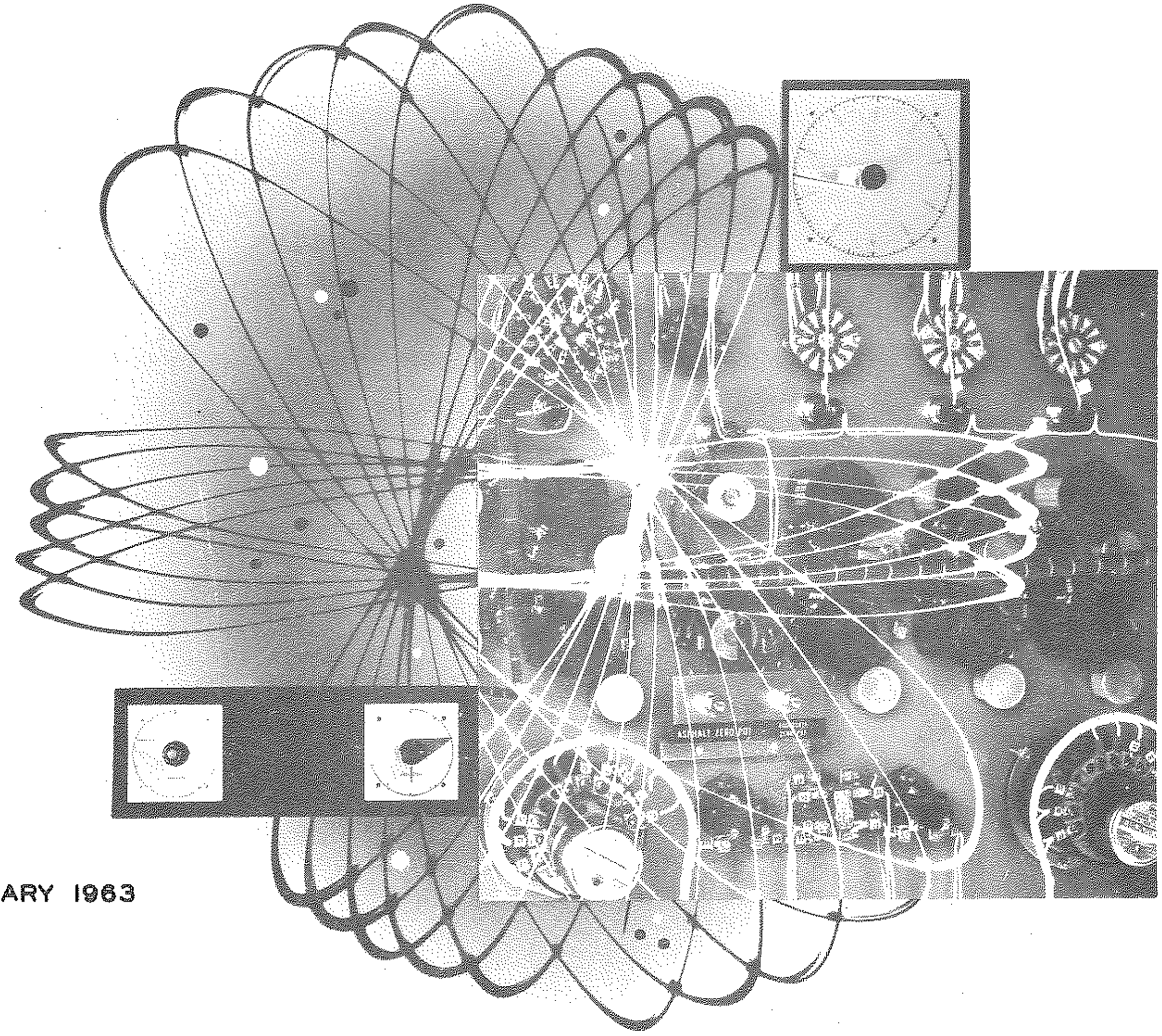
AUTOMATION of BITUMINOUS MIXTURE PROPORTIONING



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AUTOMATION OF BITUMINOUS MIX PROPORTIONING

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AUTOMATION OF BITUMINOUS MIXTURE PROPORTIONING

Synopsis

Michigan requires the use of automatic control equipment on asphalt plants for bituminous mixture proportioning. The authors describe the development of such equipment and give general details on various current types and systems, outline the training required for personnel, working with such equipment, and consider problems arising in service and care of the equipment. A statistical analysis of automatic control performance of a number of plants is reported. Future applications of automation in this field are also discussed.

INTRODUCTION

With the development of modern bituminous paving technology, there has been increasing recognition of the importance of maintaining uniformity in proportioning of the various materials composing a properly designed bituminous mixture.

Depending on locally available materials, accepted practices of different organizations, and local environment, the design of bituminous mixtures has taken various patterns. The design of some mixtures may result from time-tested experience, while others may result from painstaking laboratory investigations. Once a decision has been reached as to what the mixture design will require, it must be produced using the best available methods of proportioning of the materials making up the desired mixture.

When the asphalt batching plant was developed, proportioning of the various ingredients depended to a great extent on the ability of the mixer operator to watch his scales, discharge the materials at the right time, and time the mixing according to his wristwatch or some other timing method. Later, time locks and automatic timers were developed which reduced the likelihood of human error.

In bituminous production the working day is usually from daylight to darkness, and as this lengthy day progresses, the accuracy of manually controlled proportioning diminishes as the operator becomes fatigued. As a result, accuracy of the mixture proportioning decreases and the quality of the bituminous mixture suffers.

With continuous-type asphalt plants where the mixture is proportioned volumetrically, even though the likelihood of human error has been reduced, uniformity of continuous flow is not always dependable. The amount of material in the hot bins creates an apparent head differential; thus, changes in the level of the material in the bins may result in variations of flow over the apron feeder. Also, obstructions by foreign objects may interrupt the flow of any one of the materials, and so alter the proportioning.

DEVELOPMENT OF AUTOMATIC CONTROLS

With the continuing drive for improvement of the uniformity of proportioning, some manufacturers developed mechanical and electronic devices to monitor or control the proportioning of materials in processing plants, and later applied some of these principles to the proportioning of bituminous mixtures. Michigan has been fortunate in having an organization of asphalt paving contractors interested in cooperating with the State Highway Department toward improvement of the quality of bituminous mixtures. To this end, one member, the Ann Arbor Construction Company, voluntarily and on their own initiative installed an automatic weight batching and timing system in June 1955, to control their bituminous mixture production. In May 1956, another member contractor, the Mid-America Engineering Corporation, installed a similar unit for use on state projects.

Uniform proportioning of the mix, resulting from use of the automatic equipment, strongly indicated the desirability of automatic batching. Other contractors were thus encouraged to equip their asphalt plants with automatic controls. By the end of 1959, the desirability of automatic proportioning had become apparent. Thus, with the cooperation of the Michigan Asphalt Paving Association, the Michigan State Highway Department decided to require automatic proportioning and cycling equipment in the production of high-type bituminous concrete mixtures.

Based on the knowledge and experience gained since 1955, in the observation of the automatic controls in use, the Michigan State Highway Department developed specifications to govern automatic proportioning and cycling controls on asphalt mixing plants and concrete batching plants. After review of these specifications with the contractors and equipment manufacturers, and with the approval of the Bureau of Public Roads, they became effective on May 1, 1960, coinciding with the adoption of new standard specifications for road and bridge construction. An excerpt of the specifications applying to high-type bituminous mixtures, and supplements to these specifications, are given as Appendix A.

Basically, the end-product requirement of this specification, which was developed after reviewing specifications of other states for desirability and practicability of tolerances and is based on the Michigan hot-aggregate two-bin separation, is as follows:

1. Weight batching controls shall meet the following tolerances with respect to the various components weighed in each batch:

Coarse Aggregate Bins:	± 1.0 per cent of total batch weight
Fine Aggregate Bins:	± 1.0 per cent of total batch weight
Mineral Filler:	± 0.5 per cent of total batch weight
Asphalt	± 0.1 per cent of total batch weight

2. Total batch weight shall not vary more than 2 per cent from the designated batch weight. This means that tolerance must be checked by the automatic controls at zero, at each weight, and at combined total weight. If this requirement is not met, the interlocks are actuated, the cycle stopped, and production ceases until proper corrections are made.

TYPES OF AUTOMATIC CONTROLS

Michigan has more than 110 asphalt mixing plants qualified to perform work for the Michigan State Highway Department. Of these, 73 plants (about 65 percent) are equipped with automatic proportioning and cycling controls developed and installed by the following nine manufacturers:

1. Barber Greene Company, Aurora, Ill.
2. Gemco Electric Company, 25685 W. Eight-Mile Rd., Detroit, Mich.
3. Grand Rapids Scales Company, 1228 Division St., Grand Rapids, Mich.
4. Hardy Scales Company, 5701 Atlantic Blvd., Maywood, Calif.
5. The Howe Scale Company, 2951 Scale Ave., Rutland, Vt.
6. Jackson Vibrators, Inc. (Millermatic), Jackson Rd., Ludington, Mich.
7. Pioneer Engineering, 3200 Como Ave., Minneapolis 14, Minn.
8. Wisconsin Electrical Manufacturing Co., 1825 South 72nd St., Milwaukee 14, Wisc.
9. Wright Construction Company, 3800 Wood St., Lansing, Mich.

Two of these nine manufacturers supplied 56 of the 73 plants.

Most automatic controls use a differential transformer behind the scale dial as part of a voltage bridge circuit whose "null" output is amplified and used for control. Batch weights are set by potentiometers on the front panel. One manufacturer uses a potentiometer mounted behind the scale dial instead of a differential transformer as part of a wheatstone bridge circuit. Another manufacturer mounts a resolver behind the scale dial. A series of digital selector switches select the desired weight and feed two voltages into the resolver, which determines the scale dial shaft position at which the controls will actuate the equipment. Basic circuits of these systems are shown in Appendix B.

Several manufacturers use photo-electric cells for control. One uses a photo-electric system wherein a slotted plate is attached to the shelf-lever of the dial, and the resulting motion shades or illuminates adjustable photo-electric cells. One cell represents each material feed cutoff or tolerance checkpoint. In another instance a disc is attached to the scale dial shaft. Batch weights are set by a combination of holes in the disc. Tolerances are set by adjustable tabs on the periphery of the discs. Photo cells are located on one side of the disc and light sources on the other side.

One contractor uses a contact ring behind the scale dial pointer with adjustable blocks around the ring which are contacted by a metal whisker on the dial pointer. Width of the blocks determines tolerance limits, and position of the blocks determines feed cutoff points.

In the voltage bridge circuit, wheatstone bridge circuit, and resolver circuit, an intentional error is introduced by a mid-air material compensator control, also called a material-in-suspension compensator. It makes allowance for the material which has passed the discharge gate, but is not yet in the weigh hopper. Its setting is dictated by the amount that the batch overshoots or undershoots the desired weight. After the material is weighed, a tolerance investigation is automatically made as determined by the settings of the tolerance control. All units have auxiliary manual controls in case of breakdown or for production of bituminous mixtures which do not require automatic controls.

It is interesting to note that an often-used button on the panel is the tolerance check over-ride button. This is pushed, of course, when the weighed material is outside tolerance. It might be well to require that a loud bell be attached, to warn the inspector when this button is pushed. The button is generally located under a glass door provided with a lock which is not always locked.

The weigh hopper charging rate has much to do with the ability of the feed system to weigh within tolerance. Generally speaking, the slower this charging rate, the greater the probability that the batch will be within tolerance. This appears to be so, since the amount of material in mid-air varies with the head of material in the bins. Since this amount of material is a variable, it can be reduced by reducing the charging rate, thus reducing the probability of going outside tolerance. Most plants have sufficient slack time in their cycles to allow considerable increase in charging time without affecting the production rate. Figure 1 shows a typical automatic control panel used in Michigan.

PERSONNEL TRAINING

Once field operations were under way, it soon became evident that the plant operators and inspectors were not sufficiently trained and therefore had difficulty in determining whether the equipment was working correctly. For this reason, a portable automatic control simulator (Figure 2) was built and classes for Highway Department personnel were held at the ten district meetings during the winters of 1961-62 and 1962-63. This training device is actually a complete control system. With this device, it is possible to simulate batching operations so as to give visual indication of the checks required under Michigan specifications requiring automatic controls. This simulator incorporates all basic functions required by these specifications for an automatic control system.

In Figure 2, the control panel at left has three material pre-set dials. Below each dial is a feed light which goes on when material is feeding. The small dial on the left is the underweight tolerance control, and the small dial on the right the overweight tolerance control. Near each tolerance control dial is a light to indicate when "weights" are outside tolerances. The light on the lower left indicates when the system is ready to proceed, and the light on the lower right when the batch is completed. The small box in the center contains a selector switch which takes the weighing operation through its cycle. It also contains a control for inserting a variable electrical error into the circuit which is the equivalent of the mid-air compensator. Behind the dial is a scale dial movement and associated circuits.

It was found that the automatic controls could not be fully utilized without a workable checkout system for the equipment. To permit inspectors to determine whether these automatic controls meet existing specifications, a supplemental specification was added requiring a minor modification to the control panel and a simple dial puller (Appendix A, footnote 1). Most dial scale control systems employ a stepping switch that remains in the over-under check position while the batch is outside tolerance, and immediately steps to the next part of the cycle when the weight falls within tolerance. For checkout purposes, this supplemental specification requires that a front panel switch be added to stop the stepping switch in the tolerance

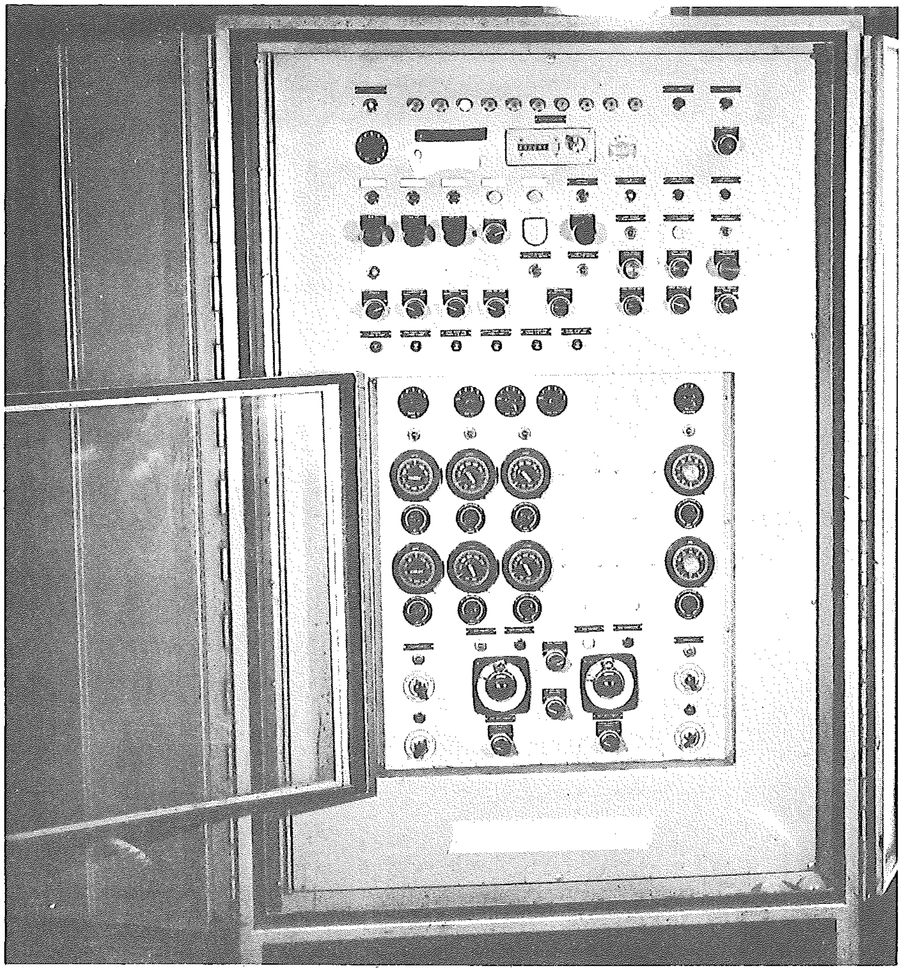
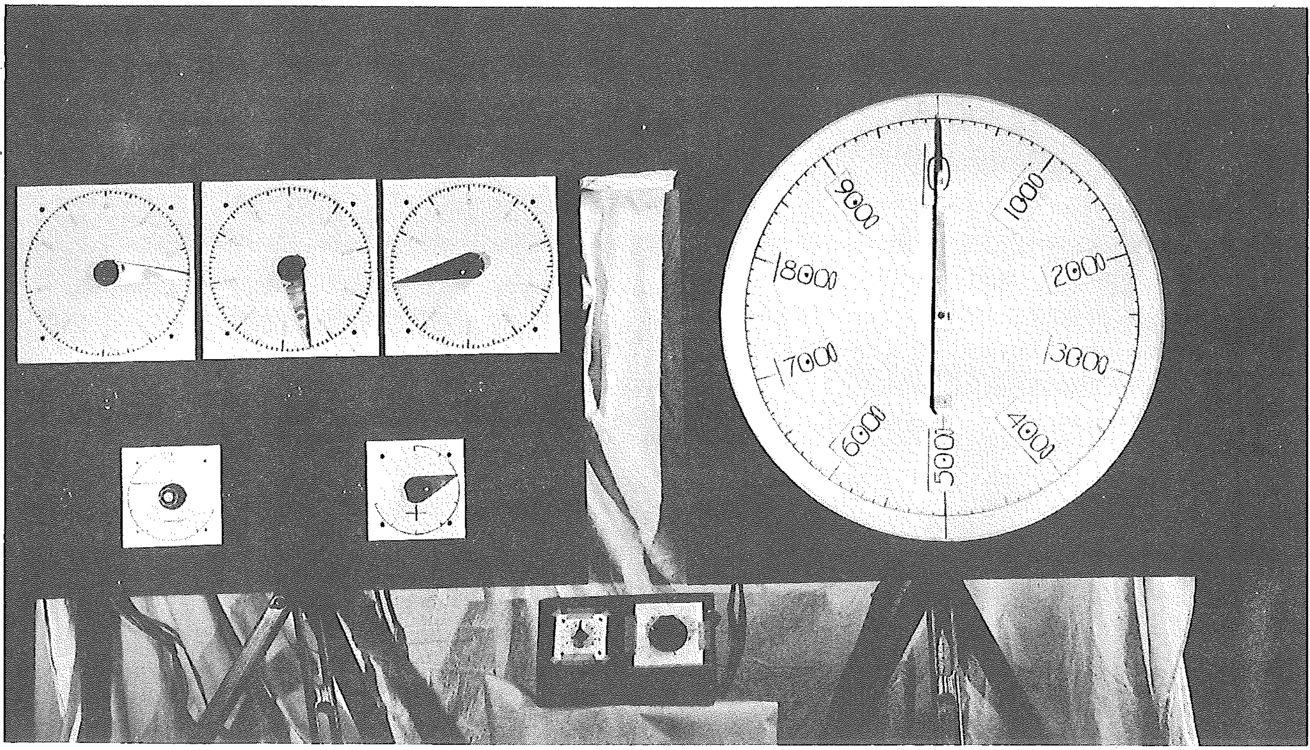


Figure 1. Typical automatic control panel.

Figure 2. Automatic control simulator used as a training device.



check position. With the material feed-gates de-energized the dial may be pulled, simulating a batching operation, and the "weight" at which the tolerance control interlock would be energized may be read from the scale dial. The procedure is simple, is not time-consuming, and does not require drawing any materials. It should be performed at least once a day to determine whether the panel is properly calibrated. The checkout time is approximately 10 minutes.

The inspectors were instructed in the checkout procedure with the training device by pulling the simulator scale dial and observing the indications on the control panel, as would be done in the field. The training device circuit included back panel controls to throw it out of adjustment for better simulation of actual conditions encountered in the field.

SERVICE AND CARE OF AUTOMATIC EQUIPMENT

Soon after automatic equipment was installed in the field, it became apparent that field service was going to be a problem. It was found that the tolerance checking circuits were not staying at their original settings in some of the voltage bridge systems using differential transformers. There appeared to be drift from the original calibration, presumably resulting from temperature variations, vibration, induced voltages in signal leads, or other possible causes. Calls for service were frequent.

Because of its nature this equipment is not readily serviced by licensed electricians or radio and television servicemen. Very few contractor personnel were capable of servicing their own equipment. Contractors were thus dependent upon manufacturer service agencies or a few independent service agencies which have sprung up to meet the demand.

To be effective, service should be both qualified and prompt. It developed that there were few manufacturers who could meet this two-fold need. Some of the servicemen who were prompt seemed to be poorly qualified and those who were well qualified were spread much too thin. Many of the problems resulted from poor field service. Most of the service calls were caused by improper operation of the tolerance check circuit, chiefly because of drifting from original calibration.

On some plants, vibration may be a problem. If a batch is actually out of tolerance and the pointer is vibrating excessively, there may well be a point at one extreme of the vibration cycle at which the pointer falls into the tolerance range and is accepted by the automatic controls.

In the few cases where both scale dials and the control console are mounted on the ground, vibration has been almost entirely eliminated. This mounting has the further advantage of placing the scale dials within readable distance for the plant operator. One contractor mounted the entire weighing mechanism in the tower on automotive-type air bags, successfully eliminating scale vibration.

Proper care of these controls cannot be overemphasized. In many cases, the control console was mounted on the plant tower by the original equipment manufacturers, near the weigh hoppers and scale dials. This is good for reading the batch weights, but the equipment suffers from the effects of exposure to dust and vibration. Many plant operators use the commodious control cabinet as a repository for their tools, flashlights, and occasional small crow-bars. Some cabinets have a door with a lock, but this door is seldom locked.

STATISTICAL ANALYSIS OF AUTOMATIC CONTROL PERFORMANCE

Data Obtained

Data for a statistical analysis were collected from three sources:

1. Daily accumulation weight records (1959). These data had been collected previously and thus became the initial source of information. The weight records consisted of individual truck load weights as recorded on plant platform scales, and were from various plants operating with different types of controls.

2. Daily accumulation weight records (1962). These data from various plants operating under different types of control were collected in the same manner as the 1959 data.

3. Field observations of scale readings on plants operating under different types of control. Personnel were sent into the field to make repetitive observations of readings for materials being weighed for a batch of bituminous mixture. On the manually operated plant the observer had to stand directly behind the weighman, approximately 6 feet from the scales. On three other plants, two observers used a pair of 7 x 50 binoculars and stood approximately 100 feet from the scales.

A set of data for each plant was organized into a frequency distribution of per cent deviation of each observed weight with respect to the set batch weight for that particular plant (Tables I, II, and Part 1 of Appendix C).

TABLE I
FREQUENCY DISTRIBUTIONS OF PER CENT DEVIATIONS OF LOAD WEIGHTS OBSERVED AT VARIOUS PLANTS

	Deviations from Set Weight, per cent	Number of Observed Load Weights Within Given Limits									
		Weight Batch (Automatic) Plant 1	Weight Batch (Automatic) Plant 2	Volume Batch (Automatic) Plant 3	Weight Batch (Automatic) Plant 4 *	Weight Batch (Automatic) Plant 5*	Weight Batch (Automatic) Plant 6	Weight Batch (Manual) Plant 7	Weight Batch (Manual) Plant 8	Continuous (Automatic) Plant 9**	Continuous (Manual) Plant 10
MINUS DEVIATION	-2.85 to -3.15										12
	-2.55 to -2.85			1							10
	-2.25 to -2.55			2			2		1		10
	-1.95 to -2.25	1		1	1		2	1	2	2	11
	-1.65 to -1.95	5	1	2	3		3	2	4	0	7
	-1.35 to -1.65	9	1	5	14		12	4	5	1	13
	-1.05 to -1.35	32	1	7	31	3	41	15	9	7	17
	-0.75 to -1.05	80	2	12	45	7	96	41	21	12	16
	-0.45 to -0.75	176	2	24	47	12	168	129	26	20	14
	-0.15 to -0.45	311	6	83	66	58	329	238	50	18	13
	-0.15 to +0.15	885	15	239	84	217	471	211	64	36	16
PLUS DEVIATION	+0.15 to +0.45	346	49	481	96	277	967	185	65	11	17
	+0.45 to +0.75	153	123	435	66	142	624	83	69	17	19
	+0.75 to +1.05	85	54	157	51	14	343	34	40	8	13
	+1.05 to +1.35	37	14	21	35	6	160	19	20	6	15
	+1.35 to +1.65	10	5	5	12	1	51	12	15	3	13
	+1.65 to +1.95	3	2	1	11		9	3	8	0	15
	+1.95 to +2.25	2	1	0	10		2	3	4	1	18
	+2.25 to +2.55	1	0	1	4		1		1	1	13
	+2.55 to +2.85		0		1				1		8
	+2.85 to +3.15		1						1		11
	Totals	2136	277	1477	577	737	3281	980	406	143	281***

* Plants with tolerance check device.

** Continuous plant with automatic dumping control.

*** Total observations for this plant were 435 of which 281 fell within the range of this table (Data collected in 1959).

TABLE II
FREQUENCY DISTRIBUTIONS OF PER CENT DEVIATIONS OF INGREDIENT WEIGHTS OBSERVED AT VARIOUS PLANTS

Deviation from Set Weight, per cent of total batch weight		Number of Ingredient Weights Observed Within Given Limits										
		Plant 1				Plant 3			Plant 7			
		Stone	Filler	Sand	Bitumen	Aggregate	Filler	Bitumen	Stone	Filler	Sand	Bitumen
MINUS DEVIATION	-1.15 to -1.25									1		
	-1.05 to -1.15									1		
	-0.95 to -1.05									1		
	-0.85 to -0.95								1	0		
	-0.75 to -0.85								1	1		
	-0.65 to -0.75		1			1			3	1		
	-0.55 to -0.65	1	2	1		1			5	6		
	-0.45 to -0.55	3	5	2		1	1		5	8		
	-0.35 to -0.45	5	10	5		2	3		4	19		
	-0.25 to -0.35	16	34	23		3	7		10	23	2	
	-0.15 to -0.25	38	76	69		5	13		26	22	8	
	-0.05 to -0.15	66	122	124	75	7	47	110	63	30	27	24
	-0.05 to +0.05	357	265	261	587	62	141	507	101	134	106	217
PLUS DEVIATION	+0.05 to +0.15	89	105	96	37	40	61	2	53	14	54	10
	+0.15 to +0.25	62	46	58		37	30		8	7	42	1
	+0.25 to +0.35	25	17	39		32	12		6	2	22	
	+0.35 to +0.45	8	4	12		28	5		1	1	8	
	+0.45 to +0.55	7	3	2		24	2				2	
	+0.55 to +0.65	4	2	1		22	1				1	
	+0.65 to +0.75	2	1	0		18					0	
	+0.75 to +0.85	2		1		11					1	
	+0.85 to +0.95	1				8					1	
	+0.95 to +1.05	1				5						
	+1.05 to +1.15					3						
	+1.15 to +1.25					2						
	+1.25 to +1.35					1						
	+1.35 to +1.45					1						
Totals		687	693	694	699	314	323	619	287	271	274	252

This eliminated the effect of changing total batch weights in the middle of a project.

For batch plants this procedure was relatively simple since the weights used as the datum were the batch weights as set up. In the case of continuous mix plants, the problem was more difficult due to the wide distribution which usually occurred. In 1962, a continuous mix plant with automatic controls gave results falling within a narrower range and resulting in a frequency distribution suitable for analysis. In this case, the net load weight used as the datum was the grand average value of all net load weights observed.

Errors

Any measurement or series of measurements is subject to a number of errors. These errors account for the discrepancy between a measured value and the true value or what it was intended to be. Systematic errors can be compensated for and blunders can be eliminated through built-in checks. However, accidental errors due to imperfections of the senses or equipment used are always present and are assumed to vary with chance or the law of probability.

The first error observed, at least in tabulating the data, was that on some high-production-rate plants, the degree of accuracy being used in weighing the truck loads exceeded the cell limits for the frequency distribution. These data were not used but subsequent data which were measured more accurately were used. Other data not used came from the first load produced each day by a plant, which generally showed as being considerably light.

It is felt that a certain amount of bias permeates the data for the scale readings observed on the manually operated plant. The proximity of the observer to the weighman, and the observer's constant watching and recording of weights, had some effect on the weighman's operations.

Although data were collected from various plants under different types of control, systematic errors and blunders were minimized as much as possible. This leaves the ever-present accidental errors, and even though different weighmen were involved, the very nature of this type of error, it is felt, justified a common analysis of the data obtained.

Data Analysis

Analysis of the collected data consisted of computing the arithmetic mean, standard deviation, and skewness of the frequency distributions established by each set of data collected. The following general equations mathematically define these statistical functions:

Arithmetic Mean $$\bar{X} = \frac{\sum_{i=1}^{n} X_i}{n}$$

Standard Deviation $$\sigma = \sqrt{\frac{\sum_{i=1}^{n} X_i^2}{n} - \bar{X}^2}$$

Skewness $$k = \frac{\sum_{i=1}^{n} (X_i - \bar{X})^3}{n \sigma^3}$$

where X_i is the individual value, and n is the number of values in the set.

It is not within the scope of this paper to derive these equations. Also, these equations are the general form and as such do not lend themselves to easy or rapid computation. For those interested, the method used in the calculations was short method No. 1 from the ASTM's "Manual on Quality Control of Materials" (Special Technical Publication 15-C, January 1951). An example of this calculation procedure is shown in Appendix C, Part 2.

The arithmetic mean is the average value for the distribution, around which all other values tend to center. The standard deviation is a special form of average deviation from the arithmetic mean, and as such is an expression of the dispersion of the values about the average value. The skewness is a numerical representation of the relative symmetry of a distribution about the average value and indicates by sign on which side the values tend to group.

Results

The results of the various sets of data are graphically presented as frequency histograms in Figures 3 through 6. These plots show the relative frequency or occurrence of the per cent deviations from the set weight. Also plotted on each chart is the value of the arithmetic mean ($\bar{X}$) computed for that particular distribution. This shows the deviation of the average value with respect to the set weight.

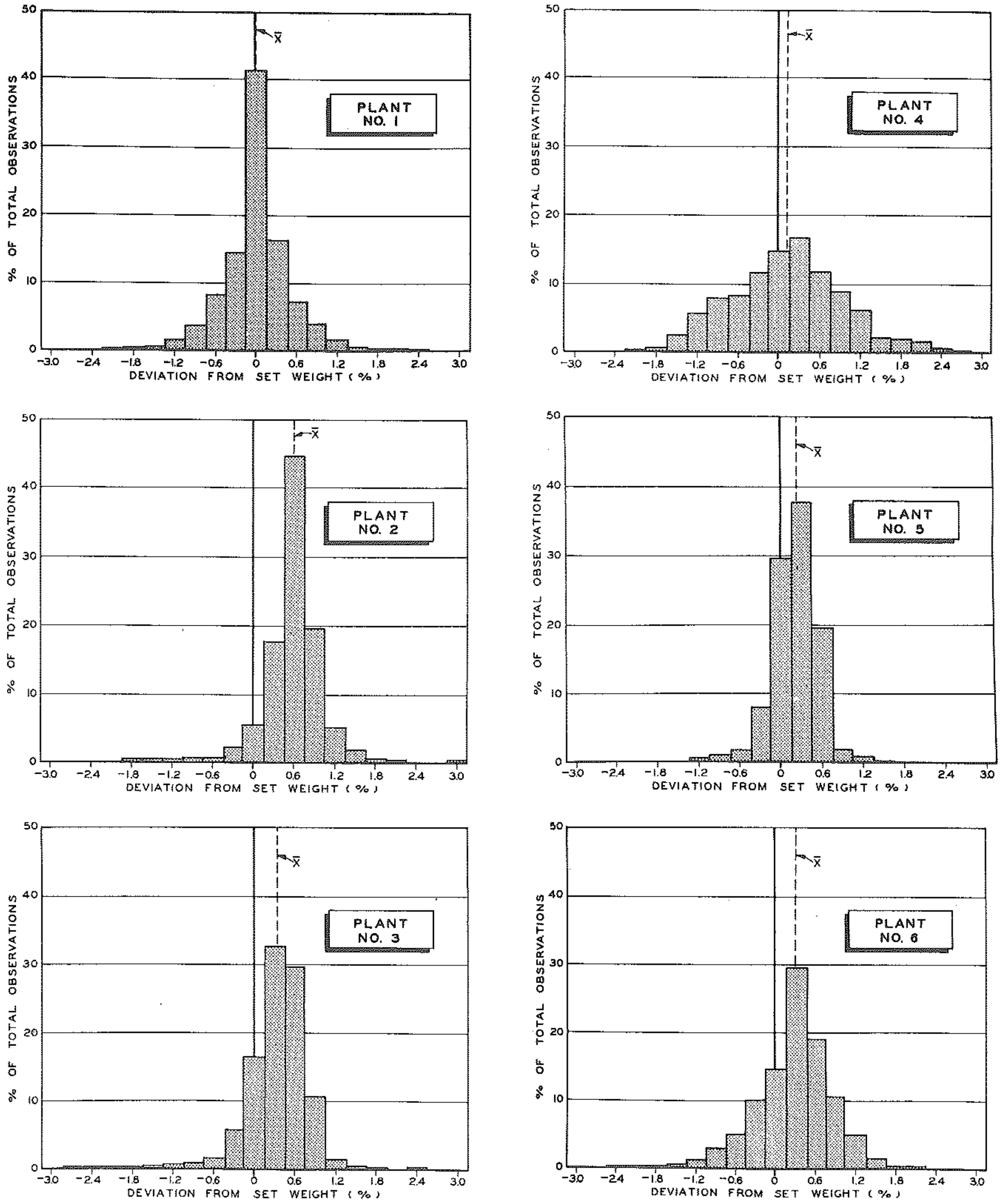


Figure 3. Frequency histograms of per cent deviations of load weights from the set weight for various plants.

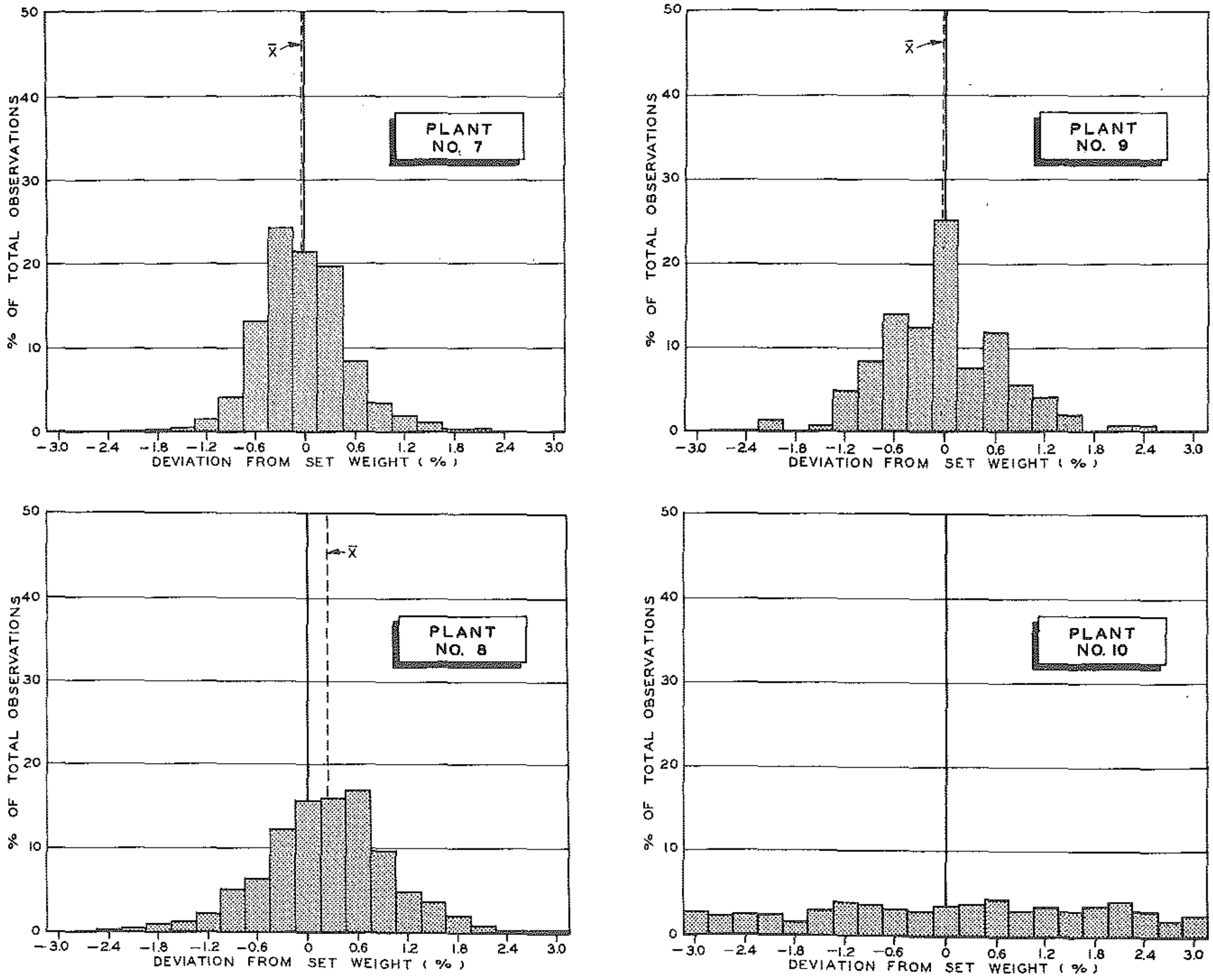


Figure 3 (cont.). Frequency histograms of per cent deviations of load weights from the set weight for various plants.

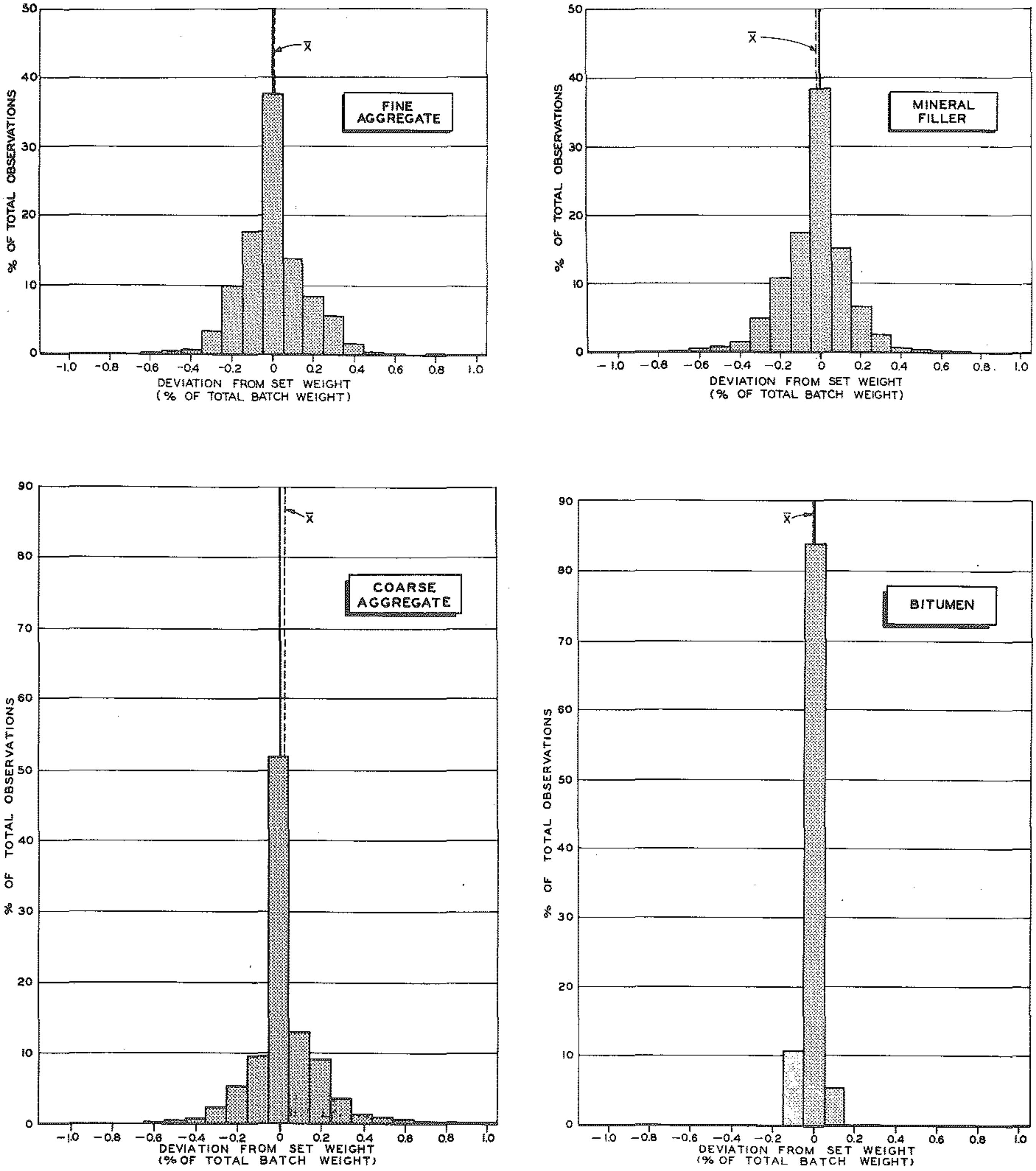
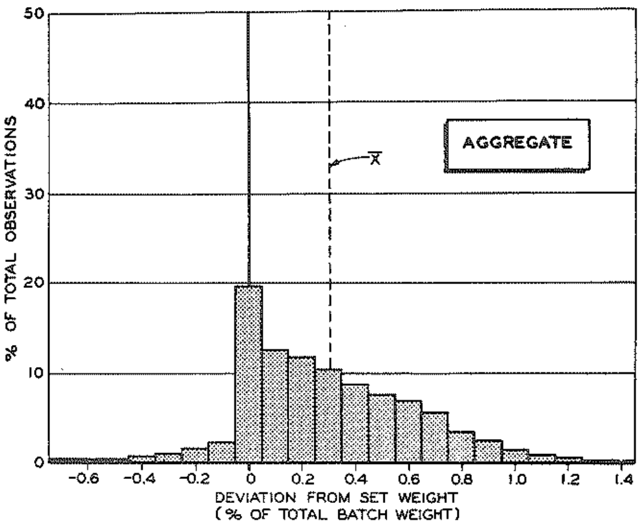
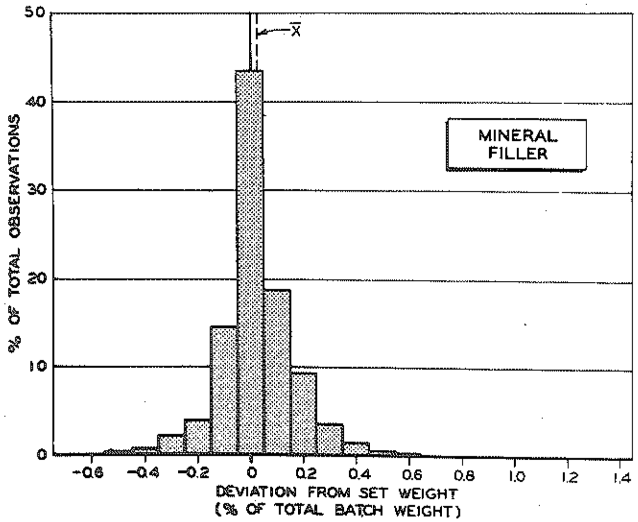


Figure 4. Frequency histograms of per cent deviations of ingredient weights from the set batch weights for plant No. 1.





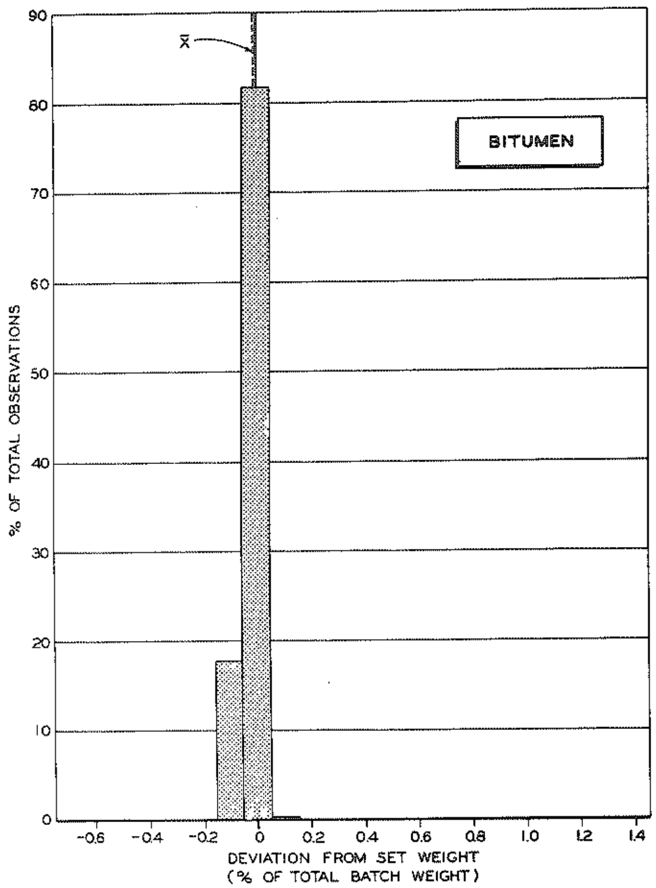


Figure 5. Frequency histograms of per cent deviations of ingredient weights from the set batch weight for plant No. 3.

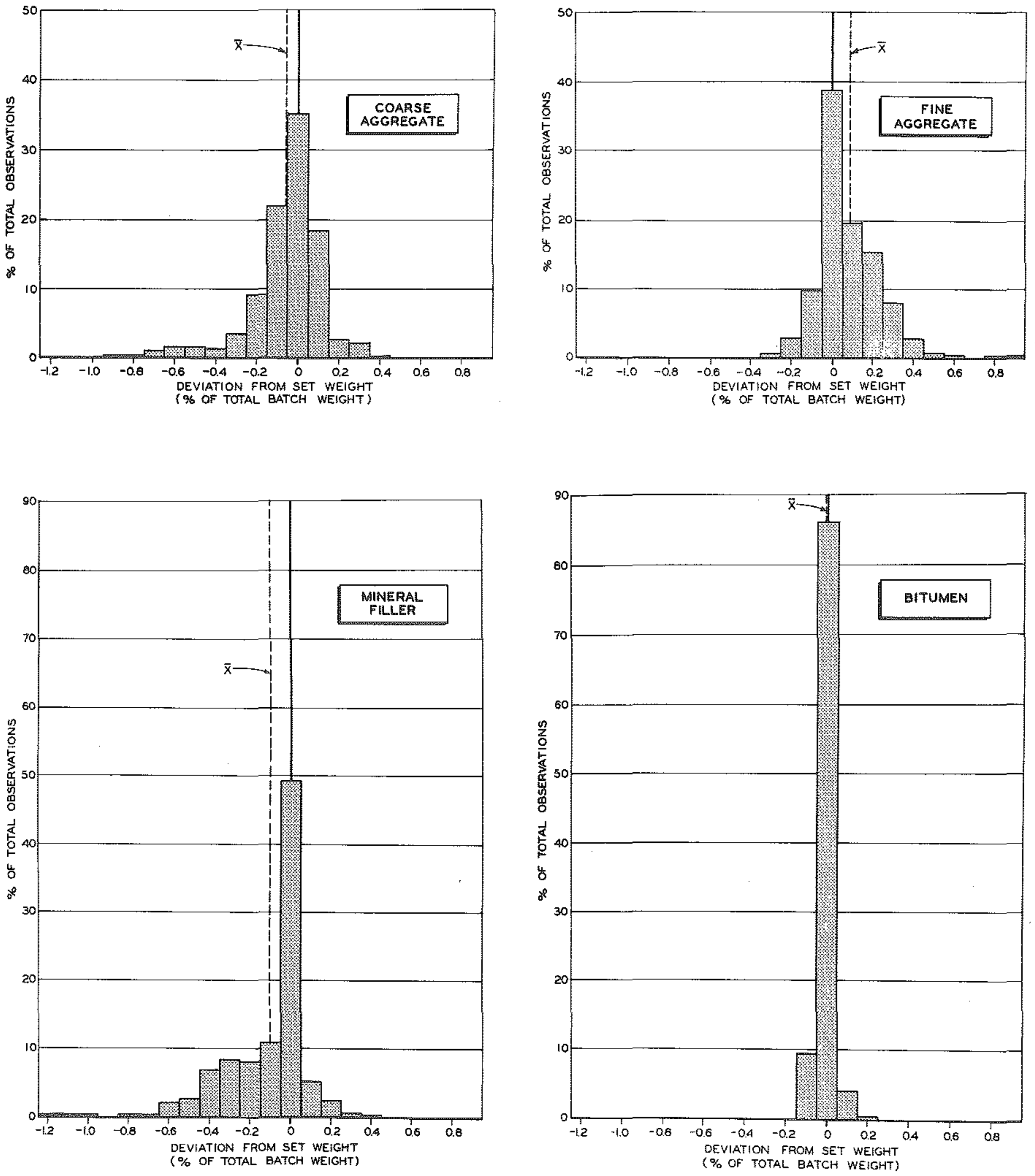


Figure 6. Frequency histograms of per cent deviations of ingredient weights from the set batch weight for plant No. 7.

Tables III and IV are compilations of the numerical values of the arithmetic mean ($\bar{\bar{X}}$), standard deviation (σ), and skewness (k), computed for the frequency distributions established by each set of data collected.

In addition, Part 1 of Appendix C provides further computed statistical values for the frequency distributions of per cent deviations of load weights observed for various plants. The number of computations required, due to the volume of all data collected, resulted in use of an electronic computer to check and verify the numerical results.

The skewness value (k) for a perfectly symmetrical distribution is zero and values are either positive or negative depending on which direction the lopsided portion of the distribution occurs. Multiplying σ , which is a statistical value based on a normal distribution curve, by 3, one can determine the approximate range within which lie 99 per cent of the observations for a particular plant. According to the ASTM Manual, this approximation is valid where the data represent a large number of observations collected under controlled conditions. Thus, since similar conditions have been considered to exist in the determination of these frequency distributions, the 3 σ values can be used to evaluate relative operating efficiency of the various plant control types studied against the tolerance limits required by the specifications.

Discussion of Results

The results in Table III warrant the following discussion:

1. The automatic batching systems controlled the batch weights better than the manual weighing systems with the following exceptions:

a. Plant 4 displayed the least control although it is a completely automated batch plant with a tolerance check device. However, this check device showed extreme drift and variation occurring in the tolerances and this job was shut down. Corrections to the automation have since been made, but there has not been an opportunity to recheck this particular plant.

b. Plant No. 7 displayed good control for the entire period when truck weight checks were made. However, some of this good control may be due to the fact that during 20 per cent of this period, observations were being made of individual ingredient weights, which contributed to this control. For this reason, the data are considered somewhat biased; nonetheless the results are much better than anticipated on the basis of the 1959 data for manual plants.

2. An improvement in batch weight control was noticed for the 1962 automatic batch plants versus the 1959 automatic batch plants. It is felt that this improvement is due to greater familiarity with the automatic controls and improved plant maintenance procedures. There also may have been some improvement in the automation systems themselves.

3. An improvement in batch weight control was also noticed in 1962, for those automatic batch plants with the tolerance check device as compared with those without. Here the improvement probably is due to better control of the tolerances, and subsequent awareness of equipment drift and deviation, through proper application of the inspection or checkout process.

4. The 3 σ range for a continuous plant in 1962, is comparable to that for manual plants observed in 1959. Although the data for 1959 continuous plants was not statistically sound, a general trend of improvement in the relative range of truck load weights is readily apparent. In 1959, approximately 70 per cent of the truck load weights were within ±3.0 per cent of the grand average value while in 1962, 90 per cent were within the ±3.0 per cent. In one completely automated plant, 100 per cent of the truck load weights were within ±2.5 percent.

TABLE III
STATISTICAL FUNCTIONS FOR DISTRIBUTIONS OF LOAD WEIGHT DEVIATIONS

Plant No.	Type		Data Year	Total Observations, (n)	Arithmetic Mean, ($\bar{X}$)	Standard Deviation, (σ)	Skewness, (k)	± Range (3 σ)
	Plant	Control						
1	Weight Batch	Automatic	1962	2136	+0.004	0.483	+0.068	1.449
2	Weight Batch	Automatic	1962	277	+0.581	0.466	-0.561	1.398
3	Volume Batch	Automatic	1962	1477	+0.341	0.437	-1.354	1.311
4	Weight Batch	Automatic*	1962	577	+0.127	0.834	+0.181	2.502
5	Weight Batch	Automatic*	1962	737	+0.210	0.340	-0.448	1.020
6	Weight Batch	Automatic	1959	3281	+0.273	0.557	-0.436	1.671
7	Weight Batch	Manual	1962	980	-0.028	0.547	+0.412	1.641
8	Weight Batch	Manual	1959	406	+0.228	0.789	-0.066	2.367
9	Continuous	Automatic	1962	143	-0.017	0.792	+0.652	2.376

* Plant has tolerance check device.

The results in Table IV show the following:

1. Fairly uniform control of ingredient weights was obtained in the automated system. The tolerance requirements for mineral filler established the allowable limits for the aggregate portions.

2. Better control of mineral filler weights was observed when weighed separately as in Plant No. 3. This resulted in a corresponding wider permissible range for the coarse and fine aggregate. However, this does not result in any increased limits for the total batch weight because of the overlapping of distributions which occur as shown by Plant No. 3 (Table III).

TABLE IV
STATISTICAL FUNCTIONS
FOR DISTRIBUTIONS OF INGREDIENT WEIGHT DEVIATIONS

	Plant No.	Aggregate	Filler	Sand	Bitumen
Arithmetic Mean ($\overline{X}$)	1	+0.029	-0.023	+0.005	-0.005
	3	+0.300	+0.025	------	-0.017
	7	-0.057	-0.113	+0.080	-0.005
Skewness (k)	1	+1.121	-0.027	+0.352	-0.458
	3	+0.478	+0.248	------	-1.548
	7	-1.493	-1.642	+1.196	-0.043
Standard Deviation (σ)	1	0.167	0.161	0.161	0.040
	3	0.331	0.144	------	0.039
	7	0.185	0.215	0.157	0.039
± Range (3σ)	1	0.501	0.483	0.483	0.120
	3	0.993	0.432	------	0.117
	7	0.555	0.645	0.471	0.117

3. The only automated plant checked that showed a plus average value for mineral filler was Plant No. 3. It is felt that this is due to weighing the mineral filler separately, and to the fact that on all other asphalt batching plants the aggregate portion is weighed first, generally showing a plus average value which affects the next ingredient average value and causes it to be opposite in sign.

CONCLUSIONS

It might be well briefly to discuss the reaction of the contractor, the equipment manufacturer, and the public agencies to the use of automatic proportioning and cycling controls in the production of bituminous mixtures. Since the installation of the first automated unit in Michigan in 1955, most contractors have generally reacted favorably. Such factors as initial cost and anticipated high cost of maintenance, have actually been overcome by increased efficiency of weighing and cycling with resultant increased production and reduced handling costs when considered on a long-term basis.

Manufacturers of asphalt plants, weighing devices, electronic devices, and other equipment, responded to the opportunity to furnish the contractor with automatic control equipment. The industry accepted the specifications enacted in 1960 by the Michigan State Highway Department, requiring automatic controls in the proportioning and cycling of all high-class bituminous mixtures. During the first year of operation, the demand for automatic control equipment exceeded the available supply.

In spite of orderly planning, detailed engineering, careful fabrication, and supervised factory installation, in the first year of operation several unexpected problems developed. There were too few trained technicians to keep up with the service and calibration of the various units in operation. In spite of complaints and difficulties experienced by some contractors, automation survived the first year and proved necessary and desirable. Even though some problems continued the following year, and it is anticipated that they may continue to some degree, the industry has made numerous improvements. It is felt that a definite contribution has been made toward improving the quality of bituminous mixture proportioning.

Asphalt plants, like automobiles, become old and worn, and even conscientious operators may become neglectful in performing necessary plant maintenance. Human controls, at best, are prone to let some inadequacies in plant operations slip by. Automation does an impartial job of forcing the corrections necessary to proper operations, where a human decision might be prone to waiver under certain circumstances.

Throughout the years, Michigan and other states have developed specifications to regulate the proportioning of the materials, and have trained engineers and technicians to ensure that these specifications are maintained. It is believed that the quality of mixture proportioning has been improved in recent years through the use of automatic controls. This discussion has attempted to show statistical data gathered during the last several years to illustrate that automation has resulted in higher quality bituminous mixtures. In addition, visual observations show the desirability of removing human error in the control of uniformity of production.

FUTURE APPLICATIONS

In the interest of continued efforts toward improvement of quality control, it would be appropriate at this time to speculate on what the future may bring in the way of more compact and relatively trouble-free control systems. With existing hardware, it appears entirely possible to attach a shaft position encoder behind the scale dial: (1) to process the encoder output and determine whether the batch is within tolerance; (2) to record the various batch weights in appropriate accumulators; and (3) to print out this information on a ticket which the truck driver could take to the street.

Present digital data recording systems rely on the mechanical calculator which has a solenoid bank over its keys for actuation. Memory requirements such as accumulating the weight of bituminous mixtures produced during the day, the individual truck weight, the weight of bitumen used during the day, and the dial readings of the various ingredients, would require a prohibitively large accumulator in a mechanical calculator. The same thing could be done by an electronic system instead of a mechanical system. The result might be a ticket giving time, date, individual ingredient weights or accumulated dial readings for each batch, total truck load weight, and total weight for the day's production. A nine-digit printout device could handle all of this information. These units should be designed with field service problems in mind. The company which produces such a system may quickly find a market for its product. Several states are considering requiring data recording, with New York State having already set up specifications to this effect. This should provide good inventory control and can be used for a basis of payment as well as for quality control.

Systems are now available which do away with the dial scale. This does not appear to be a desirable feature under existing methods of inspection, as it deprives the inspector and operator of the only visible means which they understand for checking the weighing operations while they are being performed.

If the time ever comes for an end product specification, to evaluate the quality of the bituminous mixture by inspections of the finished bituminous pavement itself, then print-out data in addition to other information would become valuable tools to assist in this evaluation.

APPENDIX A

MICHIGAN SPECIFICATIONS FOR AUTOMATIC PROPORTIONING AND CYCLING CONTROLS (Article 4.12.03-a-22 from "Standard Specifications for Road and Bridge Construction" of the Michigan State Highway Department, May 1, 1960, with supplemental specifications as indicated).

Automatic batching or proportioning of the various components of the bituminous concrete binder, leveling and wearing course mixtures will be required to meet the following specifications on all projects which are advertised for bids after May 1, 1960. The automatic proportioning controls shall include equipment for accurately proportioning batches of the various components of the mixture by weight or volume in the specified sequence and for controlling the mixing operations. Adjustable timing devices for control of the dry and wet mix times and other time delay circuits to space the individual component batching and mixing operations will be required together with the auxiliary interlock cutoff circuits necessary to interrupt and stop the automatic cycling of the batching operations at any time an error in weighing occurs or when there is a malfunctioning of any other portion of the control system.

Weight Batch Proportioning.- The weight batching controls shall meet the following tolerances with respect to the various components weighed in each batch.

Coarse Aggregate Bins:	± 1 per cent of the total batch weight
Fine Aggregate Bin:	± 1 per cent of the total batch weight
Mineral Filler:	± 0.5 per cent of the total batch weight
Asphalt:	± 0.1 per cent of the total batch weight

The total weight of the batch shall not vary more than ± 2 per cent of the designated batch weight. The weighing operations shall be equipped with an interlock to cut off the cycling and weighing operations at any time any of the individual component weights or the total batch weight exceeds the tolerances specified. All automatic batching type equipment shall be equipped with auxiliary dial scales meeting the requirements under manual weighing for use in setting the automatic weighing controls for the individual weight proportions and for monitoring the weighing at any time during operations (1) *

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* (Footnotes appear at end of Appendix A.) Sic !

Volumetric Batch Proportioning.- Batch type plant proportioning by volume shall be equipped with adjustable volume weigh boxes for each individual component of the mixture. These individual weigh boxes shall be suspended from scale beam assemblies attached to a dial indicating scale meeting the requirements stated under manual weighing to provide for means of weight calibration of the volume measurements. These scales shall also continuously monitor the volumetric batching operations during production of bituminous mixtures and shall be equipped with interlock controls to stop the cycling operations at any time the weights on the scales do not come within the tolerances specified above for the various components, or when the total weight of the individual batch varies more than ± 2 per cent from the designated weight of that batch (2). Volumetric batch proportioning plants shall also be equipped with bin level indicators installed in such a way and interlocked with the weighing system so as to stop all cycling operations at any time the level of aggregate in the individual bins falls below that necessary to provide for a sufficient quantity of material for a full batch. Volumetric batching plants shall be equipped with manual operating controls to permit manual batching into the separate volumetric measuring boxes at any time during the plant's operation when checking or recalibration of volume measurements is required.

Volumetric Metering of Bitumen on Batch Plants.- For this method of proportioning the bitumen on batch plants the metering device and auxiliary equipment specified under section 4.12.03-a-2 shall be required and shall be interlocked into the automatic batch proportioning and cycling equipment to provide for addition of the bituminous material at the end of the dry mix period and for interruption of the cycling at any time the bituminous material being metered does not meet the specified weight tolerance.

Continuous Plant Automatic Controls.- Each bin compartment shall be equipped with a bin level indicator installed to indicate when the bin compartments are filled to approximately 1/3 the minimum required capacities. These bin level indicators shall be interlocked with the volumetric proportioning unit and mixer unit on the continuous plant in such a way that at any time when the level of the material in any bin compartment falls below the 1/3 level point, mixing operations will be automatically stopped.

The adjustable feeders on the aggregate and mineral filler bin compartments shall be equipped with cutoffs that will automatically stop the mixing operations at any time the flow of aggregates varies more than ± 1 per cent or the mineral filler varies more than ± 0.5 per cent of the calibrated unit weight of mixture per revolution (3).

The asphalt metering pump on the continuous mixing plant shall be provided with an automatic cutoff to shut down the mixing operations at any time when the flow of asphalt is interrupted or decreased from the calibrated amount through depletion of the asphalt supply or the introduction of foam or air into the asphalt line. This control shall be actuated by a liquid level float in the gravity feed bitumen supply tank or by a flow indicator sensitive to air or foam installed in the asphalt circulation line just ahead of the metering pump. The asphalt supply tank or line shall also be equipped with a thermometer to indicate the exact temperature of the asphalt being delivered to the mixer. At any time the asphalt temperature varies more than ± 25 F from the temperature at which the metered volume of asphalt was set in calibrating and setting the aggregate flow gates, the mixing operations shall be stopped until the asphalt reaches the calibration temperature ± 25 F or the aggregate gates recalibrated to the new asphalt temperature.

An auxiliary revolution counter shall be installed on the mixing operator's platform and shall be directly synchronized with the standard revolution counter on continuous plants used for calibrating the volumetric proportioning unit.

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(1) Paragraphs on "Weight Batch Proportioning" augmented by "Supplemental Specifications for Automatic Controls for Batching Materials for Bituminous Mixtures and Portland Cement Concrete," dated April 9, 1962, to read as follows:

"The automatic control for each batching scale system shall be equipped with a device, such as a switch, for stopping the automatic cycle in the underweight check position and in the overweight check position for each material so that the tolerance may be checked.

"Each dial scale system shall be equipped with a mechanical device, such as a threaded rod and wingnut, which may be attached to the dial lever system so that the dial may be moved smoothly and slowly through its range to check the settings of the automatic control system."

(2) Underlined sentence revised by "Supplemental Specifications for Automatic Proportioning and Cycling Controls on Batch Type Plants with Volumetric Batch Proportioning for Bituminous Mixtures," dated October 6, 1960, to read as follows:

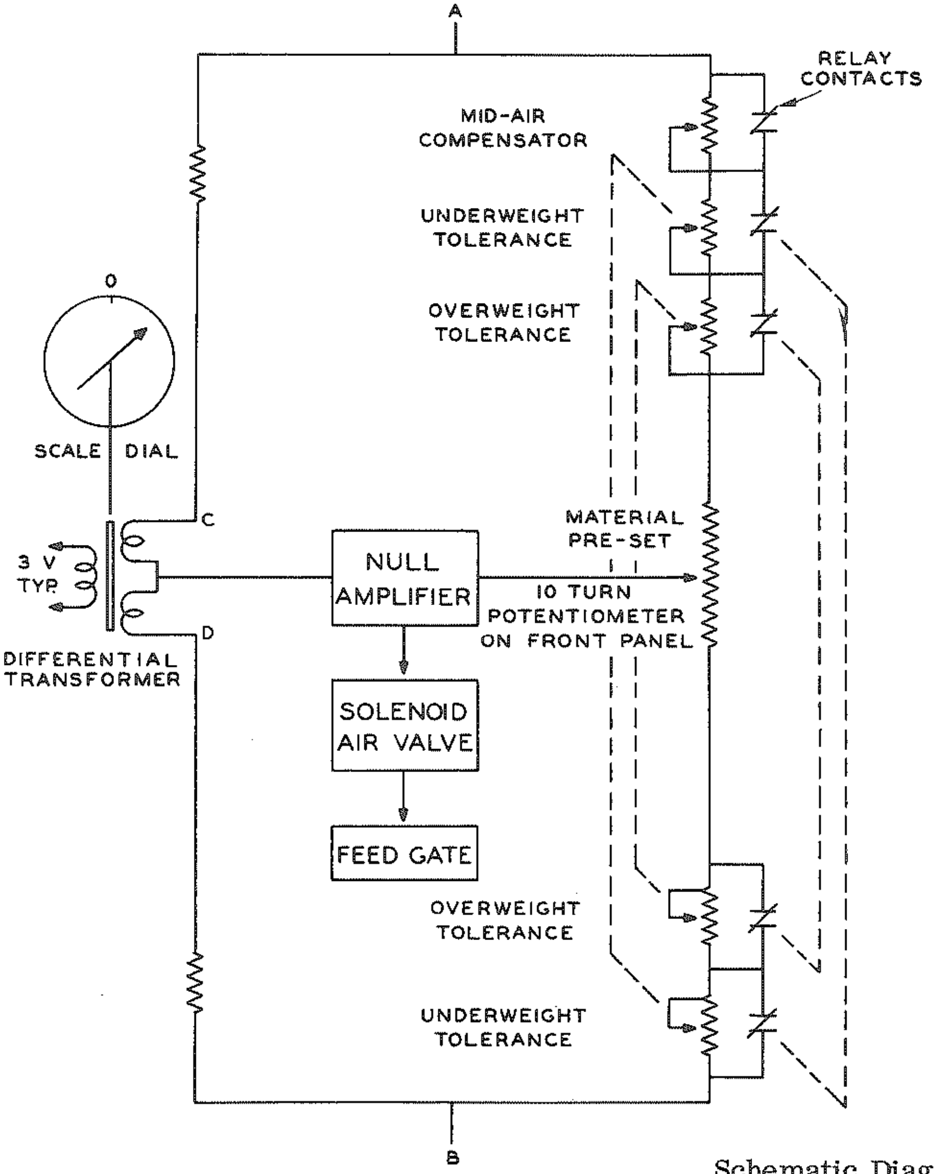
"These scales shall continuously monitor the volumetric batching operations during the production of bituminous mixtures and shall be equipped with interlock controls to stop the cycling operations at any time the weights on the individual scales do not come within the tolerances noted as follows for the separate mixture components being volumetrically measured:

Aggregate Components (combined)	± 1.5 per cent of total batch weight
Mineral Filler	± 0.5 per cent of total batch weight
Asphalt	± 0.1 per cent of total batch weight

"The total weight of any individual batch shall not vary more than ± 2 per cent of the designated batch weight."

(3) Underlined sentence revised by "Supplemental Specifications for Automatic Proportioning Controls on Continuous Type Mixing Plants for Bituminous Mixtures," dated July 7, 1960, to read as follows:

> "The adjustable feeders on the aggregate and mineral filler bin compartments shall be equipped with cutoffs which will automatically stop the mixing operations at any time the flow of any aggregate fraction or mineral filler is decreased or cut off. The accuracy of the metering gates or devices shall be such that the quantity of each individual aggregate fraction shall be measured within a tolerance of ± 1 per cent and the mineral filler within a tolerance of ± 0.5 per cent of their required weights. These tolerances are based on the total weight of mixture measured on individual test truck loads."



BASIC VOLTAGE BRIDGE CIRCUIT

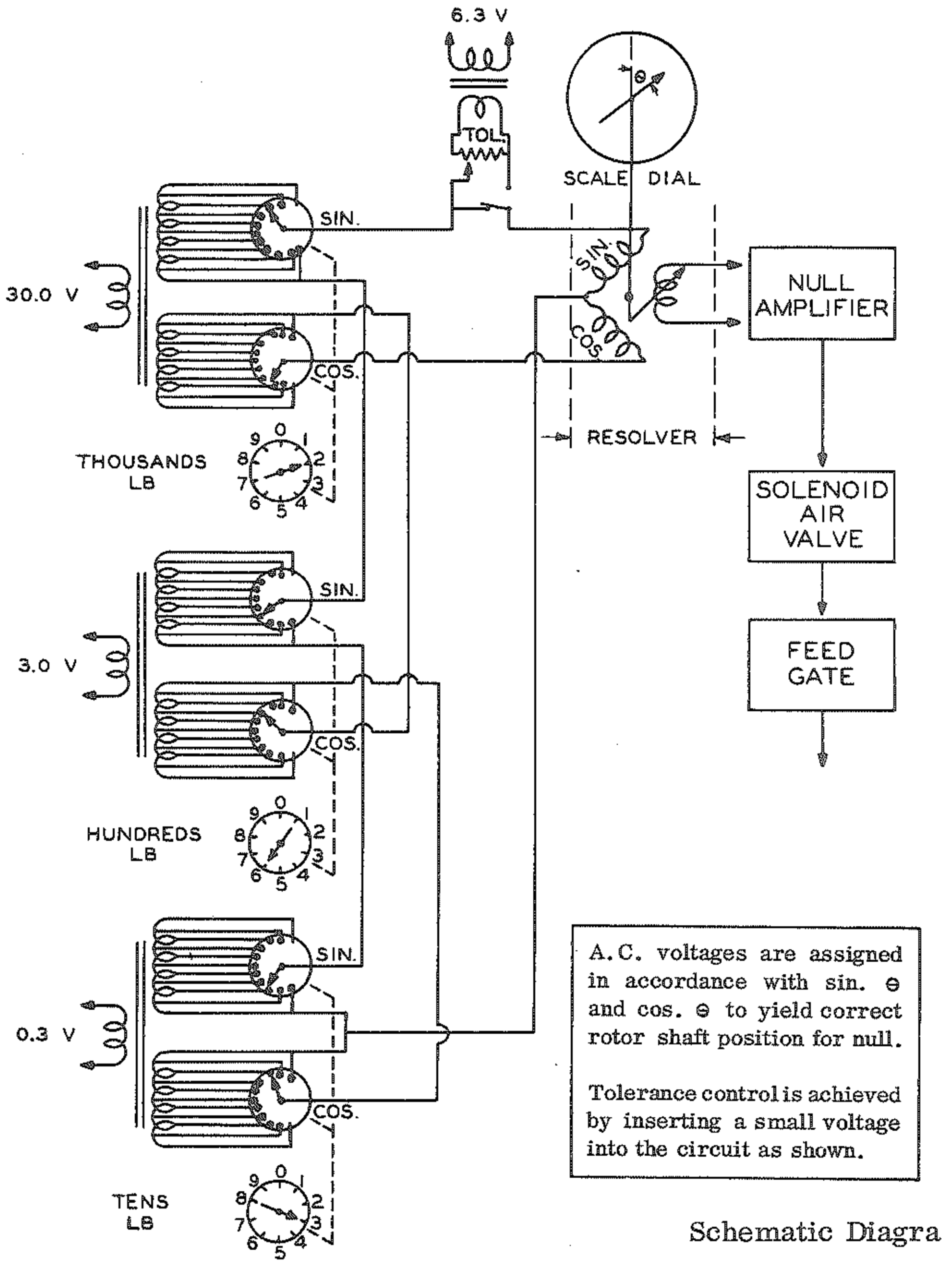
The basic circuit type illustrated is used in most bituminous control systems in Michigan. The differential transformer is connected to the scale dial shaft. The two secondaries of the differential transformer are connected series-aiding. The remainder of the circuit is generally in the control console, which preferably should be mounted on the ground in an enclosure. The linearity of the differential transformer and pre-set potentiometer is critical. The overweight and underweight controls and the mid-air compensators are switched in and out of the circuit depending upon the portion of the cycle that the system is in. One manufacturer replaces the differential transformer with a potentiometer at points C and D and imposes an AC voltage at points A and B to give a true wheatstone bridge circuit. At weight cutoff, the mid-air compensator is in the circuit and is used to introduce an error to allow for the amount of mid-air material. Because compensation here is for an unknown, the result is that this compensator compensates for other errors in the system. It may be apparent that this setting will also allow for any discrepancy in the calibration of the equipment.

When the weight check is made, the mid-air compensator is switched out of the circuit and proper calibration becomes important. The mid-air compensator is no longer in the circuit and the inherent accuracy of the pre-set potentiometer is depended upon. The circuit now is a bridge balancing the dial head output against the pre-set potentiometer output. There has been little difficulty in achieving continuously accurate weights; the chief difficulty has been in the ability of the system to check those weights. One of the inherent limitations of this system is that all of the switching is done at millivolt levels in a system where various parts of the bridge are separated by as much as 50 feet and cables carrying intermittent and varying loads are likely to be located in proximity to the signal lines in the cabinet.

Schematic Diagram of Basic Voltage Bridge Circuit

BASIC RESOLVER CIRCUIT

The other basic circuit type illustrated is used with a resolver as a transducer behind the scale dial. The resolver is geared to the scale dial shaft so that only 180° of electrical output is used. AC voltages are assigned in accordance with the respective sin θ and cos θ to yield correct rotor position for null. This circuit equates voltages to the sine and cosine values of the dial shaft position. Three voltages representing three different angles are added in the circuit to give the desired total angle in the resolver which is mechanically connected to the scale dial shaft. The angle is directly proportional to the weight read on the scale dial, and at this angle a zero or "null" output will be obtained from the armature of the resolver. Tolerance control is achieved by switching in a known voltage which represents an angle in the resolver, and determining whether the dial reading falls within this angle.



A.C. voltages are assigned in accordance with sin. θ and cos. θ to yield correct rotor shaft position for null.

Tolerance control is achieved by inserting a small voltage into the circuit as shown.

Schematic Diagram of Basic Resolver Circuit

APPENDIX C: PART I
FREQUENCY DISTRIBUTIONS OF PER CENT DEVIATIONS OF LOAD WEIGHTS OBSERVED AT VARIOUS PLANTS

	Deviations from Set Weight, per cent	Number of Observed Load Weights Within Given Limits															
		Wt. Batch (Auto.)* Plant 11 1962	Wt. Batch (Auto.) Plant 12 1962	Wt. Batch (Auto.) Plant 13 1962	Wt. Batch (Auto.) Plant 14 1962	Wt. Batch (Auto.)** Plant 2 1962	Wt. Batch (Auto.)** Plant 12 1962	Wt. Batch (Auto.) Plant 15 1959	Wt. Batch (Auto.) Plant 4 1959	Wt. Batch (Auto.) Plant 16 1959	Wt. Batch (Manual) Plant 17 1959	Wt. Batch (Manual) Plant 12 1962	Wt. Batch (Manual) Plant 18 1959	Cont. (Auto.) Plant 19 1962	Cont. (Auto.) Plant 20 1962	Cont. (Manual) Plant 21 1959	Cont. (Manual) Plant 22 1959
MINUS DEVIATION	-2.85 to -3.15		1						1				3	21	5	9	12
	-2.55 to -2.85		1					1	1		2	1	1	26	6	7	17
	-2.25 to -2.55		1				2	0	1		2	0	5	31	9	7	18
	-1.95 to -2.25		2		1	1	0	2	1	2	1	1	8	25	5	11	10
	-1.65 to -1.95		4	2	2	1	1	1	3	3	5	1	6	31	4	7	13
	-1.35 to -1.65		6	0	4	2	1	6	8	6	9	0	11	32	5	8	15
	-1.05 to -1.35		18	1	5	2	2	7	18	13	25	1	19	40	6	17	11
	-0.75 to -1.05	2	67	4	15	3	6	15	22	37	23	2	59	36	9	11	13
	-0.45 to -0.75	2	204	17	32	9	20	56	49	76	35	9	115	51	8	10	16
	-0.15 to -0.45	10	507	66	73	23	67	79	66	103	46	11	212	45	4	10	14
	-0.15 to +0.15	37	818	243	214	52	137	397	83	288	43	16	592	43	9	18	20
PLUS DEVIATION	+0.15 to +0.45	10	616	121	115	95	131	309	47	215	69	24	347	76	6	15	25
	+0.45 to +0.75	1	167	32	37	145	25	98	31	114	77	50	288	74	7	11	25
	+0.75 to +1.05		52	20	15	184	17	46	20	69	53	33	88	64	9	14	27
	+1.05 to +1.35		21	9	7	56	11	21	11	33	39	18	38	52	5	12	18
	+1.35 to +1.65		7	6	3	25	3	14	6	15	28	14	15	75	6	13	11
	+1.65 to +1.95		4	2	2	8	2	10	2	8	15	10	14	45	8	9	9
	+1.95 to +2.25		2	1	1	5	0	5	1	4	13	6	8	41	4	7	15
	+2.25 to +2.55		1			2	1	1	1	2	6	3	2	34	6	6	12
	+2.55 to +2.85		2			1	1				2	1	2	32	6	8	11
	+2.85 to +3.15		1								1			17	8	3	15
	Total Observations (n)	62	2502	524	526	614	427	1068	372	988	494	201	1833	987	145	332	821
	Arithmetic Mean ($\bar{X}$)	-0.039	+0.002	+0.116	+0.031	+0.642	+0.112	+0.162	-0.100	+0.142	+0.324	+0.655	+0.109				
	Standard Deviation (σ)	0.267	0.452	0.419	0.478	0.547	0.506	0.509	0.725	0.595	0.951	0.784	0.599				
	Skewness (k)	-0.986	+0.040	+0.697	-0.157	-0.557	+0.133	+0.174	-0.129	+0.108	-0.187	-0.525	-0.420				

* With Tolerance Check Device
** Without Tolerance Control

APPENDIX C: PART 2
SHORT METHOD FOR COMPUTING STATISTICAL FUNCTIONS $\overline{X}$, σ , AND k
Data from Plant No. 7

Cell Midpoint	Cell No. x	Observed Frequency f	fx	fx^2	fx^3
-2.1	0	1	0	0	0
-1.8	1	2	2	2	2
-1.5	2	4	8	16	32
-1.2	3	15	45	135	405
-0.9	4	41	164	656	2624
-0.6	5	129	645	3225	16125
-0.3	6	238	1428	8568	51408
0.0	7	211	1477	10339	72373
+0.3	8	185	1480	11840	94720
+0.6	9	83	747	6723	60507
+0.9	10	34	340	3400	34000
+1.2	11	19	209	2299	25289
+1.5	12	12	144	1728	20736
+1.8	13	3	39	507	6591
+2.1	14	3	42	588	8232
		n	$\sum fx$	$\sum fx^2$	$\sum fx^3$
Total		980	6770	50026	393044
			E_1	E_2	E_3
Divided by n			6.908	51.047	401.065

A = Midpoint of Cell 0 = -2.1
m = Cell Interval = 0.3

Computations:

$$\overline{X} = A + mE_1 = -2.1 + 0.3(6.908) = -0.028$$

$$\sigma = m\sqrt{E_2 - E_1^2} = 0.3\sqrt{51.047 - 47.720} = 0.547$$

$$k = \frac{E_3 - 3E_1E_2 + 2E_1^3}{(E_2 - E_1^2)\sqrt{E_2 - E_1^2}} = \frac{401.065 - 1057.922 + 659.353}{(3.324)(1.823)} = +0.412$$