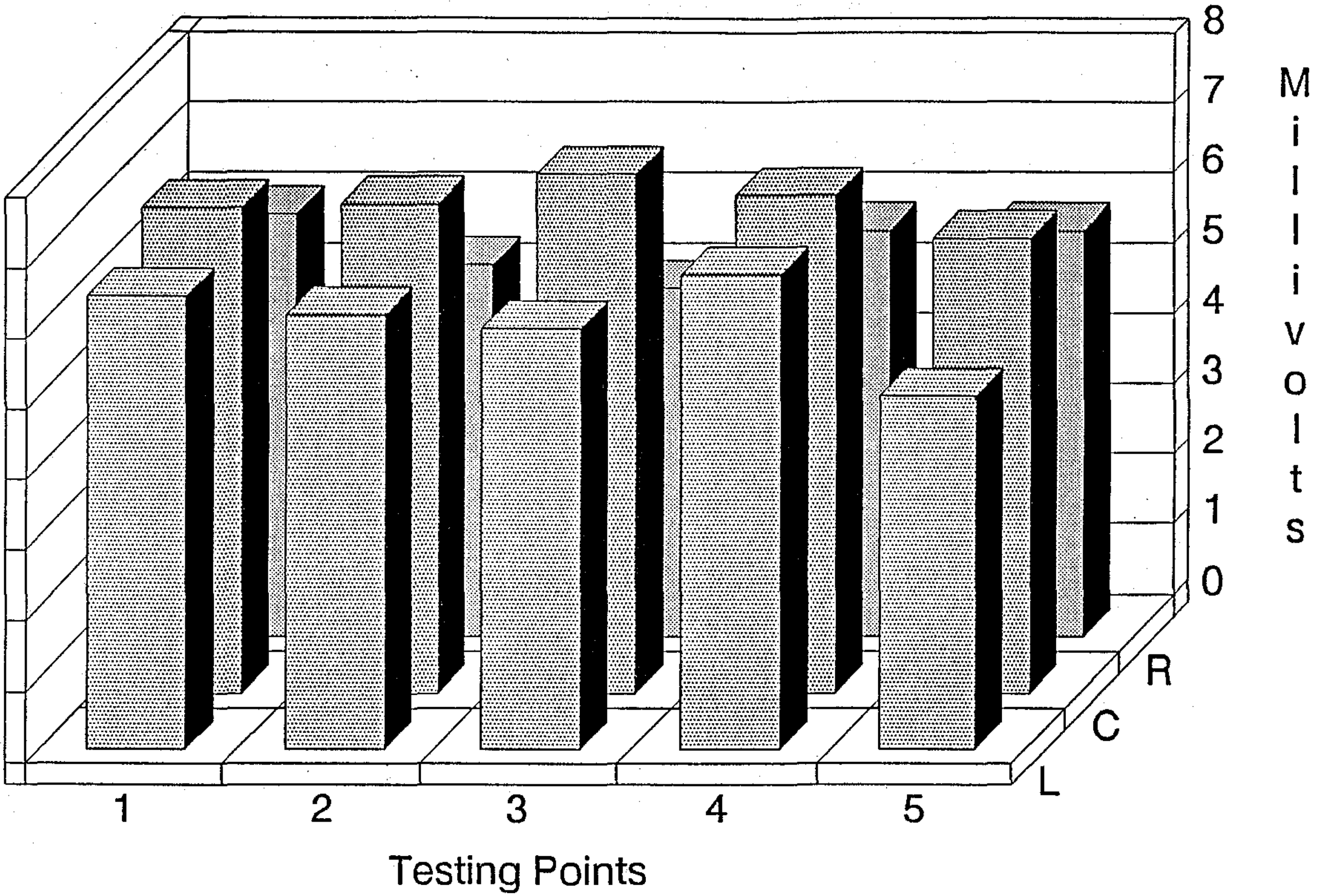

Figure 16. Capacitive Weighmat Outputs at High Temperature

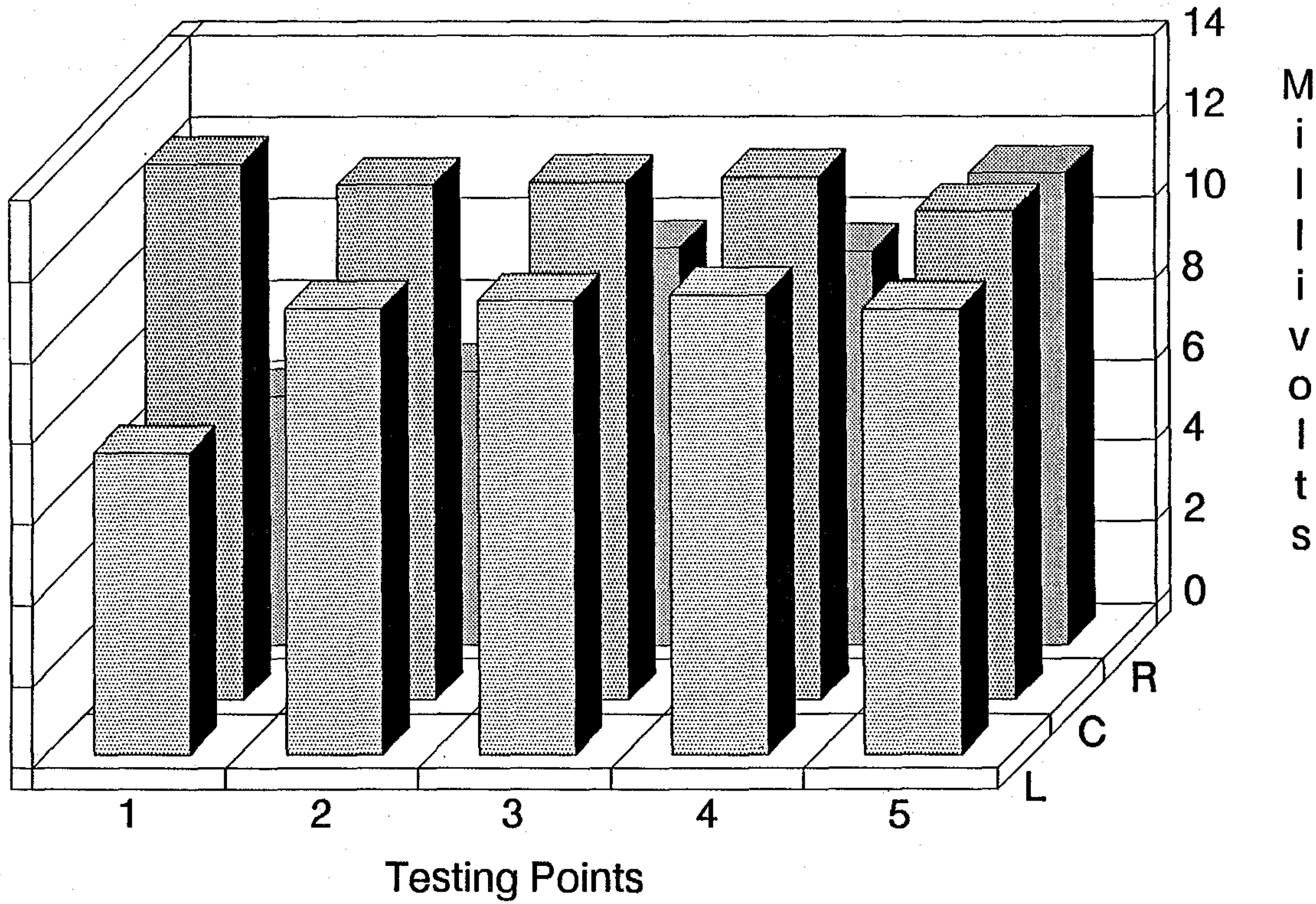

Figure 17. Capacitive Weighmat Outputs at Room Temperature

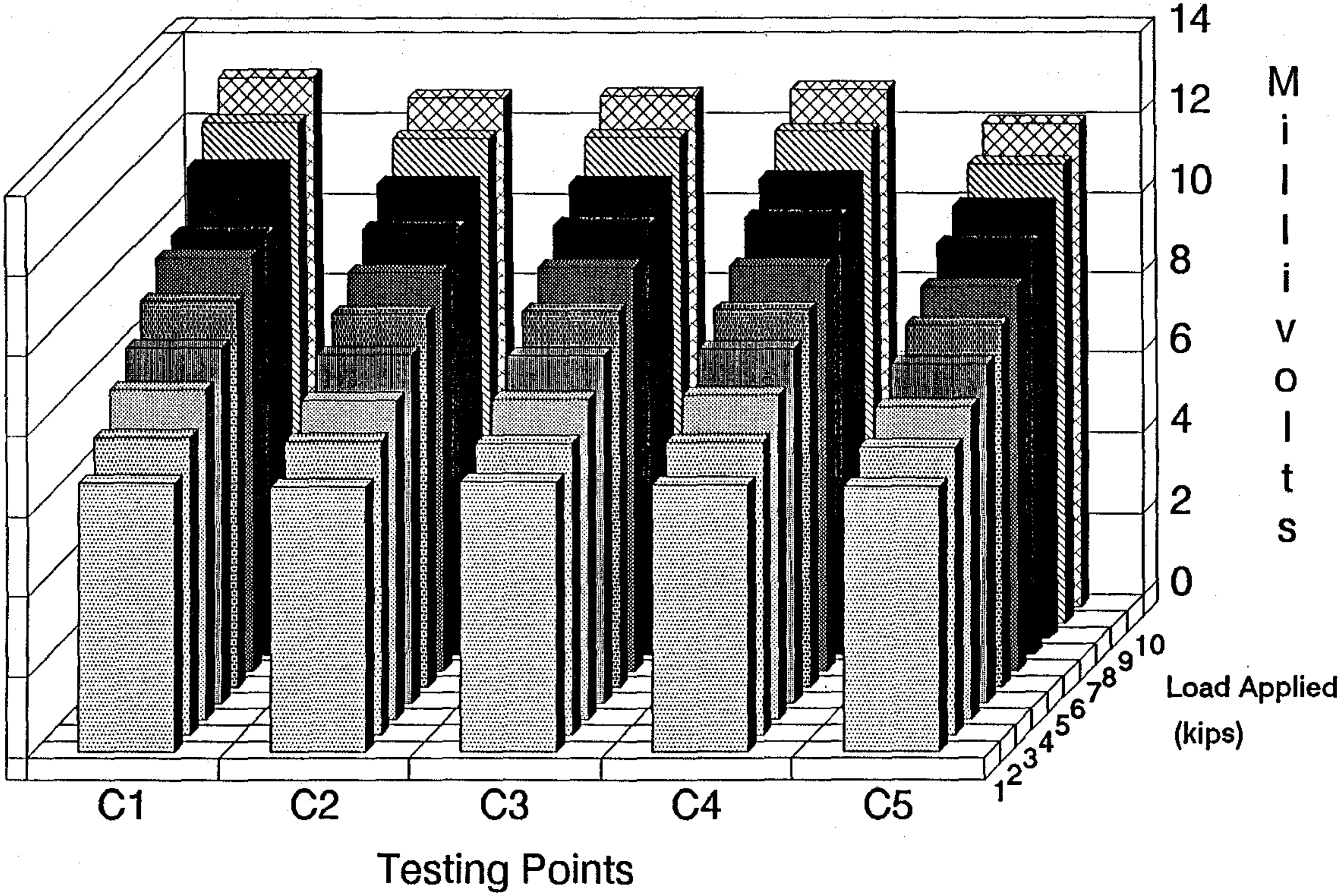

Figure 18. Capacitive Weighmat Output Response to Variable Loads at Room Temperature

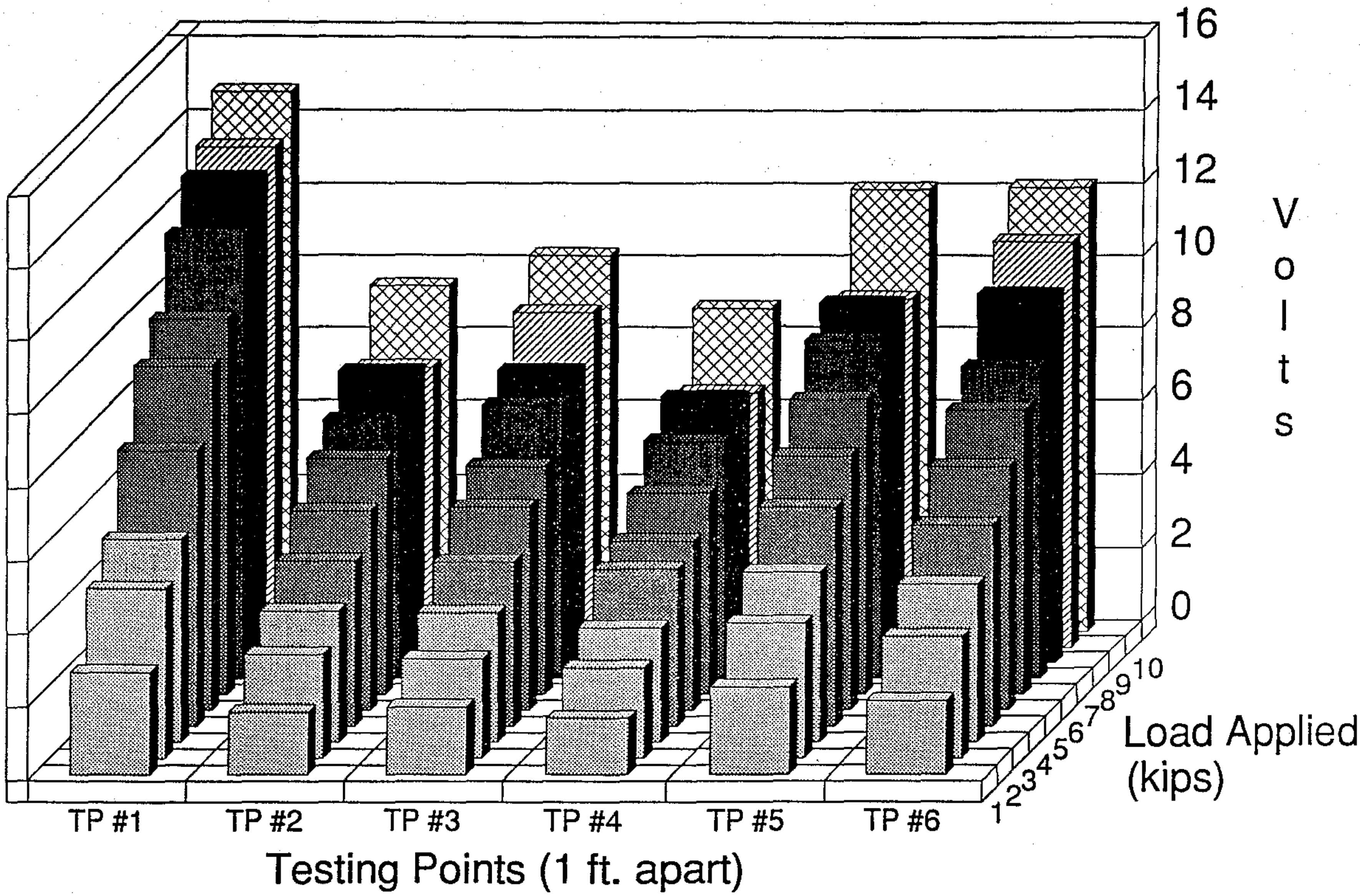

Figure 19. Piezoelectric Film Output Response to Variable Loads

FIELD TESTS

TTI assisted the Department in installing the selected low cost WIM systems on IH-35 near the current WIM location south of Austin. The WIM systems were operated in conjunction with the Department's Radian and portable Howe Richardson capacitive WIM systems to determine their relative accuracy and effectiveness in measuring the weights of the axles of the Department's WIM Calibration Truck and a sample of heavy trucks randomly selected from the traffic stream.

Field evaluation was conducted for the PAT Equipment Corporation bending plate device and the redesigned version of the low cost WIM system developed for FHWA. The field data collection procedure included the following steps:

1. Random selection of trucks from the traffic stream at the rest area located immediately upstream of the WIM site
2. Placement of a large, clearly visible number in the passenger side of the windshield
3. Automated weighing of each truck at the WIM site in conjunction with manual pairing of the assigned truck number and the vehicle sequence number produced by the WIM software
4. Manual weighing of each numbered truck at a static scale location immediately downstream of the WIM site
5. Recording of axle weights, axle spacings, and vehicle classification (according to the FHWA vehicle types given in the Traffic Monitoring Guide) for each truck selected

In addition, the Department's WIM Calibration Truck was included to assist in formulating future calibration procedures by comparison of its data to the results obtained from the randomly selected sample of trucks.

ANALYSIS OF FIELD TEST DATA

TTI analyzed the data collected during the field evaluation of the selected low cost WIM systems. The Statistical Analysis System was used to determine the characteristics of each low cost WIM alternative as well as the Department's two existing WIM systems.

The field data were analyzed by: calculating the absolute and percent difference for each axle, tandem, and gross weight and axle spacing from the WIM and static scale observations for each truck; and analyzing these differences using SAS to derive means and standard deviations as well as cumulative frequency distributions.

The results of the analysis of the data collected are shown in Tables 1 and 2 for the PAT system and in Tables 3 and 4 for the redesigned FHWA capacitive weighmat system.

Table 1. Analysis of Absolute Difference between WIM and Static Weights for the PAT Bending Plate WIM System

	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	EXTREMES
Gross Weight	179	382.46	2923.23	218.48	-6047.2/10762.5
Light Weight	149	-287.24	666.79	54.63	-2925.2/ 1797.1
Heavy Weight	64	282.47	943.40	117.93	-1291.0/ 4359.3
Light Tandem	100	-643.43	1141.24	114.12	-3101.6/ 3763.8
Heavy Tandem	161	970.60	1629.43	128.42	-3020.2/ 6733.0

Table 2. Analysis of Percentage Difference between WIM and Static Weights for the PAT Bending Plate WIM System

	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	EXTREMES
Gross Weight	179	-0.39	6.96	0.52	-17.1/21.4
Light Weight	149	-4.06	8.81	0.72	-32.6/18.8
Heavy Weight	64	2.00	7.80	0.97	-12.5/35.9
Light Tandem	100	-6.04	12.25	1.23	-30.2/65.3
Heavy Tandem	161	3.28	6.66	0.53	-15.0/28.9

Table 3. Analysis of Absolute Difference between WIM and Static Weights for Redesigned Capacitive WIM System

	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	EXTREMES
Gross Weight	171	-286.31	3199.63	244.68	-17945.2/ 6019.5
Light Single	131	-710.59	748.73	65.42	-1974.7/ 2336.1
Heavy Single	68	-806.10	1102.00	133.64	-2900.9/ 2286.3
Light Tandem	138	956.73	1508.85	155.63	-4445.5/ 4000.2
Heavy Tandem	137	-553.02	3705.89	316.62	-33410.3/ 4602.0

Table 4. Analysis of Percentage Difference between WIM and Static Weights for Redesigned Capacitive WIM System

	N	MEAN	STANDARD DEVIATION	STANDARD ERROR	EXTREMES
Gross Weight	171	0.71	8.69	0.66	-32.9/ 20.9
Light Single	131	-8.64	9.09	0.79	-20.2/ 34.4
Heavy Single	68	-7.75	9.58	1.16	-27.4/ 16.7
Light Tandem	94	9.26	14.83	1.53	-37.3/ 57.6
Heavy Tandem	137	-0.67	11.53	0.98	-62.0/ 22.8

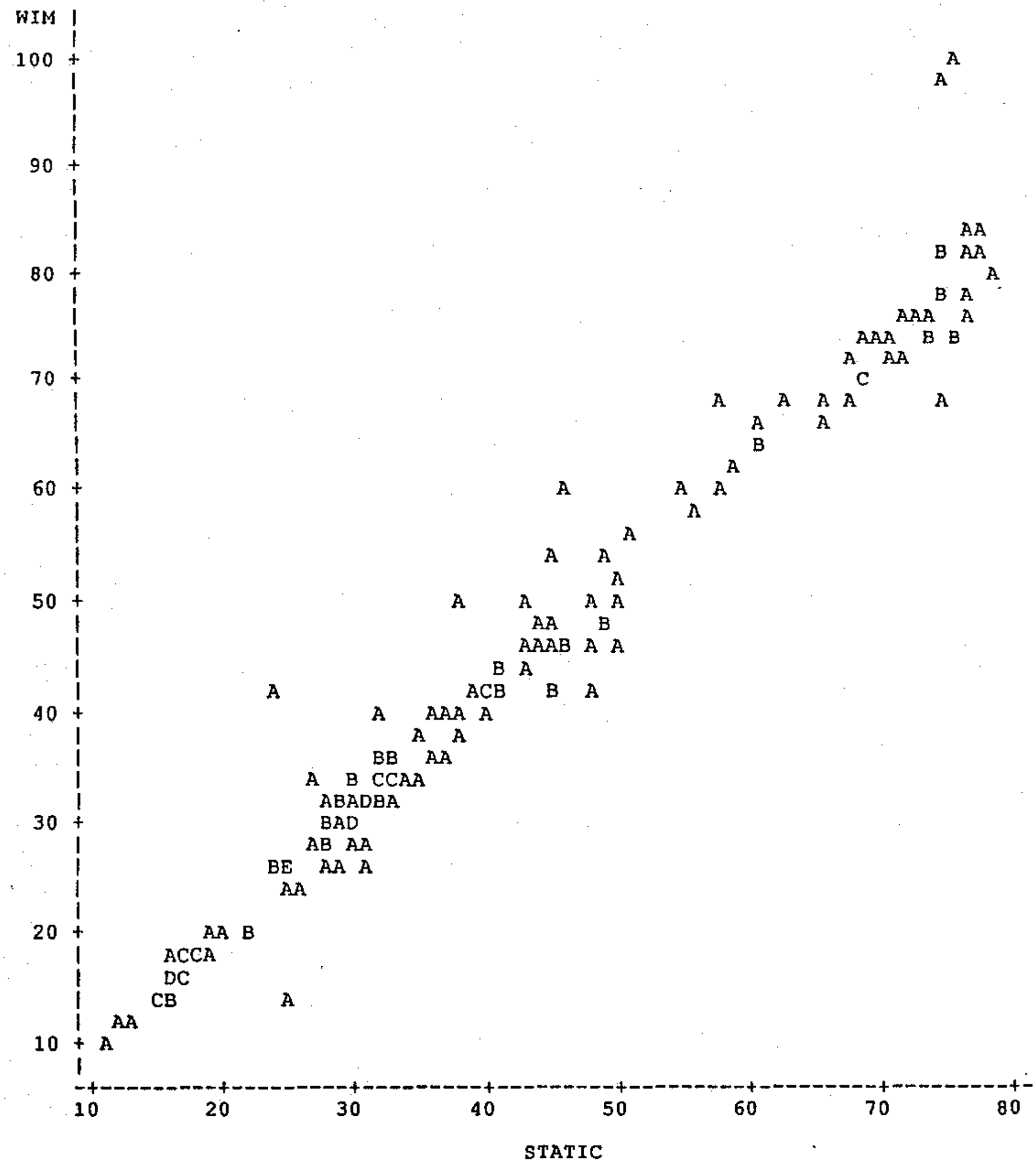

Figure 20. Plot of WIM Versus Static Gross Weights for the PAT Bending Plate WIM System

CHAPTER 5. AUTOMATION OF WIM SITES

DEVELOPMENT OF HARDWARE AND SOFTWARE FOR AUTOMATING WIM SITES

TTI developed hardware and software for automating the collection, storage, and transmission of data acquired by WIM systems. This task included the following steps: conceptual design, detailed system design, production of prototype hardware subsystems, and production of software modules.

AUTOMATION OF LOW COST WIM SITE

TTI initiated the development of hardware and software for automating the collection, storage, and transmission of data acquired by one or more of the WIM systems. Additional information about other traffic, environmental, and pavement phenomena were included.

MODIFICATION OF LOW COST WIM SYSTEM

TTI has incorporated the hardware and software previously developed with the low cost portable capacitive WIM system. The modified system was evaluated by collecting both a random sample of trucks passing the WIM test section and runs of the Department's WIM Calibration Truck. These data were analyzed to assess the relative accuracy and effectiveness of the WIM installations, including all of the traffic, environmental, and pavement information collected by the modified system.

CHAPTER 6. IMPLEMENTATION PLAN

Truck weight data in Texas are now obtained using one of two WIM technologies. The first is used in WIM equipment provided by the Radian Corporation. The Radian WIM system uses strain gauge-based transducers that are installed in one of 12 pre-prepared sites on a rotating basis. The truck weight data are acquired by connecting an electronic data collection device to the transducers. Both the transducers and the electronic subsystems are transported among the sites in a travel van that has been modified for this purpose.

Unfortunately, the Radian Corporation has withdrawn from the WIM market so that it is no longer possible either to have elements of this WIM equipment repaired as needed or to obtain replacement parts to perform repairs or rehabilitation using the Department's forces or an independent contractor. For this reason, the Department is considering obtaining equipment from other vendors to replace the Radian WIM system.

The other WIM technology that has been used by the Department is the portable capacitive weighmat. This equipment was purchased from the Howe Richardson Company. It uses a WIM transducer that is actually a large capacitor coated with neoprene. The dielectric material in the capacitor is rubber, which is compressed by the weight of a truck tire passing over it. The deformation of the transducer changes its capacitance, giving a signal that is interpreted in a roadside electronic data collection unit as a weight.

The development of an implementation plan for incorporating low cost WIM configurations included consideration of both the Department's needs and possible strategies for meeting those needs. The following measures are recommended.

1. Automate the current program of Radian WIM sites to provide continuous truck weight, vehicle classification, and traffic volume data analogous to the current ATR program. This could be done using either a low cost configuration of the bending plate WIM system or a version of the piezoelectric film technology that may be upcoming.
2. Institute a program of WIM surveys, for 48 hours duration, on all highway sections that meet certain importance criteria and are known to be candidates for rehabilitation or reconstruction.

This would involve using either the capacitive weighmat system that the Department currently owns or a portable version of the piezoelectric film technology that may be available.

In each of the items defined above, care should be taken to provide adequate sampling of minor highway facilities under SDHPT jurisdiction to ensure that they can be addressed in a manner appropriate to their relative status.