Cost-Effective Use of Manpower for Manual Pothole Repair

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ABSTRACT

The Pennsylvania Department of Transportation annually spends more than $30 million for repairing potholes. The production and productivity of pothole repair crews during 1980 and 1981 were compared with the department's performance standard. Crews were observed using an air compressor or a gasoline-operated tool for cutting. For compaction, either a 4- to 6-ton roller or a walk-behind vibratory roller was employed. Delays in crew deployment and during the repair operations were responsible for low production and productivity. Major delay categories were analyzed in detail and were found to be associated directly with ineffective management on the part of the crew foreman. Realistic reduction of the frequency and duration of delays through the exercise of leadership and effective management is discussed. The resulting time savings are incorporated into productive time to compute the production and productivity potential of five-person, six-person, and seven-person crews. It is shown that a crew of five, equipped with the slower (gasoline-operated) cutting tool, can achieve the recommended performance standard.

Productivity of pothole repair crews is a state highway agency objective that must be balanced against the need to produce a long-lasting repair. To achieve durable repairs, the repair crew must be provided with high-quality material and adequate equipment. Repairs must be made according to the proper procedure (1-3). Even with the right material and equipment, however, many repair crews are underachievers with respect to productivity (manhours per ton) and production (tons per day) (4,5).

The objectives of this paper are to isolate the significant factors that inhibit production and productivity of pothole repair crews and to describe the steps that can be taken by the crew foreman to increase output. Throughout this paper, comparisons are made to the Pennsylvania Department of Transportation performance standard for manual repair of flexible and rigid base pavements (6). The standard includes a planning unit of 6 tons per day and a productivity target of 4.73 manhours per ton. The crew should consist of a foreman and four highway maintenance workers. Safety personnel must be added.

STUDY PARAMETERS

The recommendations in this paper are the result of a comprehensive pothole research program sponsored by the Pennsylvania Department of Transportation (5). The productivity analysis presented herein represents a portion of the overall study. The evaluation of pothole repair practices is based on numerous production studies of field operations conducted during the spring of 1980 and of 1981. The data collection techniques were as follows:

- Field documentation of pothole repair,
- Time-lapse photography,
- Supplemental film notes,
- Stopwatch studies, and
- Debriefing reports and field notebooks.

A total of 56 days were spent studying repair operations in eight Pennsylvania counties. Thirty-eight legislative routes, with moderate to high average daily traffic (ADT), were included in the studies, resulting in the observation of 462 pothole repairs.

The crews that were observed used conventional repair equipment. All repairs were in flexible-base and rigid-base pavements. Both cold mix and hot mix were used as repair materials. Crew sizes ranged from five to nine, including the foreman but excluding personnel needed for traffic control.

CATEGORIES OF POTHOLE REPAIR

The production studies indicate that there are two distinct categories of pothole repair operations. The first category is characterized by highly deteriorated pavements exhibiting a large number of potholes. Highway maintenance workers (HMWs) walk from one pothole to another. Except for traveling to the work location at the beginning of the day and returning to the maintenance shed at the end of the day, little vehicular travel is required. When there are numerous potholes, each HMW can perform the same function on each hole. The performance standard in Pennsylvania covers this type of operation (6). Organizing the crew in this manner is referred to as "productionizing the work." This paper is limited to the characterization of this type of pothole repair operation.

The second category of repair operation is one in which the frequency of potholes is very low. This means that the work crew must regularly load its equipment on the truck, retrieve safety devices and personnel, and drive to another work location. Much of the day is therefore consumed by travel and setup time. Obviously, the production rate (tons per day) defined in the performance standard cannot be realized under these circumstances.

ANALYSIS OF OPERATIONS ON ROADS WITH A HIGH FREQUENCY OF HOLES

To be productive, a pothole repair crew must be aware of the operations that control the overall repair process. In addition, the time required to perform each of the steps in a repair must be determined, and an analysis of the delays associated with each step must be made.

Times for Basic Operations

A durable repair requires that the work be divided into several basic operations: cutting, cleaning, tacking, filling, leveling, and compaction (6 and Anderson and Thomas, unpublished data). Using time-lapse photography and stopwatches, the average times required to complete these operations were documented. These are given in Table 1 and are the result of numerous studies conducted under a variety of job and management conditions. It should be noted that all delays have been excluded. These times, therefore, represent ideal times for completing the work.

TABLE 1 Ideal Time for Pothole Repair Processes (excluding delays)

Operation	Probable Time[a] (Minutes)
Cutting	
Air Compressor	4.66
Pionjär[b]	7.26
Cleaning	
One HMW[c]	7.61
Two HMWs	5.58
Tacking	0.77
Filling	
One HMW	3.72
Two HMWs	2.22
Leveling	1.90
Compaction	
4-to-6-Ton Roller	8.64
Essick Roller[d]	4.79

[a]Weighted average based on the pothole volume distribution.

[b]Gas-operated pavement breaker.

[c]Highway maintenance worker.

[d]Walk-behind vibratory roller.

Data for the cutting operations were collected for the air compressor and the gasoline-operated cutting tool. Both old and new air compressors were included in the study. Although all the gasoline-operated cutting tools were relatively new, several were not properly adjusted, so their efficiency was reduced. Sharp and dull bits were noted for both types of pavement breaker. Experienced and inexperienced operators were observed. The data from Table 1 indicate that the gasoline-operated cutting tool took about 56 percent longer than the air compressor to cut a hole; however, the cutting advantage of the air compressor was partly offset by the greater mobility of the gasoline-operated tool (7).

Cleaning was performed by one or more HMWs with a shovel and broom. Cleaning time with the air hose of a compressor was treated as a delay and was not considered. The time required to clean a hole was a function of hole size and the number of HMWs performing the task. Usually no more than two HMWs performed this task simultaneously. The times required to clean an average-size hole using one and two HMWs are given in Table 1. Two points are worth noting. First, contrary to what might be expected, the addition of an extra HMW did not proportionately reduce the time required to clean the hole; in fact, the time was reduced by approximately one-fourth instead of one-half. This illustrates the inefficiency of adding extra HMWs to the crew. The second point is that cleaning is not necessarily the most time-consuming operation in the total process. The idea that cleaning controls the rate at which potholes can be repaired is only partly correct, because most of the cleaning operations observed were basically disorganized. The number of HMWs assigned to cleaning varied from pothole to pothole, and when two or more HMWs were deployed at a pothole, they often worked in an erratic fashion.

The filling operation, like cleaning, was performed by one or more HMWs. Although the introduction of a second HMW significantly reduced the filling time, it was not considered to be cost-effective because filling takes much less time than either cutting or cleaning.

The compaction operations were performed with a walk-behind vibratory roller or a 4- to 6-ton roller. In general, the production studies showed that compaction times were highly variable; this indicates the need for the state highway agency (SHA) to provide more explicit guidelines for the compaction procedure.

The data given in Table 1 illustrate the effect that failure to "productionize" the work has on crew productivity. Assume that a five-person crew is equipped with an air compressor and a walk-behind vibratory roller. The crew repairs one hole completely before moving to the next hole. Thus, two HMWs can be used for both the cleaning and the filling operation. The total ideal time can be calculated from Table 1 as 19.92 min. By assuming a density of 135 lb/ft^3 and an average hole volume of 3.60 ft^3, the ideal daily production (assuming 335 min of productive work time) and productivity can be calculated as follows:

$$\text{Ideal production} = \{[(60/19.92)(135)(3.60)]/2{,}000\}(335/60) = 4.09 \text{ tons/day}$$

$$\text{Ideal productivity} = [5(335/60)]/4.09 = 6.83 \text{ manhours/ton}$$

This ideal rate is, of course, unattainable because no delays have been considered. Nevertheless, it serves to illustrate that even under perfect conditions it is impossible to achieve the planning unit of 6 tons per day or the productivity target of 4.73 manhours per ton unless the operation is productionized (1,5).

Delays and Inefficiencies

Operational Delays

Delays are an inherent part of any operation. Although they cannot be avoided entirely, many can be controlled--controlling and avoiding delays are at the heart of the management effort. Foremen must exercise leadership in this area. In the absence of leadership, delays will be uncontrolled.

The production studies identified the delays that affected pothole repair on a daily basis. These have been categorized (Table 2) according to each basic operation. The delay times were determined from more than 95 hours of observation of 48 repair operations on roads with a large number of holes. Although all

TABLE 2 Percentage of Total Delay Time for Each Operation

Activity	Cutting: Air Comp.	Cutting: Pionjar[a]	Cleaning	Filling	Compaction
Receive Instructions	3	1	1	0	0
Wait for Instruction/Observe	29	33	3	10	3
Wait for Another Operation	4	1	2	7	9
Wait for Mix to Arrive	-	-	-	9	-
Wait for Pothole	4	-	39	37	59
Move to Another Pothole	2	2	0	3	2
Change Tools	-	-	1	-	-
Start/Refuel/Adjust Equip.	6	2	-	3	1
Clean Hole with Air Comp.	5	-	2	-	-
Wait for Traffic	0	0	0	-	0
Personal Delays	4	1	1	2	-
Undetermined Delays	3	9	2	3	2
Productive Work (Efficiency)	40	51	49	26	24

[a]Gas-operated cutting tool.

repair operations will not necessarily be performed at the same level of efficiency as those studied, the data do reflect a typical crew that was organized to work on three to five potholes at once.

The data in Table 2 highlight what is perhaps the most difficult task in controlling the productionized operation: the challenge to the foremen to keep the various operations progressing. In the 48 repair operations studied, this was achieved with only marginal success, as evidenced by the fact that approximately 31 percent of the time available for cutting the hole was spent waiting for instructions. Marking the holes would certainly contribute greatly to reducing this lost time. Improving the efficiency of the cutting operation would have a positive effect on the other operations because the major source of lost time is waiting for a hole to be available to work on. The cleaning, filling, and compaction operations had production time losses of 39, 37, and 59 percent, respectively.

How common are the delay times that are given in Table 2? This can be answered, at least in part, by examining the data given in Table 3. It should first be noted that the number of times an HMW was delayed, either by waiting for instructions or waiting for work, was roughly equal to the number of times an HMW moved to another hole. For the cutting operation, this suggests that the operator was waiting for instructions after completing each hole. For cleaning, filling, and compaction, delays due to lack of work occurred at a rate approximately equal to delays due to moving to a new hole. It can be concluded that the failure to keep the cutting operation progressing, which subsequently slowed the remaining operations, was a continuous problem and was not limited to a small number of crews. Delays of short duration can seem quite insignificant at the time, but the cumulative effect can be dramatic.

Controlling Operation

One of the time-tested principles of management is that equal energies and attention cannot be devoted to all of the tasks and subtasks constituting an

TABLE 3 Frequencies of Occurrence of Selected Types of Delays

Operation	Number of Times Observed: Wait for Instructions/ Observe	Move to Another Pothole	No Pothole Available
Cutting	70	65	2
Cleaning	22	19	47
Filling	76	94	53
Compaction	21	51	63
Total	189	229	165

operation. This principle holds true for pothole repair. It is therefore important for the foremen to know which operation controls the level of crew output, for it is there that foremen should concentrate their managerial efforts.

Analytic calculations supported by visual observations indicated that when the gasoline-operated cutting tool was being used, the cutting operation controlled the daily production rate because it took longer to cut a hole than to perform any of the other operations. When the air compressor was used, calculations showed that the cleaning operation took longest. It should be recognized that cutting and cleaning operations are performed in close proximity to each other. When the cleaning controls production, the pavement breaker operator tends to slow down so that he or she will not get too far ahead. If some distance is not maintained between the two operations, the cleaning will be delayed occasionally because there is no hole available to work on. If too much distance is maintained between the two operations, the cutting operation tends to slow down and the cleaning operation tends to accelerate. Contrary to the analytic results, it is believed that in all but very unusual situations the cutting operation will establish the pace of the work. Because each operation affects subsequent operations, foremen should concentrate most of their managerial efforts on keeping the cutting operation from slowing down.

Deployment Delays

A crew cannot achieve high levels of production unless the work is productionized and continuous throughout the day. Delays in deployment, which reduce crew efficiency, have a great effect on production.

Foremen need to be aware of the average amount of time that should be spent at the work location and the average time at which work should commence for the day. The following represents a realistic distribution of time for the total 7.5-hr shift:

Task	Time (min)
Travel to job site, deploy safety devices	30
Organize and start equipment	10
Coffee break, a.m.	15
Start up after lunch	5
Coffee break, p.m.	15
Clean up and put away tools	10
Retrieve safety devices, travel to maintenance shed	30
Productive work time	335
Total	450

Having the crew arrive at the job site on time is only one aspect of crew deployment. For the operation to run smoothly, the material should arrive no later than 15-20 min after the crew begins work. The filling of holes should begin almost immediately, because the crew is waiting and the holes have been prepared.

During the spring of 1980 the time parameters noted were recorded for 13 patching operations in four counties. Summaries are given in Table 4. Note that the filling began more than 1 hr after the holes had been prepared. This delay affected the cutting and cleaning operations. There should not be too much time between the cleaning and filling operations because this could create safety problems. The longer the crew waits to begin the filling operation, the greater is the likelihood that the cutting and cleaning will be interrupted to allow the filling to catch up.

Crew Size

What effect does crew size have on production and productivity? Table 1 shows the relative ineffi-

TABLE 4 Time Data on Crew Deployment

Work Location	Work Began	Material Arrived	Delay	Filling Began	Delay	Material
1	8:45	9:35	50	9:45	10	Cold Mix
2	8:35	9:15	40	9:20	5	Cold Mix
3	9:15	9:41	16	10:53	72	Cold Mix
4	9:53	Before 9:53	0	11:36	103	Cold Mix
5	9:00	10:00	60	10:57	57	Cold Mix
6	12:55	Before 12:55	0	2:00	65	Cold Mix
7	9:18	10:20	62	10:28	8	Hot Mix
8	10:07	9:50	0	10:15	25	Hot Mix
9	10:00	Before 10:00	0	10:30	30	Hot Mix
10	8:47	10:05	78	10:15	10	Hot Mix
11	8:10	9:15	65	9:25	10	Hot Mix
12	8:40	10:15	35	10:55	40	Hot Mix
13	9:11	10:40	89	10:40	0	Hot Mix
Average[a]	9:13	9:52	39	10:25	33	

[a]Excluding work location no. 6.

ciency of using more than one crew member in the cleaning and filling operations. Although total production may be increased slightly by adding an additional HMW to the cleaning operation, this will have an adverse effect on productivity.

Sample data on crew size gathered during 1980 and 1981 indicated that, for 18 crews involved in repair operations on roads with a high frequency of holes, the average crew size was seven. (The performance standard specifies five.) Both figures include the foreman but not those HMWs required for traffic control. The size of 15 of 18 crews (83 percent) exceeded the performance standard.

PRODUCTION AND PRODUCTIVITY CALCULATIONS

Upper Limit on 1980 and 1981 Operations

The calculation of the upper limit on production and productivity for the 1980 and 1981 pothole repair seasons was based on the time data given in Table 5. A seven-person crew using a walk-behind vibratory roller was assumed. Delays within and between operations were determined from the production studies (5).

With a seven-person crew, two HMWs could be used for both the cleaning and filling operations. Thus, for the air compressor the total time needed to complete a hole was 56.01 min. With a gasoline-operated cutting tool the total time was 58.75 min. Based on actual observations, the productive time available for repair operations to be performed averaged 285 min. In reaching this figure it was noted that on the average the crew arrived at the work location, deployed safety devices, and was ready to begin work by 8:55 a.m.

The data in Table 4 indicate that cutting typically started at 9:13 a.m., so that the net work time available (NWTA) for a single workday was 267 min (285 - 18). Furthermore, a seven-person crew using a compressor needed (56.01 - 11.80) 44.21 min to complete a pothole after it had been cut. Thus, a crew of seven equipped with a compressor could have a maximum production of

$$[267 - (56.01 - 11.80)]/11.80 = 18.88 \text{ potholes/day}$$

If the compressor were replaced with a gasoline-operated cutting tool, maximum production could be

$$[267 - (58.75 - 14.54)]/14.54 = 15.32 \text{ potholes/day}$$

Measurements taken with a nuclear gauge showed that operations achieved an average compaction density of 120 lb/ft^3. Because an average pothole has a volume of 3.60 ft^3, the seven-person crew employing a compressor could place a maximum of

$$(18.88) \times (3.60) \times (120)/2{,}000 = 4.08 \text{ tons/day}$$

With a gasoline-operated cutting tool, the same crew could place

$$(15.32) \times (3.60) \times (120)/2{,}000 = 3.31 \text{ tons/day}$$

Thus, a seven-person crew could have an average production of

$$(4.08 + 3.31)/2 = 3.70 \text{ tons/day}$$

Personal observations during the two pothole repair seasons indicated that a patching crew typically placed one truckload of approximately 4 tons. The computed production of 3.70 tons per day was therefore compatible with field observations. On the basis of these computations, it was concluded that during 1980 and 1981 patching crews were not achieving the 6 tons per day recommended in the performance standard.

TABLE 5 Actual Times for Component Operations, 1980-1981

Operation	Ideal Time (Minutes)	Time Taken by Delays Between Operations (Minutes)	Time Taken By Delays Within Operation (Minutes)	Actual Total Time (Minutes)
Cutting				
Air Compressor	4.66	5.57	1.57	11.80
Pionjär[a]	7.26	6.78	0.50	14.54
Cleaning				
One HMW[b]	7.61	7.31	1.10	16.02
Two HMWs	5.58	5.36	0.79	11.73
Tacking	0.77	--	--	0.77
Filling				
One HMW	3.72	9.49	1.67	14.88
Two HMWs	2.22	5.58	0.98	8.78
Leveling	1.90	--	--	1.90
Compaction				
Essick Roller[c]	4.79	14.08	2.16	21.03

[a]Gas-operated cutting tool.

[b]Highway maintenance worker.

[c]Walk-behind vibratory roller.

By applying the deployment data in Table 4 and assuming a daily production rate of 4 tons per day, crew productivity could be calculated as 9.42 manhours per ton. This is double the 4.73 manhours per ton recommended in the performance standard.

Production and Productivity Potential

Table 6 gives a summary of the target delay times that can be achieved through the application of improved management skills at the foreman level (1,5). These were subsequently used to compute the times needed to complete each phase of the repair. Summaries of these times are given in Table 7. Cleaning controls production when a compressor is used for cutting, and cutting controls production if a gasoline-operated cutting tool is employed.

Computations of potential production and productivity are based on the assumptions that (a) net work time available for a day's operation is 335 min, (b) the crew is properly deployed in a productionized fashion, (c) the foreman controls work flow and minimizes delays, (d) a walk-behind vibratory roller is employed, and (e) a compaction density of 130 lb/ft^3 is achieved. With this compaction density, an average patch (volume = 3.60 ft^3) will contain 0.234 ton of material.

Under these conditions, a seven-person patching crew equipped with an air compressor can achieve

$$[335 - 5.55 - (0.77 + 2.81 + 1.90 + 8.05)]/6.00 \times (0.234) = 12.32 \text{ tons/day}$$

Notice that cleaning has been considered the controlling operation. Potential productivity of this crew will be

$$7\,(335/60)/12.32 = 3.17 \text{ manhours/ton}$$

The same crew, using a gasoline-operated cutting tool, can place

$$[335 - (28.28 - 8.75)]/8.75 \times (0.234) = 8.45 \text{ tons/day}$$

The corresponding productivity will be

$$7\,(335/60)/8.45 = 4.63 \text{ manhours/ton}$$

Similar computations were made for a crew of six and a crew of five. Results are summarized in Table 8 and graphically illustrated in Figure 1. In Figure 1, a median performance line is shown. This curve represents potential departmentwide performance if half the crews are supplied with air compressors and the other half have gasoline-operated tools. As can be seen, both production and productivity can exceed the performance standard by a considerable margin for all crew sizes examined.

Manhours per ton will increase at a modest pace as crew size increases. It is evident that six- and seven-person crews offer no advantage over the five-person crew from the productivity viewpoint. As more HMWs are added, daily production must also increase if the target productivity of 4.73 manhours per ton is to be maintained. For example, a seven-person crew would need to place 8.4 tons per day. This fact offsets the apparent production advantages of larger crews. The potential production exceeds the minimum daily production by 2.66, 3.12, and 1.98 tons per day for the five-, six-, and seven-person crews, respectively, suggesting a slight advantage to the six-person crew. On a percentage basis, the potential production exceeds the minimum by 44.3, 43.3, and 23.6 percent. Thus, the choice of a five- or six-person crew seems to be a matter of preference based on other nonquantifiable issues.

From this analysis it can be concluded that the

TABLE 6 Target Delay Times for Pothole Repair Operations

	Delay Times as a Percentage of Total Delay Time				
	Cutting		Cleaning	Filling	Compaction
	Compressor	Pionjar[a]			
Communication					
Receive Instructions	4.4	1.0	0.0	0.0	0.0
Wait for Instructions/Observe	13.2	22.7	0.0	0.0	0.0
Equipment Utilization and Maintenance					
Start/Refuel/Adjust Equipment	4.4	4.1	---	14.9	0.0
Compressor Blows Holes	0.0	0.0	0.0	---	---
Move to Another Pothole/Location	15.4	12.4	4.9	14.9	15.8
Work Flow					
Wait for Another Operation	0.0	0.0	0.0	3.3	7.9
No Pothole Available	24.2	22.7	48.8	49.6	65.8
Other Delay Situations					
Traffic	4.4	4.1	0.0	0.0	0.0
Talk/Personal/Look Around	24.2	6.2	19.5	9.9	2.6
Undetermined	9.8	26.8	12.2	7.4	7.9
Change Tools	---	---	14.6	---	---
Wait for Mix to Reach Site	---	---	---	0.0	---
Total Delay Time (minutes)	45.5	48.5	20.5	60.5	38.0
(% of NWTA)[b]	16	17	7	21	13
Productive Time (minutes)	239.5	236.5	264.5	224.5	247.0
(% of NWTA)[b]	84	83	93	79	87

[a]Gas-operated cutting tool.

[b]NWTA = net work time available.

TABLE 7 Improved Times for Operations in a Pothole Repair Cycle

Operation	Ideal Time (Minutes)	Total Time[a] (Minutes)	Time Taken by Delays (Minutes)
Cutting			
Air Compressor	4.66	5.55	0.89
Pionjar[b]	7.26	8.75	1.49
Cleaning			
One HMW	7.61	8.18	0.57
Two HMWs	5.58	6.00	0.42
Tacking	0.77	0.77	--
Filling			
One HMW	3.72	4.72	1.00
Two HMWs	2.22	2.81	0.59
Leveling	1.90	1.90	--
Compaction			
Essick Roller[c]	7.00	8.05	1.05

[a]Ideal time divided by efficiencies obtained from Table 6.

[b]Gas-operated cutting tool.

[c]Walk-behind vibratory roller.

performance standard with respect to crew size, production per day, and manhours per ton is realistic and can be achieved regardless of the cutting tool used. The attainable rates exceed the minimum values by a sufficiently large amount that five- and six-person crews should be expected to meet or exceed the performance standard fairly consistently.

RECOMMENDATIONS FOR PRODUCTIVITY IMPROVEMENT

There are numerous steps that can be taken to improve both the production and productivity of pothole repair. Underlying these improvements is the effective leadership that must be exercised by the foreman and the assistant county manager. Specific recommendations resulting from the study are summarized.

1. Improving deployment: On the average, the crew should arrive at the job site within 30 min of the beginning of the work shift. Cutting of potholes should begin within 10 min. The crew should not leave the job site less than 30 min before the end of the shift. This time frame should provide a minimum of 335 min (5.58 hr) of actual work time and 390 min (6.5 hr) of time at the job site.

2. Organizing and controlling the work: Work must be organized in a production-line fashion with each HMW assigned to a specific task or operation. Failure to do so will limit the crew output to about 3 tons per day. The foreman must keep the repair process moving and remove obstacles that can delay the work. Waiting for instructions, observing other work, and waiting for potholes to work on will significantly delay the repair process.

3. Crew size: Except with a five- or six-person crew, it is unlikely that daily production rates needed to ensure satisfactory productivity can be

TABLE 8 Patch Completion Times and Potential Production/Productivity

	Seven-Person Crew Cutting Equipment		Six-Person Crew Cutting Equipment		Five-Person Crew Cutting Equipment	
Operation	Air Compressor	Pionjar[a]	Air Compressor	Pionjar[a]	Air Compressor	Pionjar[a]
Cutting	5.55	8.75	5.55	8.75	5.55	8.75
Cleaning (2 HMWs)	6.00	6.00	6.00	6.00		
(1 HMW)					8.18	8.18
Tacking	0.77	0.77	0.77	0.77	0.77	0.77
Filling (2 HMWs)	2.81	2.81				
(1 HMW)			4.72	4.72	4.72	4.72
Leveling	1.90	1.90	1.90	1.90	1.90	1.90
Compaction	8.05	8.05	8.05	8.05	8.05	8.05
Total Time (Minutes)	25.08	28.28	26.99	30.19	29.17	32.37
Production (Tons/day)	12.32	8.45	12.25	8.39	8.98	8.33
Productivity (MH/ton)	3.17	4.63	2.73	3.99	3.11	3.35

[a]Gas-operated cutting tool.

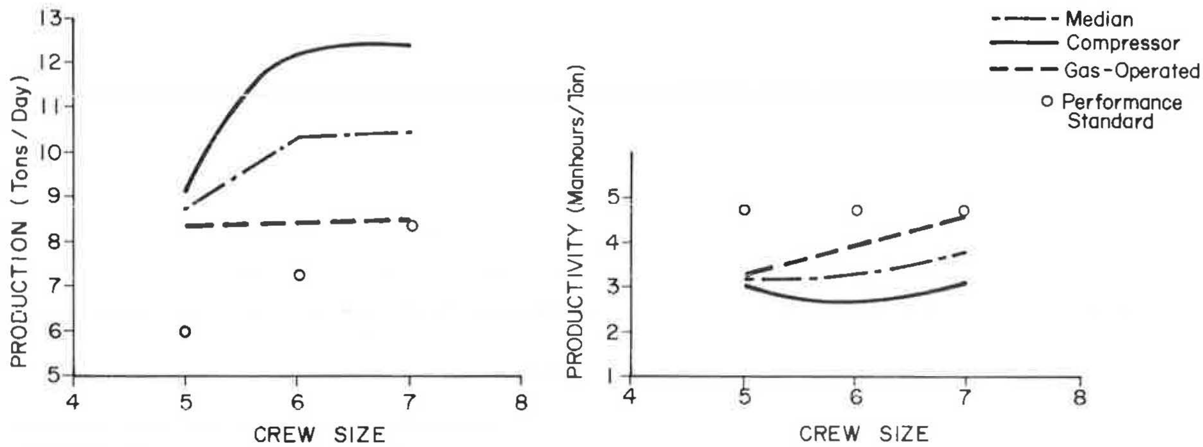

FIGURE 1 Potential production and productivity versus crew size.

achieved routinely. The most efficient crew size (exclusive of traffic control personnel) is a foreman and four HMWs.

4. Improving the cutting operation: Cutting is the most important operation in the overall repair process from the standpoint of productivity and production. The most significant delays that affect efficiency are waiting for instructions and blowing debris from holes with compressed air.

5. Communication: Waiting for instructions accounts for 30 percent of the available work time. Marking the boundaries of holes is especially important on badly deteriorated pavements where it is difficult to determine where the edge of the repair should be.

6. Improving repair quality and durability: The crew should be provided with specific guidelines for the compaction procedure required for pothole repair.

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