1930

Efficiency studies on concrete paving operations

Y. F. Zung
Iowa State College

EFFICIENCY STUDIES
ON
CONCRETE PAVING OPERATIONS

BY

Y. F. ZUNG

A Thesis Submitted to the Graduate Faculty
for the Degree of
DOCTOR OF PHILOSOPHY
Major Subject--Highway Engineering

Approved:

Signature was redacted for privacy.
In Charge of Major Work

Signature was redacted for privacy.
Head of Major Department

Signature was redacted for privacy.
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This is respectfully dedicated to
my father to whom I am indebted for
his inspiration, generosity and
foresight.

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INTRODUCTION

A. Value of Research

Research means "to search and examine with continuous care and painstaking effort; to search diligently; to search again; and to examine anew". It is an organized scientific study to insure the purposeful seeking of new knowledge. Research has been designated by innumerable names: "The life blood of progress", "The future of industry", "The welfare of race". Pasteur said, "Science is the soul and the prosperity of nations and the living source of all progress".

The value of all research is to contribute something constructive to society and to mankind. Any research project to be worthy of study should do one or more of the following things:

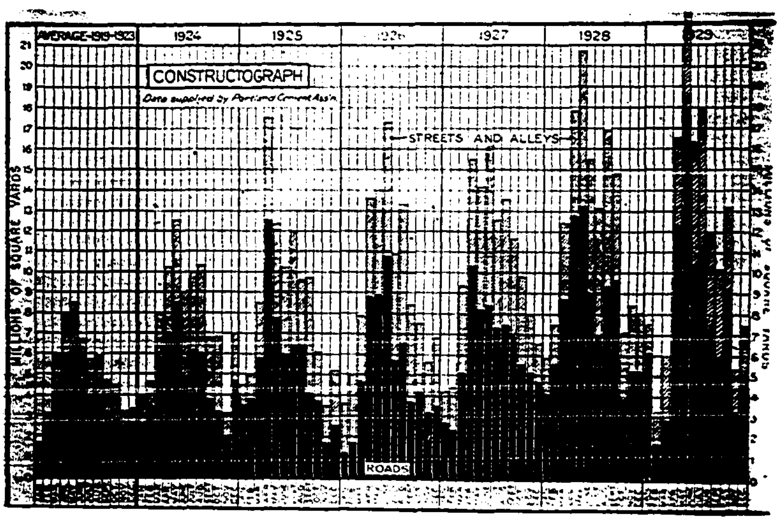
1. To obtain new and useful technical data and information contributing to some project. 2. To increase the utility of the product. 3. To increase its output and sale. 4. To decrease costs of production. 5. To decrease operating cost to the consumer. 6. To produce new business. and/or 7. To reduce the economical waste.

B. Purpose and Scope of Investigation

The ultimate object of this investigation has been practically summarized in the above paragraph; while its scope is only limited to the concrete paving operation. No attempt is made to cover the other type of construction, such as sheet asphalt, brick or stone pavement, etc. What the principles method of application and studies on the concrete pavement are will hold true to the other type of construction.

Awards of concrete surface pavement during the month of December 1929 totaled 7,460,000 square yards. Of this amount, 5,040,000 square yards was for roads and 2,420,000 square yards was for streets and alleys. The total yardage awarded during the year of 1929 was 139,660,000 (70) square yards. According to the figure presented here, it cost the Illinois State Highway Department $1.61 (152) per square yard at 528 lin. ft. per day and $1.47 (152) at 800 lin. ft. per day. There is a saving of $.14 per square yard between these two productions. If we use the above figure for illustration, a total of 139,660,000 square yards of pavement was laid during 1929; it will save the public $1,955,240 per year. If the production is 1,000 lin. ft. or 1,200 lin. ft. per day, (this record had been shown in some paving jobs under good management and rigid supervision) there will be still greater saving to the public.

In Chapter II, stress is placed upon the necessity of the application of efficiency studies to the concrete paving operation. Its significance, advantages and relationship to the production will be discussed in this chapter. In Chapter III, a general survey is made on the current paving operation and its good practice with more emphasis on the modern construction method, the use of machinery and the organization. In Chapter IV, an historical survey is made on the concrete road building plant. Eight or ten years ago, no contractors in over all



Pavement Awarded From 1924 - 1929

United States had ever laid in one day over 400 ft. of concrete pavement 18 ft. wide. Today with the modern road machinery and the improved construction method, an average output of 1,200 lin. ft. of pavement laid per day is not unusual. Emphasis is also laid on the standardization of the road equipment; why is it necessary? Time distribution on each operation of the road equipment will be stressed upon in the last part of the chapter. Chapter V will outline the effects of production on unit cost. The daily operating cost is independent of the production whether it is 500 or 1,000 lin. ft. laid per day. Studies will be made in Chapter VI of time losses analysis on paving operations and its effects upon the production. Studies have shown that the operation efficiency averages 60%. In Chapter VII, a mix-in-transit system is suggested. Its advantages over the existing paver and the central proportional plant will be discussed at large. In the last chapter the whole investigation will be summarized and recommendations drawn upon.

The writer wishes to express his sincere hope that his investigation and research will furnish useful information and data to the highway contractor and the state highway department executives and engineers, in particular, to the college professor who is offering a course in highway engineering and to the student who is taking highway engineering.

II. RELATION OF EFFICIENCY STUDIES TO PRODUCTION

The construction of concrete highway pavement is essentially a manufacturing process or progressive series of consecutive operations. If materials are loaded, they must be hauled, if they are hauled, they must be mixed, if they are mixed, they must be placed, spread and finished and they must be cured. Every operation must be coordinated and synchronized in every possible way.

A. Better Use of Time and Effort

Efficiency study is an important element in production management. Its success lies not on the assumption that men must work harder but in the fact that it induces them to work better with less wasted motion and time, thereby reducing labor costs through a higher and more uniform rate of production. It reduces the idle time of men and machinery, prevents the purchase of unnecessary and new equipment, provides the accounting department with an accurate labor cost per unit of production, assures a higher quality of product and improves labor conditions by assuring the employee a fair day's pay for a fair day's work.

B. Efficiency Study Gives Test

When the first study is made, the more serious delays are brought to light and some idea is obtained as to the capacity and adaptability of the machine or ability and skill of the laborers. Information shall be obtained and data will be analyzed and used to correct these delays and possibly to change the system or add some additional equipment, reduce or increase the crew or do other things that appear likely to aid the performance of the unit. Then after ample time to get full advantage of the corrections, other studies should be made to observe the results of the changes, noting when they have helped or hindered; these studies should be repeated till the unit works go smoothly.

C. Cost Cutting Through Efficiency Study

It was reported by H. E. Brinkman, (97) industrial engineer, Holeproof Hosiery Company in the article, "Forty Percent Saving in Worker's Time", that a cost reduction of $4,500 per year is brought about by an expenditure of only $2,200 for the study, while operations earning are increased 27% through time and motion study.

D. The Application of Efficiency Studies in Some Other Industry

Efficiency study practice has been applied to the concerns whose operations are stable and whose production is predetermined and controlled as in the steel plants and similar process industries. By improving and standardizing methods, synchronizing the work stations of the progressive process and having the time value of operation and output of the various machines, a great deal is accomplished in such organizations in terms of cost reduction.

In highly competitive industry the labor cost standards established through time study provides a real means of determining prices with which to bid for new business. These standards, plus a flexibility factor which provides for delay allowances and losses due to failure to meet standards, furnish an accurate means of supplying the data needed for such purposes.

Production standards determined by efficiency study are invaluable in the planning of schedules, since the machine and work station capacities thus determined coupled with a factor to allow for flexibility and material movement, make possible accurate planning and machine loading. The production manager so equipped is in a position to determine quickly and accurately his production possibilities, requirements and work limits in process.

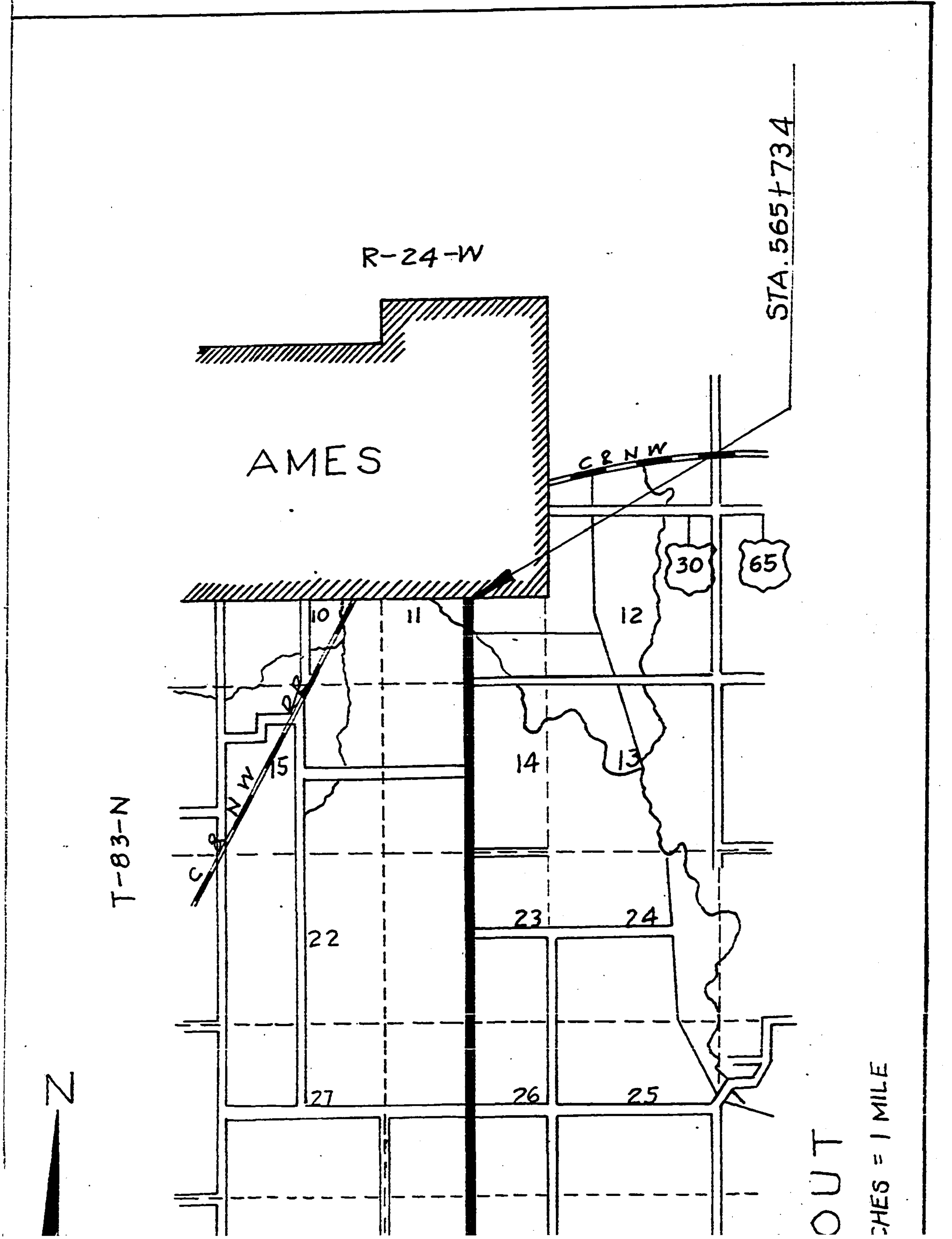
3. Efficiency Men Must be Trained and Employed on Efficiency Study

I believe the highway contractor should take up the work himself, because he has to know in the right moment every operation of the whole job. If it is not coordinated, the whole or part of the system should be changed or corrected until it is harmonized. If the man is employed as an efficiency study observer, he must possess certain qualifications and must bring to his practice a balance between correct understanding of fundamentals and theory and a practical application of the same to the problem. Too much theory coupled with an insufficient practical knowledge is a poor basis for the work; while on the o her hand, practical knowledge without sufficient education or training does not give equipment for this kind of work to interpret the various operations and production details.

Recently, (50) Booth and Olson, Inc., of Sioux City, during the course of paving operations in Boone County, Iowa, have developed a simple but extremely effective check on delays. They have hired a young man, wide awake and observant whose sole duty is to stand at the mixer with a note book and a watch and record what he sees. His entries start at 6 A.M. o'clock and his second entry in his note book is at 6:01 A.M. If a truck is slow he notes that truck number, the exact hour and minute of the day and the length of time the mixer wasted for its load. If the hose becomes disconnected he records the time of the enforced shutdown. If a high spot in the grade halts the forward movement of the mixer, that appears in the book. The summation of the minutes and fractions of minutes at the end of the day makes instantly available the total of time lost and the explanation of that loss and the record accounts for any shortage in the day's production.

The effect of this observation is not only the knowledge of delay causes. It actually results in elimination of many possible delays which would transpire without use of the system. The observer, by accustoming himself to the measurement of short periods of time by frequently looking at his watch, noticed that the mixing cycle of the mixer seemed unnecessarily long. He timed it and his checking resulted in the discovery of an easily remedied defect in the bell-signal on the mixer which was permitting each batch to be mixed according to the specification (generally 60"). Men at the mixer do not regard the checker with an unfriendly eye. They consider him in the position of one of their own number as anxious as any other member of the crew to turn out as large a day's production as possible. They have become keener themselves in watching for causes of delay. They are more than usually eager to hasten the repair of breaks and to resume operations after a shutdown, and they take pride in the fact that the time check sheet at night does not attribute any delays to their own part of the operation.

On a construction project where seconds count as they count on paving, a very considerable saving can be effected, through the slight expenditure required for placing such an efficiency man on the job.


R-24-W
AMES
STA. 565+734
C & N W
30
65
10
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C & N W RR
T-83-N
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OUT
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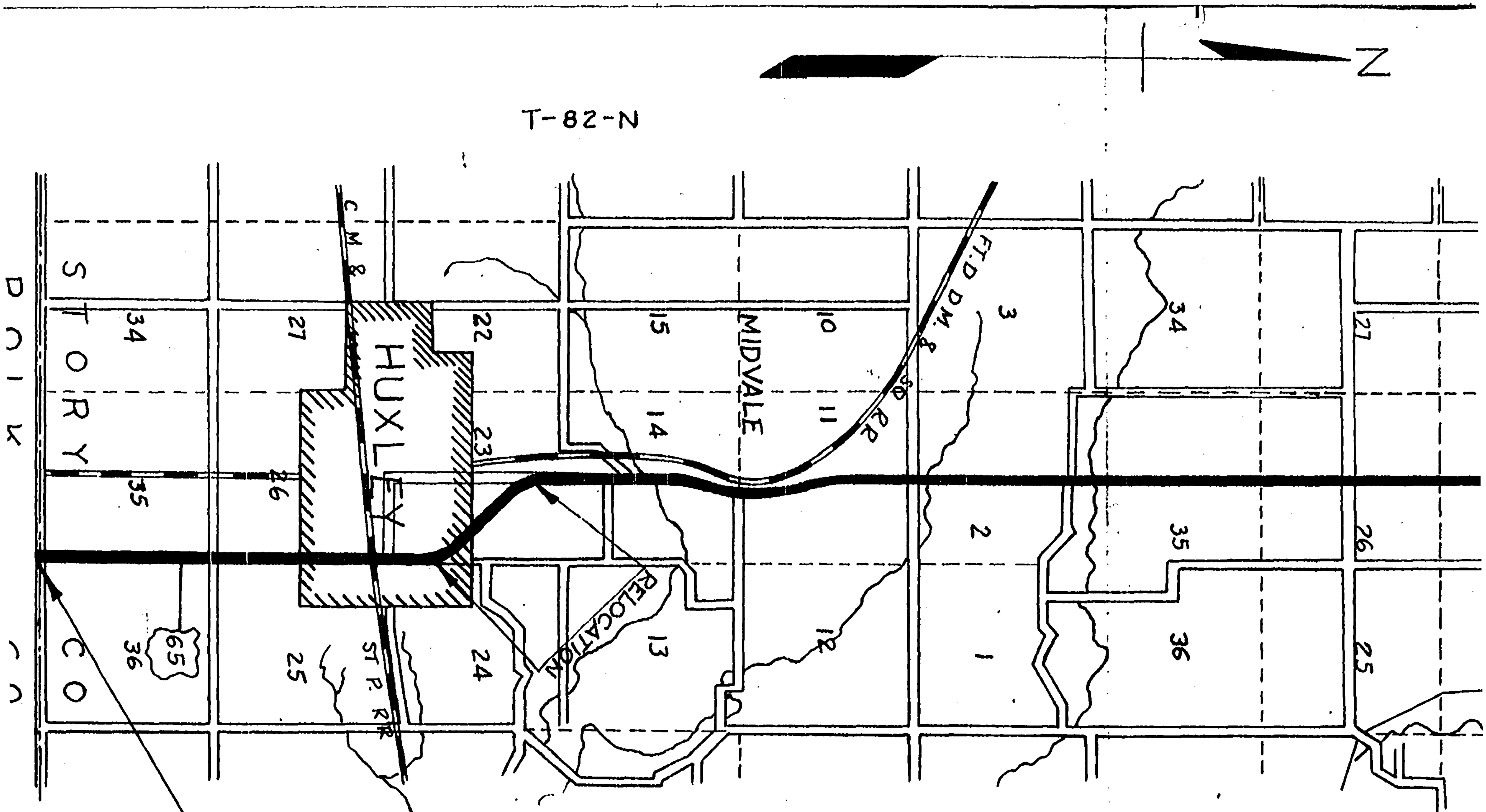
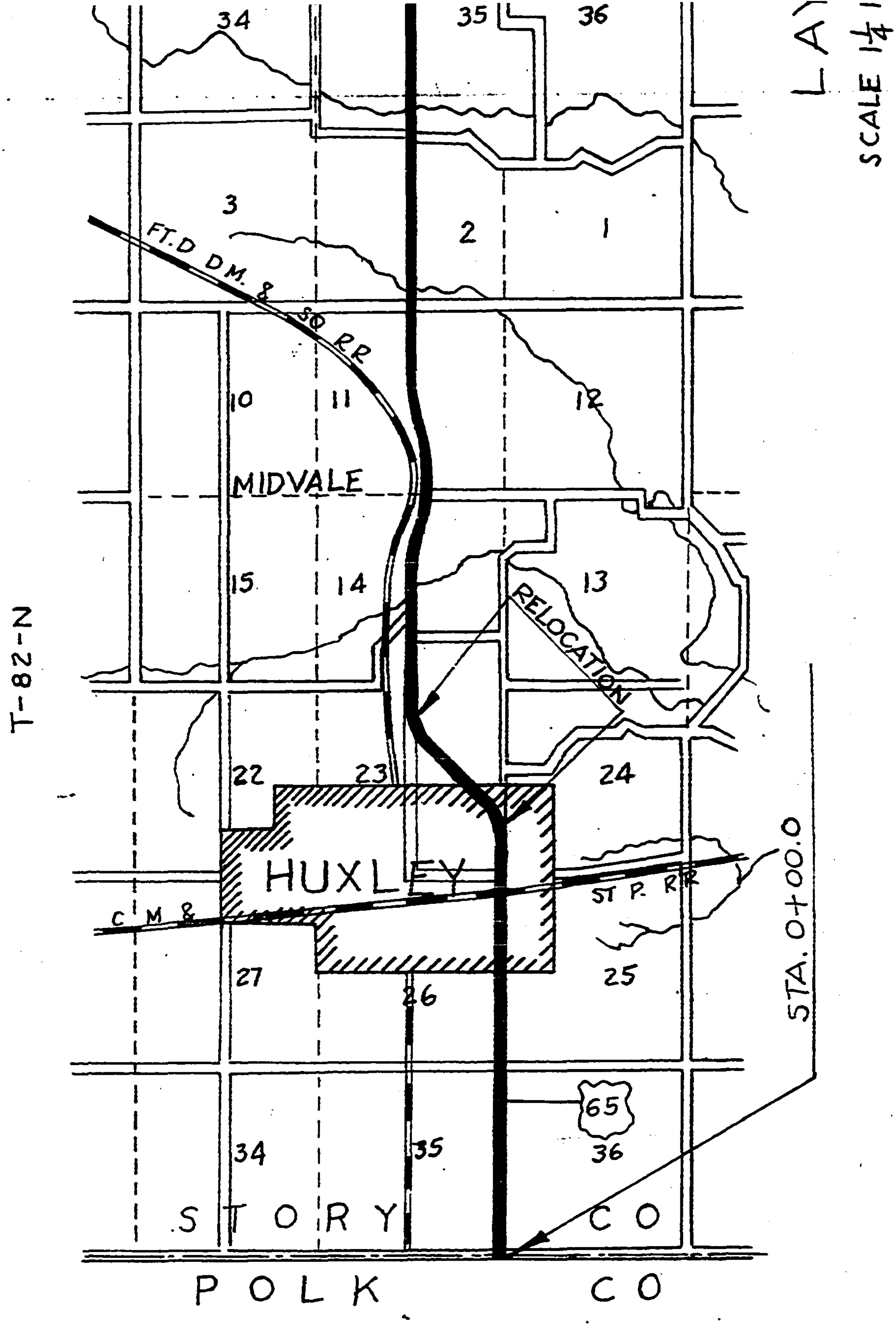


LAYOUT

SCALE 1¼ INCHES = 1 MILE



LA
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T-82-N
FT. D DM. & SO RR
MIDVALE
RELOCATION
HUXLEY
C M &
ST P. RR
STA. 0+00.0
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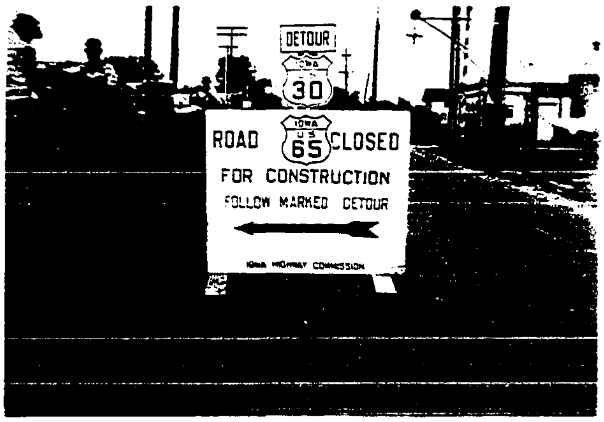
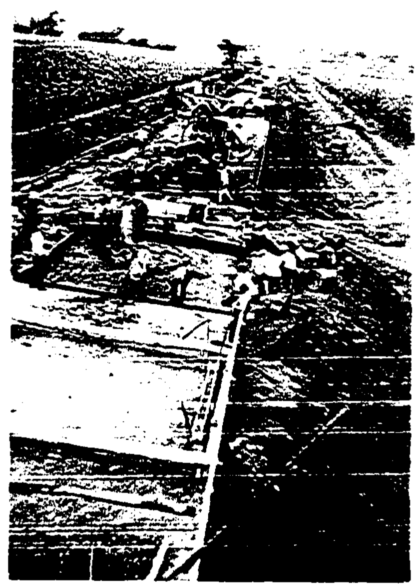
STORY CO
POLK CO



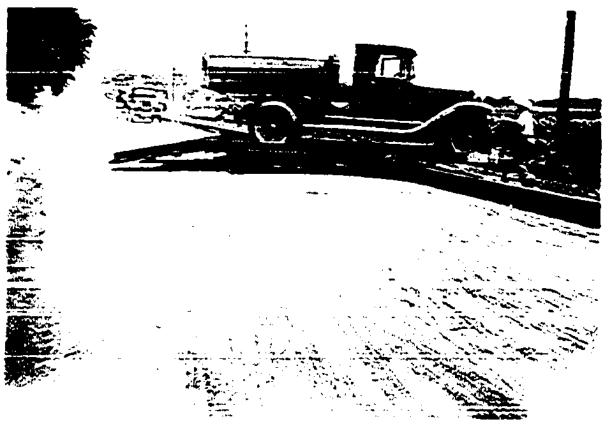
Road under construction sign



An aeroplane view of concrete paving operations

Placing the forms

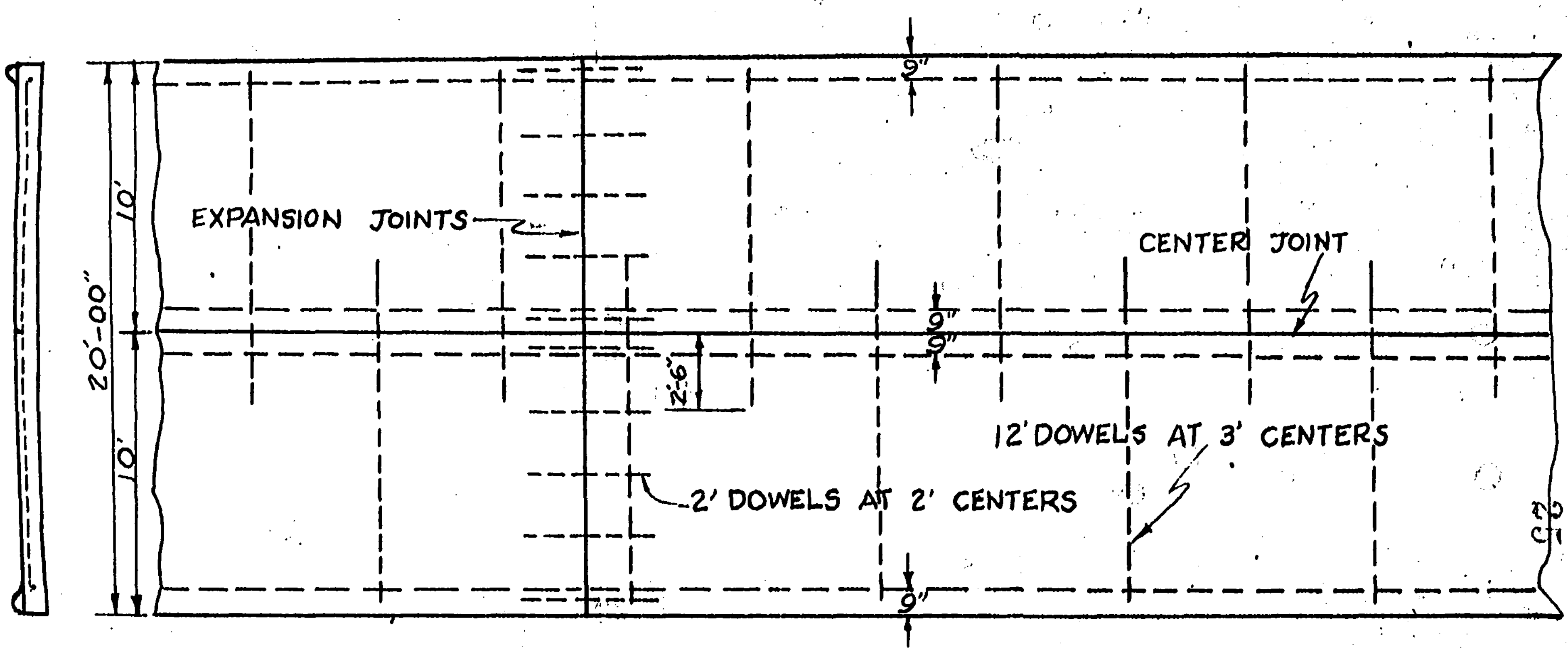
Rolling the subgrade



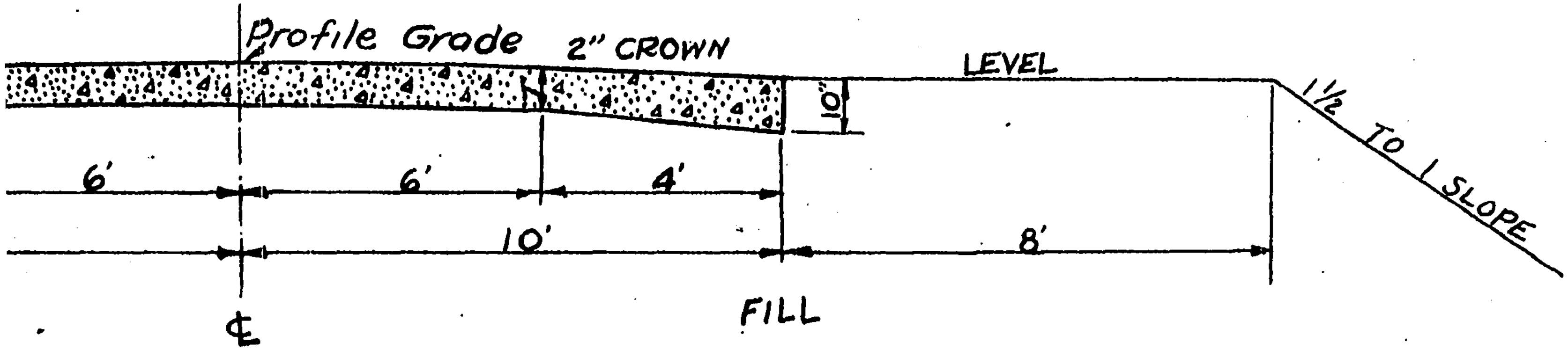
Back up the truck to the mixer

Dumping the materials

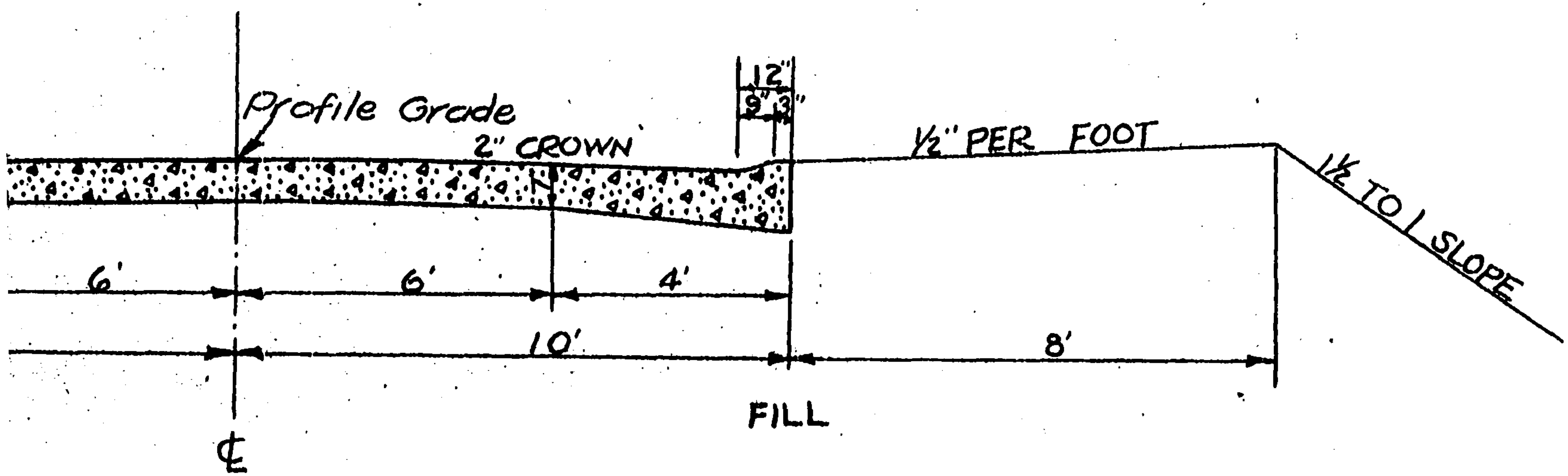
Mixing, placing and puddling

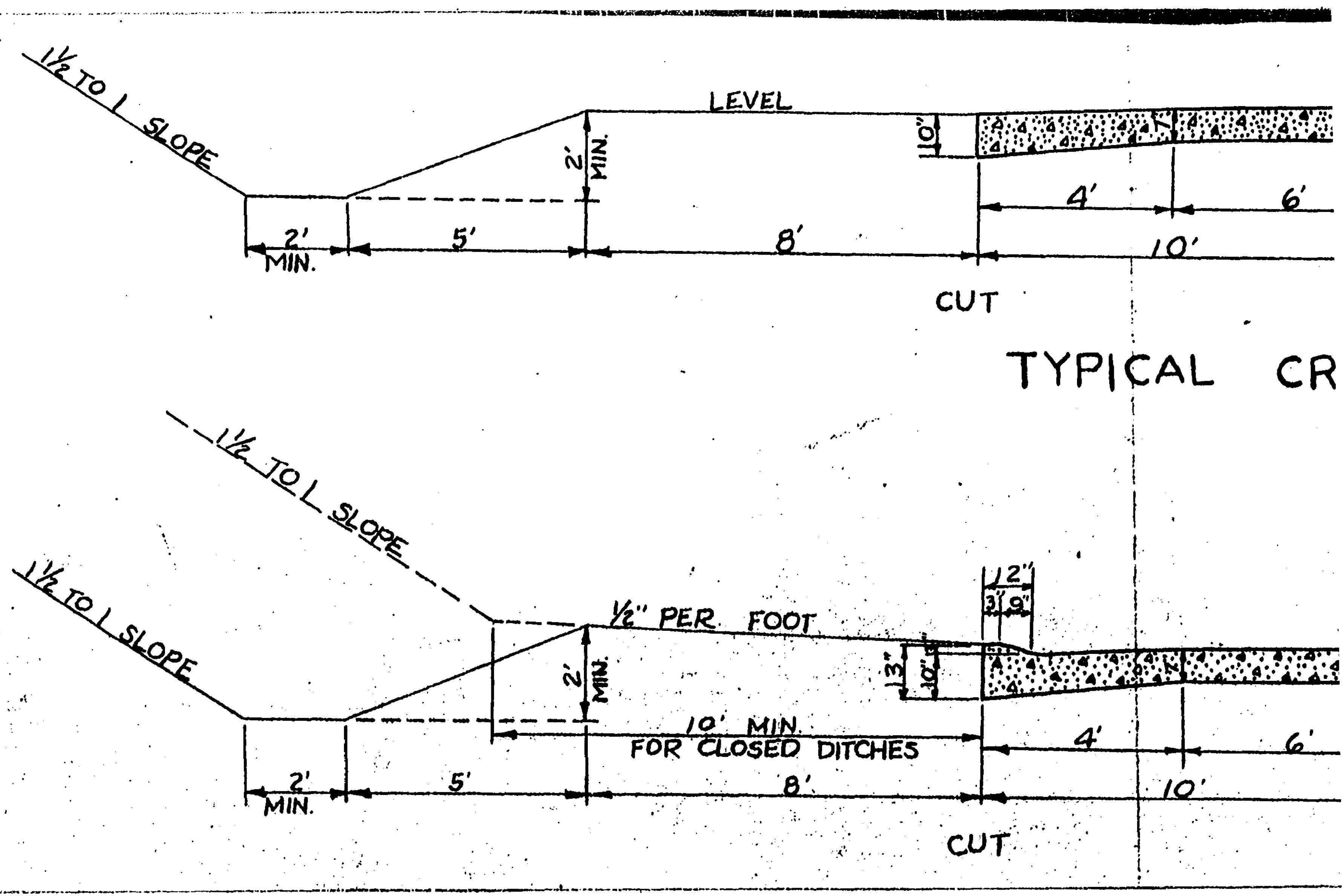


PAVEMENT REINFORCING PLAN



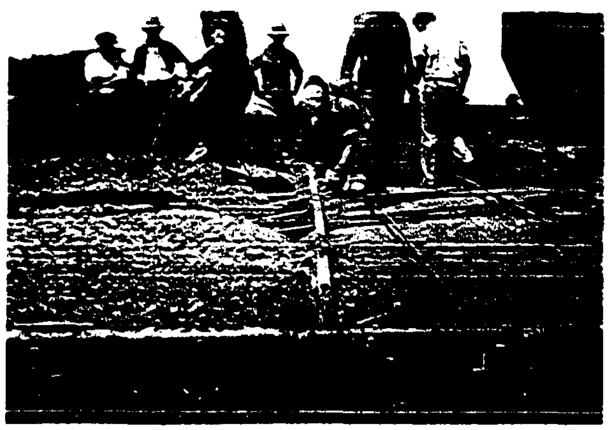
CROSS SECTIONS



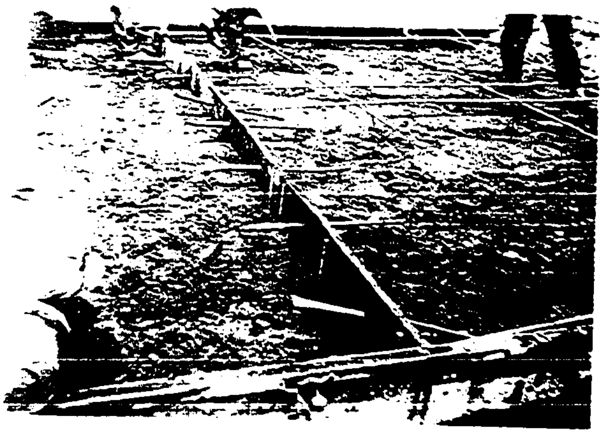


1½ TO 1 SLOPE
LEVEL
10"
2' MIN.
4'
6'
2' MIN.
5'
8'
10'
CUT
1½ TO 1 SLOPE
1½ TO 1 SLOPE
½" PER FOOT
12"
3"
9"
13"
10"
2' MIN.
10' MIN. FOR CLOSED DITCHES
4'
6'
2' MIN.
5'
8'
10'
CUT

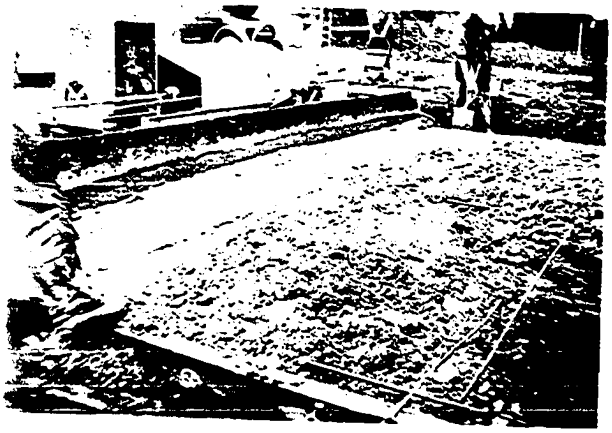
TYPICAL CR



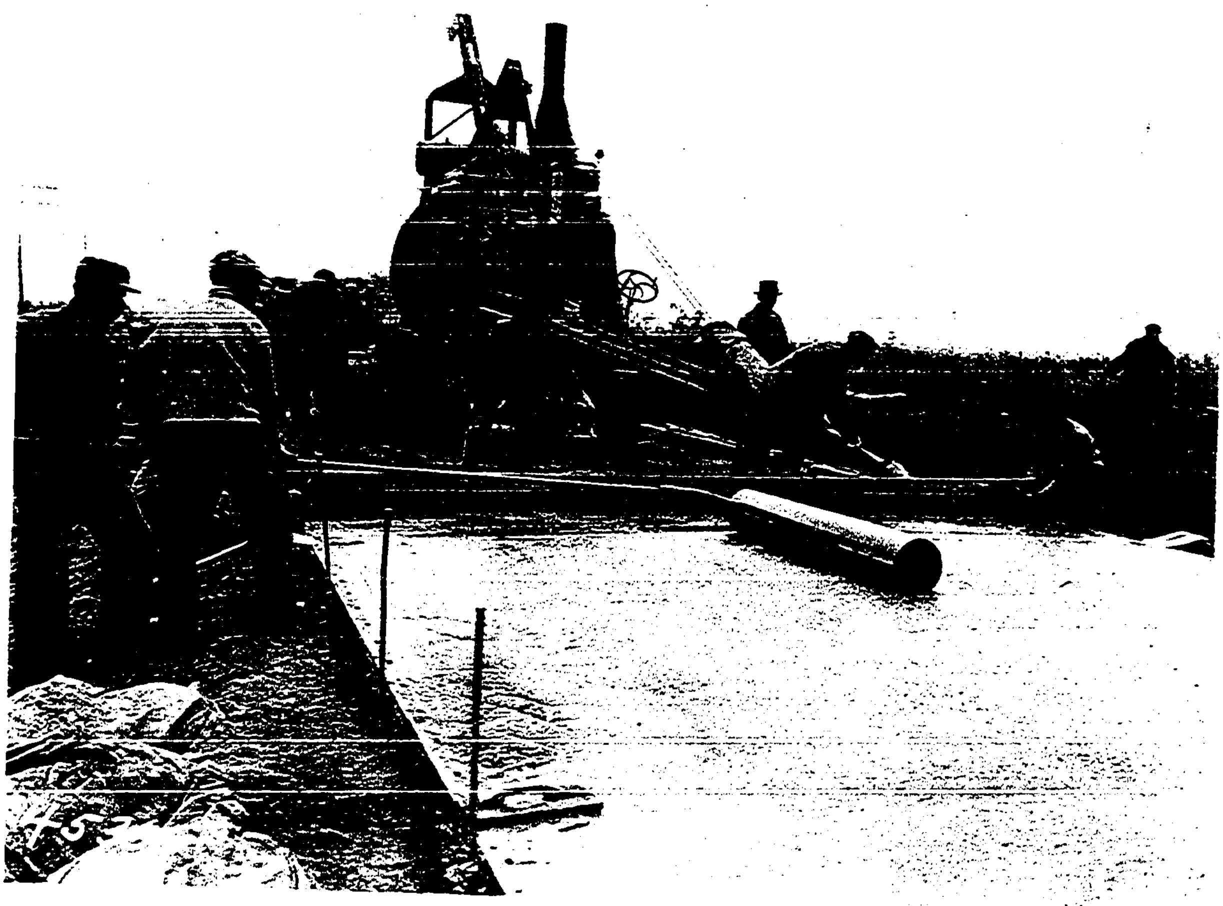
Placing the expansion joint and reinforcement



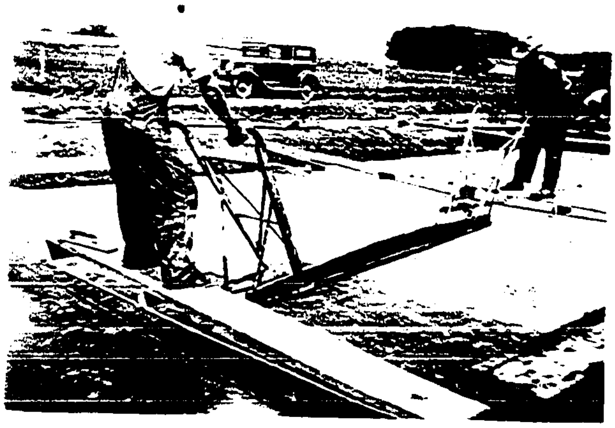
Expansion joint with dowel steel bars across



Machine finishing

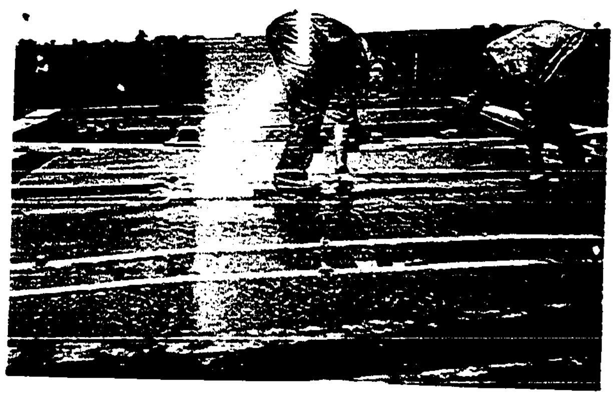


Hand finishing

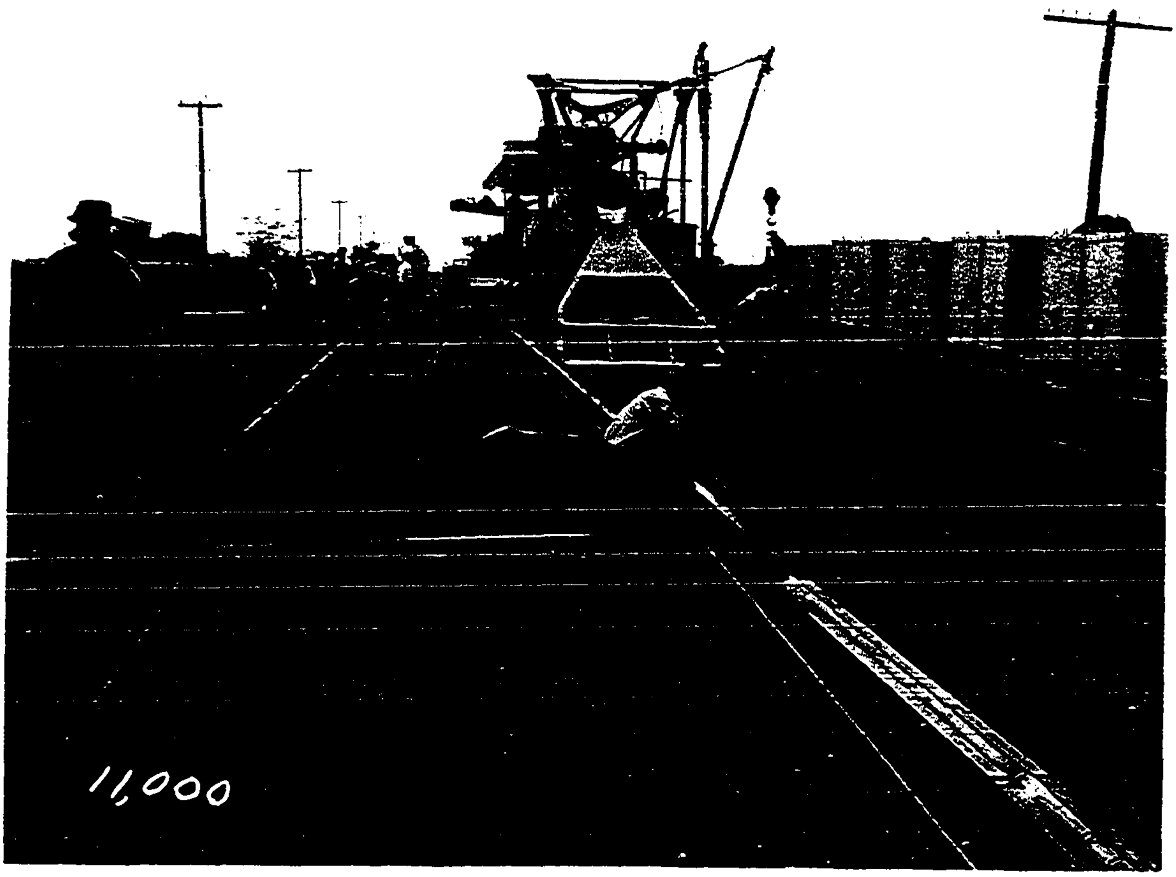


Floating

Belting



Placing the "Dummy joint" on
the center of the pavement

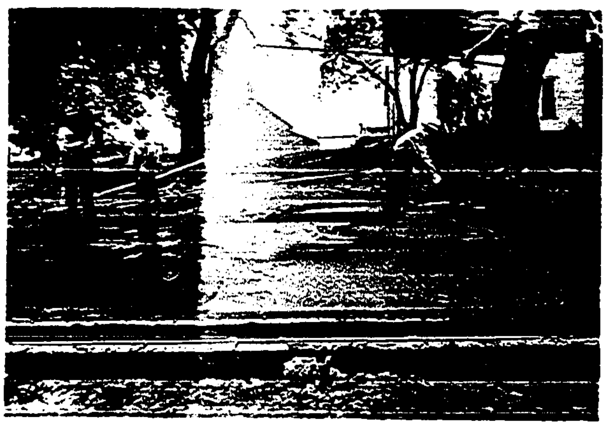


Placing the central steel plate, and longitudinal and transeverse reinforcement

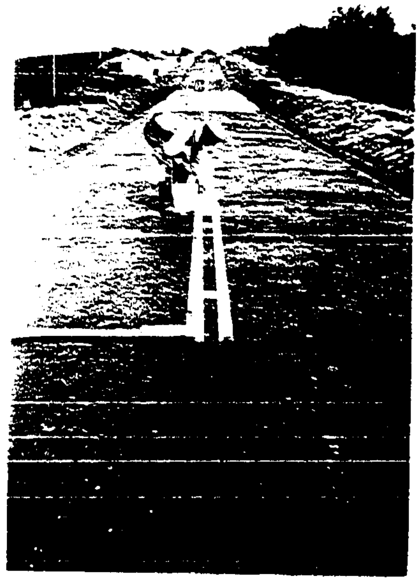
Smoothing the curb

Protect the pavement edge with asphalt oil

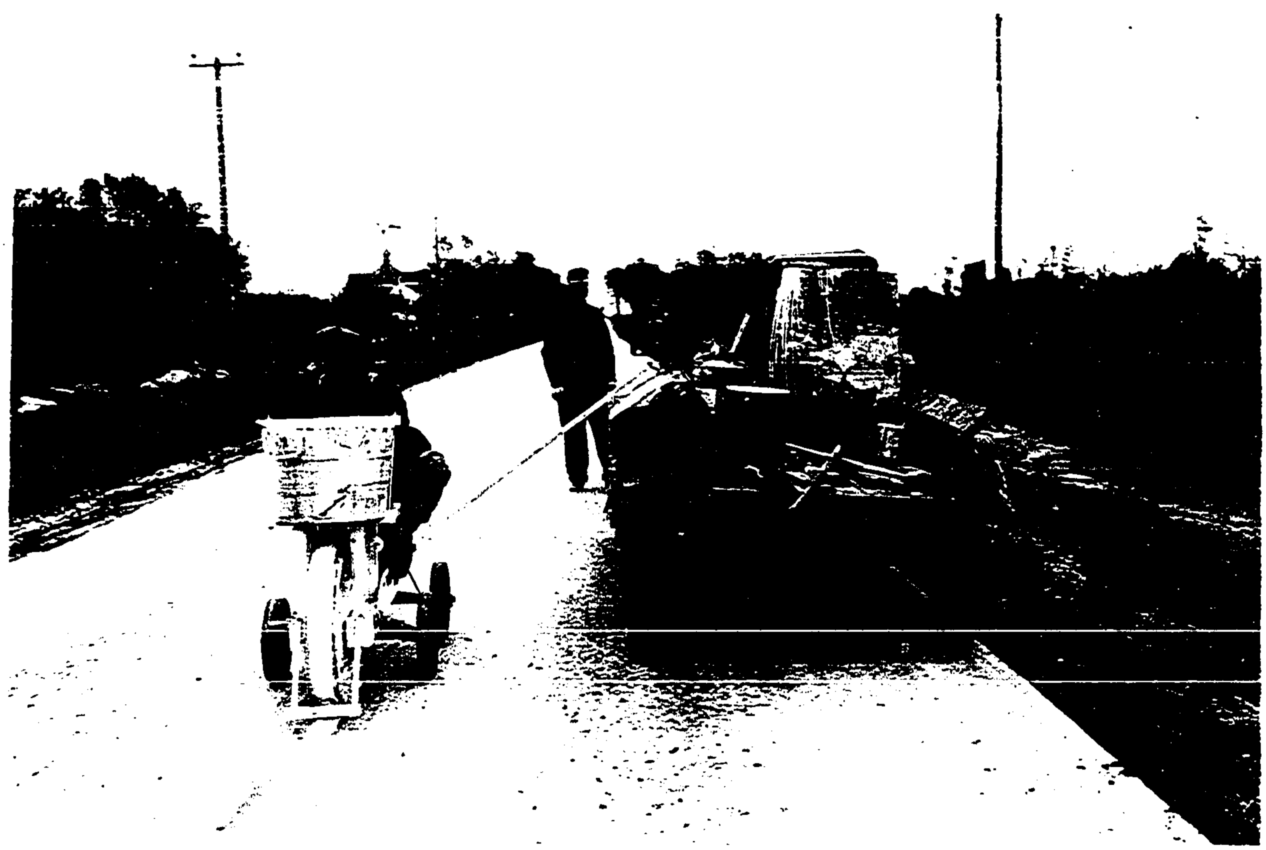
Burlap curing



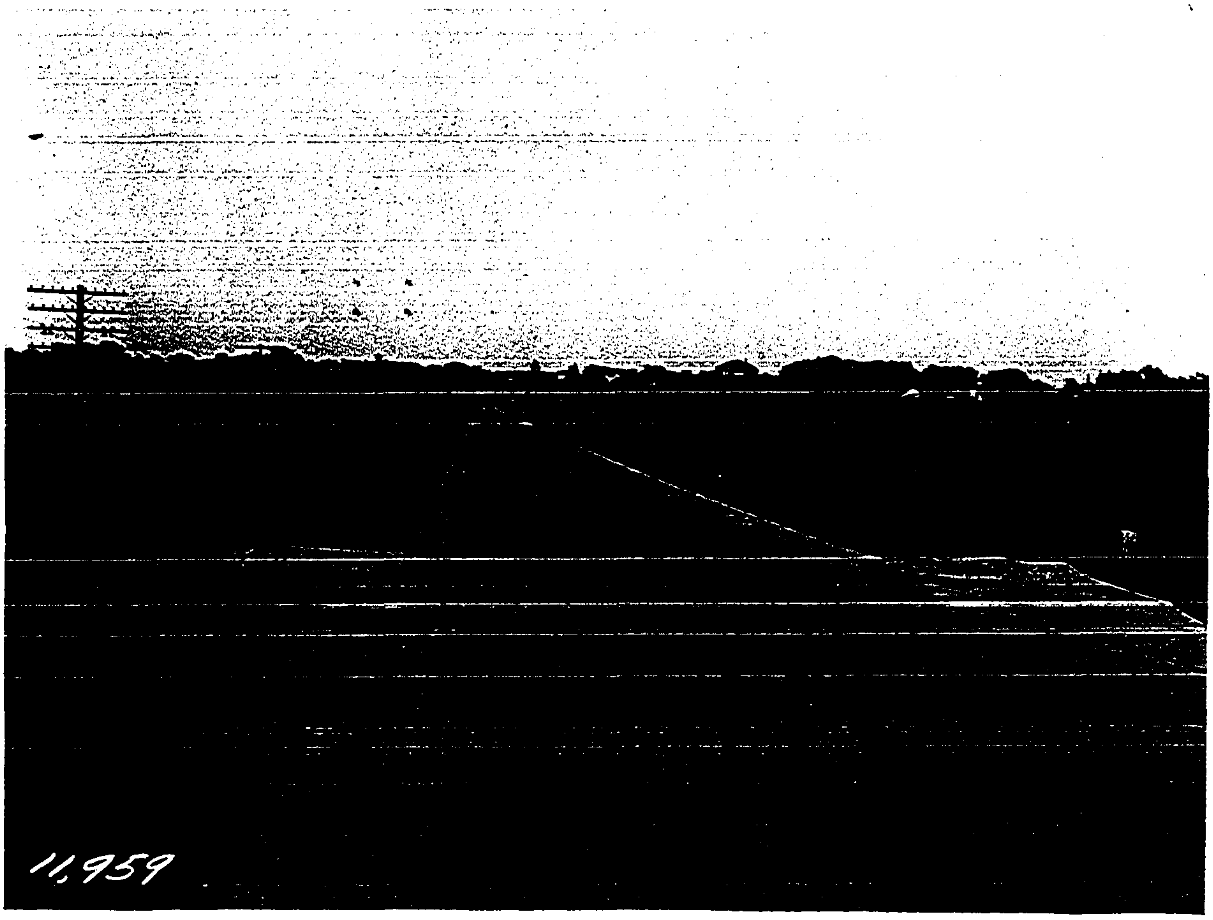
Light oil curing



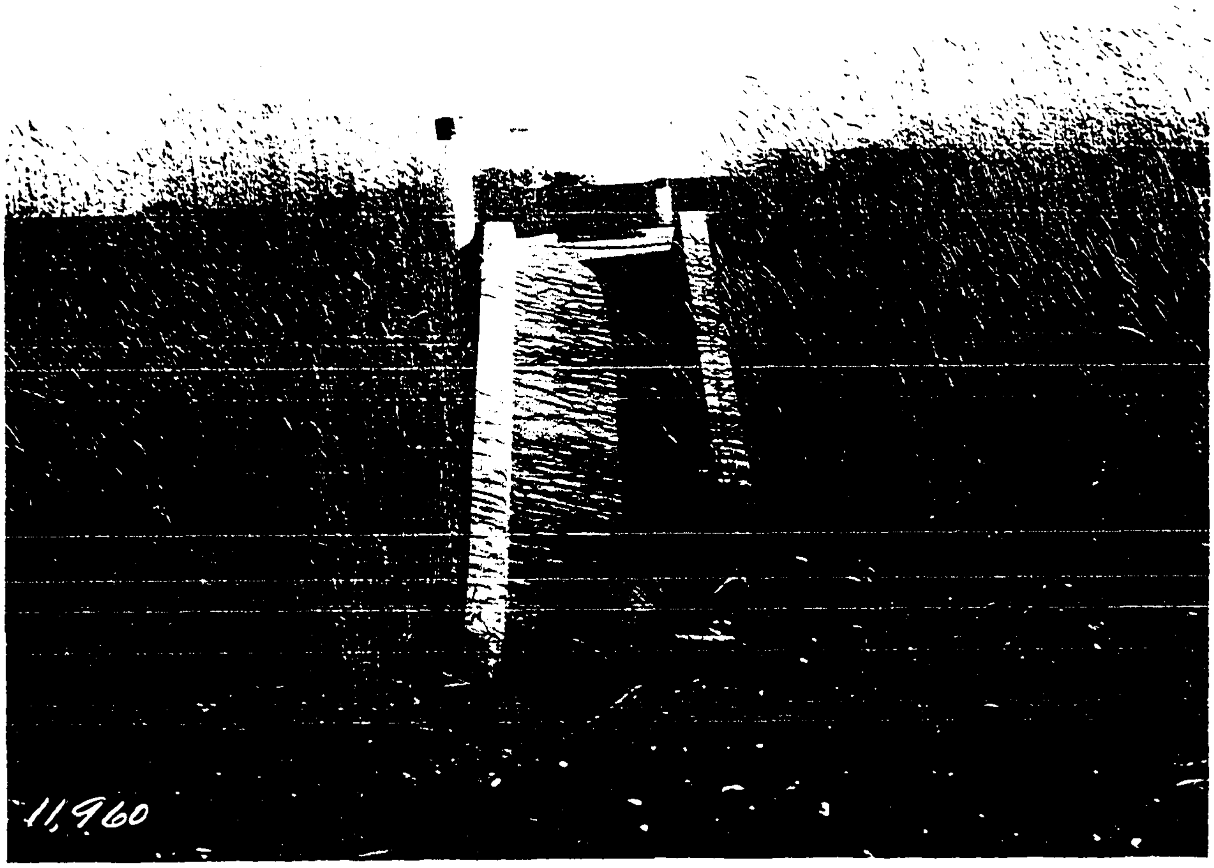
Placing the center line by hand



Placing the center line by machine



Concrete flume (top view)



Concrete flume (side view)

Material inspector

III. A RESUME OF CURRENT GOOD PRACTICE OF PAVING OPERATION

A. Grading

Three distinct classes of grading were performed. Wheeler outfits were used for light cuts; elevating grade pulled by the caterpillar tractor was used for medium cuts and steam shovels were used for heavy cuts. Following the grading outfits came the 12 foot blade grader, which was used to level the cuts and fills and put them within 1 inch of the grade. This grader is pulled by a ten ton caterpillar tractor. Both the tractor operator and the grader operator were taught to check the grading by the grade stakes. After the blade grading the high or low spots were brought to grade by two or three slip teams, which leave the grade ready for the form setting. The setting of the forms and surfacing of the subgrade were performed under one foreman, who has a 7 foot blade grader drawn by a 4 or 5 ton caterpillar tractor, which also pulls the subgrading machine when making the final cut. The 7 foot blade is used to cut the form line and to roughly shape the subgrade, after which the subgrading machine cuts or distributes the earth and the final operation is performed by a 3 or 4 ton gasoline roller. A crew of twelve men are used in subgrade work and setting the forms, approximately 6,000 feet of forms being used.

B. Paving

The paving consists of a series of operations as follows:

<u>1. Mixing.</u> Mixing was done in a 27E Koehring paver. The mixing time was rigidly held at 60 seconds. This 60 second

mixing time, together with 11 seconds for charging and 3 to 5 seconds for discharging, made each cycle about 74 to 75 seconds. Through consistent operation on this cycle, the maximum run of 400 batches was obtained. This rate of production does not permit of time losses.

2. Placing. After mixing the batch was placed upon the grade and shovel around the steel and spaded against the forms by three shovelers and two spaders.

3. Finishing. The pavement was then smoothed out by the finishing machine. Following the machine two men floated the slab longitudinally with a stiff back float. Following these floatmen, two men belted the slab longitudinally with a flexible wooden belt, and in the rear of these beltmen two edgers did the final edging and joint finishing.

4. Curing. The slab was covered with burlap. As soon as it was stiff enough, either ponding method or dirting was used.

C. Batching Plant

Proportioning aggregate by weight increased in popularity during the past year. More than ten states now definitely specify this method of proportioning, more than three have optional specifications, and in more than two other states this method is required or permitted under special conditions. Eleven states have now adopted a strength specification of proportioning either by weight or by arbitrary methods. Some of current practice in proportioning aggregate by weight may be mentioned here:

Example I. The proportioning plant was located near the midpoint of the job at a point made accessible by a cross road and on a switch track alongside a railroad crossing the work. Cement and aggregate were delivered by rail to this switch track. The cement was unloaded directly from the cars into the trucks by way of a platform constructed for the purpose, just inside the entrance to the plant area. Further along the aggregate cars were spotted on the switch track and unloaded by a crane with 1-1/4 yard clamshell bucket. By means of this crane the aggregates could be unloaded onto stock piles or into the sand and gravel bins. The batches were measured into the trucks from those bins by batches suspended beneath them in the usual manner.

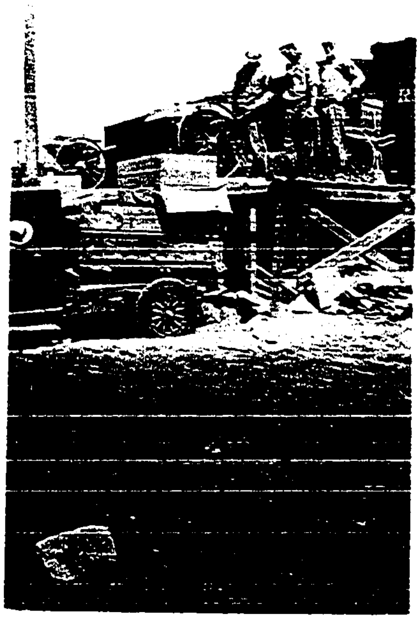
Example II. Aggregate were loaded into cars at the plant with the aid of hoist cranes and bins. The operators were prepared and waiting to pull the levers upon the arrival of an empty train, and a complete train was loaded in 4 minutes. Cement was loaded on flat cars at the plant direct from the cars by four men. A platform 4 feet wide and 20 feet long built on the floor level of the box cars in which cement was delivered to the plant, was used to stack enough cement for loading the next empty train.

Example III. A central proportioning plant was used, consisting of 30 cubic yards, Butler bin with volumetric measuring devices, and a 3/4 yard Koehring dragline with clamshell bucket for unloading coarse aggregate from cars and for charging the bin with both fine and coarse aggregates. This plant was operated with five men - a shovel operator, oiler, a batcher man and two laborers cleaning car bottoms.

D. Transporting of Materials

The following examples represent the typical operations in a score of jobs analyzed. In some cases light or heavy trucks are used; in other cases industry railways are utilized to certain advantage in transporting the materials from the loading plant to the mixer. In still others a combination of these methods is adopted. Each method has its advantage and disadvantage. As a whole there are no two jobs alike. Each job should be handled by itself. The contractor should analyze the job carefully, before he adapts each method to the best advantage.

Example I. Batch trucks. Aggregate and cement were delivered by rail and these cars spotted on a siding. Cement was stored in the car and unloaded as needed for each batch, using a platform erected so that it would be at the car door. A short distance away along the same siding aggregate cars were spotted opposite a steel bin and the aggregates unloaded into the bin or onto stockpiles by means of a crane equipped with a 3/4 yard clamshell bucket. Batch trucks then obtained their loads from batchers suspended from the bottom of the bins and proceeded from that point to the cement car for the cement for each batch. Then the load was hauled to the mixer.



Cement Loading Platform

Example II. Batch boxes. Batches were hauled from the batcher plant to the paver in batch boxes. Two boxes were loaded on each car, and trains were made up of 20 cars or 40 batches, hauled by the 8 ton gasoline locomotives. Three such locomotives were used. The track gauge was 24 inches.

This type of equipment proved feasible on the job by eliminating the cutting up of the subgrade by trucks, by keeping a steady stream of materials arriving at the paver, which eliminated waiting for batches, and because traffic tie-ups were avoided. The contractor was of the opinion that batch trucks would have been more costly to use on this particular job.

Example III. Combining truck and industrial railway. The truck hauling was sublet to a trucking contractor for so much a batch-box mile. He placed on the job six 5 ton trucks and six 8 ton trailers. The trucks carried three batch boxes and the trailers four. The batch boxes contained a 6 bag batch of 1:1½:3 mix. On the maximum haul of six miles they were pushed to the limit and the narrow gauge industrial railway was substituted. The transfer was moved on two 6x6 timbers placed on top of the batch boxes on one of the trucks. It generally took 1½ hours to move. From the transfer point, the batches were hauled over the narrow gauge track to the mixer. The transfer equipment designed by the contractor, consisted of an Ingersoll-Rand type D, 2 ton air hoist, mounted on an 8 inch steel I-beam, supported by A-frames on each side of the road. An air compressor, mounted on a Ford truck, supplied the air for its operation.

E. Handling of Materials

The following examples outline the current practice in handling the materials either from the batch truck or from the batch box to the mixer.

Example I. When the truck drove over the turntable, the operator turned it around; the truck backed up to position and dumped the first batch of dry material into the loading machine skip, again moved forward to clear it while it hoisted and delivered to the mixer drum. The empty skip was lowered and the second truck backed up again and dumped its second batch into it and moved away.

Example II. The batch boxes were transferred from the cars to the skip of the mixer by a small derrick mounted on the mixer. The weight of the descending skip furnished the necessary power. At the mixer three men were required to shift the boxes from cars to skip and back to cars.

Example III. Between the cement car and the paver, a platform was placed on the pavement. The batch trucks stopped at this platform, where the bags of cement were emptied onto the load and the sacks tossed to the roadside to be counted and baled.

F. Water Supply

Example I. Water for the various operations of the contract and for the machinery, is pumped from brooks along the way.

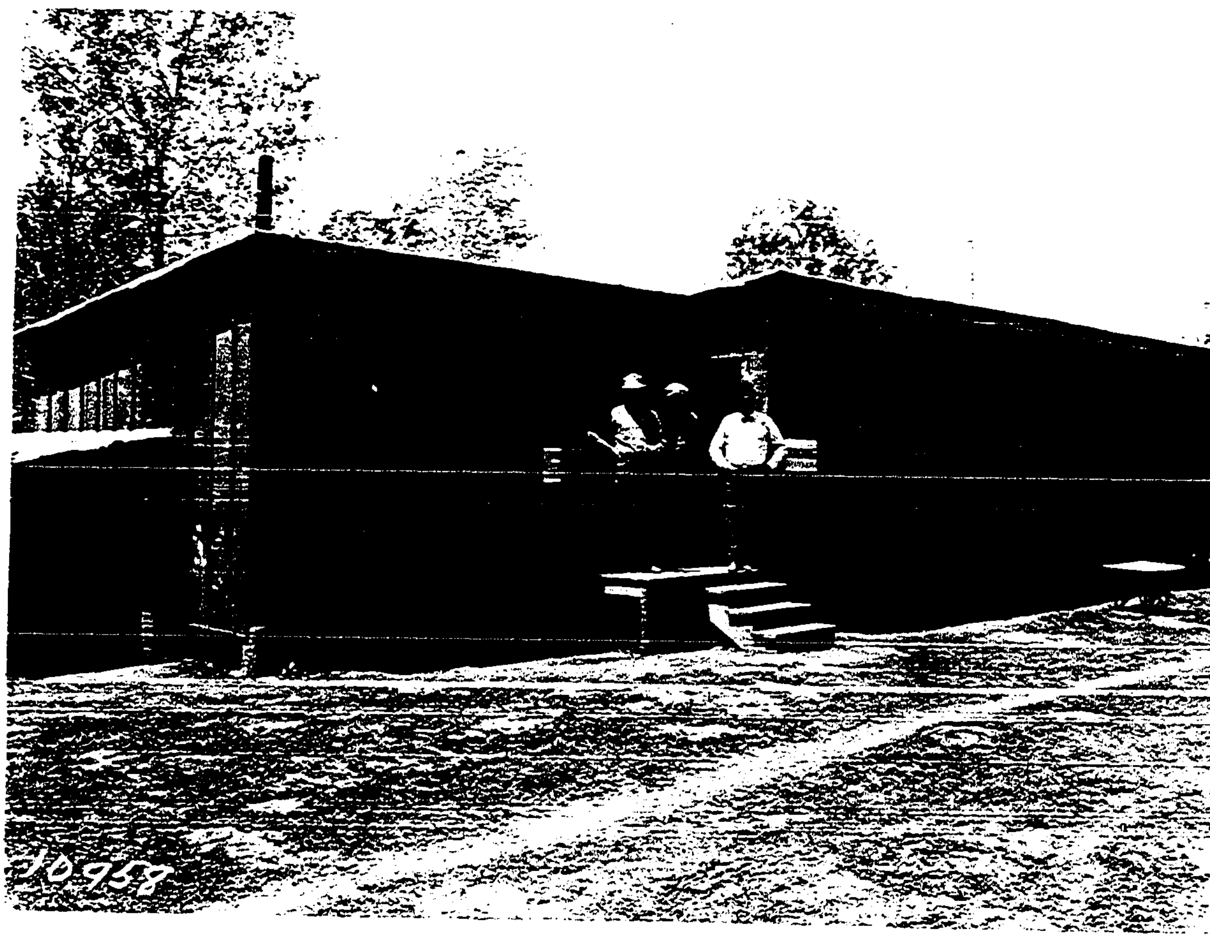
The supply line consists of $4\frac{1}{2}$ miles of 2 inch pipe, with hose outlets 300 feet apart. The pumping units consist of one C. H. W. W. pump, and a Barnes triplex powered with a Hercules engine. This latter pumped from Mongaup brook, the low point on the road, and handled water through nearly four miles of lines with a gauge pressure showing around 500 pounds all the time. There were no storage tanks, but a by-pass relief valve was provided. Other pumps on the job included a R. H. B. Douglas triplex pump, chain driven from a 4 cylinder motor and truck mounted and a Domestic centrifugal pumping unit.

Example II. The water was pumped from the stream along the road. A two inch water line was laid, and equipped with gate valves and connections at frequent intervals. Pressure was regulated by means of a length of pipe, plugged at the upper end, connected vertically in the line at one of the hose connections.

G. Camping

While most of the men come out from town every day, a camp is maintained for the convenience of those who wish to stay there and to serve meals to both classes of men. The following illustrations are the current practice adopted by the contractors to establish a camp in order that meals and lodging could be supplied close to the work.

Example I. The camp was established at the same point as the batching yard, and consisted of a kitchen and mess hall, bunk houses for 100 men, a blacksmith shop, and other facilities.



Contractor's office and workman's lodging house

Dinning room

Sleeping room

A cook and three helpers and a yard man took care of this unit. The camp was run by the contractor. Lunches were packed up each day during operating weather and hauled in a motor truck to the location of the various gangs thus eliminating the time lost by transporting men to and from the camp at the lunch hour.

Example II. This camp is maintained under sub-contract by the Wilson Commissary Company, Chicago. The sleeping quarters are unusually comfortable with clean linen supplied each week, and regular steel beds to sleep on, while the meals served are well worthwhile. About 500 regular boarders and as many as 100 dinner boarders are served each day, at a price of $14.00 per week for room and board for regular boarders and a rate of $.70 for dinners for all others. The mess hall is manned by one cook, one dishwasher, two waiters, and one yard man, all in charge of a foreman representing the company. The camp also contained a blacksmith shop, a repair shop, offices for the contractor and offices for the engineers, as well as stables, etc. This camp utilizes an old farm property, with the office in the farm house, and the barn available for teams and feed.

H. Organization

The size of the organization and equipment varies with the number of jobs handled in one season and the size of project as well. Study shows that the number of employees ranges from 37 to 180 in a single job. The following organizations are shown here for reference.

Example I. One of the contractors developed a notable construction organization and plant. The working force consisted of plant foreman, mixer foremen, subgrade foreman, grading foreman, timekeeper, bookkeeper, mechanics, blacksmith, bridge foreman and about 150 laborers. These men were taken care of by a mess hall, bunk houses and commissary. The following equipment was used:

85 teams

5 60 h.p. caterpiller tractors

4 elevating graders

4 12 ft. leaning blade graders

5 light plants

1 dragline excavator

1 locomotive crane and clamshell

3 batcher bins

3 road pumps

1 paver

1 subgrader

1 form grader

1 subgrade planer

1 finisher

8000 ft. steel forms

1 turntable

36 cement bag cleaners

2 rollers

1 8-inch centrifugal pump

10 miles of 3-inch waterline for paver

10 miles of 2-inch waterline for curing

2 scarifiers

3 supply trucks

6 passenger cars

<u>Example II.</u> The size of organization and equipment used by Mr. Scharl, highway contractor of Michigan, may be also mentioned here for reference. Mr. Scharl has 400 cars, 14 locomotives and about 21 miles of track. With this equipment, 200 cars can be kept moving to the plant and 200 loads can be on the way to the job. He has always been in favor of plenty of equipment. He owns seven machines, four equipped as shovels and three equipped as cranes. These are augmented by Austin ripsnorters, Adams leaning wheel graders, a battery of Lakewood dump carts, and a fleet of trucks and several tractors. For the maintenance of all this equipment, he has installed a complete shop and garage. Eight trained mechanics look after the work and keep things in tip top order and facilitate prompt service in the event of breakdown. Ford roadsters are always ready to take them to the scene of the delay.

<u>Example III.</u> The total crew employed on this job, including the form setters and the curing crew averaged about 70 men.

The major items of equipment consisted of:

1 27E Koehring paver

1 1 cu. yd. Koehring clamshell crane.

1 "60" caterpillar tractor

1 "30" caterpillar tractor

1 12 ton three wheel roller

9 Autocar three batch trucks

1 150 cu. yd. Blaw-Knox batching plant

2 10 ft. Ord-finishing machines

1 C.H.&.E. portable water pump.

3,000 feet steel forms

26,500 feet $2\frac{1}{2}$ inch water pipe

TABLE I. SUMMARY OF CURRENT

No.	Number or Location of Project	Actual Working Time (Days)	Actual Paving Time (Days)	Time Lost (Days)	Lin.Ft. per day (Aver.)	General Information Thickness (In.)	Width (Ft)	Length (Mi)	
1	U.S.No. 10 & 54 1928		113		830		20	18	
2	U.S.No. 287-A3	52	40	12	671			5.087	
	287-A4	30	26	4	720		18	3.550	
3	Reedwood Hwy. California 1929	162	82	80	691	9-7-7-9 9-6-6-9	20	11.4	
4	Monticello - 1927 Liberty, N. Y.	167	102	65	1800[1]	8	20	7.5	1:
5	Jefferson-Nile 1925 Ashtabula, Ohio	181	135	46	586	9-7-7-9	16	15.1	
6	Florida-Warwick, N.Y.				1600[1]	8-7-7-8	18	4.6	1:
7	Avon Lake, O. 1928	60	35	25	580	10-8-10	18	5.08	1:
8	Long-Beach Boulevard Los Angeles 1928	120	75	45	704	10-7-10	70	3.78	1:
9	Decatur-Cairo, Ill. 1924	147	85	62	1405			22.6	
10	N.Y. State Hwy. 8039	91	75	16	1000	6-7¼-6	20	9	1
11	Nashville-Spring-hope Hwy. 1923				700	6-8-6	16	15	1
12	Galveston-Houston Hwy. Texas 1928	75	43	32	1170	9-6-9	20	10	
13	Rocky-Mount Halifax, N.C. 1926				1500[2]	8-7-8	18	30	1
14	State Hwy. Proj. No. 537-B N.C.		131		575	8-7-8	18	12	1
15	State Route 64 Ill. 1928				800[3]	9-7-9	40	15	1
16	Kankakee - Chicago Ill. 1928				1050[3]	9-7-9	40	8	1
17	Ill. State Hwy. No. 51 1928				840		20	12	
18	Ill. State Hwy. No. 121 1928		162		1350	9-7-9	18	22	1
19	Ill. State Aid job No. 390 1928				800	9-7-9	20	5.38	1
20	Indiana Route No. 6 1929				600	9-7-9	20	7.855	
21	Atwood Hwy. Tenn. 1929				1000	8-6-8	18	20.7	

. SUMMARY OF CURRENT PAVING OPERATION PRACTICE

General Information				Space of Expan-sion Joints (Ft.)	Type of Mixer	No. and size of batch trucks			Amt. of ce-ment used	Loading Plant	Pro-port by
hickness (In.)	Width (Ft)	Length (Mi)	Mix			one	two	three	Bags		wt. volu
	20	18			Rex 27E		2	7	6	batching plant	weig
		5.087									
	18	3.550						6-12	7	central proport-ioning plant	volu
9-7-7-9 9-6-6-9	20	11.4		60	27E Koehring				7	batching plant	weig
8	20	7.5	1:2:3½		Rex 7S		34		7	batching plant	weig
9-7-7-9	16	15.1			Rex 21E	combination of trucks and industry rail-way					
8-7-7-8	18	4.6	1:2:3½	78½				8	6		
10-8-10	18	5.08	1:2:3	200	Rex 27E		9		7	batching plant	weig
10-7-10	70	3.78 22.6	1:2:4	100	2-27E Koehring 3E-E Koehring	Industrial railroad			9-10		
6-7¼-6	20	9	1:1½:3½	36			11		5	batching plant	volu
6-8-6	16	15	1:2:4	300		combination of trucks and industry rail-way					
9-6-9	20	10		78½			39				
8-7-8	18	30	1:2:4		2-32E Koehring	Industry Ry.			8	batching plant	
8-7-8	18	12	1:2:4						5		
9-7-9	40	15	1:2:3½		Koehring 27E	14-18			6		
9-7-9	40	8	1:2:3½			combination of Industry Ry. & trucks			6-8		
	20	12			27E Rex		10				
9-7-9	18	22	1:2:3½		Koehring 27E	Industry railroads			6	batcher plant	
9-7-9	20	5.38	1:2:3½		Koehring 27E						
					[illegible]		10		6	batcher	wei

OPERATION PRACTICE

Space of Expansion Joints (Ft.)	Type of Mixer	No. and size of batch trucks one	two	three	Amt. of cement used Bags	Loading Plant	Proportion by wt. or volume	No. of workers	Method of Curing	Reinforcement
	Rex 27E		2	7	6	batching plant	weight	50		
				6-12	7	central proportioning plant	volume	33		
60	27E Koehring				7	batching plant	weight	70		
	Rex 7S		34		7	batching plant	weight	75	hay	42lb. 7x7 mesh
	Rex 21E	combination of trucks and industry railway								
78½				8	6			36		Standard mesh Truscon
200	Rex 27E		9		7	batching plant	weight	38	earth	$\frac{5}{4}$"ø steel bars
100	2-27E Koehring							180	burlap	plain concrete
	3E-E Koehring	Industrial railroad			9-10			65	calcium chloride	
36			11		5	batching plant	volume	53	sand	100 lb. wire mesh
300		combination of trucks and industry railway						180	hay	
78½			39					150		40 lb. wire mesh
	2-32E Koehring	Industry Ry.			8	batching plant			burlap	
					5					
	Koehring 27E		14-18		6				calcium chloride	
		combination of Industry Ry. & trucks			6-8					
	27E Rex		10						calcium chloride	
	Koehring 27E	Industry railroads			6	batcher plant				$\frac{3}{4}$ø steel bars $\frac{3}{4}$ø steel

	337-B, N.C.						
15	State Route 64 Ill. 1928		800[3]	9-7-9	40	15	1
16	Kankakee - Chicago Ill. 1928		1050[3]	9-7-9	40	8	1
17	Ill. State Hwy. No. 51 1928		840		20	12	
18	Ill. State Hwy. No. 121 1928	162	1350	9-7-9	18	22	1
19	Ill. State Aid job No. 390 1928		800	9-7-9	20	5.38	1
20	Indiana Route No. 6 1929		600	9-7-9	20	7.855	
21	Atwood Hwy. Tenn. 1929		1000	8-6-8	18	20.7	
22	Ontario Paving Project 1929	52	1200	10-7-10	20	8	
23	Elginfield, Ont. 1929		1160	10-7-10	20	7	1
24	Blair, Ill. 1929		1880	9	18	5	
25	Raymond-Utica Miss. 1929		1250	9-6-9	18	16.5	
26	Pensacola, Fla. 1928		800	9-6-9	18	10	
27	Mascutah, Ill. 1929		1000	9-7-9	18	8.02	
28	Wayne, Michigan 1929		847	9-7-9	20	19.7	1
29	Little Neck Roslyn Hwy. N. Y. 1929		809	9	10	4.33	1
30	Contract No. 1795 New York 1929		1798[2]	8	30	6.3	
31	Oklahoma Federal Aid Job. No. 223 1928	26	833[3]	9-6-9	18	4.09	1

1. 8 hours work on 10 ft. strip
2. 1½ min. mixing time
3. 20' concrete per day at 10 hours

300[3]	9-7-9	40	15	1:2:3½		Koehring 27E	14-18	6	
050[3]	9-7-9	40	8	1:2:3½			combination of Industry Ry. & trucks	6-8	
340		20	12			27E Rex	10		
550	9-7-9	18	22	1:2:3½		Koehring 27E	Industry railroads	6	batche plant
300	9-7-9	20	5.38	1:2:3½		Koehring 27E			
600	9-7-9	20	7.855			Koehring 27E	10	6	batche plant
000	8-6-8	18	20.7		500	Koehring 27E	15-35	6	"
200	10-7-10	20	8			Koehring 27E	Industrial railway	9½	"
160	10-7-10	20	7	1:1½:3		Koehring 27E	15	9	"
380	9	18	5			Koehring 27E	22	6	"
250	9-6-9	18	16.5			Rex 27E	19	7	"
300	9-6-9	18	10		40	Rex 27E	15		"
000	9-7-9	18	8.02	:2:3½	1000	Rex 27E		6	"
347	9-7-9	20	19.7	1:2:3½		Rex	Industrial and truck haulage		"
309	9	10	4.33	1:2:3½	78½	27E Multi-Foote	20	7	"
798[2]	8	30	6.3			Koehring 27E	12	8	"
333[3]	9-6-9	18	4.09	1:2:3½	50	Koehring 27E	38	6	"

ork on 10 ft. strip
aixing time
ete per day at 10 hours

Koehring 27E	14-18	6				calcium chloride	
	combination of Industry Ry. & trucks	6-8					
27E Rex	10					calcium chloride	
Koehring 27E	Industry railroads	6	batcher plant				¾ø steel bars
Koehring 27E							¾ø steel bars
Koehring 27E	10	6	batcher plant	weight	34	burlap straw	¾" steel rods
Koehring 27E	15-35	6	"	"	66	burlap earth	
Koehring 27E	Industrial railway	9½	"	"	36	calcium chloride	
Koehring 27E	15	9	"	"	92	Earth	
Koehring 27E	22	6	"	"	42	calcium chloride	¾ steel bar
Rex 27E	19	7	"	"	59	silicate of soda	
Rex 27E	15		"	"	55	sand	
Rex 27E		6	"	"			
Rex	Industrial and truck haulage		"	"	42	earth	
27E Multi-Foote	20	7	"	"	38		
Koehring 27E	12	8	"	"	56	hay	
Koehring 27E	38	6	"	"	59	Calcium chloride admixture	½ D bars

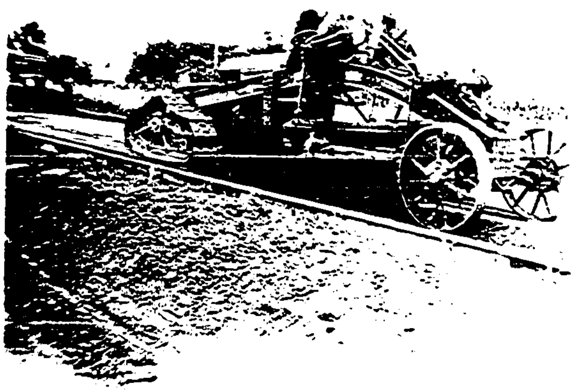
IV. CONCRETE ROAD BUILDING MACHINERY AND ITS OPERATION ANALYSIS

A. Road Building Machinery - Its Past and Present

Mechanical horse power in place of human energy: Highway construction and maintenance is using to a constantly increasingly degree motor traction and power equipment. R. T. Dana says in his handbook of Construction Equipment, "As a transformer of energy into useful work, man is about the least economic machine in the world. Working at top speed he can average in a working day not more than 1/18 of one mechanical horse power. It is therefore economical to reduce the accomplishment of human energy to the absolute minimum consistent with due coordination on the work. This means substitution of equipment in place of human labor wherever it is possible to do so. Moreover horse power developed mechanically is very much cheaper than a horse power derived from teams guided by drivers. Therefore, wherever the same work can be done by machine that would otherwise be performed by horses, the former is economically preferable". These principals account for the substitution of power equipment for hand and team work which has already been accomplished and point to a still greater development along these lines in the future.

B. Grading Equipment

1. Blade grader: Originating about half a century ago in the form of a straight steel blade hung under the body of an ordinary four-wheel horse-drawn farm wagon, the road grader



Blade grader

has been developed into a rugged, powerful machine, weighing 10,000 or more in its larger sizes, designed for the tractor haulage. From the modern grader with its all-steel construction, its reversible and blade control features, its backsloper attachments, extensible axles, leaning wheels, offset hitches, and, in the larger sizes, 12 ft. blades, it is a long journey back to the crude lever-operated woodframe machines of the seventies.

2. Elevating grader: A number of years elapsed before the grader attained widespread use, but after its design had been improved and special features added, such as the introduction of a conveyor to load the excavated earth into wagons, forming the elevating grader, the machine began to receive recognition as an important aid to the highway building.

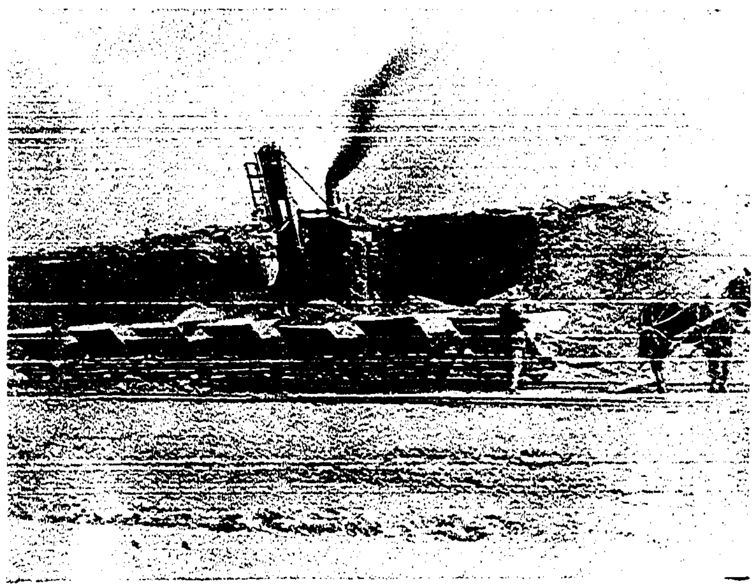
3. Caterpillar tractors: The standard power layout consisted of four or even eight head of horses or mules in front, driven by one man. Power was first substituted for stock by using round wheel gas or steam tractors adapted for farm work. There first efforts in the use of power were not very successful, as the tractors were not adapted to use over rough ground nor on soft and slippery soil. The caterpillar tractors, first introduced about 10 years ago, overcame these objections largely. Since that time the substitution of caterpillar tractors for stock on elevating graders has been growing rapidly with increasing success.

4. Power shovel: The adaption of power shovels to highway

building has been very rapid and successful. Greater mobility is being supplied by the rapid development and growing use of crawler or continuous tread traction; this type of traction enables the shovels to move over rough and soft ground under their own power without blocking or leveling, and, therefore, with but little delay and expense. While steam still maintains the leading position in shovel construction, gasoline shovels are being developed rapidly because of the advantage obtained by their use where coal costs are high or where feed water is difficult to obtain or when pipe lines are likely to freeze. A further development in the displacement of steam for shovel power was accomplished when a small type shovel was equipped with a mechanical injection oil engine of the Diesel type. With the present development of electric equipment for power shovels, it is not surprising that steam machines are being used less and less.

5. Motor trucks: Formerly the horse-drawn wagon or car and track with horses or steam dinkies were used for hauling the excavated material from the shovel. These are being displaced to an increasing degree by motor trucks and gasoline industrial locomotives. Motor trucks are especially useful where the material must be hauled 2000 feet or more. Where hauling conditions are not favorable to the use of trucks and the quantity of excavation per mile is large, car and track can be used to advantage.

6. Pneumatic drilling tools: In rock excavation on high-



Horse drawn wagon

Power drawn wagon

way building, hand drilling has given way to the pneumatic drill and portable air compressor. This equipment has also displaced the use of steam with steam drills to a large extent because of its greater mobility in the compressor and a wider range of sizes.

7. Electric battery and Cordeau-Bickford safety fuse: The electric battery has been displaced, as a detonator for the dynamite and power, with a wide range of sizes adapted to use with the various sizes of drilling outfits. The usefulness of Cordeau-Bickford is a detonating safety fuse consisting of a lead tube filled with tri-nitroluene. Its advantages are: 1. there is no danger of handling or storage; 2. its average rate of speed is 17,500 feet per second; 3. it increases the efficiency of the explosive charge.

8. Miscellaneous equipment: Fresnos, wheelers and slip scrapers have a useful place in highway grading. They are used as auxiliary equipment on large projects, or they are used alone on small jobs. Tents and tar paper shacks have given way to cook houses, dining rooms and bunk houses mounted on trucks so that they can be moved as required by tractors or trucks.

C. Paving Equipment

9. Subgrading machine: The man with pick and shovel is no longer left to worry the job out unaided. Now this hand work is supplemented by small tractors with scarifiers and bladesor by a subgrading machine riding on the forms and cutting exactly to the desired crown. The final finish in the

subgrade is insured by checking with a template of the specified section supported at its ends by the forms.

<u>10. Steel side forms:</u> The side forms are now used to furnish not only more accurate alignment and grade to the finished pavement, but they are also called upon to guide the subgrader and to withstand the weight and movement of a finish machine. These have resulted in the development of more rigid and adequately supported forms. The changes in pavement slab design by placing the thickest part of the pavement slab at the outside edge instead of the center thereby increasing the height of the form from 6 or 7 inches to 8 or 10 inches.

<u>11. Form grader:</u> While the operation of form setting is still largely hand work, now a machine known as a form grader has been developed for grading according to the depth required for the form.

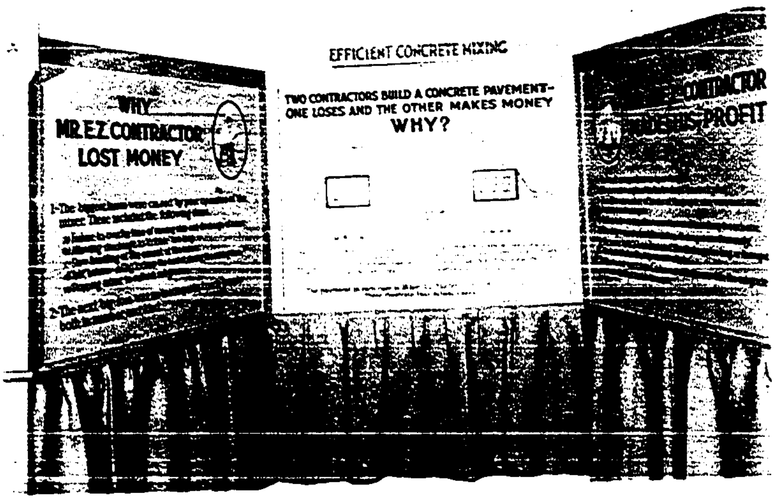
<u>12. Proportioning plant:</u> With the increased cost of labor during the World War there was introduced a belt conveyor with measuring boxes to eliminate the wheelbarrows. Later a loader was introduced to pick up the coarse aggregate and reduce the number of shovelers required. With the change in specification began the development of proportioning plants. The manufacturers have developed and placed on the market measuring devices. As a further step toward compensating for the bulking of the sand due to its moisture content now most of the state highway commissions have abandoned volume measurement and have adopted a proportioning by weight.

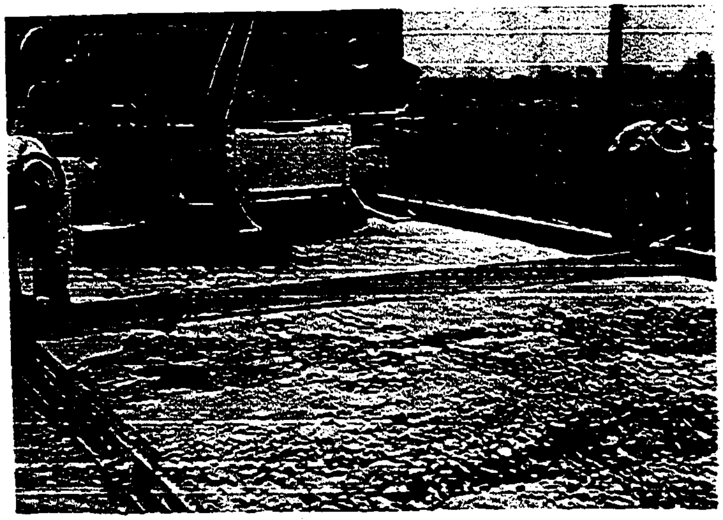
EVOLUTION

OF

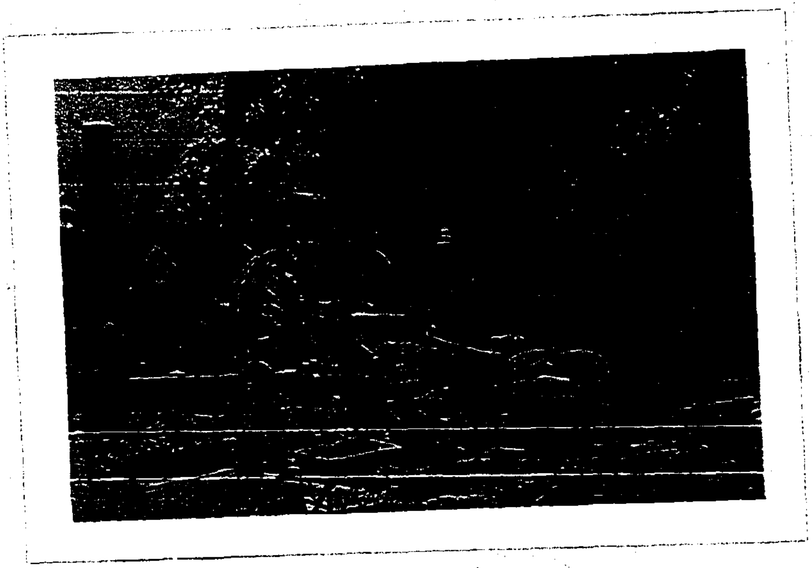
HIGHWAY CONCRETE MIXERS

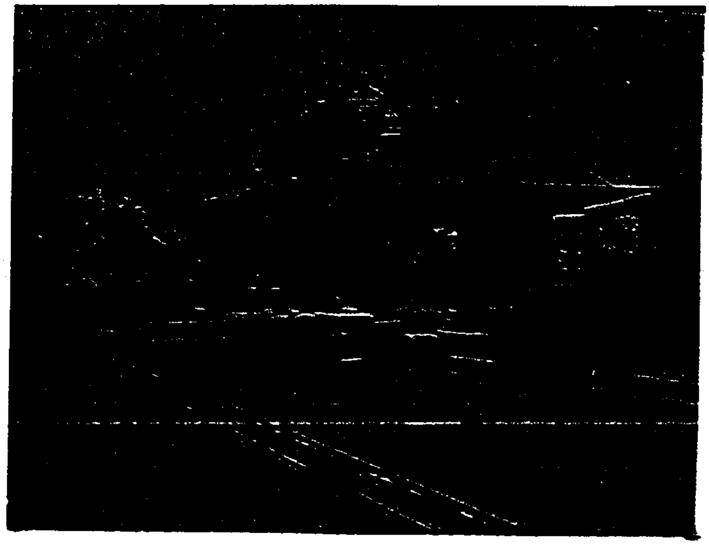
(1904 - 1930)

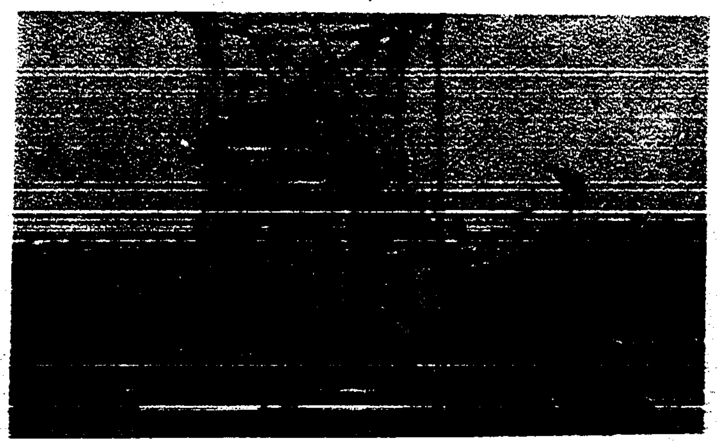

EFFICIENT CONCRETE MIXING
TWO CONTRACTORS BUILD A CONCRETE PAVEMENT-
ONE LOSES AND THE OTHER MAKES MONEY
WHY?
WHY
MR. E.Z. CONTRACTOR
LOST MONEY
PROFIT




PAVING







13. Paving mixers: In the recent years a greater improvement has been made in designing and building the paving mixer. 1. Water meter has been provided for more accurately gaging the amount of water added to each batch; 2. timing devices have been developed to automatically regulate the length of time the batch remains in the mixer; 3. power hoists have been developed for transferring batch boxes from industrial cars and dumping them into the skip or directly into the mixer; 4. suitable gas engines have been developed to such efficiency that they are practically as reliable as steam power for mixers; 5. greater portability has been secured by substituting continuous traction for the old type of wheel traction; and 6. the size of the paving mixer has gradually increased to 32-E, until the 27-E is now the big seller. Another type of paver called truck mixer is put on the market now. Its utility and advantages will gain its popularity in the near future.

14. Central mixing plant: The use of central mixing plants is made practical with regard to concrete consistency, and the discovery that concrete of the desired consistency can be hauled almost any required distance without separation of its aggregates, or any injurious effects to the concrete.

15. Finishing machine: The development of finishing machines and equipment has made it possible to finish concrete with a stiffer consistency, which results in securing a greater strength of concrete and the uniformity of the road surface.

There are recent developments of a combined tamping and screed machine which, as found at work in the field, produces an accuracy of finish which is better than that generally secured where the straight tamping machines are used.

16. Miscellaneous equipment: With the use of motor trucks, turn-tables for turning trucks on the subgrade have been used, thus eliminating the necessity of turning the truck on the subgrade. The use of plank runways for the last 100 to 200 feet adjacent to the mixer insures a satisfactory subgrade. This protection for the subgrade is especially necessary where trucks haul is used with a central mixing plant.

D. Concrete Road Building Machinery - Its Standardization vs. Obsolescence and Depreciation

1. Economics of highway equipment standardization: On the basis of present day equipment a paving outfit complete to handle adequately all construction work will involve an investment of $55,000 to $100,000. The following outfits with cost to one of the highway contractors are given here for reference.

TABLE II

Items	Cost
27-E paving mixer	$7200.00
One yard crane	9800.00
Two Triplex pumps	3000.00
One yard bucket	900.00
Turntable	600.00

TABLE II (Cont'd)

Item	Cost
Subgrader	925.00
One bin (100 yards)	2000.00
One blade	2800.00
One subgrade attachment	500.00
One roller (5 ton)	2500.00
One finishing machine	2695.00
Steel forms (4,000 feet)	3320.00
$2\frac{1}{2}$ inch pipe (6.5 miles)	7166.00
One grader rooter	295.00
Calcium chloride machine	385.00
3 concrete carts (for bulk cement)	106.00
Scale and platform	225.00
2 flat trucks (1 ton)	1400.00
2 wagons	110.00
3 fresnoes	96.00
1 plow	40.00
2 tool boxes (wheeled)	50.00
Tool house at plant	250.00
Cement shed	250.00
Campuoutfit complete	8500.00
Small tools	300.00
Burlap (2000 ft.)	320.00
Curb forms (1000 fet.)	150.00
Sprinkling hose	400.00
Total Investment	$ 55173.00

With such an enormous investment, the question of depreciation and obsolescence are serious considerations to the contractors. With standardization, he has fair assurance that the investment he makes today in an expensive machine will not be quickly impaired by the appearance on the market of a new model shortly after he purchases. The frequent introduction of new models often has the effect not only of making obsolete earlier ones before their time, but of seriously affecting the economic usefulness of other equipment operated in conjunction with them. In the highway construction work, equipment represents a large capital investment to the contractor, and the cost of ownership of this equipment is a large part of his charge to the public for construction service rendered. Standardization will help to check unwarranted changes in sizes, models, and capacities brought about by uncontrolled competition. For example, concrete mixer standardization has been successful. For a number of years the mixer manufacturers have produced a simplified line of sizes with standard capacity ratings. Saving in cost estimated at 7% has been realized, and trade practice has been greatly improved. The standard sizes of mixers and pavers have proven adequate to the needs of the contractors and the results have been beneficial to the public. The engineer, manufacturer, and contractor should cooperate in taking up this matter - standardization of road equipment.

2. Method of determining the depreciation rates for road equipment: There have been numerous instances of failures to

understand depreciation or to comprehend the application of depreciation rates and its method to the various highway equipment by the contractor. This undoubtedly has been accountable for more variation in bid prices than all other elements entering into the cost of construction. The committee of the Associated General Contractors have agreed upon five methods (203) of depreciation, and recommended that the most applicable method be selected for each item of equipment. However, the method as selected, should be followed consistently with respect to that item.

a. The straight line method: Under this method the useful life of each piece or group of equipment is estimated in years, and a fixed percentage of the initial cost is charged off as depreciation each year during the estimated life. This charge-off is made whether or not the equipment is in use. Example: If the useful life of a machine is estimated at four years, then one-quarter, or 25%, of its cost is charged off each year.

b. The unit of work method: By this method the life of a piece of equipment is estimated in units of work and depreciation is written off each year in proportion to the number of units delivered by the equipment during that year. The units of work may be tons, cubic yards, square yards, or any other unit by which the working life of a machine can be measured. No depreciation is charged off when the equipment is idle. Example. If a concrete mixer cost $2000 and is estimated to deliver 20,000 cubic yards of concrete during its life, then each yard of concrete mixed by the machine represents $0.10 in depreciation, and if the machine mixes 5,000 cubic yards during a season then $500 is depreciated the first year.

c. The job charge-off method: This method provides for charging depreciation of particular machines against the job for which they were purchased. The amount charged is the difference between the original cost of the equipment and its actual or estimated salable value at the end of the job. This method is suggested for special equipment for which the contractor will have no further use after the job is completed. This method would be used primarily y companies which buy equipment for each new project and sell it upon completion of the work. However, it may e used in conjunction with the straight-line depreciation method or the unit of work method to write off the undepreciated cost during the remaining service life. This can be done by charging off of depreciation to the first job, estimate the remaining useful life in years or units of work, and thereafter depreciate according to the first or second method above explained. Example: If a paving mixer cost $8,000, at the completion of the job this might bring $4500. In this case, charge off $3500 in depreciation, on the first job or season's work. If the contractor decides to keep the machine, thereafter charge off the remaining $4500 at 33-1/3% or $1500 per year. The same process could be followed using units of work instead of years as the basis of charge-off.

d. The composite rate method: This method is a weighted average rate determined for each contractor according to the character of his equipment. The sum total of the depreciation is developed by applying the straight line or unit of work method to each individual item, and then dividing the total amount of depreciation for all items by the total investment to establish a percentage rate. This rate will be applied each year to the equipment as a whole, and will remain consistent unless the contractor's equipment outfit is altered by a change in the type or number of items. Example:

Item	Useful life	Depreciation rate	Cost	Depreciation
1 concrete mixer	2 yrs.	50%	$400	$200
1 " "	4 yrs.	25%	2000	500
1 steam shovel	8 yrs.	12½%	14000	1750
20 dump wagons	3 yrs.	33-1/3%	6000	2000
10 dump trucks	4 yrs.	25%	40000	10000
Total			$ 62400	$ 14000

The composite rate = $\frac{14450}{62400}$ = 23.16%

e. Appraisal of useful life method: Under this method the unexhausted useful life of each item of equipment is periodically estimated by appraisers and the proper percentage of the value is charged off as depreciation. The factor of market value is not considered and the appraisal concerns use only the percentage of useful life consumed and that remaining in terms of the original cost. Example: A piece of equipment is purchased for $3000. By periodical repairs it is still in good condition, and although the straight line depreciation formerly used showed that it had a value of only $1000 by the addition of repairs and good useage during its life it was felt by the appraisers that it was worth $1500. This would be the fair value of the equipment.

f. Rental charges: In applying the rental charges, the question arises whether the rental rates for 120 working days a season should be twice as much as the rental rates for the 240-day season. Unquestionably, equipment depreciates even if not used, but there is a question whether it depreciates in direct proportion; that is, if the equipment is not working a certain number of days a year, if it depreciates as fast as if it were working. Example= If a piece of equipment - say a tractor - cost originally $5000 and is depreciated at the rate of 20% a year, which would be $1000, the interest on the initial investment of $5000 at 6% would be $300 per year. The insurance would probably be around $50 a year. Irrespective of how much the equipment operated, there would be a fixed charge of $1350 a year, and if the equipment were operated 120 days the cost per day would be over $11 exclusive of repairs and operation costs. If the equipment operated 240 days, there would be a cost of a little over $5.50 per day for the above-named items, but probably an increased cost in repairs.

E. Road Equipment Operation and Time Distribution Analysis

1. Land leveler operation - the advantage of the land leveler: The land leveler has been used successfully as a medium of earth transportation in subgrade construction. The leveler couples the functions of an immense fresno with those of rotary scrapers, wheelers, and in some cases of dump wagons, and with the added advantage that the leveler constructs as it travels, constantly planing slight elevations and filling small depressions. It has been claimed that the distinct advantage over fresnos lies in the leveler's ability especially the larger types powered by a 60 or similar tractor to maintain a more level plane of roadway during construction, thus giving an easier and more economical finish.

The weight of any of the larger types of leveler is such that its blade will bite deeply into firm earth, or partly broken stone, saving much loosening with plow or scarifier. Turning area is an important consideration both in time and convenience. More is true of the larger leveler. It was found more economical to travel empty a distance of 150 feet to another pickup than to "back and fill" once.

The Best-30 and 2.5 cu. yd. leveler is not economical for deliveries exceeding 250 ft. The Best-60 and 3.5 cu. yd. or 5.0 cu. yd. leveler attains its efficiency in hauls from 100 to 400 feet in dry soils.

2. Fresno operation: The rate offresno operation is

almost entirely a matter of proper plowing and general management so long as the material is such that it can be so broken up or loosened that it will load readily. The amount of such material which is carried to the dump per fresno load varies with the sizes of the fresno, character of the material, care of the drivers and the proper supervision of the foreman. In fresno work the various necessary operations of loading, dumping, turning at each end of the trip and throwing the fresno back into loading position can readily be performed within an average time of 40 seconds. For all jobs studied by the Bureau of Public Roads the average time for these operations is somewhat over one minute. If the management is very lax, the time required for these operations often approaches two minutes per trip, which means a 50% decrease in production. The following table (187) shows the time required to perform several operations of loading, dumping, and turning plus the actual travel time to and from the dump at various lengths of haul and the production possible at each rate under the three grades of management.

TABLE III

Haul	Time required per round trip - min. Good	Average	Poor	Cubic yards per hour Good	Average	Poor
50	1.1	1.6	2.4	18.2	12.5	8.3
75	1.3	1.8	2.6	15.4	11.1	7.1
100	1.5	2.0	2.8	13.3	10.0	7.1
150	2.0	2.5	3.3	10.0	8.0	6.1
200	2.4	2.9	3.7	8.3	6.9	5.4
250	2.9	3.4	4.2	6.9	5.9	4.8
300	3.3	3.8	4.6	6.1	5.1	4.3
400	4.1	4.6	5.4	4.9	4.3	3.7

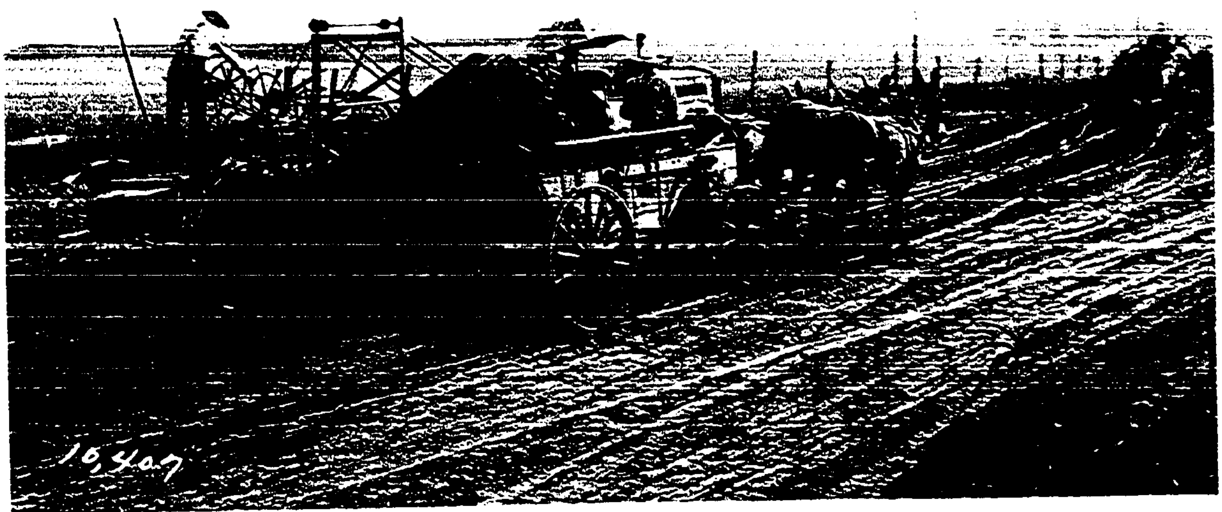
3. Wheel-scraper operation - significant difference between wheeler and fresno outfits: In a fresno outfit the only force required in addition to the drivers and teams for the fresnoes themselves is that which is needed for plowing. Each wheeler, on the other hand, requires 2 mules and a driver for the haul, but for loading and dumping additional force is required which usually consists of a snatch team, a loader, and a dumper. The force required for plowing is the same in either case. Hooking on and unhooking the snatch team also increases the loading time, the total time required to perform the standard operations of loading, dumping, turning, etc., is considerably longer for the wheeler than for the fresno. There is also more of a tendency for waits and delays to occur at the cut. On the other hand, there is a tendency for the

teams to maintain a slightly faster pace and to tire less than on the longer fresno hauls. With good management on wheeler work the time-constant can be kept within an average of two minutes per round-trip, while the average for all jobs which have been studied by the Bureau of Public Roads is very close to three minutes. Another significant difference is that the fresno is more economical than the wheeler for hauls up to 300 or 400 feet. The following table (187) shows the average time required per round-trip and production possible at each rate for various hauls of 200 feet and over.

TABLE IV

Haul (Ft.)	Time required per round trip - Minutes			Cu. Yd. per hour		
	Good	Average	Poor	Good	Average	Poor
200	3.7	4.7	5.6	8.1	6.4	5.4
300	4.5	5.5	6.5	6.7	5.5	4.6
400	5.3	6.3	7.3	5.7	4.8	4.1
500	6.2	7.2	8.2	4.9	4.2	5.1
600	7.0	8.0	9.0	4.3	3.8	3.4
700	7.8	8.8	9.8	3.9	3.4	3.1
800	8.7	9.7	10.7	3.5	3.1	2.8

4. Elevating grader operation: The ideal field of the elevating grader is adapted to rolling prairie regions, where cuts are usually fairly long and the side slopes slight so as to avoid much dead-heading and the soil reasonably free from



Elevating grader

rocks, large boulders, or many stumps and roots, while the power shovel is adapted to rocky, very sandy or stumpy ground, and where the side slopes are steep or the longitudinal surface slopes are abrupt and much broken. The power shovel is far less affected by the contour of the surface or the character of the material. But neither the power shovel nor the elevating grader can do shallow short haul work in common excavation as cheaply as the fresno.

Factors affecting high rate of production: In elevating grader work a high rate of production is dependent upon the following factors: A. Proper operation of the hauling equipment, especially as to exchanging wagons. B. A sufficient provision of proper hauling equipment. C. Operating the elevating grader at the proper space. D. The plow cutting at the bite must be such that it will give the elevator the maximum amount of material that it can handle. E. A proper supervision and management on the part of foreman and superintendent.

With team-drawn wagons, the grader speed should be maintained at about 212 feet per minute. With motorized hauling equipment the grader can be speeded up to 240 feet per minute. If 1-1/2 cu. yd. wagons are used the teams can readily be made to walk at the rate of 4 feet per second, so that if the loading is begun at the front end of the wagon the gain of the team over the grader will be just sufficient to complete the load without spilling. The empty wagon should be made to follow closely on the wagon completing its load. The loaded wagon should immediately swing away sharply from the grader and then continue forward until clear of any chance of interfering with the following wagons. This method will facilitate a quicker exchange of wagons and reduce grader delays. The following table (187) shows the time in seconds required for the various operations under different management.

TABLE V

	Good	Average	Poor
Loading time	18	23	30
Exchange time	7	13	20
Turning at end of cut	35	45	55

Another table shows the number of loads or trips per hour which each wagon should move at the spped 4 feet a second, and the time in minutes per round trip for various lengths of haul.

TABLE VI

Haul (Ft.)	Time per round trip (Minutes)	Number of trips per hour
100	2.57	23.3
200	3.39	17.7
300	4.21	14.2
400	5.03	11.9

TABLE VI (Cont'd)

Haul (Ft.)	Time per round trip (Minutes)	Number of trips per hour
500	5.85	10.2
600	6.66	9.0
700	7.48	8.0
800	8.30	7.2
1000	9.94	6.0
1200	11.58	5.2
1400	13.22	4.5
1600	14.85	4.0
1800	16.49	3.6
2000	18.13	3.3

<u>5. Power shovel operation.- Effect of material on time required for filling the dipper:</u> The following table gives a very fair impression of the difference between work in good ground and work in difficult material. In general, fast operation in good material was accompanied by large dipper loads and the quantity decreased with difficulty in loading as indicated by the time element.

Power shovel

TABLE VII

Kind and character of material	Time to load dippers (In seconds)
Light clay, free roots and stones	6.0
Light clay, with roots and stones	6.7
Medium clay	7.5
Clay and soft shale	8.2
Light clay with small amount of rock	9.2
Sandstone	11.0

Effect of angles of swing on time required to return the dipper: The following table shows the total cycle in loading, swinging, dumping and returning the dipper for several jobs where the swing ranged from 30° to 270° and when the swing was 90° or less. It is apparent that when the point of loading and the point of dumping are within the operator's vision at the same time he can keep his mind far enough ahead of his work. As he digs his load he determines where he will get the next bite, and so on. The saving in time is small per load, but it is enough to make considerable difference in the day's run.

TABLE VIII

Shovel	Angle of swing total cycle 90° or less	90° - 270°
A	22.2	24.3
B	21.6	25.4
C	24.7	29.1
D	20.9	24.5
E	21.2	21.5

Effect of sizes of shovel on yardage moved per dipper: It will be noted that while the ratio of the indicated capacities of the dippers for the sizes of 3/4 cu. yd. and 1 cu. yd. shovels is 1.33, the ratio of the average yardage moved per dipper load of the 3/4 cu. yd. and 7/8 cu. yd. group to the 1 cu. yd. and 1-1/8 cu. yd. group varies for the different materials from 1.40 to 1.60, the average being about 1.52. In other words, the group consisting of shovels having dippers with indicated capacities of 1 cu. yd. and 1-1/8 cu. yd. moved about 50 per cent more material per dipper load than did the 3/4 cu. yd. and 7/8 cu. yd. shovels.

Grade of management: Under favorable conditions in good common excavation, a power shovel can be made to load wagons or trucks at the rate of four well filled dippers per minute, providing the swing does not exceed 90°. A good operator can continue this rate for intermittent periods throughout the day.

This is very close to the maximum limit of shovel operation and permits of no delay or interference of any kind. However, many jobs have been found where under normal field conditions in materials which were easy to dig and dump, the rate of operation was at the rate of three well filled dippers per minute. To maintain this rate consistently requires a shovel in first class condition, a high grade operator, an ample supply of suitable hauling equipment, loading at the side of the shovel so that the average angle of swing does not exceed 90° and, above all, a carefully trained and well supervised personnel. A continuing rate of three well filled dipper-loads per minute in good common excavation may therefore be taken as the measure of excellence in the management of a power shovel job. As the materials become hard, tough, or sticky, digging becomes more difficult with the result generally both the number of dipper-loads per hour and the yardage per dipper-load are reduced.

TABLE IX (187)

Kind of material	Dippers per hour of continuous operation Good	Aver.	Poor	Cubic yard per hour Good	Aver.	Poor
Common excavation which digs easily and dumps freely	180	150	120	90	75	60
Common excavation which dumps freely but is so hard that full bite exceeds available power at normal engine speed	150	120	90	70	55	40
Common excavation which digs easily but which sticks in dipper	150	130	100	75	60	45
Common excavation, hard and sticks in dipper	120	90	60	50	40	25
Well blasted material	140	110	80	55	40	30
Poorly blasted material	100	75	50	35	25	15

Note: The above table is based on 3/4 cu. yd. shovel and averaged 4 feet deep.

6. Crane operation - modern handling method: In place of gravity pit and belt conveyor, the crane has proved to be a dependable piece of equipment. The standard setup is simple. The hoppers are set at such a distance from the track that the crane with the crawler type and a 3/4 yard bucket, can work freely between the hoppers and the cars. The distance between stock piles should be such that two cars, one of sand and one

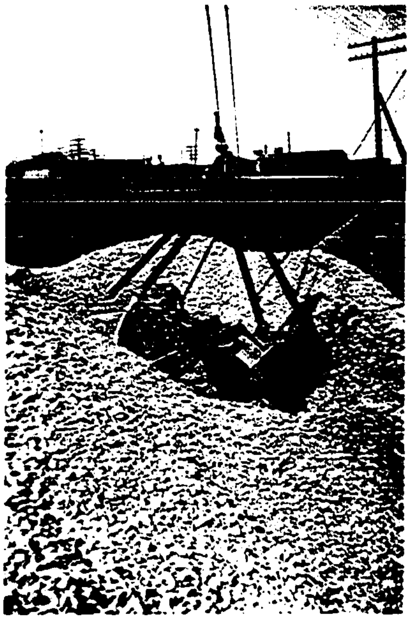
TABLE X—EFFECT OF KIND AND CHARACTER OF MATERIAL ON RATE OF SHOVEL PRODUCTION

(Average time in seconds required for each operation as obtained from analyses of 48,000 cycles.)

Kind of Material	Load	Swing	Dump	Return	Total Cycle	Angle of Swing	No. of Cycles Analyzed	Average Cut, Ft.	Dipper Loads per Hour
All material	10.46	[illegible]	[illegible]	[illegible]	25.76	107	47,920	8.5	146
All material	10.32	[illegible]	[illegible]	[illegible]	25.73	110	28,982	9.3	140
All material	10.5	[illegible]	[illegible]	[illegible]	25.90	[illegible]	15,025	8.5	139
All material	9.7	4.0	[illegible]	[illegible]	25.3	112	3,913	7.2	142
Common, all kinds	9.59	[illegible]	[illegible]	[illegible]	30.10	102	30,500	7.5	145
Shale, all kinds	10.6	4.0	5.0	6.2	26.2	115	2,901	8.8	137
Rock, all kinds	12.34	[illegible]	[illegible]	6.10	27.82	118	14,050	11.4	129
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Table X

Unloading the materials from
the cars to the stock pile.



Loading the materials from the
stock pile to the bin.

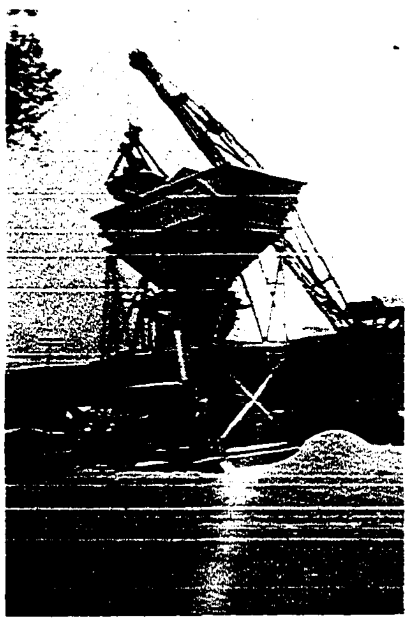
of gravel, may be reached. The crane will then unload either into the hoppers or onto the stock piles, in some cases two cranes and two loading bins will be used, this being governed by the number of cars to be handled and the requirement of the mixer.

Daily output of the crane: A good 1 cubic yard crane in the hands of a skillful operator will move a bucket every half minute from a freight car into the hoppers, and will operate at a slightly higher rate from the stock piles into the hoppers, as indicated by the actual stop-watch readings presented in the following table. When handling dry sand the loads average close to the rated capacity. When handling crushed stone or gravel the loads average about 0.6 cubic yards. While working from a freight car, the average load obtained is about 0.6 cubic yards for sand, and about 0.5 cubic yards for stone. A skillful operator can take a cubic yard of gravel or stone out of a freight car every minute, and a little more than that amount of sand. With good operation, the output should be about 60 cubic yards per hour; but the daily output will hardly reach the hourly output multiplied by the number of hours. The reason is the delay caused by shifting cars or machine breakdown.

Capacity of the crane: The question is often asked whether the crane can keep up with the demands of the mixer. It is presumed that the mixer at full efficiency can produce 48 batches of concrete an hour. Supposing the mix is 1:2:4, which requires 5 cubic feet of cement, 10 cubic feet of sand, and 20 cubic feet of stone or gravel per batch, which equals 9 cubic yards of cement, 18 cubic yards of sand and 36 cubic yards of stone or gravel an hour. It will be clear that the crane is able to keep pace with the mixer even when it is working from the cars to the hopper and the mixer is operating at full efficiency. If a 6 or 9 bag mixer is used, then a heavier crane with a larger bucket will be needed to keep pace with the mixer when the latter is operating at 48 batches an hour. The following table shows the various operating cycles of stop-watch readings of time required to handle material by crane from cars to batcher plant, while the time required to handle material from stock pile to batcher plant is slightly less.

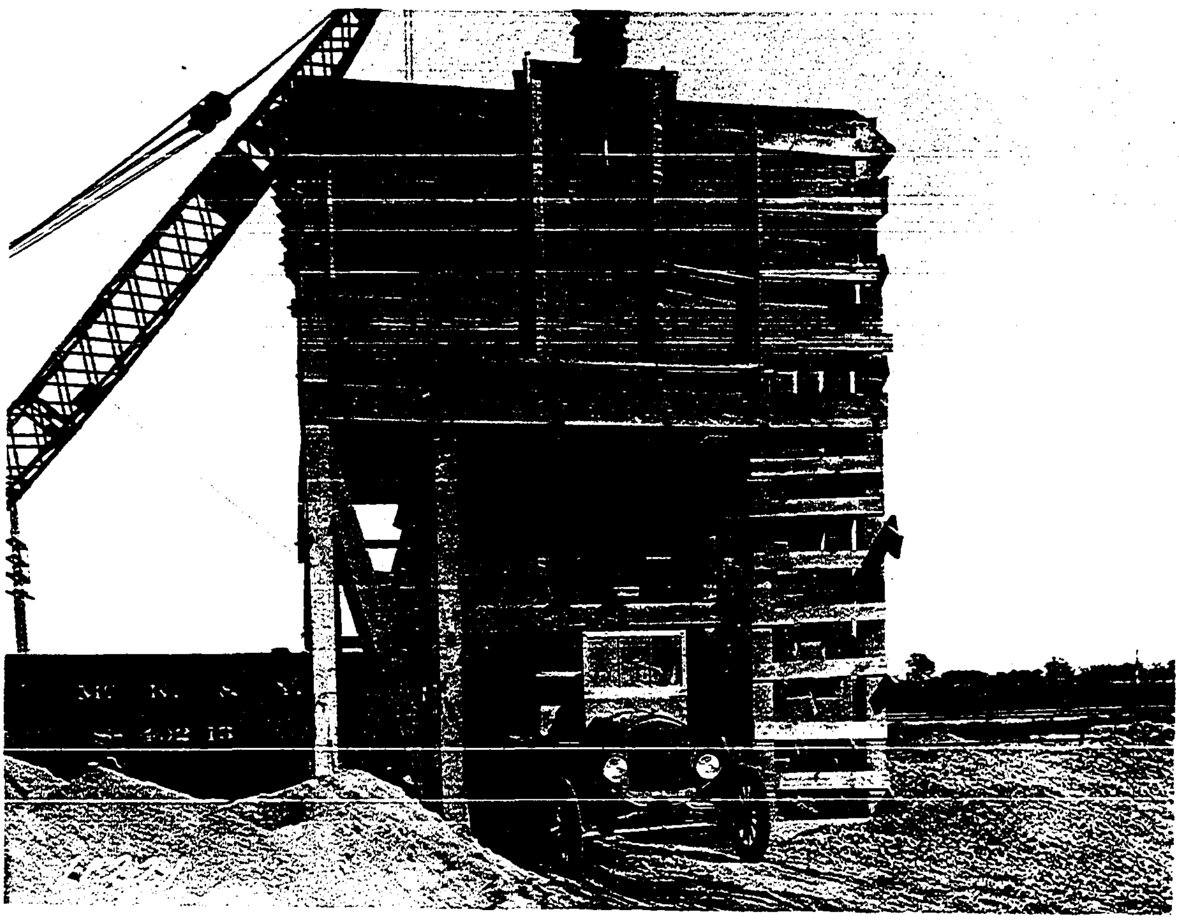
TABLE XI

Complete cycle	Time in seconds for each cycle
Loading	8
Swinging (50°)	9
Dumping	7
Returning	6
Total	30



Proportioning plant

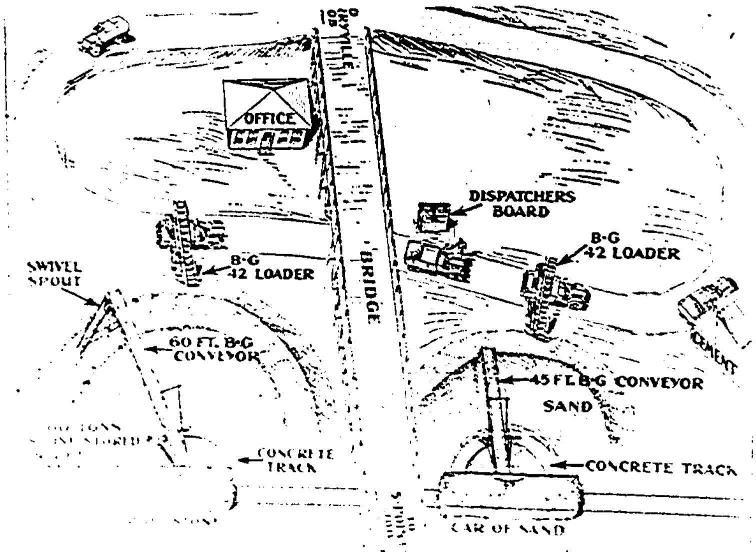
Modern steel bin



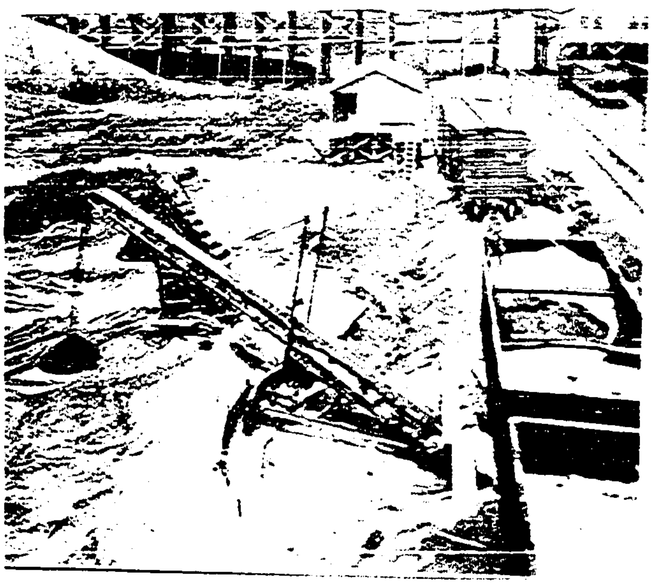
Old home made bin

7. Loading plant: The modern contractor has generally adopted the better type of steel bins. They can be moved from job to job and the measuring or weighting devices are faster, more reliable and above all more accurate. The old homemade bin is gradually getting out of use, as the measuring device often takes a minute or so to load the coarse aggregate and half that time to load the sand, while the modern steel bin will dicharge a 6 bag batch in approximately 20 seconds as actually timed by the stop-watch in the field. The total swing in loading time from the use of the modern steel bins is justified.

8. Bucket loaders and belt conveyors: In place of steel bin and shell crane, a 60-ft. Barber-Greene conveyor was used on the stone and the 45-ft. Barber-Greene conveyor on the sand were used in one of the Pennsylvania highway jobs. Barber-Greene bucket loaders with strike-off hoppers were used in the sand and stone, and a fleet of 2 batch trucks carried the materials. The hazards of being low on stone, and of complying with the state specifications in placing it in 4 ft. layors were overcome by putting a spout about 15 feet long on the 60 ft. conveyor. This spout is counter-balanced and may be easily swung around 180 degrees with one hand. Also the machine itself may be swung an equal number of degrees as the wheels are swiveled; a similar track was built for the sand conveyor. As much as 1700 tons of stone have been stored at one time with this method, allowing an ample supply for both mixers, enough



Material yard lay-out



Bucket loader and belt in action

to take care of any reasonable shortage, or railroad tieup - and storing in 4 ft. layers even more easily than with a crane. On loading the 2 batch trucks the Barber- Greene loaders with strike-off hoppers proved most effective both in speed and accuracy. The operators have the strike-off hoppers on the loaders full before the trucks drive under. When the trucks are beneath the hopper, only a few seconds are required for the first batch to be emptied. On the sand about 20 seconds are usually required to refill the hopper for the second batch, and on the stone about 45 seconds. As an average the trucks stay under the stone loader 1-1/2 minutes and under the sand loader one minute, getting both batches. Getting the stone, dispatching ticket, sand. and cement usually requires less than five minutes.

9. Mixer operation - the mixer: On a concrete paving job the mixer is considered as the "key producer". The production capacity of a five bag mixer may be taken at 48 batches an hour at 100% efficiency. If the mixing cycle is taken as 1 minute, one batch should be taken every 75 seconds. If the contractor fails to meet this standard, he is failing to reach full efficiency in production. If a 1-1/4 minute mix is required, one batch should be obtained every 90 seconds, and if a 1-1/2 minute mix is required, one batch should be obtained every 105 seconds. The 1-1/4 minute mix reduces output to 40 batches an hour, and the 1-1/2 minute mix to slightly over 34 batches an hour. These reductions in output will affect

the unit cost on the bid price that will be told in the later chapter.

Mixing cycle: The mixer in turning out a batch of concrete involves the following cycles:

1. Loading skip: While the previous charge is being mixed, the skip is loaded. The time required to transmit the material from the truck to the skip averages 13 seconds.

2. Raising skip: The skip is raised to a vertical position in order to dump the batch into the drum. A modern mixer with a skillful operator will take 10 to 11 seconds on this operation.

3. Discharging skip: The material in the skip is never fully discharged when the skip reaches the vertical position. If the fine and coarse aggregates are dry, it will take as little as 3 seconds to discharge the skip after it is in a vertical position. If the aggregates are wet enough to moisten the cement appreciably it takes from 4 to 5 seconds to discharge the skip.

4. Mixing: The material must be retained in the drum the full specification period, in most cases, 60 seconds.

5. The discharge: As soon as the complete mixing period is reached, the material must be discharged. A wet mix can be quite thoroughly discharged from a modern mixer from 9 to 10 seconds.

6. Dumping the bucket: Finally the batch is deposited on the subgrade, while the next batch is being mixed. This

operation does not affect the mixing cycle.

7. Discharging lag: The modern mixer has on it some timing device. A timer which rings a bell at the completion of the mixing period is generally used. When the bell rings, the operator must move the discharge lever and the discharge mechanism must open the discharge before the material is poured into the bucket. These operations generate a lag, it is because of the fact that no human is able to react instantly to any ordinary stimulus and that it takes time for the discharge mechanism to work. Generally from 2 to 3 seconds is allowed for the discharge lag.

Time required for the various operations may be summarized as follows:

TABLE XII

Various Operations	Seconds
Raising skip	10
Discharging skip	3
Mixing	60
Discharge lag	2
Total time actual mixing cycle	75

10. Truck supply - choice of trucks: The common method of transporting materials in the concrete highway construction

Truck hauling equipment

is direct delivery from the loading plant to the mixer in batch trucks. The trucks are generally either of single or two batch capacity. Larger and heavy trucks are sometimes seen, but are not in common use. The transportation problem is largely a truck problem, involving a choice between single and two-batch trucks.

A. First cost: The capital investment in equipping with single batch trucks is low. It was estimated on a 5 mile haul, 29 single batch trucks are needed as against 12 high speed, two batch trucks. The 29 single batch trucks would cost in the neighborhood of $20,000 as against 12 high speed two batch trucks which cost about $60,000.

B. Capacity and suitability: The weight of 5 bag batch (sand, coarse aggregate and cement) varies from 3,200 to 3,800 lbs. This is too great a load for the single batch trucks now in use and as a result their rate of depreciation is high. Two-batch trucks are relatively stronger and the rate of their depreciation is not visibly affected, if reasonable care is exercised in their use on this work.

C. Current repairs and maintenance: The cost of current repairs and lost time while repairs are being made appears to be a larger factor where single batch trucks are used than where 2 batch trucks are used.

D. Operating charges and overhead: Let us take an example for illustration - if single batch trucks are used, the payroll will carry, say 24 drivers in 4 miles haul, at a rate of $4.00 a day or a total of $96.00; if heavy duty trucks are used, the payroll will carry 15 drivers for 4 miles haul at a rate of $4.00 a day, or a total of $60.00. In a 120 day working season, a saving of $4320 will be made in favor of two batch trucks. Saving is also involved in gas, oil, and accessory parts.

F. Interest in capital investment: As mentioned in first paragraph "A" the capital investment for the 29 single batch trucks will be $20,000 and for the 2 batch trucks $60,000, say at 4% interest, a saving on the difference of $40,000 will be $1600. Assuming the life of the truck is 3 years, a total saving will be made of $48,000. From the above discussion, each factor must be weighted and counter-balanced, and each particular job should be given it's own thought and attention, before the trucks are chosen. Perhaps no two jobs are alike in the modern highway construction.

Whether the trucks are owned or hired: In delivery of materials from loading plant to the mixer, there are several methods in use today. One is to hire the truck; another is to own the truck; still others make the contract hauling to the sub-contractor. Each method has its advantages and disadvantages. But they are all worthy of consideration by the contractor. Perhaps the following statements made by J. L. Harrison, highway engineer, U. S. Bureau of Public Roads, may be quoted here to clarify this contract hauling business. On one of the projects observed, the main contractor, firmly entrenched behind a contract guaranteeing the delivery of material to him at a fixed cost per square yard of pavement laid, was thereafter indifferent as to the location of his material yard with the result that the haul was needlessly lengthened to the material detriment of the subcontractor. On another job, the main contractor installed a loading plant which operated so badly that the trucks could not make a reasonable number of trips per day and lost money from this cause. This trouble was complicated by a long delay, amounting to three weeks or more, in moving from the first setup to a second setup.

During this period the trucks which had been working on the job were withdrawn and when the main contractor was ready to begin operations again there was a good deal of trouble in getting a new truck train. Still on another job the subcontractor provided trucks which were originally believed to be sufficient to meet the haul requirements but when the main contractor improved the efficiency of his operation, the subcontractor was unable or unwilling to supply additional trucks. On the other hand, it is not justified or economical for the contractor to own or to purchase the whole fleet of trucks. Supposing say for a 4 mile haul, 15 heavy duty trucks are needed. For the full length of haul, every truck is utilized to the full capacity. At the last two or three mile haul there are more trucks than are actually needed. Thereby it is necessary for some trucks to be idle, until there are some demands for them. A modern heavy duty truck will cost from $4000 to $5000. The annual interest on this sum will amount to from $240 to $300. Dead storage will cost $60 to $100 a year, and taking the truck to and from the job averages from $40 to $80. These items do not include the depreciation and capital investment on the idle trucks. This would be another situation, if the contractor has two or three jobs in subsequence or at the same time. The trucks can be shifted around so that every truck will be utilized to the full capacity if possible. After these problems are analyzed in this manner, either to own, to purchase or to let the hauling to the sub-contractor will not pay. This may be done either by agreement with numerous individuals or with the local concern which does the hauling business. The writer has observed that the last method has been used very successfully on many jobs. There are always plenty of trucks waiting for the mixer. The contractor has no trouble whatever in this operation. As the job goes on, the contractor can add or subtract the number of individual trucks, as the condition permits. And yet the contractor secures the best service from the truck supply. He has no difficulty in obtaining the experienced truck drivers in performing this kind of work. At his own judgment he can discharge or change those who are inexperienced, or the truck driver may be given instructions at the first start. The contractor pays every batch mile that the truck owner can make it.

Developing the formula for number of trucks required:

Let d = distance in miles from the loading plant to the mixer.

V_1 = speed in miles per hour from the loading plant to the mixer.

V_2 = speed in miles per hour on the return trip from the mixer to the loading plant.

$t_1 = (\frac{d}{V_1})60$ = time in minutes required from the loading plant to the mixer.

$t_2 = (\frac{d}{V_2})60$ = time in minutes required on the return trip from the mixer to the loading plant.

t_3 = time in minutes taken in the field, including 1. loading sand and coarse aggregate; 2. loading cement; 3. turning table; 4. backing the truck to mixer; 5. dumping onto the skip, to the time required for these operations those must be added about 1 or 2 minutes for unavoidable delays and the total times required are given in the following formula.

$$t = t_1 + t_2 + t_3$$

$$t = (\frac{d}{V_1})60 + (\frac{d}{V_2})60 + t_3$$

$$t = \frac{60d(V_1 + V_2)}{V_1V_2} + t_3$$

Where $t_3 = 5$ (see Table XIV). V_1 = 18 mi. per hr., V_2 = 20 Mi. per hr. (average reading taken from the field)

As substituted and simplified, the above equation becomes:

$t = 6.4d + 5$ (1)

For illustration: If the haul is 4 miles (including the dead haul), how many single batch trucks would be necessary in order to provide a full supply of materials for the mixer operating at 100% efficiency. The working day being 10 hours: solution = Batches required , 48 batches per hour for 10 hours = 10 x 48 = 480 batches per day. Working day = 10 x 60 = 600 minutes. $\therefore t = 6.4d + 5$ (1)

By substitution= $t = 6.4 \times 4 + 5 = 30.6$ minutes per trip or per load.

$600 \div 30.6 = 20$ trips or loads per day

$480 \div 20 = 24$ trucks required for 4 mile haul.

If we develop the formula,

let L = number of loads hauled per truck per day

N = number of trucks required in order to reach 100% production at 48 batches per hour or 480 batches per day.

$$\therefore N = \frac{480}{L} = \frac{480}{\frac{600}{64d + 5}} = 480 \times \frac{(64d + 5)}{600}$$

$$N = \frac{4}{5}(64d + 5) \quad (2)$$

If in a 12 hour working day 576 is in place of 480 batches and there will be 720 minutes, the formula may be developed for heavy duty two batch trucks but the velocity V_1 and V_2 would be different and times required for 1. loading cement, 2. sand and coarse aggregate, 3. turning table, 4. backing and 5. dumping onto the skip would not be the same. All these readings have to be observed and tabulated in the field. The speed of trucks is dependent upon the following factors: 1. condition of the road, 2. skill of the driver, 3. kind and size of the truck, and, 4. other related elements. All these factors must be taken into consideration before the formula for the number of trucks required can be developed. The contractor is warned whether the trucks are owned or hired, it is always advisable to provide 1 or 2 more trucks than is actually needed in order to guard against any delays due to machine breakdown or holding up on the wet subgrade. These experiences are not unusually happening in the concrete road building. The number of single batch trucks required for various lengths of haul and number of working days are shown in the following table.

TABLE XIII

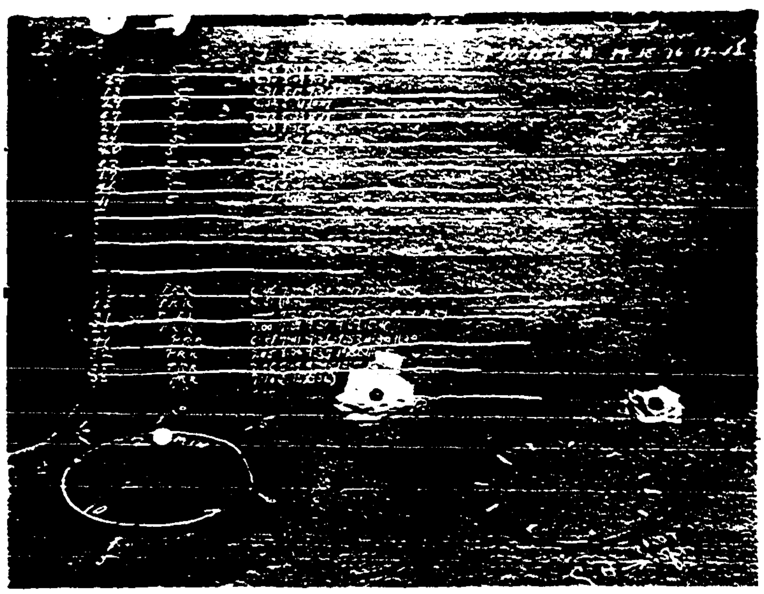
Distance in Miles	Average number of trucks required	Number of working days at 6 days per mile
1	9	6
2	14	12
3	19	18
4	24	24
5	29	30
6	35	36
7	40	42
8	45	48

Time required in 1. loading sand and coarse aggregate, 2. loading cement, 3. turning table, 4. backing to mixer, 5. dumping on the skip, and 6. miscellaneous delay.

TABLE XIV

Description	Minutes	Seconds
At loading plant:		
loading aggregates	1	30
loading cement	1	12
At mixer:		
turning table		12
backing to mixer		30
dumping load		16
miscellaneous delay	1	70
Total	5	0

11. Truck dispatching system: On a recent Pennsylvania road job, (48) the H. J. McMahon Construction Co. of Pittsburgh, had adopted successfully a truck dispatching system. The jobs were located near Slickville, Pa., one consisting of $2\frac{1}{2}$ miles of pavement from Five Points toward Greesburg, and the other of a 5 mile stretch from Slickville to Perrysville. The central batching plant was located at Slickville. Thirty 2 batch trucks were assigned to the two jobs, and it was the condition sought by the contractors to keep two trucks waiting



Truck dispatching board

at each mixer all the time. The central dispatching board shown in the accompanying illustration was to obtain the distribution of trucks sought. The three circular slots in the horizontal board represent the plant and the routes to and from the two pavers. The points on the large discs farthest from the plant represent the locations of the mixers. Trucks are represented by the small discs or buttons which slide in the slots. Thus, the board gives a picture of the truck distribution at any time, when the discs representing trucks are moved in accordance with truck schedules and information supplied by checkers at the mixers. The vertical board is used to keep a record of the movements of each truck.

The trucks were operated on a five minute schedule and, the time to and from the mixer having been determined, the discs were moved to show the progress of the trucks. The routes shown by the discs were marked off in five minute intervals and the small discs were moved forward one graduation every five minutes. As each truck returned to the plant, its time was checked and the positions of the small discs were corrected if necessary. At the mixer, each truck driver was given a slip showing the number of trucks in waiting at the time. This slip was handed to the central dispatcher upon return to the plant, thus giving him fairly complete information concerning the location of trucks and allowing him to send out trucks from the plant accordingly. When the photograph reproduced was taken, the trip to the Perrysville mixer with a loaded truck required 20 min. and the return trip took 10 min. The trip to the Five Points mixer required 35 min. and the return trip with an empty truck took 20 min. If the board at any time showed, for example, that two trucks were waiting at the Perrysville mixer while only one was waiting at the Five Points destination, the next incoming Perrysville truck was transferred to the Five Points job and the discs were moved accordingly. The checkers at the mixers also recorded on the slips issued to the truck drivers, weather and road conditions break-downs and other information essential to the operator of the dispatching board. It is estimated that truck control on this job saved two trucks or $50 a day. Installation of a telephone line from plant to mixers would result in more accurate dispatching.

12. Industrial railways - comparative investment in transportation equipment: The general practice to run the industrial railway on the shoulder permits of the uninterrupted preparation of subgrade and setting of forms and avoidance of truck operation over the finished subgrade. In spite of the advantage which the industrial railway has in this particular, its use appears to be decreasing. The main reason is that a highway contractor who invests in this form of equipment finds that a large part of his working capital is tied up in equipment. Another reason is the high cost involved. Twenty-pound track with ties, switches, etc., is worth perhaps $5000 a mile. Engines cost from $3000 to $6000 each. Cars are worth

Industrial railway

about $85 each and batch boxes about $60. The cost of full industrial railway equipment for a 5 mile maximum may reach $75,000. To obtain a reasonably accurate view of the comparative investment in transportation equipment which is involved, this sum should be compared with the $20,000 required for single batch trucks and the $60,000 required for high speed two batch trucks to meet the same maximum haul.

Round-trip train cycle: The time required in handling a train of say, 24 cars is as follows:

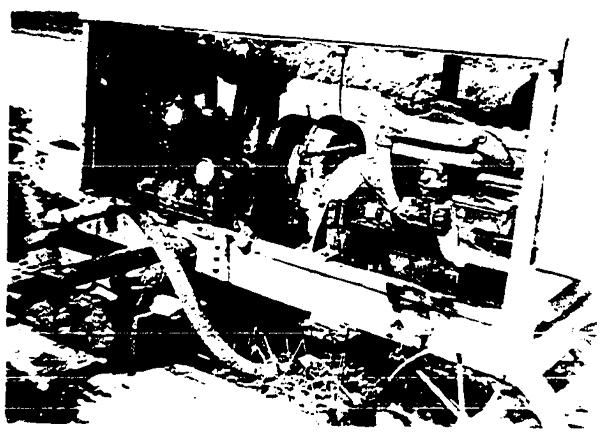
TABLE XV

Various operations	Minutes
Loading 24 batches of aggregate	10-15
Loading 24 batches of cement	10-15
Switching per trip	10-20
Unloading at mixer (at rate of 45 batches per hour)	32
Operation alone, exclusive of haul	60-82
Travel time for each mile haul, at 4 miles per hour	30

It is assumed that 75 minutes represents the average time per trip spent on operations alone, then on a 1 mile haul the round trip time will be about 1-3/4 hours. In a 10-hour working day, the trips per train will be 10 ÷ 1-3/4 = 5-5/7 making 5 trips on every 2 hours on a trip. Now if the trains are carrying 24 batches, 2 trains must be delivered per hour in order to maintain 48 batches an hour. Therefore, 4 trains are required. (1/2 grain equals the delivery per train unit per hour, 2 ÷ 1/2 = 4). If the haul is 6 miles, the total round trip time, on the same basis, will be about 4-1/4 hours. In a 10 hour working day, 2 trips per day can only be made, or one trip every 5 hours. In order to maintain the full production, 10 trains are to be operated, 10 locomotives must be used and 120 cars with 240 batch boxes must also be provided.

13. Water line: Only one system of handling water is in common use today. It is pumped through a pipe line laid along the right-of-way to the mixer. In the common practice provision is made at regular intervals - generally 200 to 300 feet - for taking water from the pipe line, and a hose connection is used to feed the mixer. There hose connections are also used to obtain water for sprinkling and for any other job requirements. The adequacy of the pumping plant depends absolutely on the use of a pipe line of such size that the pressure-head will always be within the limits for which the pump is designed. There are vital differences between a pump designed to deliver 100 gallons a minute against a pressure-head of 100 pounds and one designed to deliver at the same rate against a pressure-head of 400 pounds. This raises the question as to what pressure-head is required in delivering water.

Water supply data for concrete paving: The state highway



Water pump engine

Water Supply Data

Loss of head due to friction in steel pipes for water used in paving

Length Paved Per Hr. Ft.	Gal. Water Required Per Hr.	V Feet Per Sec.	Length of Pipe ½ Mi.	1 Mi.	1½ Mi.	2 Mi.	2½ Mi.	3 Mi.
			2-inch Pipe					
—	2000	3.188	79	158	237	316	395	474
—	2400	3.825	111	222	333	444	556	667
—	2800	4.463	148	296	445	592	741	[illegible]
—	3200	5.100	190	381	571	761	952	1142
—	3600	5.738	237	474	711	948	1186	1422
50	4000	6.37	288	577	866	1155	1444	1732
60	4800	7.65	406	812	1218	1624	2030	2436
70	5600	8.92	542	1083	1625	2167	2708	3250
80	6400	10.20	695	1391	2086	2781	3477	4172
90	7200	11.47	867	1733	2600	3466	4333	5200
100	8000	12.75	1055	2111	3166	4221	5277	6332
			2½-inch Pipe					
—	2000	2.233	33	65	98	130	163	195
—	2400	2.679	46	91	137	183	229	274
—	2800	3.126	61	122	183	244	305	366
—	3200	3.572	78	157	235	313	392	470
—	3600	4.019	98	196	293	391	488	586
50	4000	4.47	119	238	357	476	595	714
60	4800	5.36	167	335	502	669	836	1004
70	5600	6.25	223	446	669	893	1116	1339
80	6400	7.15	286	573	859	1146	1432	1719
90	7200	8.04	357	714	1071	1428	1785	2142
100	8000	8.93	435	870	1304	1739	2174	2609
			3-inch Pipe					
—	2000	1.448	11	22	33	44	55	66
—	2400	1.737	16	31	47	62	78	93
—	2800	2.027	21	41	62	83	104	124
—	3200	2.316	27	53	80	106	133	159
—	3600	2.606	33	66	99	132	166	199
50	4000	2.89	40	80	121	161	201	241
60	4800	3.47	57	113	170	226	283	339
70	5600	4.05	75	151	226	302	377	452
80	6400	4.63	97	194	291	388	485	581
90	7200	5.21	[illegible]	[illegible]	362	483	604	725
100	8000	5.79	[illegible]	[illegible]	442	[illegible]	[illegible]	[illegible]

[illegible]

Water supply table XVl

department of Pennsylvania has compiled the following information (90) for use in determining the sizes of pipe line to be used for the water supply on concrete paving projects. The information is based upon 50% of the water being required for curing and 50% being required for the mixer and subgrade. The department states that if calcium chloride is used for curing the amount of water required for the lengths paver per hour can be reduced one-half. The table given under the sizes of pipe lines is figured without modification for head, and the same table at the bottom of the tabulation gives the information for the connection for the head. The tables are based on a requirement of 8000 gal. of water for 100 feet of paving apportioned as follows: 1/2 for curing, 1/4 for subgrade, 1/4 for mixer. The pavement is assumed to be 18 feet wide. The head given is based on friction loss only. To this must be added the height of the outlet of the pipe above the source of supply. The formula used is the Hazen-Williams Formula: $H = \frac{KLV1.87}{d\ 1.25}$, where H = loss of head due to friction, K = .00038, L = length of pipe in feet, V = velocity of water in feet per second, d = diameter of pipe in feet. A 2 inch pipe = 2.067 internal diameter. A 2½ inch pipe = 2.469 internal diameter. A 3 inch pipe = 3.068 internal diameter. How the tables are used: Example: 1. Estimated progress of paving 70 ft. per hour, water required - 5600 gal. per hour, maximum water pressure in pump - 150 lbs. per square inch.

Pipe 2 inch diameter, pump 12 feet above level of supply. Outlet 40 feet above pump. How far from the pump can the work be supplied? 150 lb. pressure = 345 ft. head as per conversion table. 345 - 12 - 40 = 293 ft. net head. The head required for 1 mile of pipe is 1083 feet. Distance water can be supplied $= \frac{293}{1083} = 1/4$ mi.

Example 2. Estimated progress of paving - 70 ft. per hour. Maximum water pressure in pump - 500 lb. per sq. in. Maximum distance water must be forced = 2½ miles. What size pipe is required? 500 lbs. = total water pressure available, which corresponds to 1,152 ft. head. 2 in. pipe under these conditions requires 2,708 ft. head or 1175 lb. pressure and is too small. 2½ in. pipe is necessary and required 1,116 ft. head, which corresponds to 484 lb. pressure. A 3 inch pipe requires 377 ft. head which corresponds to 163 lbs. pump pressure.

Example 3. Estimated progress per hour = 90 ft. Distance water must be forced = 2½ miles. What horsepower and pressure are required? 2 in. pipe requires 4333 ft. head by table or 1880 lb. pressure. Water required = 7200 gal. per hr. = 2 gal. per sec. = 16.7 lb. per sec. 16.7 x 4333 = 72,360 ft. lb. per sec. ÷ 550 = 132 horsepower. 2½ inch pipe would require 1785 ft. head by table or 775 lb. pressure. 16.7 x 1785 ÷ 550 = 54 horsepower. 3 in. pipe would require 604 ft. head by table or 250 lbs. pressure.

16.7 x 604 ÷ 550 = 18 horsepower.

V. EFFECT OF PRODUCTION AND MANAGEMENT ON UNIT COST

A. Effect of Mixing Time on Production

Some engineers specify one and one-half minutes for mixing time of concrete while others specify one minute. It is found that a considerable number of field tests indicate that with the better designed mixers and adequate control over materials and water content, three-quarters of a minute of mixing will give a concrete of so nearly the same strength as a minute or a minute and a half that the extra cost of the longer mixing time does not seem warranted. Cutting the mixing time by this amount and keeping the mixer fully occupied are very important items in a cost reduction program. The following table XVII shows that the maximum number of batches of concrete that may be turned out per hour with a mixing time of 1½ minute is 34, for 1-1/4 minute, 40, for 1 minute 48, and for 3/4 minute, 60. It is assumed that there is no loss of time between batches, and that the mixer is operated continuously for the full length of the working day. In practice such full production is seldom attained; and production averaging 75% of the theoretical maximum is not unusual. For a 10-hour working day, the cost of paving is increased about $400 per mile of pavement laid for each one-fourth minute added to the mixing time.

TABLE XVII

NUMBER OF BATCHES TO BE PRODUCED PER HOUR FOR VARIOUS MIXING TIMES

Various Cycles	1-1/2 Min.	1-1/4 Min.	1 Min.	3/4 Min.
	Seconds	Seconds	Seconds	Seconds
To raise skip	10	10	10	10
Discharge skip	3	3	3	3
Discharge leg	2	2	2	2
Mixing time	90	75	60	45
Total time required	105	90	75	60
Batches per hour	35	40	48	60

B. Effect of Size of Batches on Production

The following table will throw some light on the relationship of sizes of batches on rate of production. The larger the size of batches will be the higher the rate of production. The daily output is limited by the 27E paver to a fixed maximum number of batches and the corresponding number of cubic yards laid. Therefore, the paver holds the "key and bottleneck" in production. At the present time the 27E and 32E have reached their capacity, unless a new system is introduced such as truck mix or so-called mixed-in-transit system that will be outlined in the later chapter. The following table is on the basis 1:2:3½ concrete mix; the yield is 4.74

cubic feet per sack of cement and the average output is 400 batcher per 10 hour working day; each cubic yard of concrete can lay in the neighborhood of 2.1 lin. ft. of pavement 20' wide and 10-7-10 cross-section.

TABLE XVIII

Size of batches	Cu. yds. in 10 hours	Lin. ft. laid in 10 hours
5	352	739
6	424	890
7	492	1033
8	564	1178
9	636	1335
10	704	1478

C. Effect of Length of Haul on Production and its Unit Cost

The daily cost of operating a modern road building plant is nearly independent of the rate of production. In the case of the power shovel wagon used as an illustration, we noted a daily operating cost of $75.00 for the former and $70.00 for the latter; the cost holds good whether much material is dug or little. On the other hand, it will be apparent that the number of teams required in order to transport the material which this shovel can dig will vary with the distance it must be hauled. The Bureau's studies show that teams travel about

250 feet a minute. These studies also show that such matters as waiting while the load is put on at the shovel, turning at the shovel, turning at the fill, droping the load, etc., should not require more than two minutes per load hauled. If, then, the distance the dirt must be hauled is 250 feet, a load can be hauled every four minutes. If the shovel can put a dipperful of good common excavation onto a wagon every 20 seconds - as most shovels can if properly operated, two dipperfuls making a wagon load - a wagon can be loaded every 40 seconds, as to keep the shovel supplied with wagons a train of six wagons (4 x 60 = 240 seconds ÷ 40 sec. = 6) is required. If the haul distance is 500 feet, the round trip for the wagons becomes six minutes and nine wagons (6 x 60 ÷ 40 = 9) are required. At 1,000 feet, the round trip time becomes ten minutes and 15 wagons are needed to keep the shovel busy at all times. At 2,000 feet, 27 wagons are required, and at 4,000 feet, 51 wagons are required. While the speed of the truck is 600 feet per minute, or 10 feet per second; if the haul distance is 250 feet, the round trip for the trucks becomes 2-5/6 minutes and 4 trucks (2-5/6 x 60 sec. ÷ 40) are required. At 500 feet, the round trip time becomes 3-2/3 minutes and six trucks are required. At 1,000 feet, 8 trucks, and at 4,000 feet, 23 trucks must be supplied. If the crawler tractor is used, its speed is 300 feet per minute, or 5 feet per second. At 250 feet haul, the round trip time becomes 3-2/3 minutes and 6 tractors (3-2/3 x 60 ÷ 40) are

required. At 500 feet haul, the round trip time becomes 5-2/3 minutes and 8 tractors must be supplied. At 1,000 feet, 13 tractors, at 2,000 feet, 23 tractors, at 4,000 feet, 43 tractors are required. In these studies 2 minutes are allowed for waiting, while the load is put on at the shovel, turning at the shovel, turning at the fill, dropping the load, etc., while 40 seconds are allowed for two dipperfuls making a full load. The following table shows the number of various haul equipment and the round trip time required at various lengths of haul.

TABLE XIX

NUMBER OF VARIOUS HAUL EQUIPMENT AND ROUND TRIP TIME REQUIRED AT VARIOUS HAULS

Haul in Ft.	Wagons		Trucks		Tractors	
	Time in Min. Required	No. Required	Time in Min. Required	No. Required	Time in Min. Required	No. Required
250	4	6	2.8	4	3.7	5
500	6	9	3.7	6	5.7	8
1000	10	15	4.86	7	8.6	13
2000	18	27	7.7	12	15.3	23
3000	26	44	10.6	15	22	33
4000	34	51	13.4	20	29	44

If we assumed that the cost of maintaining a team and wagon with driver is approximately $7.00 a day, and that ten wagons are sent out with the shovel, the daily cost of operating the wagon is $70.00, while the daily operating cost of the shovel is in the neighborhood of $75.00, then the total production cost becomes $145.00 a day. Ten wagons can take all of the diggings from the shovel as long as the haul is under 600 feet, but beyond that distance the hauling equipment is insufficient and production falls. There is a production capacity so far as the loading unit is concerned, of 1000 cu. yds. per 10 hour working day, but at 1,000 ft. production has fallen to 67% ($\frac{10}{15}$ x 1000 = 670 cu. yds. ÷ 1000 cu. yds. = 67) of the possible maximum because there is not enough transportation to handle what the shovel can produce. At 2,000 ft. production is at 37% ($\frac{10}{27}$ x 1000 = 370 ÷ 1000 = 37) of shovel capacity; at 3,000 ft. it is 23% ($\frac{10}{44}$ x 1000 = 230 ÷ 1000 = 23), and at 4,000 ft. is under 20% ($\frac{10}{51}$ X 1000 = 200 ÷ 1000 = 20), and the unit cost of handling the dirt has been affected in inverse ratio. Up to 600 feet, it was a little under $.15 ($145 ÷ 1000 cu. yd. = $.15), at 1000 ft., $.22 (67% x 1,000 cu. yd. ÷ $145 = .22), at 2,000 feet, $.39 (37% x 1000 cu. yd. ÷ $145 = .39), at 3,000 feet, $.62 (23% x 1000 cu. yd. ÷ $145 = .62) and at 4000 feet is under $.73 (20% x 1000 cu. yd. ÷ $145 = .73) The following table shows that the affect of unit cost on production as the result of inadequate supply of haul equipment when the length of haul is increased.

TABLE IX.

Haul in Ft.	Number of cu. yd. dirt shoveled per 10 hour day	Production Efficiency %	Unit cost per cu. yd. in cents
600	1000	100	15
1000	670	67	22
2000	370	37	39
3000	230	23	62
4000	200	20	73

D. Effect of Various Operations on Production and Its Unit Cost

The data presented here is on a 10-mile concrete pavement job built by the Michigan State Highway forces; this is to show the effect of various operations of each paver on the unit cost. Paver No. 1, a 5-bag machine using a truck haul for supplying the aggregate, poured 1.81 miles with a dead haul of 4.7 miles, while paver No. 2, also a 5-bag machine, poured the remainder 8.34, using a narrow gauge industrial with a dead haul of 0.25 miles. The average haul for paver No. 1 was approximately 5.6 miles, while for paver No. 2 the average haul was approximately 4.42 miles, making the average haul for the entire job approximately 4.63 miles. The following table draws a comparison between the production of the two pavers and also their corresponding unit cost. The average run of paver No. 1 was 586 feet per day. The former encountered much rainy weather and other sources of delay, while the latter had favorable weather and maintained a very good space. This resulted in lower unit costs for the various operations connected with this paver than with those of paver No. 1. Item A (paver No. 2) greatly exceeds that of paver No. 1 in cost per square yard. This is due to the heavy expense connected with bringing the industrial equipment to the job. On practically every other item of work the unit costs of paver No. 2 are less than those of paver No. 1. This is caused principally by the better showing made by paver No. 2 after the rainy season. Item J (on paver No. 2) is higher than on the other setup because of the industrial track located on the shoulders, thereby causing the workmen to obtain practically all of the cover material from one side of the slab instead of from both sides. The .008 ct. per sq. yd. difference between the materials is caused by the slightly higher freight rates on the aggregates.

TABLE XXI.

COMPARISON OF COST OF VARIOUS OPERATIONS OF EACH PAVING UNIT (127)

Items	Paver No. 1 (5-bag) Quantity sq. yd.	Total cost	Unit Cost	Paver No. 2 (5-bag) sq. yd.	Total Cost	Unit Cost
A. Moving Equipment	21499.6	529.91	.0246	95,297.9	4859.95	.0510
B. Trenching	"	1354.47	.0630	"	6006.19	.0650
C. Water lines	"	631.82	.0294	"	2699.87	.0283
D. Forms	"	692.97	.0322	"	2659.97	.0279
E. Truck Haul	"	7704.83	.3583			
F. Industrial Haul				"	15739.44	.1652
G. Mix Place Finish	"	2654.87	.1234	"	10663.56	.1121
H. Curing	"	673.25	.0313	"	3625.30	.0380
I. Materials	"	12690.54	.5903	"	55503.48	.5824
J. Shoulders	"	1920.75	.0893	"	8513.87	.0893
K. Yard-Setup	"	778.40	.0362	"	1466.89	.0154
L. Yard Operation	"	2149.31	.0999	"	7447.35	.0782
M. Overhead	"	1585.39	.0730	"	5495.16	.0577
Total Cost	21499.6	33366.41	1.552	95,297.9	124681.03	1.308
Average Cost is 1.353 exclusive of cement						
Days Worked	18 days			70 days		
Average Run	586.2'			629.2'		
Total Time	26 days			93 days		
Average Run	367.3'			473.6'		

E. Effect of Time on Operating Cost

Studies by the Bureau of Public Roads show the daily cost of operating a modern concrete paving plant is about $400 whether the daily production of pavement be 500 or 1,000 feet. Assuming a short stretch of pavement 10 miles long, and 20' wide, if the daily output is 500 feet, it would take 106 working days to finish, 600 feet, 88 days, 800 feet, 66 days, and so on, while the total daily operating costs are $42,400, $35,200 and $30,400 respectively; the time saving in each case is 18 and 12 days, while the amount of saving in dollars is estimated at $7,200, $4,800 and so on. From a general survey of the paving jobs over all the parts of the country, a daily production of over 1000 feet is not unusual, while a daily production under 600 feet is still found in some paving jobs; this is because of poor management and inadequate machinery. The following table gives a general idea of how the daily production affects the daily operating cost, and of the time saving in days and the amount of saving in dollars with the result of high and low production.

TABLE XXII.

Number of ft. laid per day	500	600	700	800	900	1000	1100	1200
Number of days actually spent	106	88	76	66	59	53	48	44
Time saving in days		18	12	10	7	6	5	4
Daily operating cost of $400	43400	35200	30400	26400	23600	21200	19200	17600
Amount of saving in dollars		7200	4800	4000	2800	2400	2000	1600

F. Effect of Production on Unit Cost

In the preparation of a bid in highway work, the contractor should make himself familiar with the main items and their percentages in construction cost upon which his bid is based upon. The following tabulation indicates some proportion of expenses in construction cost.

TABLE XXIII

1.	Equipment	20% - 25%
2.	Materials	35% - 40%
3.	Labor	15% - 20%
4.	Overhead	10% - 12%
5.	Profit	10% - 10%

The most effective way to decrease unit production costs without impairing the quality of finished products is to increase the output. This can be done by eliminating or reducing the time losses and waste motions connected with all direct operations; in coordinating and synchronizing the rate of production of the various subsidiary operations with the mixer; and in finding means of eliminating unnecessary operations and of expediting those which are necessary. The following table (153) which summarizes all the items which enter into the construction gives comparisons of two jobs; in one job the unit cost is $1.61 per sq. yd. at a rate of production of 528 ft. per day, while in another job the unit cost is comparatively low, $1.475 per sq. yd. at the rate of production, of 800 ft. per day. This strongly indicates that the road unit cost is cut by speeding up the production.

TABLE XXIV

Equipment	Cost	528 ft./day cost per sq. yd.	900 ft./day cost per sq. yd.
Depreciation	$19,500		
Repairs	10,600		
Fuel	5,300		
Freight	1,000		
Storage	500		
Total	$36,900	34.9	34

TABLE XXIV. (Cont'd)

Materials	Cost	528 ft./day cost per sq. yd.	900 ft./day cost per sq. yd.
Cement			
Sand	$17,200		
Gravel	35,000		
Water	200		
Steel	7,600		
Calcium chloride	4,000		
Total	$64,000	60.6	60.6
Labor			
Superintendence	4,400		
Unloading aggregate	3,600		
Handling cement	2,900		
Hauling	3,500		
Water	1,500		
Forms	4,000		
Steel	1,500		
Mixing and placing	4,600		
Finishing	1,400		
Curing	800		
Subgrade	4,200		
Moving	1,600		
Total	34,000	32.2	21.5

TABLE XXIV. (Cont'd)

Overhead	Cost	528 ft./day cost per sq. yd.	900 ft./day cost per sq. yd.
General expenses			
Contractor's drawing			
account	4,000		
General office	3,400		
Field office	500		
Plant setup			
Property rental	500		
Switch or trackage	1,500		
Finance			
Interest	1,000		
Bonds	2,800		
Insurance	3,100		
Contingencies	3,000		
Total	$19,800	18.8	13.0
Profit			
10%	$15,400	14.6	13.4
Total estimate	170,100	1.611	1.475

G. Effect of Yard-Layout on Unit Cost

Before the concrete paving job is started, decision must be made as to the points from which work will be started. Often this decision cannot be made until a good many elements such as source of material supply, freight charge, cost of moving the material-handling plant, length of haul, and cost of hauling, etc., are thoroughly examined. The following examples are given to illustrate how the location of loading plant affects the unit cost of the whole job. For illustration:

First choice: Set up the plant at Ames by the side of the Northwestern Railroad Station. Total haul, distance from Ames to Huxley is 8 miles. Using heavy duty trucks, assuming $.30 per batch mile, 40 batches an hour or 400 batches a day, (allowance for time lost incidental to plant operation), it takes an average of 5.8 days to build a mile of concrete road, or 2300 batches per mile.

1 x .30 x 2300 =	$ 690
2 x .30 x 2300 =	1380
3 x .30 x 2300 =	2070
4 x .30 x 2300 =	2760
5 x .30 x 2300 =	3450
6 x .30 x 2300 =	4140
7 x .30 x 2300 =	4830
8 x .30 x 2300 =	5520
Total cost	$ 24840

Second choice, there will be two setups. First setup at Ames, another setup at Huxley. Assuming the cost of moving and assembling the load plant at approximately $1000. Average haul distance is 4 miles in both directions.

1 x .30 x 2300 = $ 690

2 x .20 x 2300 = 1380

3 x .30 x 2300 = 2070

4 x .30 x 2300 = 2760

	6900
	2
	13800
Cost of moving and assembling plant	1000
Total	$ 14800

Third choice, set up the loading plant by the side of Ft. Dodge Des Moines R. R. about 6 miles from Ames and 2 miles from Huxley.

1 x .30 x 2300 =	$ 690	
2 x .30 x 2300 =	1380	
3 x .30 x 2300 =	2070	
4 x .30 x 2300 =	2760	
5 x .30 x 2300 =	3450	
6 x .30 x 2300 =	4140	
Cost of 6 mile haul	$ 14490	$14490
1 x .30 x 2300 =	690	
2 x .30 x 2300 =	1380	
Cost of 2 mile haul	$ 2070	2070
Total		$ 16560

From the above analysis, in the first choice the total hauling cost is $24,840; in the second choice, $14,800; in the third choice $16,560. The second choice is most preferable. It saves the contractor $10,350 by setting up the loading plant at Ames and then moving it to Huxley.

VI. TIME LOSSES ANALYSIS ON GRADING AND PAVING OPERATIONS

A. Time Losses Due to Weather Condition

The days lost for paving operations include not only the loss of time during the winter months, when no work can be carried on for comparatively long intervals of time, but also the days lost during the normal working season due to low temperature and rain. The tabulation made from data collected by the American Road Builder Association may be briefly summarized as follows:

For grading operations, working days range from 140 to 300; for paving from 100 to 300. Precipitation ranges from a maximum of 72.1 inches to 55.82 inches. The maximum average high temperature is 113 degrees in Arizona and New Mexico; and minimum average low temperature is 52 degrees below zero in Northeastern Montana. In Florida the average last day of frost in the spring is March 10 and first frost in the fall is December 1. But in western Wyoming the last frost in spring averages July 15 and the first frost in the fall averages August 10. The combination of cold weather and relatively high precipitation make for a short working season in New Hampshire, which reports only 100 working days for paving operations; 42 inches of precipitation, and only three months in the year when frost may not be expected. On the other hand, Alabama reports a relatively long working season of from 240 to 300 days in spite of precipitation of 49 and 55 inches.

Studies by the Bureau of Public Roads show that larger percentage of the available working time lost on account of rain and wet subgrade. About one-fifth of the total time lost charged to the combined causes are due to the actual fall of rain during working hours. On one fairly typical job the total losses charged to rain and wet subgrade amounted to 385-3/4 hours, and of this total only 53 hours were due to actual rainfall during working hours. The detrimental effect of the rainfall on the subgrade or the road or track over which the hauling is done is therefore clearly the major factor in this class of time losses. The following table (9) draws a comparison of time losses due to weather conditions and the various causes, such as machine break down, lack of material and so on, on various projects. Total time losses occupy 47.4%; while weather losses are 22.6%.

TABLE XXV.

Proj. No.	States	Date	Total time losses due to various causes %	Weather Losses: rain and wet sub-grade	Weather Losses: cold weather
1	Texas	Mar. 24-June 2	60.3	39.3	
2	Oklahoma	Oct. 27-Nov. 10	44.7	13.5	10.7
3	Texas	Mar. 1--Apr. 30	49.7	45.5	
4	Missouri	Apr. 7--June 6	40.3	28.8	
5	"	May 2--July 31	43.5	30.0	
6	"	May 27--July 31	38.8	23.9	
7	"	July 10-July 31	44.7	9.3	
8	"	Apr. 22-Sept. 18	29.8	21.6	
9	"	Aug. 1--Aug. 25	36.0	25.6	
10	"	Aug. 18-Aug. 27	29.4	17.3	
11	Nebraska	Sept.14-Sept.30	25.0	23.7	
12	Missouri	Aug. 10-Nov. 19	45.8	25.6	3.9
13	"	June 12-Nov. 24	48.4	29.6	2.6
14	"	Oct. 9--Nov. 29	62.9	36.0	
15	Illinois	Apr. 30-Nov. 7	48.5	21.1	2.5
16	"	May 18-Nov. 6	53.6	19.8	0.2
17	"	May 18--Nov. 5	46.7	13.3	5.1
18	Florida	Oct. 9--Jan. 19	64.4	12.9	1.1
19	"	Apr. 25-Jan. 28	44.8	17.6	
20	Mississippi	Oct. 24-Dec. 7	57.9	23.0	
21	Texas	Apr. 16-July 31	51.8	14.9	
22	"	June 15-July 11	58.0	35.8	
23	"	June 17-Aug. 1	41.6	3.5	
24	"	Aug. 9--Aug. 21	64.1	26.1	
25	Missouri	May 24--Sept. 25	55.8	29.6	
26	Michigan	June 7--Sept. 11	34.0	10.3	
27	"	June 14-Sept. 11	48.4	15.8	
28	"	June 21-July 10	26.0	.3	
29	Missouri	June 14-Sept. 4	55.0	24.7	
30	Oklahoma	June 14-July 17	28.9	20.7	
31	"	June 21-July 31	35.0	16.8	
32	"	Aug. 9--Sept. 11	50.1	16.0	
	Average		47.4	21.5	1.1

So far as the record can be traced, total lost time on the three jobs because of weather and subgrade on the Pennsylvania State highway paving job at Trout Run, Pa., in 1922 averaged 37% of total time. Record is also found in the Iowa State highway paving job in 1921, 1922 and 1923; for the average last three years, time losses due to snow, rain and frost was 15%. This does not include the time lost due to subgrade on account of weather. If this figure is accummulated, the total time losses due to weather and subgrade would run up to 25% - 30%, while the percentage of days lost due to weather alone in the paving operations in the northern states was 24.94.

Improved construction methods and well selected equipment and personnel will do much to overcome delays caused by unfavorable weather conditions and short working seasons. Up to 1923 no paving contractor in North Carolina had laid in one day 1000 feet of concrete pavement 18 feet wide; but since then that amount has been exceeded in the state many times. The weather has not changed but methods and equipment have been improved.

B. Time Loss Due to Mixer Operation

Unless the operator is familiar with the correct manner of operating the mixer, he can be the cause of considerable lost time. Handling a batch of concrete consists of three different operations: charging the drum, mixing and discharging. It takes from 9 to 11 seconds to raise the skip from the ground to the vertical position, while the length of mixing time is specified. The discharging operation can be overlapped with charging. That is, an experienced operator will start the discharge at the instant the timing device sounds. At about the same time he will start raising the mixer skip, allowing from 1 to 2 seconds between the two operations. The discharge gate is closed a second or two before the skip reaches the vertical position, with a charging time of 10 seconds and a batchmeter setting of 60 seconds for the specified mixing time and 5 seconds for all materials to enter into the drum after the timer is set. The experienced operator can turn out an average of 40 batches per hour, while the inexperienced one cannot do more than 30 batches an hour. This was actually observed in the field. Ten batches per hour is a great saving. In a 10 hour working day, the output is reduced by 100 batches. Inexperienced operators often cause delays because they do not properly place and spread the concrete. This makes unnecessary work for the puddlers and finishers, and the paver often has to stop until the finishing operations catch up. Another delay is caused by a failure to properly prepare the fine grade ahead of the mixer. Attempting to prepare the fine grade behind the mixer usually causes a delay every time the mixer moves. It was found that time losses due to subgrade not prepared are 3.2%; moving the mixer 2.8%, and mixer trouble 4.8%.

C. Time Loss Due to Laborers

Studies by the Bureau of Public Roads show that the average laborer does not actually work over about 70% (187) of the time for which he is paid. The low labor working time is partly due to some men's natural inclination to shirk or loaf, and partly due to the mechanical equipment which sets the pace in order to have sufficient men to serve the equipment, when operation is at its maximum and then when the rate of production slows down, these men are not fully occupied. Suggestions have been made by the Bureau of Public Roads that the size of the organization should be determined by a measure of the greater capacity of such a permanent crew over that of the annually recruited outfit. The holding of, in idle times, a shrewd superintendent, expert machine operators and capable foremen is reflected in their ability to work more effectively in busy times, and the overhead cost of keeping them may be offset by using them to put all equipment in first class condition. With reference to operation of equipment it is advantageous to secure the highest type operators or train them and pay what is necessary to retain them. This has proved that the time lost and the neglect and careless handling of machinery by a poor and inexperienced operator will pay for an expert. All of these considerations suggest the necessity for rigid control of and thorough knowledge of unit costs of performing work and for constant study of the exact productive ability of each outfit.

D. Time Lost on Power Shovel Grading

Studies (95) by the Bureau of Public Roads on the operation of 71 power shovel grading projects during the past three seasons in all parts of the United States is summarized as follows: Total hours available for operation, 16,996; actual hours that equipment operated, 12,406, or 71% of the available working time. The 4,950 hours or 30% that were lost are composed of delays of over 15 minutes' duration. The delays that are avoidable under proper management are:

TABLE XXVI

Description	%
Moving shovel	3
Drilling and blasting	2
Hauling equipment	1
Water and fuel	1
Operator	1
The unavoidable delays are:	
Shovel repairs	3
Moving shovel	2
Handling rocks and stumps	3
Blasting	1
Handling traffic	2
Miscellaneous delays	4

This means that the average power shovel outfit actually operates only 71% of the construction season during which it is actually on the job, and that during the time it is operating it loses 38% of the time through small delays, the greater part of which can generally be avoided through proper management. The delays that are unavoidable:

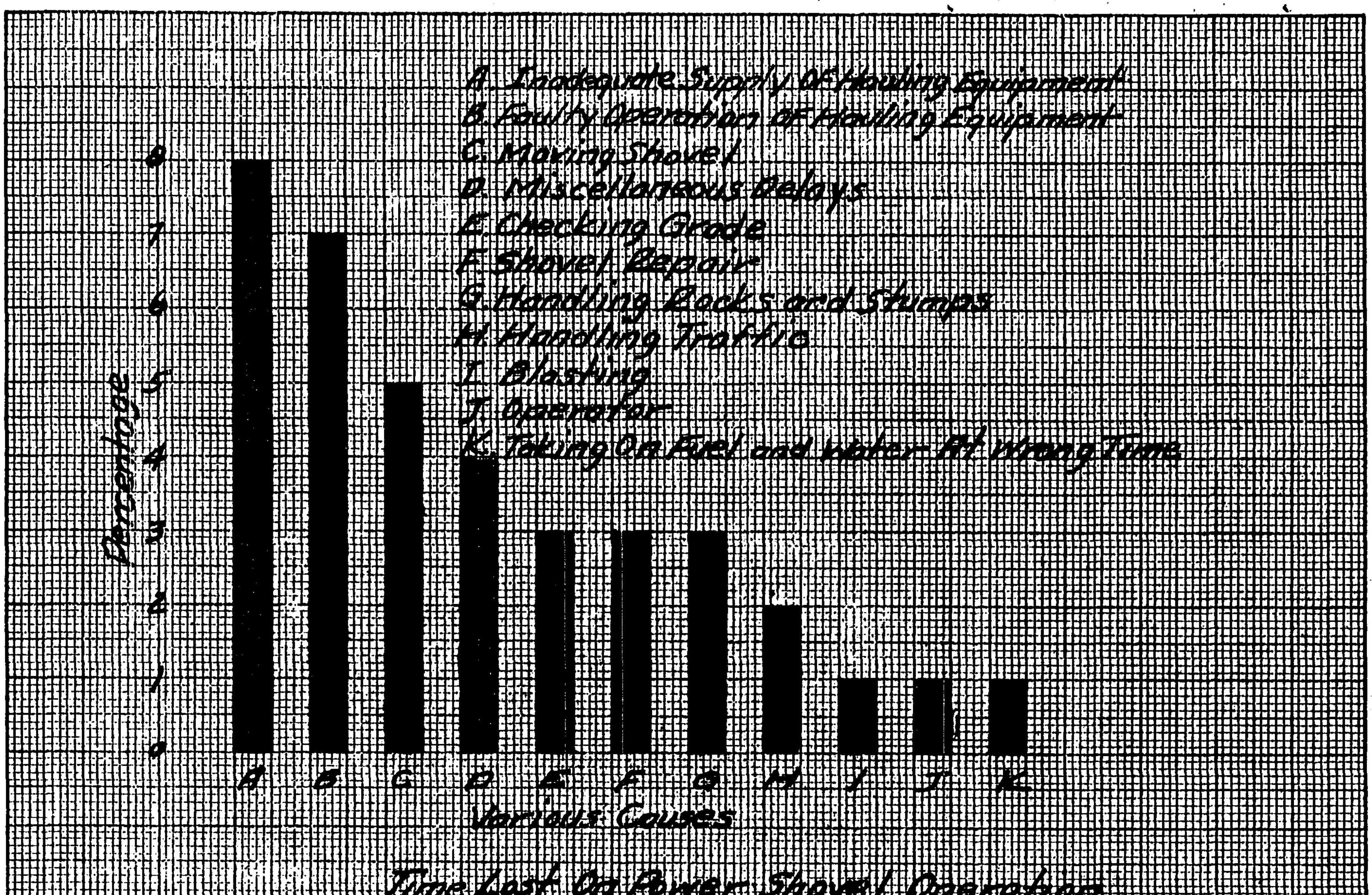
Description	%
Shovel repairs	10
Unfavorable weather and wet grade	9
Miscellaneous delays	3

During the 12,046 hours that these 71 shovels were actually in operation, they were timed with a stop-watch for 1,760 hours. During this timing period 674 hours, or 38% of the stop-watch study time, was lost through small delays of less than 15 minutes' duration. The avoidable delays are:

TABLE XXVII

Description	%
Faulty operation of hauling equipment	7
Inadequate supply of hauling equipment	8
Moving shovel	3
Checking grade	3
Taking on fuel and water at wrong time	1

Form E-5


A. Inadequate Supply Of Hauling Equipment
B. Faulty Operation Of Hauling Equipment
C. Moving Shovel
D. Miscellaneous Delays
E. Checking Grade
F. Shovel Repair
G. Handling Rocks and Stumps
H. Handling Traffic
I. Blasting
J. Operator
K. Taking On Fuel and Water At Wrong Time
Percentage
0
1
2
3
4
5
6
7
8
A B C D E F G H I J K
Various Causes
Time Lost On Power Shovel Operation

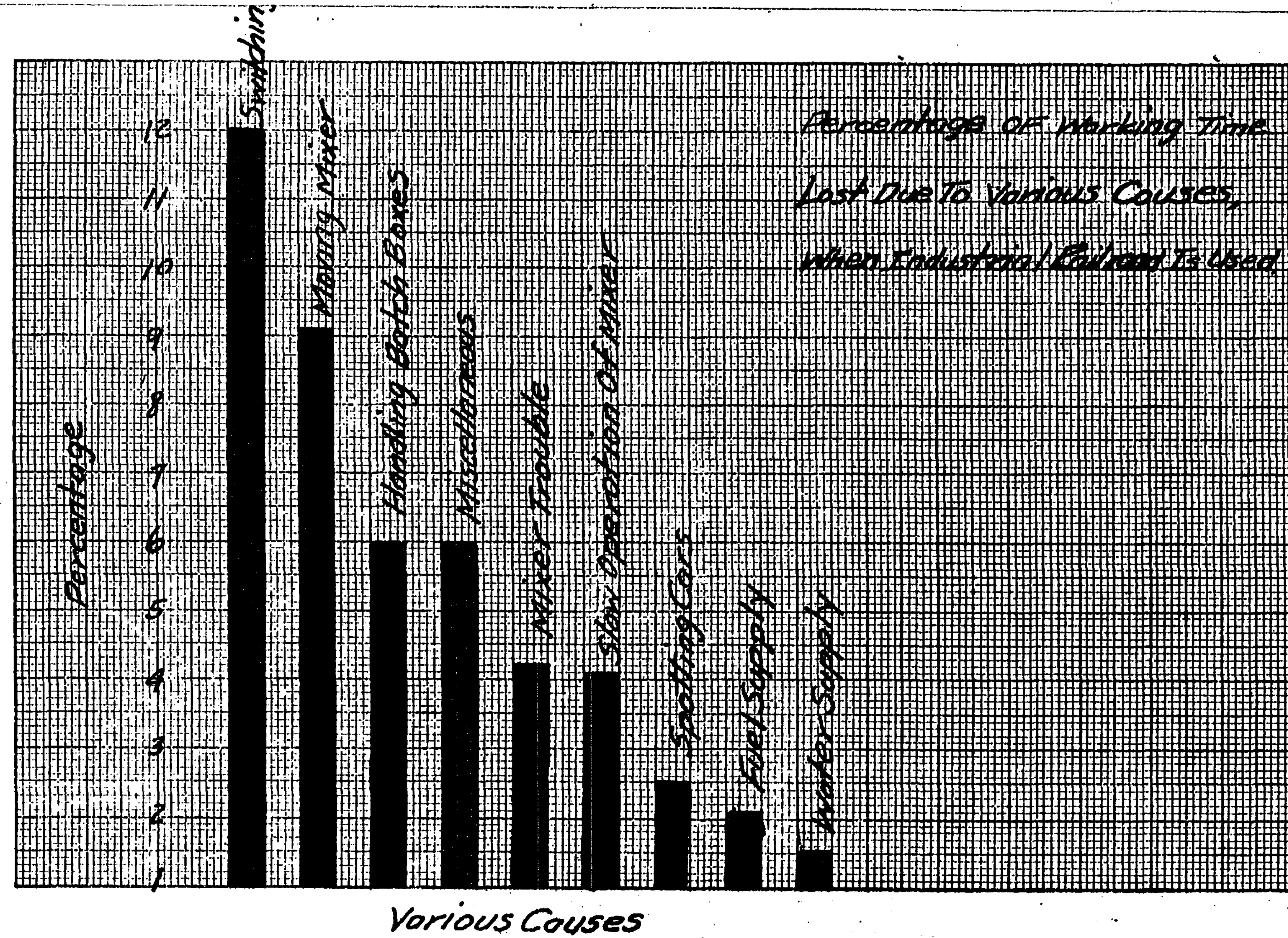
E. Time Lost on Industrial Railway

Studies (134) by the Bureau of Public Roads indicate that the mixer is in operation at a little better over 50% of working time, when the industrial railway is used. Percentage of working time lost because of various causes averages 48%. The time taken in shifting trains is a common cause of mixer delays. Derailments are also a common cause; they not only cause rather frequent mixer delays, but also the spilling and loss of numerous batches. The loss of time from switching trains at the mixer is another delay. The following table summarizes the percentage of working time lost due to various causes.

TABLE XXVIII

Description	%
Proportion of working time mixer was in operation	52.5
Time losses due to:	
Handling batch boxes	6.0
Spotting cars	2.5
Switching	12.0
Mixer trouble	4.2
Slow operation of mixes	4.1
Moving mixer	9.1
Water supply	1.5
Fuel supply	2.1
Miscellaneous	6.0
Total	100.0

Form E-5


Percentage Of Working Time
Lost Due To Various Causes,
When Industrial Is Used.
Percentage
12
11
10
9
8
7
6
5
4
3
2
1
Switching
Moving Mixer
Handling Batch Boxes
Miscellaneous
Mixer Trouble
Slow Operation Of Mixer
Spotting Cars
Fuel Supply
Water Supply
Various Causes

No time losses on account of weather and subgrade are included in the above studies.

F. Time Lost on Elevating Grader

Delay of one kind or another accounting for time losses may be summarized under three headings - breakdowns, clean-up and stock resting. Elevating graders are often continued in service long after they have become so badly worn that breakage is frequent and trouble with the elevating mechanism more or less chronic. The result is not only the definite time losses, but a constant loss of efficiency. The chain drives and belt give the most trouble. Other parts break occasionally. Lack of proper and constant maintenance is the outstanding cause of this trouble.

The clean-up around the lower roller stops the outfit oftentimes each day. The continued operations of the elevating grader are caused by the tendency of droppings to accummulate above the bottom roller and on the belt itself. These accummulations must be removed from time to time as often as once for every 13 wagons loaded. The clean-up takes an average of 4 minutes. In a 10 hour day, the loss of time from this cause is considerable.

The last delay results from the stock-resting. This is most conspicuous when the grader is drawn by 16 or 20 horses. The time losses on horse drawn jobs sometimes run in the neighborhood of 20% in hot weather, whereas the time losses on caterpillar tractor jobs is 5%. It is evident that the caterpillar tractor shows its great advantage. It does not tire as the percentage of time under full load is increased and hot weather has no adverse effect on it. Where a high rate of production is to be obtained, the caterpillar tractor offers a source of power at once dependable and effective.

G. Time Losses on Fresno and Wheeler

The studies which have been made by the Bureau of Public Roads indicate that the losses suffered by contractors doing fresno work fall under the two categories of managerial losses and bidding losses. The former consists of those due to improper adjustment of equipment to the work, short haul, time lost in loading, turning, careless dumping, and a number of miscellaneous losses not directly related to these, while the latter results from a failure to gauge correctly the influence of haul. Poor plowing is often a factor in short loading; failure to remove the roots of trees results in light loading and loss of time in loading. All these affect the time spent in loading. The loss of but a tenth of a minute on each load due to long swing of fresno means the loss of a hundred yards on the day's output. Studies also show that very stiff clay tends to increase the time required for loading, unloading, and turning. Time losses due to weather and wet subgrade are considerable. The mules move a little more slowly and there is a tendency to lose time in loading and dumping.

Studies also indicate that the time required to operate the wheeler per each load is as follows:

1. turning at the cut, 18 sec., 2. turning at the fill, 16 sec., 3. loading, 21 sec., 4. and dumping 14 sec. These are operations which must be performed with every load, and the fact that they sum up to only 1.25 minutes as against an average consumption of 3 minutes per load, in addition to the time used in hauling and in returning from the dump draws attention to the importance of miscellaneous losses as a factor in cutting down output. This loss of 1.75 minutes per load is about 30% of the time required for a 400 ft. haul and about 20% of the time required for an 800 ft. haul. Such losses arise from all kinds of delays which are similar to the losses encountered on fresno jobs.

H. Summary of Time Losses on Concrete Paving Project

The labor and equipment cost per day for operating a mixer varies but little whether the production is 300 or 400 batches per day. The value of eliminating all avoidable delays whether they are large or small can readily be appreciated. Studies show that the average highway contractor's outfit operates only about 60 to 65 per cent of the available working time that is actually spent on the job and the rest of 35 to 40 per cent is lost due to various causes as summarized in the following table. Time losses due to weather, holidays and Sundays occupy larger percentages of time losses. Inadequate supply of hauling equipment to supply the mixer with the maximum number of batches it can mix per hour is one of the causes of delay on some paving jobs. Trouble with water supply for mixing and curing causes another delay on the average job. These delays may be due to a leaky pipe line, to a pipe line that is only 2 inches in diameter when a $2\frac{1}{2}$ inch or 3 inch line is necessary, or to a water pump that does not have the capacity to supply the necessary amount of water, or that may be worn out. Time loss is sometimes caused by lack of materials at the plant because of uncertainty of shipments of aggregates or cement. Time loss due to lack of prepared and wet subgrade, results of rain, is most serious toward paving operation. Another delay is the mixer breakdown which is inevitable in a continuous operation every minute. The so-called miscellaneous delays are due to moving the turntable, placing the expansion joints, interference by the inspector and superintendent, slow operation of the mixer operator, etc. The delays so summarized may be classified as those avoidable and unavoidable. In so far as avoidable delays, the contractor can eliminate the lost time to a minimum by rigid and proper supervision and careful study over every operation. Without these even the best equipment and skilled labor will not produce.

TABLE XXIX

RESULTS OF TIME LOSSES ON CONCRETE PAVING OPERATION OVER ALL PARTS OF THE UNITED STATES

Time Losses Due to Various Causes (%)	Project No. or Location					
	U. S.[1] (1927)	U. S. (1925)	Pennsylvania[2] (1922)	Iowa[3] (1921, '22, '23)	Texas (1927)	Ames[4] (1929)
Operating Efficiency	58	57.3		63.5	48.4	65
Inadequate supply of hauling equipment	3	13.6	3			
Mixer trouble	2	4.9			4.94	4.8
Lack of materials	4			4.32		2.5
Inadequate water supply	2					
Lack of prepared subgrade	4	1.6			7.76	3.2
Weather	9		37	13.23	24.94	6.6
Wet subgrade	9					4.4
Moving the plant	3		5	2.77	4.58	1.7
Excess length of mixing cycle		3.5				0.6
Slow operation other than mixing cycle		8.4			.60	7.8
Delays due to handling trucks		4.0			2.94	1.4
Trouble with water supply		2.0			2.86	2.8
Finisher		4.0				0.8
Holidays and Sundays			21	13.34		2.4
Freight embargo			21			
Breakdown			21	0.77		
Strike			3			

Miscellaneous	4	0.7	5	2.05	2.99	1.0

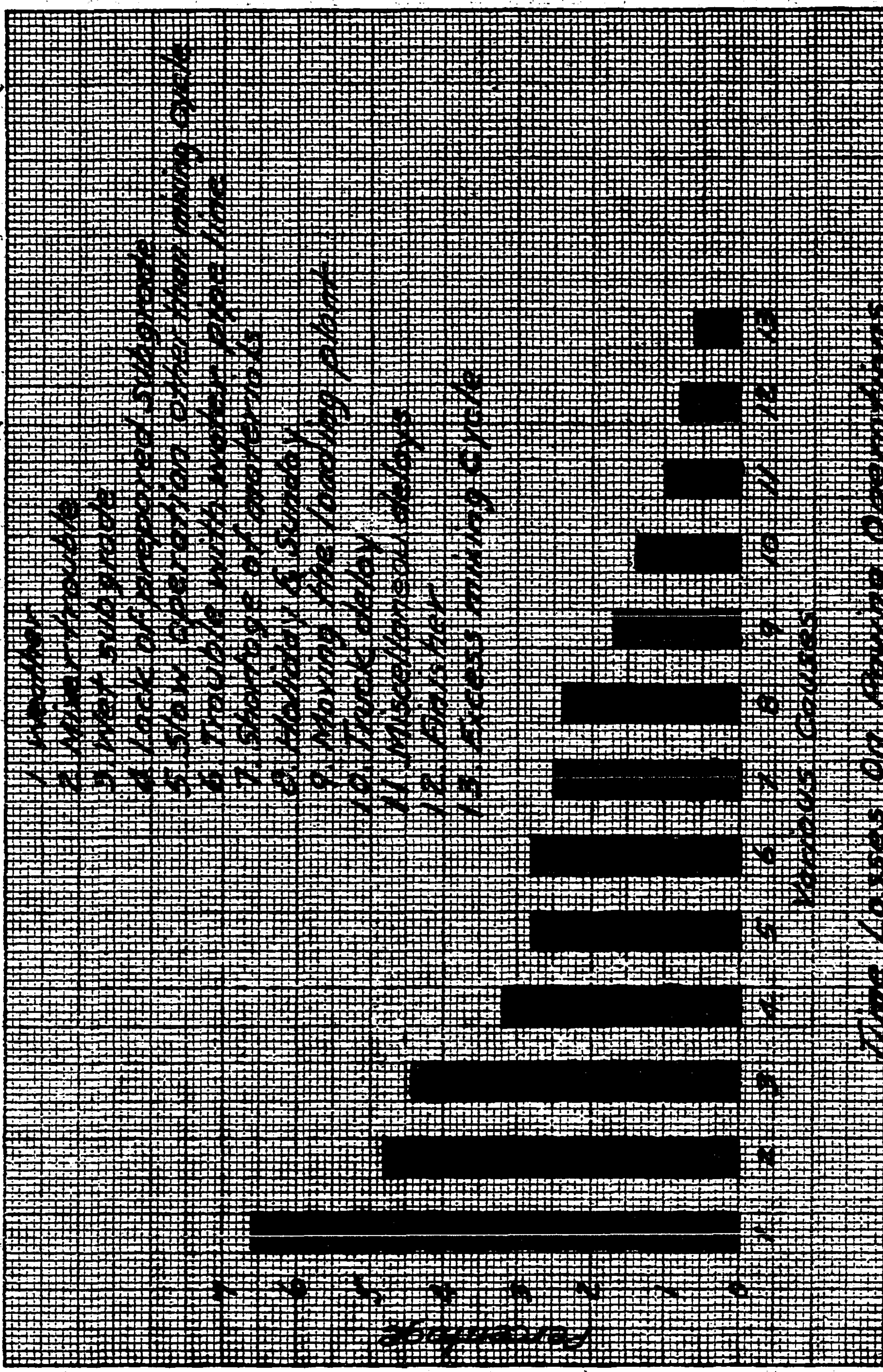
[1]Studies by Bureau of Public Roads covered 44 concrete paving projects during the past two years in all parts of the United States

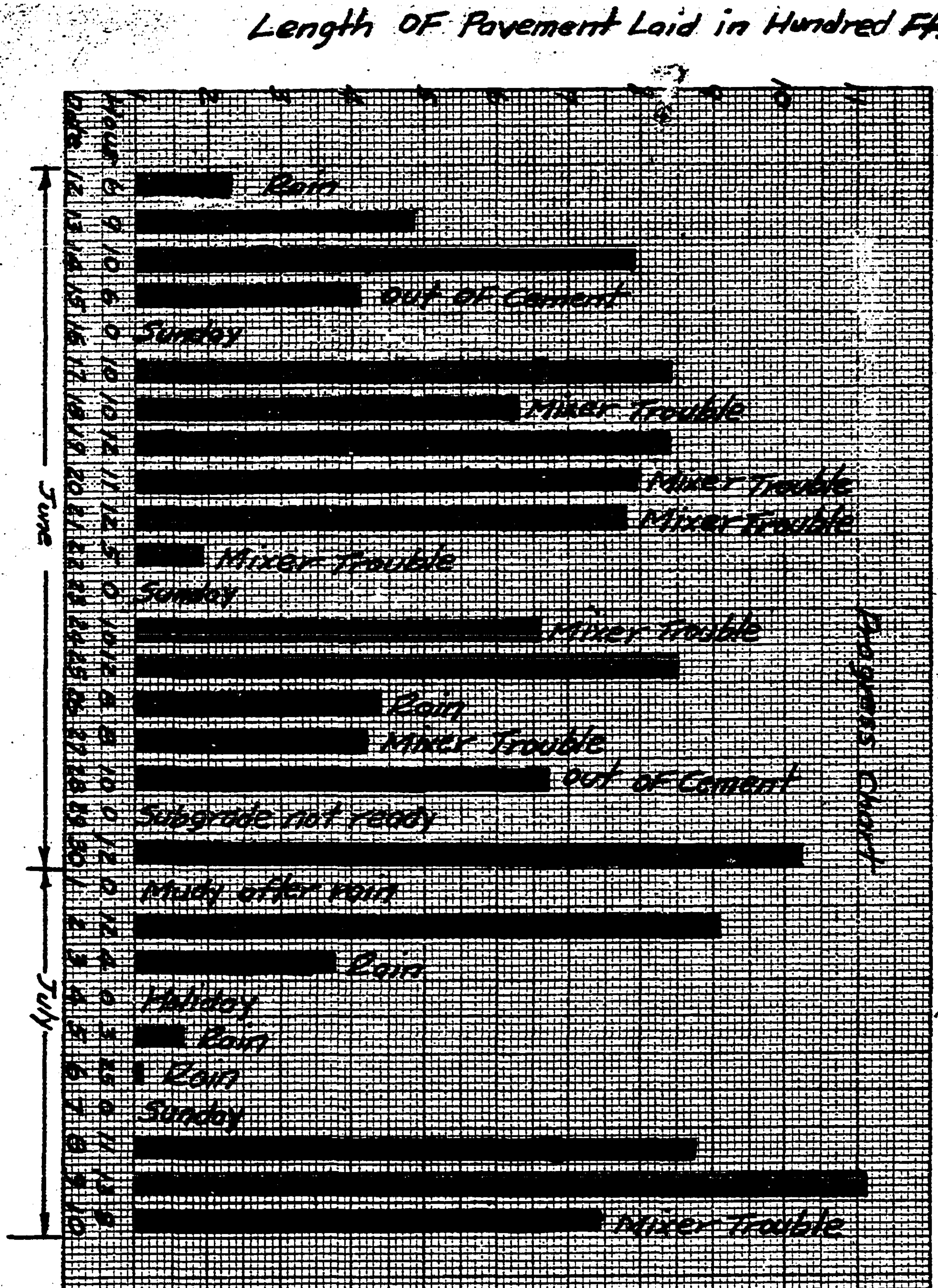
[2]Averaged three concrete paving jobs

[3]Averaged three years of concrete paving projects

[4]Data obtained by the writer in the field.

Form E-5


1. Weather
2. Mixer trouble
3. Wet subgrade
4. Lack of prepared subgrade
5. Slow operation other than mixing cycle
6. Trouble with water pipe line
7. Shortage of materials
8. Holiday & Sunday
9. Moving the loading plant
10. Truck delay
11. Miscellaneous delays
12. Finisher
13. Excess mixing Cycle
Percentage
0
1
2
3
4
5
6
7
1
2
3
4
5
6
7
8
9
10
11
12
13
Various Causes
Time Losses On Paving Operations


Length OF Pavement Laid in Hundred Ft.
Progress Chart
Date
Hours
June
July
Rain
out of Cement
Sunday
Mixer Trouble
Mixer Trouble
Mixer Trouble
Mixer Trouble
Sunday
Mixer Trouble
Rain
Mixer Trouble
out of Cement
Subgrade not ready
Muddy after rain
Rain
Holiday
Rain
Rain
Sunday
Mixer Trouble

Form E-5

VII. MIXED-IN-TRANSIT SYSTEM

A. Advantages of The Truck Mixer Over The Paver

As it is generally recognized, the paver holds the "key and the bottle neck" in paving production. It seems that the present pavers 27E and 32E have reached their maximum capacity and usefulness. No higher production can be obtained on the present paver unless a new system is introduced. Recently the so-called mix-in-transit system or truck mix was put in the market. Its advantages and significance over the paver may be summarized as follows:

1. The truck mixer system of mixing in transit combines in one operation, hauling and mixing.

2. It consists simply of the truck mixers and a semi-portable batching plant similar to that now used in dry-batching for paver operation.

3. The additional cost invested on the pumping and pipe line equipment for delivering water to paver operations on the subgrade is greatly reduced or entirely eliminated by mixing in transit, if the calcium chloride or light oil is used in curing.

4. At the present time thirty states specify the 1-minute mix. Ten states require a 1-1/4 minute mix. Eight states require 1-1/2 minute mix and one state requires 1-3/4 minute mix. As mentioned before 3/4 minute mix will produce 60 batches per hour, 1 minute mix, 48 batches, 1-1/2 minute mix, 35 batches, and 1-3/4 minute mix, 30 batches. In the

truck mixer system, if the effective mixing time is longer than average 60 seconds, it will not shorten the daily production. There is a great advantage to those who shorten the mixing cycle to 3/4 second and sacrifice the strength for the production.

5. The present paving mixers are pretty near standardized: they are 10S, 13S and 27E. Its maximum capacity is 1 cu. yd. While the size of the truck mixer ranges from one to five cu. yd. capacity in mixed concrete per batch, it is possible to plan and maintain concrete production on any scale desired. It does not depend upon the proportions used or the length of mixing time, which are important factors in paver output.

6. With truck mixers, delays will be eliminated to a minimum due to mixer break-down, moving of the mixer, placing of the steels on the subgrade, preparation of the final subgrade, inadequate supply of transportation, equipment, etc.

7. The cost of truck mixer equipment is only 6% to 10% more than the investment required in paver equipment for a 5-mile road job on the same truck hauling basis. The following comparative analysis* shows it will increase production 15% to 20% at a lower equipment cost per cubic yard.

*"What Road Paving Really Needs", F. C. Wilcox, New York, 1929. page 22.

TABLE XXX
COMPARISON OF PAVER AND TRUCK MIXER PRODUCTION AND PRODUCTION COSTS EXPRESSED IN PERCENTAGES. (211)

Item	Basis of Comparison	Paver Operation	Truck Mixer Operation	Percentage of Increase or Decrease
Plant Cost (Note 1)	Cost of plant for a 5-mile road job	$128,000.00	$135,800.00	6% increase over paver plant
Production in cu. yds.	Max. truck capacity 1 mile haul, 2 cu. yd. batch, 10 hrs. operation	365 cu.yds.	470 cu.yds.	Maximum of 28½% increase over paver operation
	Av. assumed per day 60% of maximum.	219 cu.yds.	282 cu.yds.	
	Number of cu.yds. in 4 years based on season concreting operations of 100, 150, and 200 days			
	100 days for 4 years	8[illegible],600 cu.yd.	112,800 cu.yd.	
	150 days for 4 years	131,400 cu.yd.	169,200 cu.yd.	
	200 days for 4 years	175,200 cu.yd.	225,600 cu.yd.	
Cost per cu. yd. on the basis of depreciating plant investment in 4 years (labor and repair costs not included)	Cost per cu. yd. exclusive of labor and repair costs			
	100 days operation for 4 years	$1.461 per cu.yd.	$1.203 per cu.yd.	17% decrease compared to paver operation
	150 days operation for 4 years	.974 per cu.yd.	.802 per cu.yd.	
	200 days operation for 4 years	.73 per cu.yd.	.601 per cu.yd.	

Note 1 - Comparison based on 2-batch trucks (7 bags per batch) for dry-batching to paver, and 2-cubic yard truck mixers, total capacity in each case assumed to be the equivalent of two 7-bag batches at 1:2:3½, or 58.8 cubic feet (2.1777 cubic yards) of mixed concrete per trip.

VIII. CONCLUSION AND RECOMMENDATION

1. The construction of concrete highway pavement is essentially a manufacturing process or progressive series of consecutive operations. If materials are loaded, they must be hauled, if they are hauled, they must be mixed, if they are mixed, they must be placed, spread and finished and they must be cured. Every operation must be coordinated and synchronized in every possible way.

2. The application of efficiency studies to the paving operations will throw some light and have some check upon the capacity and adaptability of the machine and the ability and skill of the laborers; it induces them to work better with less wasted motion and time, thereby reducing labor costs through a higher and more uniform rate of production; it reduces the idle time of men and machinery; it eliminates to the minimum the time losses of various avoidable and unavoidable delays through the findings of stop-watch readings; it provides the contractor with an accurate account of labor cost per unit of production; and it assures a higher quality of product.

3. Indication of current good practice of concrete paving operation:

a. Proportioning aggregates by weight increased in popularity during the past year in the concrete highway construction.

b. Quite a few states have adopted a strength specification either by weight or by arbitrary methods. In nearly all cases the compressive strength specified is 3,000 pounds per square inch at 28 days. Proportioning strictly in accordance with the water-cement ratio law was practiced in numerous jobs throughout the country. The usual specification is 5 to 6 gallons of water per bag of cement.

c. The general trend to increase mixing time still remains to be seen. About eighteen states now specify that concrete shall be mixed for a period longer than one minute. The usual increase has been to 1-1/4 to 1-1/2 minutes. Field studies show that the specification of increased mixing time does shorten daily productions.

d. The general practice of surface finishing has been reduced to striking off (by machine), initial belting, removal of excess surface water by means of a roller or float, checking surface with the straightedge. Excessive tamping and floating have been prohibited in all states.

e. The practice of laying burlap directly on the pavement surface has become standard practice in all states. The method of curing is optional in most states. Wet earth and ponding are still the favorite methods employed by contractors. Calcium chloride is also often used. The so-called "Hunt Process" method for curing concrete pavement has been adopted by some states. It will prove its usefulness and convenience in the modern concrete paving construction.

f. Continuous longitudinal edge bars, painted or oiled to prevent bonding are quite generally used in all sections of the country in concrete pavements. There has been a general tendency to specify wire mesh in concrete pavements now being built in the vicinity of metropolitan cities, which carry heavy traffic.

g. Most states now specify transverse expansion joints, with their placement ranging at intervals of 30 to 200 ft. The usual specification is between 40 and 80 ft. The construction of 4" wide expansion joints at 1000 ft. intervals is specified by the Illinois State Highway Department. Practically every state now specifies a longitudinal center joint. The "dummy joint" has been used quite extensively in concrete pavement construction in Pacific Coast states.

h. The usual section of the thickened edge type of pavement is 9-6-9 inches, although a number of states have specified 9-7-9 and 10-7-10 sections.

i. The 20' pavement seems to be standardized. The construction of 40' wide roads has heretofore been confined more or less to main arteries leading to metropolitan cities. In constructing them, one-half the width, or 20 ft. is built at a time. This half, after being properly cured, may then be used by traffic while the second strip is being built alongside.

j. The use of 7-bag 2 batches truck seems to be most popular; while three batches truck is sometimes used. In a long haul over twenty miles, the use of industrial railways is not unusual, where the grade is not over 5%. Hauling by the combination of trucks and industrial railways has been done in some paving jobs. Studies show transfer of the load from the trucks to the rails or vice versa is the most serious delay.

k. The general practice of loading the aggregates seems to favor the batching plant method. Central proportion plant method is not often used in the rural highway construction.

4. Studies show that in order to attain the higher or uniform production, the following requirements must be met:

a. Adequate and suitable road equipment must be used.

b. Skilled labor must be employed.

c. The weather must be such that the work in question can be carried on.

d. Rigid supervision and efficient management must be secured.

5. Road building machinery and its operation analysis:

a. The substitution of power equipment for hand and team work which has already been accomplished will point to a still greater development along these lines in the future. Every time as the road machinery is improved, the daily production is also increased.

b. The question of depreciation and obsolence are serious considerations to the contractors. With standardization, he has fair assurance that the investment he makes today in an expensive machine will not be quickly impaired by the appearance in the market of a new model shortly after his purchase.

c. In fresno work the various necessary operations of loading, dumping, turning at each end of the trip and throwing the fresno back into loading position can readily be performed within 1 minute. A normal fresno job will show an average haul of 175 feet. On such a job the average output under average management would be about 72 cubic yards per fresno per 10 hour working day.

d. Field studies show that the total time required to perform the standard operations of loading, dumping, turning, etc., is considerably longer for the wheeler than for the fresno. The time constant for these operations averages three minutes. Over 400 feet haul the wheeler is more economical than the fresno.

e. The ideal field of the elevating grader is adapted to rolling prairie regions where cuts are fairly long and the side slope slight so as to avoid much dead-heading and the soil reasonably free from rocks, large boulders or stumps. With team-drawn wagons, the grader speed should be maintained at about 225 feet per minute. With motorized hauling the grader can be speeded up to 250 feet per minute.

f. The power shovel is far less affected by the contour of the surface or the character of the material. The daily output is affected by the kind of materials, angles of swing, size of shovels and the alertness of the operator.

g. A good 1 cu. yd. crane in the hands of a skillful operator will move a bucket every half minute from a freight car into the hoppers and will operate at a slightly higher rate from the stock piles into the hoppers as indicated by the actual stop-watch readings. With good operation, the output should be about 60 cubic yards per hour; but the daily output will hardly reach the hourly output multiplied by the number of hours. The reason is the delays caused by shifting cars or machine break down.

h. The old homemade bin is practically out of use, as the measuring device is not so accurate and reliable and it takes a minute or so to load the coarse aggregate and half that time to load the sand, while the modern steel bin will discharge a 6 bag batch in approximately 20 seconds as indicated by the stop-watch readings.

i. In place of steel bins, a combination of bucket loader and belt is sometimes used. There is not any data available to show which type of loading system is more economical, but it does indicate that the bucket loaders and belt takes considerably more time to load in a 2 batch truck than the modern steel bins.

j. On a concrete paving job the mixer is considered as the "key producer". The production capacity of a 6 bag mixer may be taken at 45 batches an hour in the hands of an experienced and alert operator; but the daily output will hardly reach the hourly output multiplied by the number of working hours. The reason is the delay caused by inadequate supply of materials and hauling equipment, mixer break-down, unprepared subgrade, etc.

k. To hire the trucks on the batch mileage basis is more economical to the contractor than to purchase a fleet of trucks, if all the factors are considered such as, first cost, interest, depreciation, maintenance and repair and overhead. The number of trucks to be supplied depends upon the size of truck used, whether 2 or 3 batch, distance to be hauled, speed of the trucks, condition of the road, the total time required to load the aggregates and cement at the material yard and miscellaneous delays. The contractor is warned to have one or more trucks on the job than are actually needed in order to guard against any unexpected delays which cause the mixers to stop operation.

l. The fact that the use of industrial railways appears to be decreasing is that a highway contractor who invests in this form of equipment finds that a large part of his working capital is tied up in equipment and other reasons are the high costs involved.

m. The adequacy of the pumping plant depends absolutely on the use of a pipe line of such size that the pressure head will always be within the limits for which the pump is designed. There are vital differences between a pump designed to deliver 12[illegible] gallons a minute against a pressure head of 120 pounds and one designed to deliver at the same rate against a pressure head of 400 pounds.

6. The daily cost of operating a modern road building plant is nearly independent of the rate of production. We note a daily operating cost of $75.00 for the power shovel and $70.00 for the wagon; the cost holds good whether the material dug is 400 or 800 cu. yd. a day. And the daily cost of operating a fleet of road paving equipment is $400.00 whether the daily production of pavement be 500 feet or 1200 feet. The following considerations strongly indicate that a proper and efficient management has great effect on production and correspondingly its unit cost.

a. Mixing time

b. Size of batches

c. Length of haul

d. Various operations under poor and good management

e. Time saving in days means amount of money saved in dollars with the result of high daily output.

f. The higher the daily output will be lower the unit cost

g. Location of material yard and the number of setups.

7. The production efficiency of operating a concrete road paving job is a little over 80% and the rest of percentage of time lost is due to avoidable and unavoidable delays. They are.

a. Weather (snow, frost, rain)

b. Mixer trouble

c. Lack of materials (cement, aggregates)

d. Inadequate water supply

e. Lack of prepared subgrade

f. Inadequate supply of hauling equipment

g. Wet subgrade

h. Moving and assembling the plant

i. Excess length of mixing cycle

j. Slow operation of the mixer operator

k. Holiday and Sunday

l. Trouble with water pipe or water pump

m. Miscellaneous (finisher, moving of the mixer and turntable, interferences by the inspector and superintendent, strike, placing of the joints and reinforcements, etc.)

8. As it is generally recognized, the paver holds the "key and the bottle neck" in paving production. It seems that the present pavers 27E and 32E have reached their maximum capacity and usefulness. No higher output can be expected on the present process, unless a new system is introduced. Recently, the so-called mix-in-transit system or truck mixer wasplaced on the market. It offers a great possibility of increasing the daily output. Its advantages and significance over the present power are worthy of consideration and adaption by the highway contractor.

IX. ACKNOWLEDGMENT

The writer wishes to express his appreciation and gratitude to the following persons under whose instruction and guidance for several years he has been specializing in Transportation in the Graduate School, Iowa State College: T. R. Agg, professor of highway engineering, W. L. Foster, professor of railway engineering and E. B. Smith, professor of research in aeronautical engineering.

He is also indebted to R. A. Moyer, assistant professor of highway engineering for reading over the manuscript and giving suggestions and comments on the subject matter in regard to this investigation.

Acknowledgment is also extended to Professor A. H. Fuller, head of Civil Engineering Department for his courtesy and frankness toward the Chinese students who have been associated with him in the past years.

X. BIBLIOGRAPHY

1. Allen, T. W.
Control of construction unit costs. Con. Engr. 53:143-6. Jl. 19 '27.

2. Allen, T. W.
Increasing production in highway construction. Rds. and Sts. 67:485-9. Nov. 11 '27.

3. Allen, T. W.
Waste in construction. Eng. N. 103:939-40. D. 12 '29.

4. Allen, T. W., and Anderson, A. P.
Hauling with large tractor drawn wagons in power shovel operation. Rds. and Sts. 68:241-44. Mar. '28.

5. Allen, T. W. and Anderson, A. P.
Power-shovel operation in highway grading. Pub. Roads. 8:251-62-74. F. '28; 9:9-23. Mar. '28.

6. Alexander, H. F.
Record paving job by Avon Lake village. Pub. Works. 59:469-71. D. '28.

7. Ames, L. R.
Largest paver in the world. Rds. and Sts. 67:3-5. Ja. '27.

8. Anderson, A. F.
Power-shovel production grading highway road bed. Eng. N. Rec. 103:860-1. N. 28 '29.

9. Anderson, A. F.
Time losses in concrete road construction. Pub. Roads. 7:193-208. Dec. '26.

10. Anderson, A. F.
Value of the foreman on fresno and wheel scraper work. Pub. Roads. 7:56-6. My. '26.

11. Anon.
15 miles road paved in 125 days. il Eng. and Contr. 63:80. Ja. 7. '25.

12. Anon.
1928 accomplishments in concrete pavement construction. il Concrete. 34:13-6; 48-9. Ja. '29.

13. Anon.
6-1/4 miles concrete road in 52 days. il. Eng. and Contr. 63:715-16. Ap. 1 '25.

14. Anon.
A close check on costs. Eng. and Contr. 19:55-9. Jl. '29.

15. Anon.
A graphic record of highway growth. Eng. N. Rec. 101:8-10. Ja. 3 '29.

16. Anon.
A New York state concrete highway job. Pub. Works 60:464-6. Dec. '29.

17. Anon.
A well balanced organization makes high average for concrete poured. Eng. and Contr. 19:81-2. Sept. '29.

18. Anon.
A well planned unloading plant. Eng. and Contr. 19:82. Jl. '29.

19. Anon.
Batching plant planned for a truck a minute. Eng. and Contr. 19:74-6. Sept. '29.

20. Anon.
Central mixing plant on 4.41 mile Canadian concrete road. Eng. and Contr. 19:54-6. Aug. '29.

21. Anon.
Central mixing plants. Western Construction News. 4:282-4. Je. 10 '29.

22. Anon.
Clearing and grubbing costs on California job. Eng. and Contr. 68:196. My. '29.

23. Anon.
Combination haul on road job; Niles-Ashtabula road. il. Eng. and Contr. 63:325-8. F. 4 '25.

24. Anon.
Commercial road-mixed concrete for county road. il. Pub. Works. 60:155. Ap. '29.

25. Anon.
Comparison of expenditures 1904-1923. Eng. and Contr. 61:711-3. Ap. 2 '24.

26. Anon.
Concrete control on Iowa pavement job. Concrete. 33:21-3. O. '28.

27. Anon.
Concrete pavement placed under contract in the United States from 1909-1925, inclusive. Concrete Highway magazine. 10:14-5. Ja. '26.

28. Anon.
Concrete paving record in Illinois. Pub. Works. 55:359-62. D. '24.

29. Anon.
Concrete road building experience in New York. Eng. and Contr. 19:83-4. Jl. '29.

30. Anon.
Concrete road building plant and its operation. Eng. and Contr. 19:81-4. O. '29.

31. Anon.
Concrete road construction experienced in Illinois. Eng. and Contr. 19:74-6. Aug. '29.

32. Anon.
Concrete road built with combination haul plant. il. Concrete. 26:205-6. Jl. '25.

33. Anon.
Concrete road plants. Pub. Works. 60:344-6. Sept. '29.

34. Anon.
Concrete road with machine molded center joint. il. diags. Eng. N. Rec. 95:354-5. Aug. 27 '25.

35. Anon.
Concrete yardage awards maintain high level through July, 1928. Good Roads. 71:522. Sept. '28.

36. Anon.
Construction equipment and materials. Eng. N. Rec. 102:569-71. Ap. 4 '29.

37. Anon.
Construction equipment - past and present; the road grader. Eng. N. Rec. 93:80-2; 102-2. Jl. 10-17 '24.

38. Anon.
Construction of the Pensacola scenic highway. Eng. and Contr. 19:76-8. O. '29.

39. Anon.
Contractor turns inventor (concrete transporting body). Eng. and Contr. 68:48. Je. '29.

40. Anon.
Construction method on federal-aid, state highway in northern Illinois. Rds. and Sts. 68:491-2. O. '28.

41. Anon.
Construction plant and method for highways. Am. Soc. C. E. Proc. 55:639-66. 2046-8. Mr. O. '29.

42. Anon.
Contract practices in five hundred cities. Pub. Works. 60:117-9. Mar. '29.

43. Anon.
Contractors aggregate producing plant. il. Rds. and Sts. 67:350. Aug. '27.

44. Anon.
Cost of grading Caddo, Parish, La. Eng. and Contr. 68:316. Aug. '29.

45. Anon.
Cost of operating central mixing plant. Eng. and Contr. 68:249. Je. '29.

46. Anon.
Cost of tractor blade grading. Rds. and Sts. 682:268. Je. '28.

47. Anon.
Day and night shifts in concrete paving. Eng. and Contr. 64:1228. D. 2 '25.

48. Anon.
Dispatching system saves trucks on paving job. il. Eng. and Contr. 68:195-6. My. '29.

49. Anon.
Double hose connection on mixer increase output. Concrete Magazine. 10:26. F. '26.

50. Anon.
Efficiency man increase production. Rds. and Sts. 69:414. Nov. '29.

51. Anon.
Efficient road construction in Colorado. Pub. Works. 60:162-3. Ap. '29.

52. Anon.
Eliminating time losses in road building through subgrade production. Concrete Highway and Pub. Improvements. 12:77. Ap. '28.

53. Anon.
Five miles of concrete pavement laid by batch box method. Rds. and Sts. 68:287-9. Je. '28.

54. Anon.
Good plant layout on State road job near Detroit. Eng. and Contr. 19:88-8. Aug. '29.

55. Anon.
Graphic record of highway growth. Eng. N. Rec. 102:8-9. Mar. 3 '29.

56. Anon.
High-production paving job on Illinois highway shows careful planning. Il. Rds. and Sts. 69:97-8. Mr. '29.

57. Anon.
Industrial railway on 8-mile Ontario paving project. Eng. and Contr. 19:66-8. Sept. '29.

58. Anon.
Iowa experiment with "Dummy" longitudinal joint. Concrete. 35:17-8. Aug. '29.

59. Anon.
Job organization. Western Construction News. 4:78. F. 10 '29.

60. Anon.
Labor saving machinery for street construction work. Gas Age Rec. 54:391-3. Sept. 20 '24.

61. Anon.
Long batch haul does not slow up 5 mile county concrete job. Eng. and Contr. 19:77-8. Sept. '29.

62. Anon.
Methods of accounting and depreciation rates for construction equipment. Eng. and Contr. 68:153-6. Ap. '29.

63. Anon.
Method used in laying 86- feet of 20 ft. concrete pavement per day in Indiana. Eng. and Contr. 19:70-2. Dec. '29.

64. Anon.
Mileages by States of concrete pavement in U. S. Eng. N. Rec. 96:426. Mr. 11 '26.

65. Anon.
New and improved form grader. Rds. and Sts. 62:535. Sept. 3 '24.

66. Anon.
New design expected to cut cost of concrete roads. diag. plan. Eng. N. Rec. 92:614-5. Ap. 10 '24.

67. Anon.
Notes on estimating in road construction work. Mun and Co. Engr. 65:465-7. My. 16 '24.

68. Anon.
Obtaining efficiency in concrete road construction. Rds. and Sts. 68:457-9. Sept. '28.

69. Anon.
Organization of a Tennessee highway contractor. Eng. and Contr. 19:58-60. Sept. '29.

70. Anon.
Pavement awarded from 1924-1929. The Contractor. 12:56-7. F. '30.

71. Anon.
Paving outfit organized for 128 ft. per hour. Eng. and Contr. 19:71-3. Nov. '29.

72. Anon.
Prison labor road construction. Eng. and Contr. 62-769-70. O. 1 '24.

73. Anon.
Profits from reduced overruns. il. Concrete. 28:13-5. My. '26.

74. Anon.
Progressive speed record in laying concrete pavement. Pub. Works. 55:375-6. D. '24. O. 15 '21.

75. Anon.
Rapid highway work on Long Island. Pub. Works 51:287-91. O. 15 '21.

76. Anon.
Recent development in equipment for the road-builder. il. Eng. N. Rec. 96:39-41. Ja. 7 '26.

77. Anon.
Relative costs of material and labor in building construction. Eng. and Contr. 68:72. F. '29.

78. Anon.
Road bureau studying means of cutting pavement cost. Concrete. 28:31-2. My. '26.

79. Anon.
Road roller operation cost. Rds. and Sts. 64:1227. D. '25.

80. Anon.
Some concrete equipment that is new. il. Concrete. 28:26-32. Ja. '26.

81. Anon.
Some typical concrete road building in Illinois. Highway Eng. and Contr. 18:40-2. Mr. '28.

82. Anon.
Supplying water on a 5.59 mile road job. Eng. and Contr. 19:79. Jl. '29.

83. Anon.
The depreciation of road contractors' equipment. Good Roads. 72:244-6. My. '29.

84. Anon.
The outfits cost. The Highway Magazine. 20:267-8. O. '29.

85. Anon.
Time losses in concrete road construction. Good Roads. 71:295. My. '28.

86. Anon.
Trend in practice in road machinery. Con. Engr. 56:265-6. F. 26 '29.

87. Anon.
Truck and batch-box methods used in different sections of same project. Rds. and Sts. 68:471-3. O. '28.

88. Anon.
Using duplicate outfits on 15 mile 40 ft. state highway. Rds. and Sts. 68:335-8. Jl. '28.

89. Anon.
Water delivery makes long haul of batches economical. il. Eng. N. Rec. 97:335. Aug. 26 '26.

90. Anon.
Water supply data for concrete paving. Rds. and Sts. 67:198. My. '27.

91. Anon.
Winter highway work. Rds. and Sts. 67:354-5. Aug. '27.

92. Ballard, W. H.
The land leveler as a medium of earth transportation in subgrade construction. Rds. and Sts. 68:417-9; 60-62. Aug.-Sept. '28.

93. Beggs, N.
Central mixing plants for concrete. Con. Engr. 57:8[illegible]1-4. Dec. 17 '29.

94. Bell, T. L.
Concrete road building plant and its operation. Rds. and Sts. 69:235-9. Jl. '29.

95. Blanchette, W. A.
Production studies on highway construction. Rds. and Sts. 69:117-21. Ap. '29.

96. Boston, W. G.
Using charts in estimating operation time. Am. Mech. 69:322. Aug. 23 '28.

97. Brinkman, F. E.
40% saving worker's time; motion-time analysis. il Manuf. Ind. 16:103-6; 213-6. Je.-Jl. '28.

98. Brown, W. [illegible].
Highway construction cost keeping. Rds. and Sts. 68:413-5; 573-82. Aug.-Dec. '28.

99. Brown, V. T.
Analysis of overhead-job cost relationship. Eng. and Contr. 68:65-6. F. '29.

100. Bullen, J. T.
Cost of grading in Caddo Parish, La. Eng. and Contr. 68:316. Aug. '29.

101. Bushwell, J. F.
Concrete-mixer improvement and progress. Eng. N. Rec. 102:552-5. Ap. 4 '29.

102. Chapman, H. D.
Cashing in on a longer road construction season. Concrete. 32:21-3. Ja. '28.

103. Chapman, H. P.
Steady plugging overcome weather handicaps. Contr. and Engr. 17:228-30. O. '28.

104. Charles, W. T.
Concrete highway problem solved by modern road-making machinery. il. Dun's Int. R. 45:37-40. My. '25.

105. Charles, T. W.
Modern machinery supplanting the pick and shovel in road building. il. Dun's Int. R. 48:33-9. S. '26.

106. Collingnon, L. P.
Cost of subgrade preparation, mixing, laying, finishing concrete highway paving. Munic and Co. Eng. 71:327-8. D. '26.

107. Connel, W. H.
Contract working time and liquidated damages. Munic and Co. Eng. 71:292-4. N. '26.

108. Conner, C. N.
Working days and climatic conditions. Pub. Works. 60:252-4. Jl. '29.

109. Conner, C. N.
Progress in road construction methods and equipment during 1928. il. Pub. Works 60:8-14. Ja. '29.

110. Conner, C. N.
Relation of form setting to riding qualities of concrete pavement. Munic and Co. Eng. 68:111-6. Mr. '25.

111. Copeland, F. L.
Practical advantages of standardizing. Eng. N. Rec. 102:541-2. Ap. 4. '29.

112. Cummings, W. S.
Mechanical labor-saving devices on road work. Constructor. 5:29-30. Ap. '23.

113. Dale, R. B.
Epochal developments made in equipment engineering. Eng. N. Rec. 102:550-1. Ap. 4 '29.

114. Davis, E. K.
What is a day's work building concrete roads? Eng. N. Rec. 92:1063-4. Je. 19 '24.

115. Davlin, T.
Elements of risk in contracting. Eng. and Contr. 63:1008-9. My. 6 '25.

116. Denton, A. P.
Record construction of concrete on Redwood highway. Western Construction News. 4:247-9. My. 10 '29.

117. Dieck, R. G.
Daily labor vs. contract in Walla County, Washington. Eng. and Contr. 62:272-7. Aug. 6 '24.

118. Dickinson, D. E.
Profit or loss on contract. Rds. and Sts. 69: 209-10. Je. '29.

119. Edwards, H. W.
Establishing a state record in concrete road-building on California State paving project. Rds. and Sts. 69:343-5. O. '29.

120. Emerey, R. W.
Equipment standardization an economical need. Eng. N. Rec. 102:548-9. Ap. 4 '29.

121. Faulker, H. F.
Dummy joints prevent cracks in Seattle concrete pavement. Eng. N. Rec. 102:607-8. O. 17 '29.

122. Foster, J. E.
Recent practical development in concrete road construction. Contract Rec. 42:201-4. F. 22 '28.

123. Gage, R. B.
Factors that control the quality of concrete used in pavement construction. Rds. and Sts. 69:284-8. Aug. '29.

124. Gardiner, L.
Machinery's part in road building. Eng. N. Rec. 101:29-31. Ja. 3 '29.

125. Giles, R. T.
Large mixing plant tried out on road work. il. Eng. N. Rec. 97:866-7. N. 25 '26.

126. Gurney, J. A.
Bucket loaders and belt conveyors on road job. Rds. and Sts. 69:169-70. My. '29.

127. Hammer, M. O.
Cost data on a 10 mile concrete pavement job built by state forces. Rds. and Sts. 69:185-6. My. '29.

128. Hampsch, C. H.
Concrete paving costs in Tennessee. Rds. and Sts. 66:275. N. '26.

129. Harley, F. E.
Record keeping on highway building. Eng. N. Rec. 94:286. F. 12 '25.

130. Harrison, J. L.
Economical use of wheel scrapers. Pub. Roads. 5:16-23. D. '24.

131. Hathaway, C. M.
A summary of 1928 construction in Illinois. Concrete Highway and Pub. Improvements. 80:123-4. Nov.-Dec. '29.

132. Hathaway, C. M.
Increase efficiency of road construction. Eng. N. Rec. 101:25-8. Ja. 3 '29.

133. Hathaway, C. M.
Maximum production of concrete pavement. Contr. and Engr. 16:242-6. Ap. '28.

134. Harrison, J. L.
Efficiency in concrete road construction. Pub. Roads. 6:194-202; 241-50; 269-76; 7:18-24. Nov. 25 - Mar. 26.

135. Harrison, J. L.
Efficiency in the supervision of the construction of concrete road surfacing. Rds. and Sts. 65: 223-33. Ap. 7 '26.

136. Harrison, J. L.
How shall the highway contractor handle "Extra"? Good Roads. 72:21-5. Ja. '29.

137. Harrison, J. L.
Managing highway construction for profit. Eng. and Contr. 18:50-60; 83-6. Ja. - F. '28.

138. Harrison, J. L.
Management on concrete paving job. Munic and Co. Eng. 70:220-5. Ap. '26.

139. Harrison, J. L.
Production and profit coincident on road work. Eng. N. Rec. 99:886-8. D. 1 '27.

140. Harrison, J. L.
The cost of grading with fresnoes. Pub. Roads. 5:10-23. O. '24.

141. Harrison, J. L.
The effect of haul on the cost of earth work. Pub. Roads. 5:14-17. Sept. '24.

142. Harrison, J. L.
The element of haul in grading. Eng. and Contr. 67:517-9. O. '28.

143. Harrison, J. L.
Wagon and the elevating grader. il. diags. Pub. Roads. 6:25-33; 59-68; 73-80. Ap.-Je. '25.

144. Harrison, J. L.
What should be the hauling cost on concrete paving? Eng. N. Rec. 96:762-4. My. 13 '26.

145. Haskell, L. W.
The relation of time-study to production. S. A. E. J. 25:273-4. Mr. '29.

146. Hasseharn, W. C.
Cost cutting through time study. il. Manuf. Ind. 16:369-72; 433-5. S.-O. '28.

147. Helmers, N. F.
Contingency factors in road contractors. Eng. and Contr. 62:742. O. 1 '24.

148. Henry, S. T.
The trend in the design of construction equipment. Am. Rd. Bldg. Ass'n. Proc. p. 10-20. '29.

149. Hibbard, F. G.
Mechanical methods expedite track paving in Milwaukee. il. diag. Elec. Ry. J. 72:866-70. N. 17 '28.

150. Hill, C. S.
Winter construction methods and plant. Eng. N. Rec. 99:466-9. S. 22 '27.

151. Hirst, A. R.
Estimating the job. Munic and Co. Eng. 70:26-30. Ja. '26.

152. Hunter, A. H.
Camp and plant site for pavement work. Eng. and Contr. 19:366. Jl. '28.

153. Hunter, A. H.
Equipment factor in estimating costs. il. Eng. N. Rec. 102:537-40. Ap. 4 '29.

154. Hunter, A. H.
Important cost items; how to figure on equipment; depreciation and obsolescence. Rds. and Sts. 67:445-6. O. '27.

155. Jacob, R. C.
Highway estimating and cost accounting. Rds. and Sts. 67:316-8. Jl. '27.

156. Jay, H. B.
Good management the key to profits in road construction. Highway Magazine. 20:90-2. Ap. '29.

157. Johnson, J. M.
Concrete overflow pavement. diag. Rds. and Sts. 66:49. Jl. '26.

158. Johnson, T. H.
Time as a factor in making concrete pavement. Am. Concrete Inst. Proc. 23:458-67. Jl. '27.

159. Jones, G. W.
Multiple-lane paving job organized for fast work. il. diags. Eng. N. Rec. 102:506-8. Mr. 28 '29.

160. Kellog, J. M.
Analyzing cost of grading. Eng. and Contr. 64:666-8. S. 16 '25.

161. Kipp, O. L.
Evolution of road construction and maintenance equipment. Rds. and Sts. 63:229-40. F. 4 '25.

162. Knill, R. R.
Time studies give facts; observations only opinions. Coal Age. 33:689. N. '28.

163. Lichtenberg, E. H.
Advance in equipment engineering. Eng. N. Rec. 102:545-7. Ap. 4 '29.

164. Lichtenberg, E. H. and Shepard, J. A.
Labor saving equipment in road construction. Mech. Eng. 47:414-5. May '25.

165. Lichtner, W. O.
Time study and job analysis. The Ronald Press Co. New York. 1921.

166. Macpherson, L. F.
Road machinery and its economic aspect. Con. Eng. 44:357-61. Mr. 27 '23.

167. Mahon, A. A. and Tappan, C.
Some records of time distribution in road building. Eng. N. Rec. 95:455-6. O. 1 '25.

168. Marson, J. E.
Economic uses of the bucket loader in moving work. Rds. and Sts. 64:511-17. S. 2 '25.

169. Marston, G.
Road construction and maintenance machinery. Con. Engr. 57:134-5; 135-6. O. 1 '29.

170. McQuaide, J. H.
Detail cost records and time studies on earth job. Eng. and Contr. 68:379-82. S. '29.

171. Miles, E. L.
Contractor in highway work. Con. Engr. 54:385. Mar. 20 '28.

172. Miller, I. A.
The importance of having a complete knowledge of costs. Eng. and Contr. 68:125-6. Mar. '29.

173. Miller, J. G.
Power shovels show revolutionary advance. Eng. N. Rec. 102:556-9. Ap. 4 '29.

174. Miller, R. R.
Finishing machines for roads. il. Con. Eng. 57:611-2. O. 8 '29.

175. Mottashed, J. C.
Neglected values of time-study. Soc. Auto. Eng. J. 21:691-2. D. '27.

176. Mullen, J. H.
Winter letting of highway work. Eng. and Contr. 65:104-6. F. 3 '26.

177. Nikirk, F. A.
The science of dirt moving. Eng. and Contr. 16:395-7. Je. '28.

178. O'Conner, R. E.
How to stop cement overrun in pavement construction. Rds. and Sts. 65:135-40. Mr. '26.

179. Perry, J.
Time-distance comparison of power scraper grading cost. Engr. and Contr. 15:41-3. O. '26.

180. Peterson, R. P.
Unloading practice on road work. Eng. N. Rec. 96:278-80. F. 18 '26.

181. Pope, C. S.
Elements affecting concrete construction. Rds. and Sts. 65:253-4. My. 25 '26.

182. Potts, A. H.
Record concrete paving under desert heat conditions in Imperial Valley, Cal. Western Construction News. 4:285-7. Je. 10 '29.

183. Powell, C. H.
Economics of highway equipment standardization. Munic and Co. Eng. 70: 30-3. Ja. '26.

184. Purcell, C. H.
Profit and loss in road contracting. Rds. and Sts. 63:1197-9. Je. 3 '25.

185. Purinton, D. V.
Lost-time history of a concrete road job. Eng. N. Rec. 102:757-60. My. 9 '29.

186. Roger, C. F.
An unusual construction record. Pub. Roads. 7:185-9. N. '26.

187. Roger, C. F.
Economic effects of management in highway grading work. Rds. and Sts. 69:193-8. Je. '29.

188. Schaffner, R. A.
Effect of weather conditions on bids. Eng. and Contr. 65:68-9. F. 3 '26.

189. Scribner, H. A.
All about a highway record maker and why. Eng. and Contr. 62:1009-11. N. 5 '24.

190. Scherwood, N.
Rush paving job at Liberty, N. Y. Pub. Works. 58:414. N. '27.

191. Skinner, F. W.
Nashville-Springhope highway. Pub. Works. 55:1-5. Ja. '24.

192. Sloan, E. D.
Road concrete and work manship control in South Carolina. Eng. N. Rec. 99:711-12. N. 3 '27.

193. Smith, W. R.
Keeping construction cost records. Munic and Co. Eng. 70:14-6. Ja. '26.

194. Smith, W. R.
The depreciation of road contractors' equipment. Good Roads. 71:103-4. F. '28.

195. Sogard, L. T.
Trucking within the construction lines of a road job. Eng. and Contr. 65:5-8. Ja. 6 '26.

196. Spindler, W. H.
Is the highway industry enjoying too much winter idleness? Highway Magazine. 19:38-40. F. '28.

197. Stellhorn, A.
Economics of road paving operations. Coh. Eng. 56:193-5. Ja. 29 '29.

198. Stellhorn, A.
Hints for better paving. Eng. and Contr. 19: 75-6. Jl. '29.

199. Stellhorn, A.
The economics of grading and paving operation in highway construction. Rds. and Sts. 69:65-7. F. '29.

200. Sydner, L. F.
Use of a measuring hopper in rapid batching of aggregates by loaders. Good Roads. 69:366. S. '26.

201. Talbot, C.
Hauling road material. Rds. and Sts. 67:187. Ap. '27.

202. Trainer, L. S.
Trend of practice in concrete paving. Con. Engr. 55:291-5. O. 9 '28.

203. Van Duzer, W. A.
Depreciation of equipment used in highway construction and maintenance. Rds. and Sts. 69:59-62. F. '29.

204. Wasser, T. J.
Factors affecting construction. Rds. and Sts. 64:1017-21. N. 4 '25.

205. Webster, A. E.
Laying 18 miles concrete in one season. Rds. and Sts. 69:26-8. Ja. '29.

206. Weidner, T. J.
Combining truck and industrial railway hauling in highway work. Munic and Co. Engr. 70:147-8. Mr. '26.

207. Weyrauch, H. C.
High speed concreting marks New York highway job. Pub. Works. 60:371-40. O. '29.

208. Wheeler, E. M.
Cost of convict road work. Pub. Works. 55:196. Je. '24.

209. Wilcox, F. C.
What road paving really needs. Pelham Manor, New York City. 1930.

210. Willemin, E. G.
Contractors' plant and other concrete pavement. Pub. Works. 55:110. Ap. '24.

211. Wilson, H. H.
Factors frequently undervalued in estimating. Eng. and Contr. 61:1000-1. My. 7 '24.

212. Wise, A. J.
Fast concrete road building under rush orders. Eng. N. Rec. 101:466-8. S. 27 '28.

213. Wise, A. J.
Notable Texas road project. Contr. and Engr. 16:1-4. Ja. '28.

214. Zass, W. W.
Concrete paving units. Concrete. 26:189-91. Je. '25.