Cost vs Mixing Time on Dual-Drum Paving

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Many paving contractors can consistently produce portland cement with controlled mixing time in the range of 35 to 45 sec. The increased tempo required for operating a paver with a short cycle and the consequent short mixing times has been achieved in part through use of larger and faster batch trucks having greatly improved stability during batch dumping operations at the skip. Another essential element in achieving increased production has been the contractor's demonstrated awareness of the importance of eliminating unnecessary time losses which eat up valuable production time. Technological advancements in supporting equipment have helped to maintain the stepped-up pace.

Savings ranging from 10 cents to $3.08 a cubic yard are indicated if all mixing time specifications are reduced to 45 sec. Below 45 sec the savings are less than 10 cents per cu yd for each 5-sec reduction. Quality, of course, is an important consideration in dealing with mixing time problems.

●THE KEY to high-speed paver performance centers around the ability of the paver operator to run a short skip cycle, the batch truck driver to dump his batches into the skip on schedule, and to a lesser degree on the coordination between these and other operations in front of and behind the paver. Careless or sluggish performance by either the paver operator or the batch truck driver which results in delays can effectively stifle the orderly flow of material as well as disrupt both supporting and dependent operations.

A short paver cycle (a paver cycle is the interval between successive batches of concrete; the minimum time for a cycle is normally controlled by the batchmeter) means short mixing time and clearly it means also that there is less time in which to perform essential operations at the paver without incurring delays. Delays not only disrupt the orderly flow of material but they also extend the paver cycle. Extended paver cycles inevitably result in longer mixing time, thus nullifying the time saving advantages of operating with a short cycle. Most delays become apparent at the skip and it is here that one can find not only a place to measure qualitatively the contractor's management but also the clue to interdependence of mixing time and batch truck performance.

If the paver operator is slow for any reason in getting the skip down, the batch truck driver has less time in which to dump without a delay occurring even though he may perform his job within the allotted time. If, on the other hand, the batch truck driver fails to keep his truck within a few feet of the skip between batches, does not back up promptly when the skip comes down, or fails to have the dump bed raised before backing to the skip, he may be slow in disposing of his batch and the paver operator will be delayed subsequently in raising the skip to begin a new cycle. In each case the paver cycle is extended by the delay and mixing time is thereby increased.

Many contractors have successfully mastered the problems of getting essential coordination and performance at the skip as well as keeping attendant supply lines moving. They have, in fact, become so successful, due to adroit management and good equipment, that sustained production at the rate of 98 batches per hour has been recorded using one paver. For intermittent periods lasting up to 2 hr this rate reached 110 batches. In other words, the paver discharged a batch of concrete every 33 sec including delay time. When a small number of lengthy supply delays, due to lack of batch trucks, were eliminated from the computation this figure was further reduced to the remarkable time of one batch every 30 sec. Remember, this is an average. Thus, it should not come as a surprise that individual paver cycles were being completed in 24 sec and less when delays did not occur. Mixing time (mixing time as used in this report is defined as the interval between entry of all solid material into drum and begining of discharge for the batch in question) during the 24-sec cycles was less than 30 sec.

Figure 1 shows job average performance data for a group of 47 dual-drum pavers on which production studies were made. Individual studies usually covered a period of 2 to 4 weeks. Note that each of the four jobs with the fastest performance had an average cycle including minor delays of less than 40 sec.

To the engineer these fast cycles pose two problems. One is quality control, usually expressed in terms of mixing time, and the other is cost. Quality control, although important, is not a consideration of this report. Mixing time, per se, is discussed only in relation to production rates and cost.

For any given paver cycle time there is a maximum mixing time that can be obtained when the paver is adjusted and operated in a manner consistent with the manufacturers' recommendations. Any other method of operation has the effect of reducing mixing time in relation to paver cycle time. Although other methods of operation are common, often involving beating the batchmeter, it will be assumed in this report that paver operations are in accord with the manufacturers' recommendations.

Design of dual-drum pavers permits two batches to be mixed simultaneously during a portion of the paver cycle. Mixing time which can be obtained with any given paver cycle is equal to twice the paver cycle minus three constants plus a smaller constant. This is expressed by the following formula:

$$\text{Mixing time} = 2X - D - T - C + DL$$

In which

X = paver cycle time,
D = discharge chute open time,
T = transfer chute open time,
C = charging lag time—from close of transfer chute by skip vertical until all solid material is in the drum,
DL = discharge lag time—from opening of discharge chute until concrete appears.

Normal values for discharge and transfer chute open time are 9 sec each, for the charging lag a value of 4 sec is possible, and the discharge lag is usually about 1 sec. Obviously, any increase in the time taken for the first three constants will reduce mixing time in relation to the paver cycle time.

By substituting in the formula a 33-sec paver cycle and constants just noted, the following mixing time is obtained:

$$\begin{aligned}\text{Mixing time} &= (2 \times 33) - 9 - 9 - 4 + 1\\ &= 66 - 21\\ &= 45 \text{ sec}\end{aligned}$$

Performance records show that paver cycles can be completed regularly in 30 sec and sometimes in 24 sec. With a 30-sec paver cycle the maximum mixing time without delays becomes 39 sec. If the occasional 24-sec cycle is used then mixing time is 27 sec.

The aforementioned paver cycle values and consequent mixing times represent actual performance on only one job. Therefore, the performance requirements for completing a short paver cycle will be examined. During the paver cycle the skip must be raised, the mixing drum charged, the skip returned to the ground, and then the skip reloaded. The skip cycle is seldom accomplished in less than 15 sec and it took an average of 20 sec on jobs studied. The difference between the skip cycle time and the paver cycle time is available for reloading the skip. During reloading of the skip the batch truck must back up and cover the skip, dump its batch and pull away, and the paver operator react to the truck being clear before starting the skip to begin a new cycle.

Batch trucks on fast moving jobs consistently cover the skip in 2 or 3 sec. On some jobs the trucks can then dump and pull away from the skip in another 3 to 5 sec. On several other jobs up to 85 percent of the batches were dumped in less than 8 sec. This is indicated by curves A and B in Figure 2. Note, however, that such performances

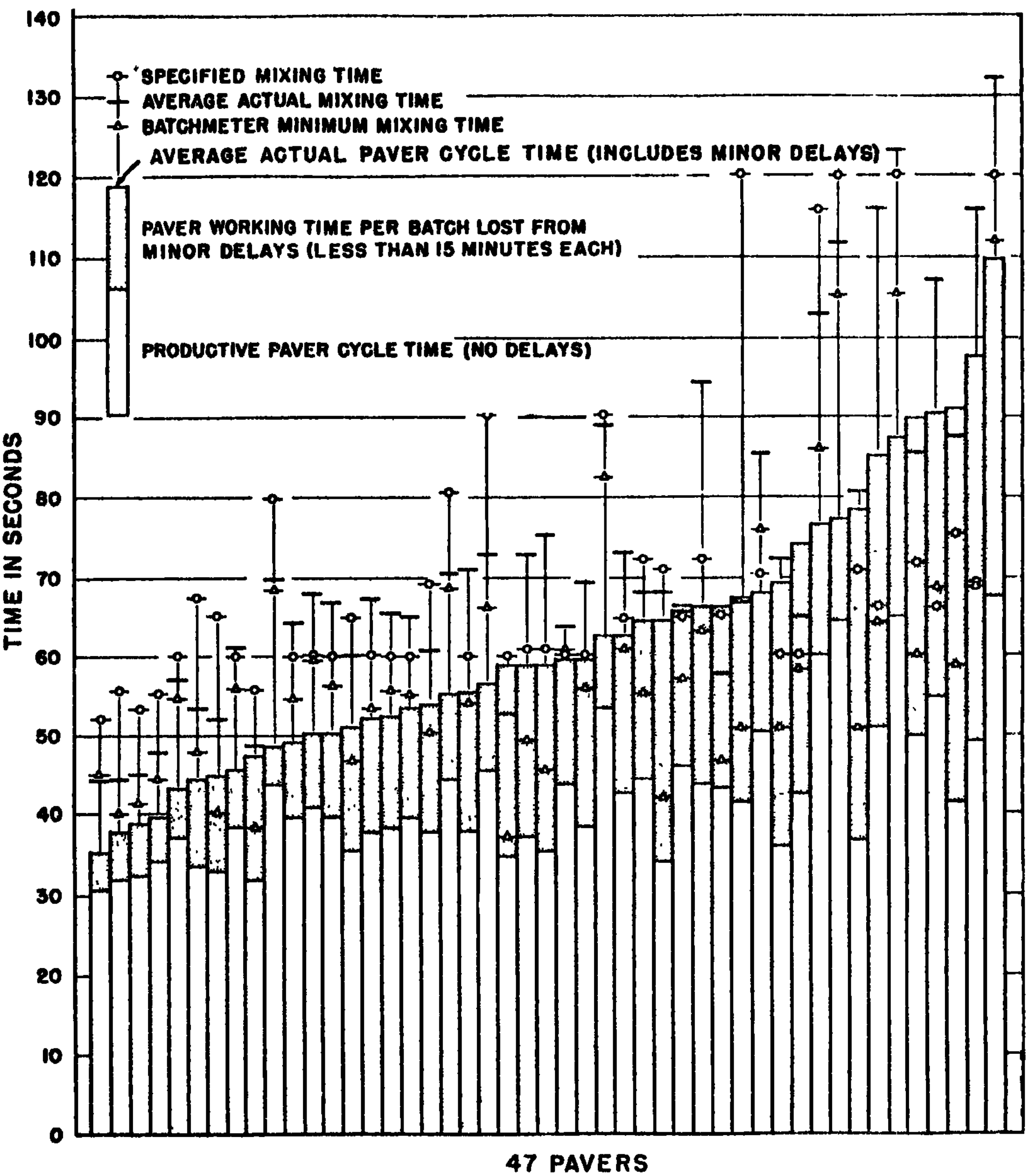

Figure 1. Comparison of 34-E dual-drum paver performance by a group of 47 pavers.

were attained only with 4- or 5-batch trucks. The best performance with 2-batch trucks (curve C) shows 85 percent of the batches took 15 sec or less. After a batch truck clears the skip the paver operator usually required about 2 sec before he actually started a new cycle.

By using a 15-sec skip cycle, 3-sec backup time, 8-sec dump time, and 2-sec operator reaction time, a paver cycle of 28 sec is derived. If 5-sec dump time is used, which is the fastest performance encountered on jobs studied, then the paver cycle becomes 25 sec. A 28-sec paver cycle will give 35-sec mixing time and a 25-sec cycle will give 29-sec mixing.

When a 15-sec dump time is used, such as indicated for 2-batch trucks, a paver cycle of 35 sec is derived and mixing time becomes 49 sec. If the 85 percentile value for curve D is used as dumping time, which is good performance with 2-batch trucks, the paver cycle is increased to 40 sec and mixing time becomes 59 sec.

Two methods have been used in arriving at a minimum paver cycle time and the re-

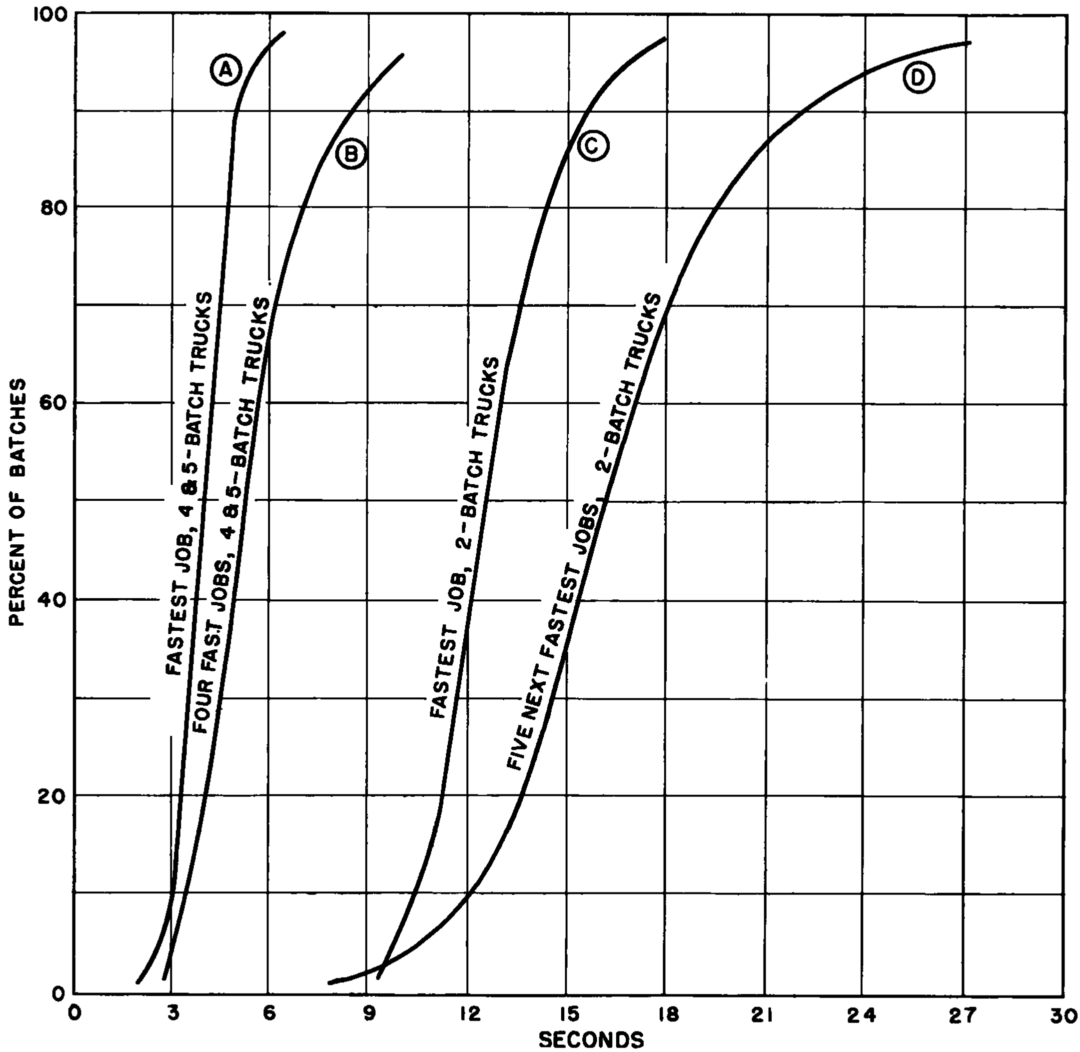

Figure 2. Cumlative frequency distributions of average time to dump one batch into the paver skip and get the truck out.

sulting mixing time which can be attained on fast jobs. In one case study data revealed that the operator ran for a 2-hr period with an average paver cycle of 33 sec which would permit mixing time of 45 sec. When a few long delays were removed from the computation, the cycle was reduced to 30 sec and mixing time to 39 sec. Mixing time was further reduced to 27 sec for individual batches. In the second case paver cycles were derived from performance data obtained from numerous jobs. A 28-sec cycle was found to be entirely possible and 25 sec could be attained in some cases. These cycles would produce mixing times of 35 and 29 sec, respectively. However, no allowance was made for delays.

In considering the problem of delays, it is a notable fact that as a general rule, more delay time per batch is lost by pavers with a long paver cycle than is lost by pavers with a short paver cycle. This paradoxical fact is plainly evident in Figure 3, in which the difference between curves A and B represents delay time. This difference is also shown by curve C. Note that as the paver cycle time per batch is reduced, paver delays also become less. The most logical explanation for this paradoxical pattern of delay trends on dual-drum paving jobs would seem to be that as the permissible production potential increases with shorter paver cycles, management becomes more alerted and more responsive to the needs and possibilities for reducing or eliminating delays.

Regardless of peculiarities relating to the magnitude of delays, it is an inescapable fact that they influence costs. Delays tend to push costs up, other things being constant. With equal assurance it can be said that mixing time requirements influence costs when delays remain constant.

The cost of operating a paving outfit tends to be a fixed amount and is almost independent within reasonable limits of the rate of production. Labor and equipment costs run about $350 per hour. When production is 50 batches per hour the unit cost is $7 per batch. However, if production goes up to 70 batches per hour, which is entirely possible with good performance by batch trucks, the unit cost drops to $5. The reduction is $2 and it is important. However, if production is increased by another 20 batches, to 90 per hour, the additional reduction is only $1.10 or a total of $3.10. This amount, incidentally, is a function of the percentage increase or decrease in production.

Data presented in Figure 3, curve D, indicate hourly production rates, including only delays of less than 15 min each, go down from a high of about 92 to a low of 35 batches per hour as paver cycle time increases. When the data used included only those pavers where 50- and 120-sec mixing time specifications were in force the production rates averaged 85 and 40 batches, respectively, per hour. Because of the fact that certain delays in excess of 15 min occurred while a full labor force was employed on these jobs, the rates of 85 and 40 batches were reduced accordingly to 75 and 34 batches, respectively. Thus, with the premise of a fixed

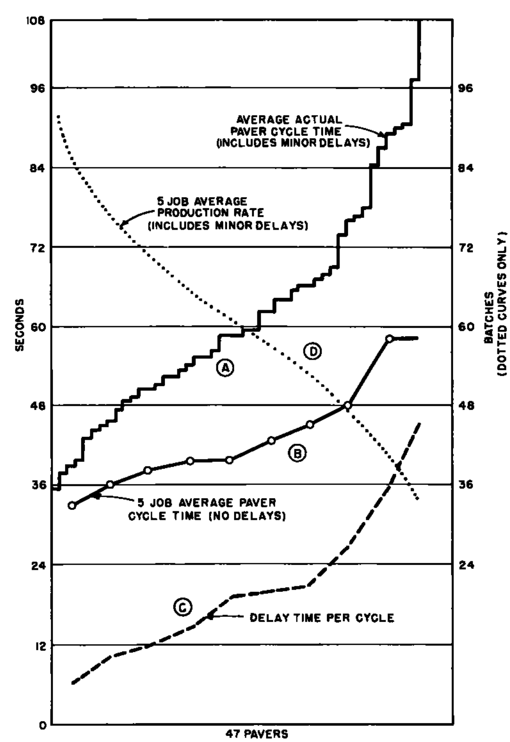

Figure 3. Comparison of 34-E dual-drum paver performance by a group of 47 pavers.

cost at $350 per hour, the cost differential between 75 and 34 batches per hour becomes $5.63 per batch or $4.06 per cubic yard with a normal 37.4-cu ft batch. Further adjustment is desirable under certain circumstances to account for the fact that where 50-sec mixes are used the batch size is usually about 40.8 cu ft. Thus, the difference per cubic yard increases to $4.34 when comparing 75 batches at 40.8 cu ft per batch with 34 batches at 37.4 cu ft per batch.

Specific cost data are not available for each rate of output in batches per hour. It may be assumed, however, that hourly costs are somewhat less when producing 34 batches per hour than for 75 batches per hour. The effect of this is to reduce the unit cost differential. To illustrate, let it be assumed that the $350 per hour cost go down by 10 percent for the 34-batch rate and increase by 10 percent for the 75-batch rate. Instead of having a differential of $4.06 per cubic yard it drops to $2.98.

What has been said thus far about unit costs is largely hypothetical but it serves to establish a means for computing the cost differential due to variations in mixing time specifications.

Another source of information on this subject, and one used quite frequently, is a comparison of bid prices per cubic yard and specified mixing times for portland cement concrete placed on Federal-aid projects. This is shown for the year 1957 in Figure 4.

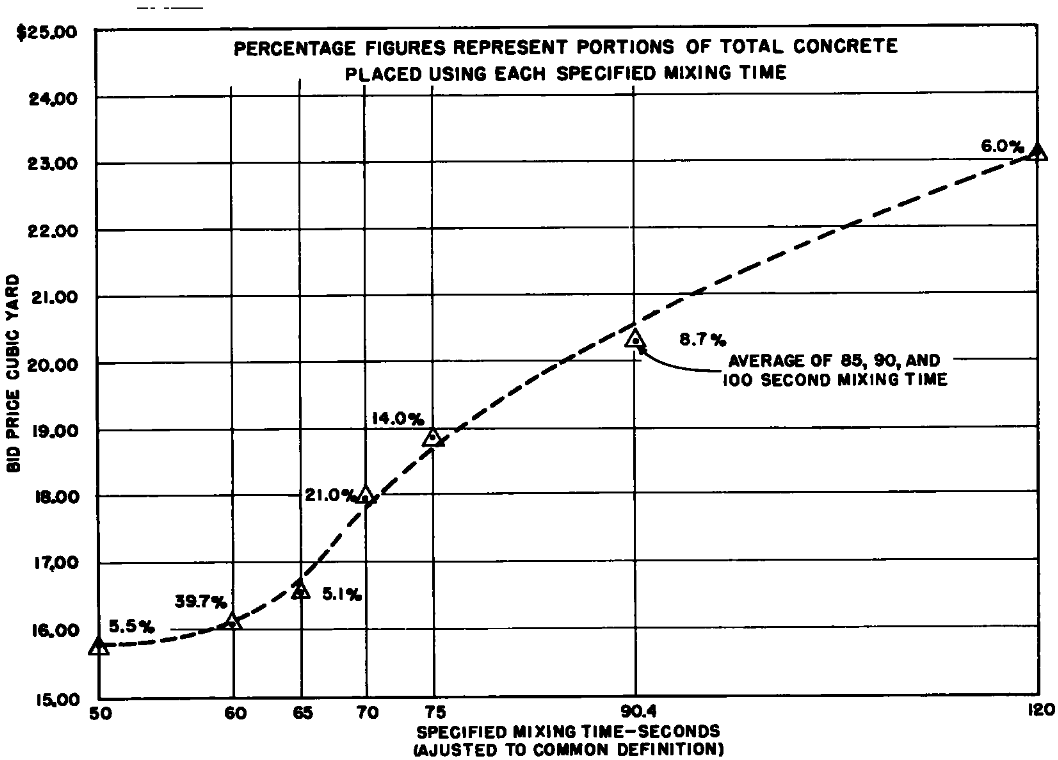

Figure 4. Comparison of bid price per cubic yard and specified mixing time for portland cement concrete placed on Federal-aid projects.

It may be noted that from a low bid price of $15.75 per cubic yard for 50-sec mixing there is a gradual increase in bid prices to $23.15 for 120-sec mixing. The difference is $7.40. It is more apparent than real. If this is a true indication of the differential which results from a 50- to 120-sec range in mixing time, then it also means that the labor and equipment cost of running a paving outfit exceeds $700 per hour. Such an hourly cost is unrealistic if not impossible and cannot be accepted at face value as representing an average.

A more plausible explanation appears to be that about one-half of the $7.40 difference could be charged to mixing time and that the balance represents costs generated by different design practices, longer hauls, variations in labor productivity, wage rates, climatic conditions, materials prices, etc. In this case it is not without significance that most states with longer mixing times are in the northeast whereas those with shorter mixing times are in the south and southwest where year-round work is possible.

It is believed that the so-called fixed hourly cost premise offers a greater degree of logic as a basis for the determination of possible savings which might result from reduced mixing time. To develop along this line an amount for any change, either an increase or a decrease in mixing time, the following values were used as control points and intermediate readings were then taken from a straight line projection through these points:

Mixing time seconds	120	50
Production—batches per hour (37.4-cu ft batch)	34	75
Hourly cost for labor and equipment	$350 less 10%	$350 plus 10%

Remember, an increase in the percentage adjustment of the hourly cost reduces the unit cost differential.

After making the necessary computations the following unit costs per cubic yard were derived:

Mixing Time (sec)	Unit Cost
120	$6.69
90	4.84
75	4.33
70	4.18
65	4.05
60	3.92
50	3.71
45	3.61
40	3.52
35	3.44

The difference in unit cost per cubic yard between each mixing time interval is given in Table 1.

Figure 4 showed the distribution of total concrete produced under each mixing time interval on Federal-aid projects during 1957. Using this distribution and a yearly program of 20 million cu yd (the 1958 Federal-aid program, except secondary projects, totaled approximately 18 million cu yd of pavement concrete) it was determined that the following quantities would be associated with each mixing time interval.

Mixing Time (sec)	Quantity
120	1,200,000
90	1,740,000
75	2,800,000
70	4,200,000
65	1,020,000
60	7,940,000
50	1,100,000
	20,000,000

TABLE 1

AMOUNT OF REDUCTION IN UNIT COST PER CUBIC YARD IN CHANGING FROM ONE MIXING TIME INTERVAL TO ANOTHER

Mixing Time To / From (sec)	90	75	70	65	60 (sec)	50	45	40	35
120	$1.85	$2.36	$2.51	$2.64	$2.77	$2.98	$3.08	$3.17	$3.25
90	-	0.51	0.66	0.79	0.92	1.13	1.23	1.32	1.40
75	-	-	0.15	0.28	0.41	0.62	0.72	0.81	0.89
70	-	-	-	0.13	0.26	0.47	0.57	0.66	0.74
65	-	-	-	-	0.13	0.34	0.44	0.53	0.61
60	-	-	-	-	-	0.21	0.31	0.40	0.48
50	-	-	-	-	-	-	0.10	0.19	0.27
45	-	-	-	-	-	-	-	0.09	0.17
40	-	-	-	-	-	-	-	-	0.08

TABLE 2

COMPUTATION OF POSSIBLE SAVINGS DUE TO DECREASED MIXING TIME

Mixing Time			
Current Specs (sec)	Reduced to (sec)	Total Cubic Yards	Total Savings per Year
120	90	1,200,000	$2,220,000
90 & above	75	2,940,000	3,719,400
75 & above	70	5,740,000	4,580,400
65 & above	60	10,960,000	7,297,400
60 & above	50	18,900,000	11,266,400
50 & above	45	20,000,000	13,266,400
50 & above	40	20,000,000	15,066,400
50 & above	35	20,000,000	16,666,400

From a performance standpoint many of today's contractors can use mixing times between 35 and 45 sec to increase their productiveness. In general, their production will approximately parallel and be limited somewhat by performance of the paver operator and the batch truck driver. Four-batch trucks are essential for short paver cycles. More and more contractors are using this size of truck and it can be said that the industry is ready for shorter paver cycles and the resulting shorter mixing times. A considerably more realistic consideration, however, is evident from an examination of the data in Table 2. Substantial savings amounting to over 13 million dollars are indicated if all mixing times are reduced to 45 sec. It is of major significance, however, to note that only 2 of the 13 million total is obtained by the reduction from 50 and above to 45 sec.

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