

lic employees who travel regularly within the jurisdiction.

7. Establish a program to document conditions that surround highway accidents. The ability to defend a tort suit often depends on evidence that may be difficult to establish several years after a highway accident when a claim may reach the settlement stage. Evidence should be gathered immediately following an accident by a person knowledgeable about the highway facility. Such evidence, which should include photographs, should document the condition of the highway and traffic control devices as well as information that may be needed to reconstruct an accident.

8. Develop procedures to ensure timely notification of highway accidents. Immediate documentation of the conditions that surround an accident obviously is dependent on timely notification of accidents likely to result in tort claims. Arrangements should be made with the appropriate law enforcement agencies to ensure that the highway agency receives such timely notification.

ACKNOWLEDGMENT

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Procedure for Evaluating Efficiency of Power-Operated Cutting Tools in Localized Pavement Repair

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This paper describes a procedure for evaluating the cutting efficiency of air- and gasoline-operated pavement breakers. The procedure was developed as part of a comprehensive study of the pothole-repair procedures used by the Pennsylvania Department of Transportation. Cutting times and delay times are recorded by using the stopwatch study technique and time-lapse photography. A stepwise linear-regression-analysis procedure is used to determine the significant variables, and this information is subsequently used to compare cutting performance. Cutting times in minutes per cubic meter and most probable cutting time in minutes are used as the basis for further comparisons. Management delays are documented for duration and type for both cutting tools. These productivity efficiency factors are then used to show that the air-operated hammer is approximately 25 percent more productive than the gasoline-operated hammer. A procedure is demonstrated that applies the unit cutting rate and the productivity efficiency factor to establish a reasonable productivity goal or to verify an existing productivity or performance standard.

There is little doubt regarding the importance of proper equipment selection in the development of an efficient and productive construction or maintenance operation. All organizations that routinely deploy and use construction equipment are keenly interested in the selection of the right equipment to do the job. Examples of such organizations include contractors, owners who perform force-account construction and maintenance, and state departments of transportation.

Much has been written about the selection of heavy construction equipment, such as cranes, dozers, scrapers, and trucks (1-3). Typically, criteria are presented to help the user decide whether to rent or purchase, and the decision is largely one of economics. In determining the applicability of the equipment to perform the given task, the key reference source is often the manufacturer's specifications and performance characteristics (4).

The procedures noted above have two important

shortcomings. First, they are applicable to high-cost, specialized pieces of equipment intended primarily for the earth-moving contractor. Little guidance is available for evaluating the more common pieces of construction equipment, such as an air compressor. Second, for hauling equipment, the production characteristics are reasonably well defined by the manufacturer. Thus, handbooks provide the contractor with the needed information for evaluating equipment based on an approximate productive output. Unfortunately, production rates for smaller pieces of construction equipment cannot be determined, except by trial evaluations, because productivity is primarily established by (a) the operator, (b) field conditions, and (c) the effectiveness of management. These factors are not addressed by the literature available from the equipment vendor. As pointed out in a recent Value Engineering study of bituminous patching operations, there is a need for further study and evaluation of mechanical cutters, tampers, and compactors and a comparison with current methods (5).

OBJECTIVE AND SCOPE

The objective of this paper is to describe a systematic procedure for evaluating the cutting efficiency of air- and gasoline-operated pavement breakers. The important aspects related to cutting performance, field conditions, and management will be considered. A second objective is to assess the significance of the condition of the cutting bit relative to performance. This information is useful to the manager in planning a bit-sharpening program. The final objective is to demonstrate how field evaluation data can be used to establish a reasonable productivity goal or to verify an existing productivity or performance standard.

The procedures presented in this paper were developed during a comprehensive research study of the pothole-repair strategies used by the Pennsylvania Department of Transportation (6). This study encompassed an evaluation of management practices, pothole-repair procedures, materials, and craft productivity, equipment needs, and applicability. The portion of this study reported here is limited to the evaluation of the pavement-breaker type cutting tools used for removing distressed material from asphaltic concrete pavements. Both flexible-base asphaltic concrete and overlaid portland cement concrete pavements were studied. The equipment that was studied included gasoline-operated Pionjär, model-120 pavement breakers and air-operated jackhammers powered by air compressors. The compressors can be divided into two groups. The first group consists of a number of older model compressors owned by the department. This equipment is characterized by its age, which means that maintenance is a continual problem. These compressors have only a single-line capability, meaning that only one tool may be operated at a time. The second group includes new compressors, both those rented and owned by the department. These are characterized by two- and three-line capability. Compressors in the first group are in the 0.040 m³/s (85 ft³/min) class. Compressors in the second group are in the 0.082 m³/s (175 ft³/min) class.

DATA COLLECTION

An evaluation of equipment performance characteristics and worker use factors requires the measurement of (a) cutting times and (b) delay times associated with the cutting operation. These data were gathered by using time-lapse photography and stopwatches. In addition, the physical dimensions of each hole were documented, including the depth at key locations and the layout of the cut area. By using the dimensions of the holes, areas, and volumes, unit cutting rates were calculated. Other data that were gathered included the condition of the cutting bit, hammer weight, type of pavement, and the pavement condition.

A total of 13 patching operations were studied, which comprised 116 potholes. These holes were located on 12 legislative routes in four counties in central and western Pennsylvania. Seventy-six holes were repaired in asphaltic concrete pavements and 40 were repaired in composite pavements (asphaltic concrete over portland cement concrete). Equipment used for cutting included Pionjär, model 120; gasoline-powered breakers; and air compressors. The Pionjär weighed 26 kg (57 lb). The air-operated hammers were observed in three weight classes--27, 34, and 41 kg (60, 75, and 90 lb). Six crews used the Pionjärs, and seven crews used air compressors. The Pionjärs were essentially new; however, five of the seven compressors studied were old. Two new Ingersoll-Rand compressors were observed. One, which was owned by the Pennsylvania Department of Transportation, had three-line capability, and the other rented compressor had two lines.

DATA ANALYSIS

The effective deployment and use of pavement-cutting equipment requires that the manager understand the significance of those variables that affect cutting performance. The identification of factors was done by using the statistical analysis system (SAS) that is available from the SAS Institute (7). A stepwise linear-regression-analysis procedure with the MAXR option was used on the Pennsylvania State University IBM model 370 computer. The MAXR option provides

the capability of looking at essentially all possible regression combinations, because multiple models are evaluated at each level and the best model is selected.

Significant Factors

The stepwise linear-regression analysis was performed with cutting time in minutes as the dependent variable and the independent variables described below. The data were obtained as part of the stop-watch study.

1. Two types of equipment were considered--air compressors and Pionjär;
2. Breaker bits were classified as sharp, intermediate, and dull;
3. Cutting operations were limited to asphaltic concrete and composite pavements;
4. Pavement condition was classified as either sound or distressed (obviously a distressed condition is associated with a pothole; however, for this study, pavement was considered sound if surrounding material remained reasonably intact as the cutting edge was applied; a pavement that had essentially lost most of its life and seemed to fall apart under the action of the cutting tool was considered distressed; the distressed condition was limited almost exclusively to those holes along the edge of the roadway);
5. Hole depth;
6. Holes lying along the edge of the pavement were usually cut along only three sides;
7. Hole area; and
8. Hole volume.

The results of the regression analysis indicated that a four-variable regression equation that has an R² value of 0.81 was the best model. Significant variables in this equation were (a) hole volume, (b) type of equipment, (c) interaction between equipment type and pavement type, and (d) interaction between equipment type and pavement condition.

Surprisingly, the most significant variable is the volume of the hole. Figure 1 shows that hole size is noticeably skewed toward smaller-sized holes; however, note that almost 14 percent of the holes have volumes in excess of 0.23 m³ (7.99 ft³). One may wonder whether such large holes should even be defined as potholes. Hole volume may seem unimportant to the manager, who has little prior knowledge of the size holes to anticipate. Nevertheless, hole volume is very important to the engineer, who must evaluate various types of cutting equipment. Subsequent analyses will be done on the basis of data related to hole volume.

Figure 2 shows the relationship between actual cutting times and hole volume. The regression equations for the air compressor and the Pionjär are shown. A measurable difference between cutting rates can be observed. While this difference is widely accepted throughout the industry, the magnitude of the differential is generally not known. By using the regression equations for an average hole volume of 0.10 m³ (3.52 ft³), as determined from Figure 1, the likely mean cutting time for the air compressor and the Pionjär is 4.39 and 6.79 min, respectively. The difference between cutting rates is discussed below in greater detail.

Comparison of Equipment

The numerical comparison of cutting performance is very important to the manager because the rate at which holes are cut and prepared establishes the production rate of the crew. Figure 2 shows the

Figure 1. Distribution of holes according to approximate hole volume.

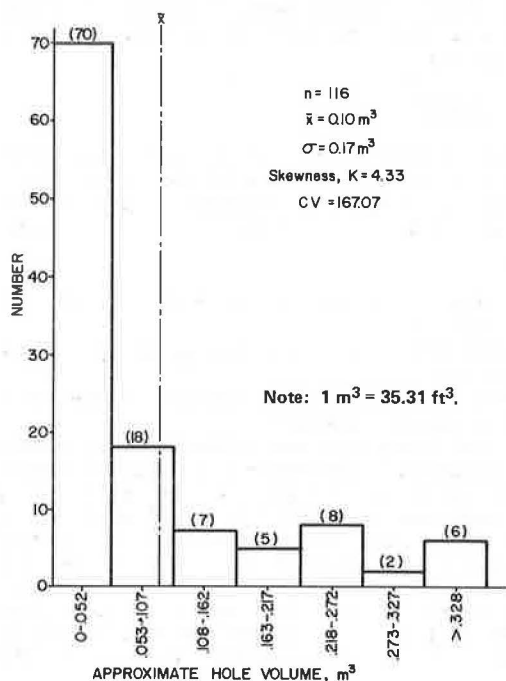


Figure 2. Plot of cutting time versus hole volume.

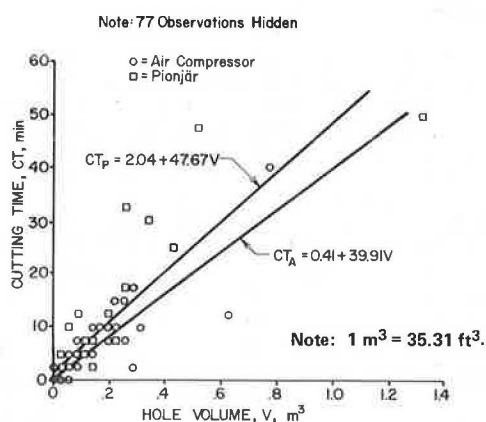


Figure 3. Frequency histogram of cutting rate.

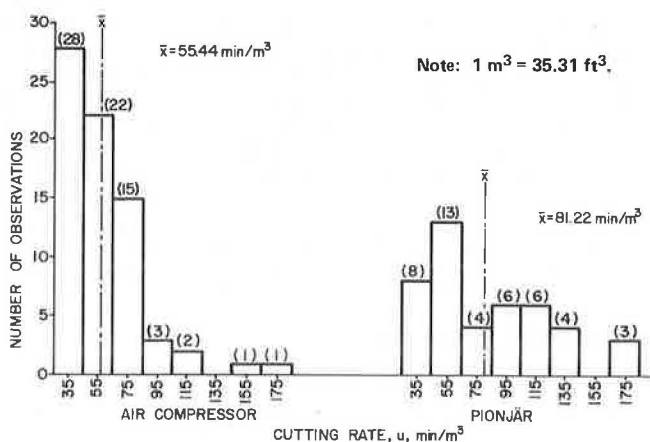
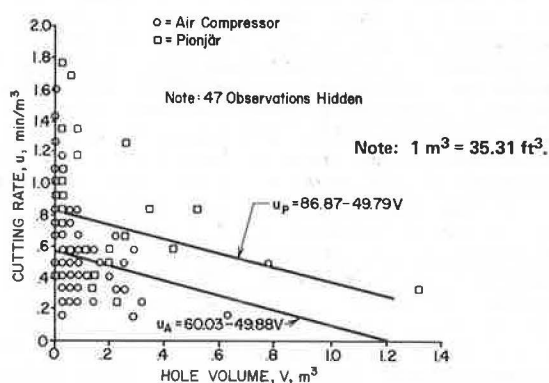


Figure 4. Plot of cutting rate versus hole volume.



plot of cutting time versus hole volume and the anticipated difference in mean cutting times for the air compressor and the Pionjär. The difficulty in using these values as the basis for comparison is that the distribution of hole volumes is definitely skewed toward smaller-sized holes. Furthermore, approximately 14 percent of the hole volumes are very large [i.e., exceed 0.23 m³ (7.99 ft³)]. Since the cutting time differential widens significantly as the hole size increases, concerns should be raised about use of the approach shown in Figure 2 as a predictor of relative performance. Note also that the holes prepared by the Pionjär tended to be larger than those cut by the compressor. This information is summarized below (note 1 m³ = 35.3/ft³).

| Item | Compressor (%) | Pionjär (%) |
|---------------------------------------|----------------|-------------|
| Percentage of holes exceeding 0.10 m³ | 19.4 | 31.8 |
| Percentage of holes exceeding 0.14 m³ | 16.7 | 20.5 |
| Percentage of holes exceeding 0.28 m³ | 5.6 | 9.1 |
| Maximum volume (m³) | 0.77 | 1.30 |

The use of an average size hole of 0.08-0.11 m³ (3-4 ft³) should also be questioned because the probability of observing such a hole is relatively small ($p = 0.06$). What is needed is a measurement of total performance for cutting all sizes of holes, not just a typical hole.

Unit cutting rates are next examined as a possible measure of performance. The distribution of unit rates is shown in Figure 3. The average cutting rate for the air compressor and the Pionjär is 55.4 min/m³ (1.57 min/ft³) and 81.2 min/m³ (2.30 min/ft³), respectively. These mean rates suggest that the Pionjär will require approximately 47 percent more time than an air compressor to cut a hole of equivalent size. However, once again, there should be concern over how the unit rates are affected by hole size. As can be seen in Figure 4, the unit rate for each type of equipment decreases as hole size increases.

The most appropriate measure of performance is the probable cutting time or weighted average. This parameter accounts for the fact that (a) all hole sizes will be encountered, (b) the distribution of hole size is skewed, and (c) the unit rates in minutes per cubic meter are uniquely described for each equipment type and hole size. The procedure for computing probable cutting time uses the following equation:

Table 1. Probable cutting time.

| Interval, i | Lower Class Limit (m ³) | Upper Class Limit (m ³) | Probability of Occurrence, P _i | Avg Volume, V _i (m ³) | Avg unit Rate, u _i (min/m ³) | | P _i x V _i x u _i (min) | |
|----------------|--|--|---|--|--|---------|---|---------|
| | | | | | Air Compressor | Pionjär | Air Compressor | Pionjär |
| 1 | 0.00 | 0.052 | 70/116=0.603 | 0.025 | 58.62 | 85.46 | 0.88 | 1.29 |
| 2 | 0.053 | 0.107 | 18/116=0.155 | 0.077 | 56.15 | 82.99 | 0.67 | 0.99 |
| 3 | 0.108 | 0.162 | 7/116=0.060 | 0.136 | 53.33 | 80.16 | 0.44 | 0.65 |
| 4 | 0.163 | 0.217 | 5/116=0.043 | 0.195 | 50.15 | 76.99 | 0.42 | 0.65 |
| 5 | 0.218 | 1.416 | 16/116=0.138 | 0.410 | 39.55 | 66.39 | 2.24 | 3.76 |
| Total | | | | | | | 4.65 | 7.34 |

Note: 1 m³ = 35.31 ft³.

Table 2. Analysis of delay times for cutting operations.

| Activity | Frequency of Occurrence | Stopwatch Study Number | | | | | | Total | |
|-----------------------------------|-------------------------------|------------------------|-------|-------------------|---------|--------|-------|--------|----------------|
| | | Air Compressor | | | Pionjär | | | | |
| | | 1 | 2 | 3 | 4 | 5 | 6 | No. | Percent |
| NWTA ^a | | 124.32 | 80.72 | 47.16 | 128.99 | 149.35 | 40.31 | 570.85 | |
| Cutting time | | 71.70 | 62.31 | 40.02 | 118.19 | 124.25 | 19.60 | 436.07 | 76 |
| Delay time | | | | | | | | | |
| Traffic | 11 | 0.71 | | | 1.04 | 1.27 | | 3.02 | 2 ^b |
| Change hammers | 1 | 2.30 | | | | | | 2.30 | 2 |
| Clean hole with shovel | 8 | 0.51 | 2.77 | | | 13.08 | | 16.36 | 12 |
| Clean hole with air compressor | 28 | 48.38 | 7.47 | 7.02 ^c | | | | 55.85 | 41 |
| Change operators | 6 | | 2.02 | 0.54 | | 0.68 | | 3.24 | 2 |
| Instructions | 13 | 0.51 | 3.17 | | | | | 3.68 | 3 |
| Personal | 17 | | 2.98 | 0.41 | 1.35 | 4.15 | 18.85 | 27.74 | 21 |
| Move to new hole | 31 | 0.21 | | 6.19 | | 1.83 | 0.45 | 8.68 | 6 |
| Refuel Pionjär | 9 | | | | 8.41 | 3.50 | 1.41 | 13.32 | 10 |
| Adjust equipment | 1 | | | | | 0.59 | | 0.59 | 1 |
| Total | | 52.62 | 18.41 | 7.14 | 10.80 | 25.10 | 20.71 | 134.78 | 24 |
| Efficiency ^d | | 58 | 77 | 85 | 92 | 83 | 47 | 76 | |

^aNWTA = Net work time available is the total study time less time spent on coffee breaks, major equipment breakdown, etc.^bPercentages for delay times are expressed as a percentage of the total delay time.^cThe cleaning time is not included in the total delay time because a dual-line compressor was used that permitted cutting to continue without interruption.^dEfficiency = (Cutting time/NWTA) x 100.

$$CT = \sum_{i=1}^n P_i V_i u_i \quad (1)$$

where

CT = most probable (weighted average) cutting time (min),

P_i = probability of encountering a hole whose volume is within a specified class interval (i),

n = number of classes into which the distribution of hole volumes is divided,

V_i = average volume (m³) of those holes located within interval i, andu_i = average unit rate (min/m³) for those holes located within interval i.

The distribution of hole sizes shown in Figure 1 was divided into five intervals. The probabilities (P_i) and the average volume within each interval (V_i) were computed by using actual hole data. By using V_i, the unit rates can be determined from the regression equation in Figure 4. The calculations necessary for the application of Equation 1 are summarized in Table 1, from which the probable cutting times are computed to be as follows:

Probable cutting time for air compressor = 4.65 min/m³ and

Probable cutting time for Pionjär = 7.34 min/m³.

It would appear then that a relative comparison of

the two cutting tools will favor the air compressor by a considerable margin because the Pionjär requires approximately 58 percent more time to cut a group of holes that are distributed as per Figure 1.

Significance of Bit Condition

In addressing the question of the significance of bit condition to cutting performance, only data for the Pionjär and the 27-kg (60-lb) class air hammers were considered. This was done to minimize any possible bias introduced because the data gathered for the 34-kg (75-lb) and 41-kg (90-lb) class hammers were from only one roadway. The remaining data were statistically unbalanced because there were no dull bits for the compressor or intermediate bits for the Pionjär observed. Therefore, it was felt that a regression equation developed from the data would not be reliable.

To assess the significance of bit condition, only the Pionjär data were reviewed. The average unit rate in minutes per cubic meter was determined for sharp and dull bit conditions. Twenty-six holes were prepared, at an average rate of 69.6 min/m³ (1.97 min/ft³), by using a sharp bit. A dull bit was used on the remaining 18 holes. The average unit rate was 97.8 min/m³ (2.77 min/ft³), which is approximately 41 percent greater than the rate for the sharp bit. Although more studies need to be conducted, an intensive bit-sharpening program would appear to be justified.

Management Practices

To evaluate management effectiveness relative to the cutting operation, the delay times recorded during six stopwatch studies were identified by magnitude and type. These are shown in Table 2. Studies 1, 2, and 3 are of air compressors, and studies 4, 5, and 6 are of the Pionjär. As can be seen, approximately 76 percent of the net work time available (NWTa) was spent in actually cutting the holes. NWTa is defined as the time available that actual cutting can take place after coffee breaks, travel time, major equipment failures, and so forth have been excluded. The delay time (24 percent) is primarily attributed to (a) cleaning the hole with compressed air (air compressor only), (b) personal breaks, (c) waiting for the hole to be cleaned via shovel, and (d) equipment refueling (Pionjär only). A number of the categories where ineffective time can be minimized relate directly to the ability of the foreperson to manage work by the crew. For example, in study 2 it would appear that, by properly marking the cut area around the hole, the need for giving instructions would be greatly reduced. However, the management areas where maximum potential for improvement exists appear to be cleaning of the hole with compressed air and the refueling of the Pionjär. These two aspects are presented below.

The description of crew efficiency according to the type of equipment provides an interesting observation. The crew efficiency is as follows:

| Time | Air Compressor (%) | Pionjär (%) |
|---------|--------------------|-------------|
| Cutting | 69 | 82 |
| Delay | 31 | 18 |

These data suggest that the advantages in cutting performance enjoyed by the compressor are at least partly offset by improved crew efficiency with the Pionjär. In order to further investigate this finding, the delays inherent with the air compressor were documented.

The two most significant delays associated with the air compressor are (a) cleaning the hole with compressed air and (b) moving to a new hole. Obviously, little can be done by management to reduce the time required to move to a new hole. Cleaning the hole is another matter. Study 1 vividly demonstrates the disadvantages of single-line compressors. The excessive cleaning time noted includes actual cleaning of the hole, disconnecting and reconnecting the hammer, and opening and closing the shutoff valve. This latter operation is usually performed by a second worker, which in itself is not an effective use of personnel. Regardless, the productivity of the crew was greatly reduced because cleaning and cutting could not be done simultaneously. For study 1, the roadway surface was particularly poor and, for this reason, studies 2 and 3 may reflect a typical situation more accurately. Nevertheless, the cleaning times are still significant, approximately 11 percent of the NWTa. This percentage represents a corresponding loss in productivity. It would appear that the department should adopt a policy that all new compressors, whether rented or purchased, should have a minimum of two lines, one of which is reserved for cleaning of the hole. This was the case with study 3, where the hole cleaning did not affect production.

The refueling of the Pionjär is of interest because not only does it contribute to lost production but, more importantly, it is a good indicator of (a) maintenance practices and (b) how well the operator is able to adjust the air-gasoline fuel mixture that affects the energy delivered to the cutting tool.

In study 4, the operator refueled a total of six times, as opposed to twice and once for studies 5 and 6, respectively. It was calculated that the Pionjär in study 4 consumed fuel at a rate of 4.16 L/h (1.10 gal/h) as compared with 1.59 L/h (0.42 gal/h) as stated by the manufacturer. In study 5, the calculated rate was 1.55 L/h (0.41 gal/h). Insufficient information was available to determine the rate in study 6.

Additional studies are needed to establish whether or not the situation found in study 4 is an isolated incident. If not, operator training would, of course, be appropriate. Better-trained operators will lead to improved Pionjär efficiency by (a) decreasing the delay time for refueling and (b) decreasing the unit cutting times through increased fuel efficiency.

PRODUCTIVITY GOALS AND PERFORMANCE STANDARDS

Most organizations require a minimum acceptable level of productivity against which actual performance can be measured. For pothole-repair operations, productivity is usually measured in kilograms (tons) of material. One such parameter is the kilograms per day (tons per day) of material placed. Since the cutting rate also establishes the filling and compaction rate of the crew, the amount of material placed must equal the amount of material removed. The information presented previously is sufficient to allow this parameter to be determined. A hypothetical situation is presented below.

| Item | Time (min) |
|--|------------|
| Travel to the job site, deploy safety devices, and start cutting operation | 60 |
| Coffee break, add 5 min for re-starting operation | 20 |
| Restart operation after lunch | 5 |
| Cleanup and put away tools | 10 |
| Remove safety devices and return to maintenance shed | 60 |

The time remaining is production time, which is NWTa. In this example, NWTa is 295 min.

At this point, recall that the crew efficiency, which is the ratio of cutting time to NWTa, varies by equipment type. If one assumes that cutting will be in progress throughout this 295-min period, then the actual cutting time can be computed as

$$\begin{aligned}\text{Cutting time for air compressor} &= 0.69 \times 295 \text{ min} \\ &= 204 \text{ min and} \\ \text{Cutting time for Pionjär} &= 0.82 \times 295 \text{ min} = 242 \text{ min.}\end{aligned}$$

The most probable cutting rate can be computed by

$$u' = \sum_{i=1}^n P_i u_i \quad (2)$$

where u' is defined as the most probable cutting rate (min/ft³).

By using the information in Table 1, these rates are as follows:

$$\begin{aligned}u' \text{ for air compressor} &= 54.9 \text{ min/m}^3 \text{ (1.55 min/ft}^3\text{)} \\ \text{and} \\ u' \text{ for Pionjär} &= 81.7 \text{ min/m}^3 \text{ (2.31 min/ft}^3\text{)}.\end{aligned}$$

Divide the unit rates into the available cutting times to get the daily production:

$$\begin{aligned}V_a &= 204/54.9 = 3.7 \text{ m}^3/\text{day (130.3 ft}^3/\text{day) for} \\ &\quad \text{air compressor and} \\ V_p &= 242/81.7 = 3.0 \text{ m}^3/\text{day (104.7 ft}^3/\text{day) for} \\ &\quad \text{Pionjär.}\end{aligned}$$

If we assume that asphaltic concrete can be compacted to a density of 1920 kg/m³ (120 lb/ft³), then the equivalent daily tonnage of material is

$$T_a = (3.7)(1920)/1000 = 7.1 \text{ Mg/day (7.9 tons/day)}$$

and

$$T_p = (3.0)(1920)/1000 = 5.8 \text{ Mg/day (6.3 tons/day)}.$$

Several important points should be made about these rates. First, recall that the Pionjär requires approximately 58 percent more cutting time than does the compressor if probable cutting times are used as the basis for comparison. However, when one considers that there is less delay time associated with the Pionjär (i.e., it has greater flexibility and mobility), then the advantage of the air compressor is reduced to approximately 23 percent. Second, observe that significant improvements in megagrams per day can result by increasing NWTa. For example, a 30-min increase in NWTa will increase the daily production for the compressor to 7.83 Mg/day (8.63 tons/day), a 10 percent gain. On a weekly basis, a 150-min increase corresponds roughly to the difference between working five 7.5-h work days and working three 10-h days and one 7.5-h day. Production could also be substantially increased by using a triple-line compressor with two hammers or by using two Pionjärs. Of course, management must also consider whether or not the crew can fill and compact the holes at this accelerated rate.

USE OF PERFORMANCE STANDARDS

One of the basic principles of effective management is that one must evaluate past performance. The performance standard is the means by which the maintenance manager can perform this function. Clearly, many variables will influence the productive output of a repair crew. These must be recognized; however, consistent subpar performance should be a signal that crew leadership may be deficient. The causes should be sought out and corrected. The productivity levels suggested in this paper are realistic because they were based on the actual equipment capabilities plus an acceptable percentage of delays. The productivity output can be achieved by the average crew foreperson provided he or she exercises some management skills. It is the responsibility of the state transportation agency to develop those skills.

CONCLUSIONS

The comprehensive study of the cutting performance of air compressors and gasoline-operated Pionjärs has led to several important conclusions. These are summarized below:

1. The most significant variable that accounts for variability in cutting times is the volume of the hole. Any study of cutting equipment must incorporate this parameter into the analysis before valid comparisons can be made.

2. The comparison of the actual cutting performance of the air compressor and the Pionjär was done on the basis of probable cutting times. Probable times were used to minimize any bias resulting from the skewness of the hole volumes and unit cutting rates. The Pionjär was found to require approximately 58 percent more cutting time than the air compressor for an equivalent size hole.

3. In evaluating management practices, a number of delay times were noted. The crew could make more efficient use of the Pionjär (82 percent) than the air compressor (69 percent). Several suggestions for increasing this efficiency were noted.

4. A procedure for establishing a productivity goal or verifying an existing performance standard was outlined. When the influences of cutting efficiency and management effectiveness are included, the advantage of the air compressor over the Pionjär is reduced considerably. Approximately 23 percent more material could potentially be removed with the air compressor than the Pionjär.

5. Achievement of daily production rates of 7.1 Mg/day (7.9 tons/day) for the air compressor and 5.8 Mg/day (6.3 tons/day) for the Pionjär are clearly realistic because these rates were developed by considering actual field data relative to equipment and management effectiveness. Substantial compliance for most crews should be expected. However, this will occur only through effective leadership by the crew foreperson.

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