maintenance and repair, and logical project development. The savings are primarily through cost avoidance due to eliminating waste of overdesign and the cost of premature repairs due to underdesign. This was clearly demonstrated in the design process for the current $2 million received for road repairs. Traditional designs that previously would have been accepted were independently considered and compared to alternatives developed with the aid of PAVER. The traditional designs did represent both overdesign and underdesign for given sections and proved to be costly.

Additionally by using a minimum acceptable PCI, sections are flagged for repairs in a timely fashion. Identifying sections that need major repairs and accomplishing those repairs before complete failure will also save considerable money. Repair costs increase in a curvilinear relationship with decreasing PCI. Logical project development groups sections into efficient construction projects of similar work and geographical confines. That should keep bid prices down.

MANAGEMENT CONCLUSION

Finally, the investment for PAVER, which consists of the $120,000 implementation cost and approximately $10-20,000 per annum in computer support costs, has proved to be a worthwhile investment for the Navy at Great Lakes. Flexible and easily understood, PAVER is a powerful tool for meeting the maintenance challenges of modern public works managers. Effective management has resulted; and for the first time, network and project level management has become a reality. The shortcomings of traditional methods, which had not been fully recognized, were eliminated. At the same time no increase in public works staff has been necessary nor has this placed an unreasonable burden on the existing staff. Time spent by the various groups are approximately the same as before but much more has been accomplished. All will agree they are managing better with PAVER.

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Abridgment

A Management Information System to Monitor Routine Maintenance Productivity

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ABSTRACT

Measures are discussed that are most suitable for reflecting maintenance productivity and a procedure that produces straightforward reports of maintenance unit productivity levels is presented. The generated information is then examined to identify maintenance units with low productivity; these units can then be compared on a statewide basis. Higher levels of management will be able to relay this information to individual units, indicating each unit's production level and how it compares with other units and the statewide average. Providing maintenance unit personnel with a guideline to evaluate their operations, in the form of a checklist of factors found to contribute to low productivity, will help them to identify areas for improvement. The

result would be cost savings as well as improvement in the quality of maintenance operations.

To manage a highway routine maintenance program effectively and efficiently, managers must be able to monitor the performance or the productivity of maintenance forces. By monitoring and comparing productivity of the various subdistricts, highway managers will be able to identify areas where resources are not being used efficiently and will be guided to investigate further and take corrective measures. On the other hand, highly efficient work methods may also be identified and transferred to other areas of the state.

Productivity may be measured in terms of a resource used per production unit or cost per production unit for a given activity. The number of man-hours per production unit is one such measure. This would be suitable for maintenance activities that are measured in units other than man-hours, such as shallow patching where productivity can be measured in man-hours per ton of bituminous mixture placed. However, the production unit of many activities is measured in man-hours, such as cutting brush and maintaining signs. For these activities, another productivity measure would be necessary.

An alternative to man-hours per production unit would be the amount of a given material per production unit, for example, the amount of herbicides used per man-hour of herbicide treatment. A problem may arise in deciding which particular material to include in the productivity measure, however, when an activity involves the use of several materials. Furthermore, many activities do not always use the same mix of materials. If the material chosen as a productivity measure is not always used, the usefulness of the measure is diminished.

Another approach to measuring productivity is to calculate the average cost per production unit for an activity. The reason for monitoring productivity is to control and improve the efficiency of maintenance operations, where efficiency refers to the cost of performing the maintenance. If man-hours or material use were chosen as a measure of productivity, the factor of primary interest, namely the cost, may be masked. Therefore, cost per production unit for a given activity was judged to be the most appropriate measure of productivity, and a computer program was developed to analyze crew-day-card records and compare productivity of the subdistricts for a given activity.

DESCRIPTION OF COMPUTER PROGRAM

The Indiana Department of Highways (IDOH) Division of Maintenance has a detailed system of maintenance data collection in the form of crew day cards. Each time a crew performs a maintenance activity, pertinent information about the crew's performance is recorded on a crew day card. With the exception of equipment use, the information from the crew day card is coded and recorded on magnetic tape. A computer program was developed to use the crew-day-card data to produce relatively simple and straightforward reports showing various factors by which subdistrict performance may be assessed.

Based on the crew-day-card records, the program determines the number of times a given activity was performed by each subdistrict, the total amount of work accomplished in the time period under study, the average accomplishment per crew day, the average crew size, the average number of man-hours (both regular and overtime) per crew day, and the number of man-hours per production unit. Also determined are the percent of time a given material is used, the average quantity of the material when it is used, and the average quantity of material used per production unit. The average cost per production unit is calculated along with the labor cost and material cost per production unit. A summary of production amounts, labor, and material use for each of the six districts and the state as a whole is also calculated.

After determining these values for each subdistrict, the program calculates the average and standard deviation of the cost figures for each subdistrict. Then the productivity of each subdistrict is checked to see if it falls outside the range of the average plus or minus a given number of standard deviations. These deviate units are then listed, and relevant summary information is presented in bar charts. These computations can be made for the Interstate or Other State Highway classes separately or for the entire highway system.

PRODUCTIVITY MONITORING PROCEDURE

There are five basic steps in the productivity monitoring procedure for a given maintenance activity.

1. Identify deviate units. The computer program is used to determine which subdistricts deviate from the average unit cost. The analysis may be performed for an entire year or for any number of months. One method is to divide the fiscal year into a number of periods, say six, and run the program for each 2-month period as well as the entire year. In this way, subdistricts that deviate consistently throughout the year may be identified or seasonal trends may be revealed.

2. Analyze labor and material factors. The program calculates several factors that describe the use of labor and materials by each subdistrict and plots their values in bar chart form. These factors include the average crew size, average number of labor hours per unit of accomplishment, average amount of a specified material used per accomplishment unit, average daily accomplishment, and total accomplishment during the analysis period. By examining these charts, along with the chart of average cost per accomplishment unit, some relationships between the factors and cost may be found that provide insights to the reasons for the high and low costs. For this study a statistical analysis of these data was conducted to determine if trends identified by visual examination of the charts corresponded with those indicated by statistical analysis.

3. Review equipment records. A sample of crew day cards must be reviewed manually to determine the type and amount of equipment used. Equipment information can help determine if the procedures outlined in the performance standards are being followed and may provide clues as to the quality of work. For example, a shallow patching crew with only a pickup truck would be expected to perform lower quality work than a crew that uses a portable patcher and roller. Examination of these records may indicate a problem of equipment availability or scheduling.

4. Conduct field inspections. Because the crew-day-card records do not provide an indication of quality or roadway conditions, firsthand inspection of the work crews in the subdistricts under study is necessary. A subdistrict with a high average unit cost may be performing higher quality work than a subdistrict with a low unit cost. Or, using shallow patching as an example, roadways in a low-cost subdistrict may be in worse condition than those in a high-cost subdistrict. Although it is possible to draw conclusions based on information provided by

the crew-day-card data, field visits are needed for confirmation.

5. Draw conclusions and take appropriate action. Based on findings in the steps above, a conclusion can be drawn as to whether those units under study with costs that deviate from the average have problems that need to be corrected, whether they have been using innovative techniques that should be shared with other subdistricts, or whether the deviations are the result of special circumstances. If some action is deemed appropriate, it should be taken and the subdistricts affected should be monitored to evaluate the effect of the action.

DEMONSTRATION OF PROCEDURE WITH CRACK SEALING

An analysis for activity 207, crack sealing, in fiscal year 1982-1983 is presented to demonstrate the procedure.

Identification of Deviate Units

Subdistricts that deviated from the average were identified by running the computer program for six consecutive 2-month periods and for the entire fiscal year. The results of this analysis are summarized in Figure 1. Considering data for the entire year, seven subdistricts were in the high-cost group and eight were in the low-cost group; 22 subdistricts were assessed to be average.

Analysis of Labor and Material Factors

Appropriate bar charts were produced showing the average cost and average labor hours per ton of mix, total accomplishment, average daily accomplishment, average crew size, and average quantity of material 4431 (bituminous material) per lane mile for the entire fiscal year. Examination of these charts indicated that the high-cost subdistricts tended to have above average labor hours per lane mile, and low-cost subdistricts tended to have below average labor hours per lane mile. In general, low-cost subdistricts tended to do more total crack sealing than subdistricts in the high-cost group, indicating there may be an economy of scale. As expected, there appeared to be a strong relationship between cost and average accomplishment, with the low-cost subdistricts exhibiting a higher average accomplishment than the high-cost subdistricts. The bar charts did not clearly indicate a relationship between crew size and cost, but there seemed to be a strong relationship between the amount of bituminous material used per lane mile and cost, with the low-cost subdistricts using less material than the high-cost subdistricts.

A statistical analysis was conducted to confirm these trends using data from the six 2-month period analyses. An analysis of variance with covariates was used. The dependent variable was average cost, and covariates used in the analysis were frequency (number of times activity was performed), average accomplishment, average crew size, and average amount of bituminous material used per lane mile.

The analysis of variance revealed that after removing the effects due to the covariates, there was no significant variation in cost attributable to the main factor of subdistrict group. Furthermore, a relatively large amount of the variation in cost was removed when the amount of bituminous material used (P4431) was considered.

Review of Equipment Records

A manual review of crew-day-card records was conducted for three subdistricts: 5300 (Columbus) from the low-cost group, 1300 (Fowler) from the average-cost group, and 4200 (Monticello) from the high-cost group. Crew-day-card records for the months of October, November, and December 1982 were examined to determine the type of equipment used. The performance standard for activity 207 calls for the use of pickup and pickup crew cab trucks, dump trucks, an air compressor, and a tar kettle (1).

All three subdistricts used dump trucks and pickup or pickup crew cab trucks 100 percent of the

District	Crawfordsville						Fort Wayne						Greenfield						LaPorte							Seymour						Vincennes					
Subdistrict	11	12	13	14	15	16	21	22	23	24	25	26	31	32	33	34	35	36	41	42	43	44	45	46	47	51	52	53	54	55	56	61	62	63	64	65	66
Period																																					
July-Aug. '82																																					
Sept.-Oct. '82				+	+	+			-											+														-			
Nov.-Dec. '82				+		+	+											+		+								-		-	-			-		-	-
Jan.-Feb. '83			+							+		-			+	+		+	+			-		+				-		-							-
Mar.-Apr. '83			+	-						+	+															+										-	
May-June '83																						+		+													
July '82-June '83					+		+		-		+							+	+	+		+						-		-	-		-	-		-	-

\- Indicates that Productivity (cost in \$/lane-mile) was below the average for all subdistricts by at least one standard deviation.

\+ Indicates that Productivity (cost in \$/Lane-mile) was above the average for all subdistricts by at least one standard deviation.

Period	Average Cost \$/lane-mile	Standard Deviation \$/lane-mile
July-Aug. '82	No work this period	-----
Sept.-Oct. '82	303.03	140.65
Nov.-Dec. '82	269.84	79.87
Jan.-Feb. '83	283.03	94.32
Mar.-Apr. '83	259.33	108.58
May-June '83	300.49	134.25
July '82-June '83	262.09	56.37

FIGURE 1 Statewide deviation analysis summary for Activity 207—Crack Sealing (fiscal year 1982-1984).

time. There were, however, differences in the use of air compressors, tar kettles, and distributor trucks. Air compressors are used to clean out cracks prior to sealing. A tar kettle contains and heats the bituminous material used for sealing. Workers fill hand-carried pots from the tar kettle and pour the bituminous material into cracks from these pots. A distributor truck is a tank truck that holds the bituminous material that is applied using a hand-held spray bar.

The high-cost subdistrict reported use of an air compressor 100 percent of the time as contrasted with the average-cost subdistrict that never used an air compressor and the low-cost subdistrict that reported use of an air compressor 35 percent of the time. The high-cost group reported approximately the same average accomplishment as the average-cost group but used a larger crew. In the low-cost group, larger crew sizes and larger average accomplishment were reported when an air compressor was used than when it was not. It appears that use of an air compressor requires a larger crew but does not seem to have an effect on average accomplishment. If this is indeed the case, use of an air compressor would cause these subdistricts to have a higher unit cost without increasing the number of lane miles that can be sealed in a day; this is because an extra crew member is needed to run the compressor.

The high-cost subdistrict that used a distributor truck 100 percent of the time had larger crews and accomplished less per day than the low-cost subdistrict that used a tar kettle 100 percent of the time. The average-cost subdistrict used a tar kettle 52 percent and a distributor truck 48 percent of the time. When a tar kettle was used in the average-cost subdistrict, a larger crew and smaller accomplishment were reported on the average than when a distributor truck was used.

Based on these observations, it appears that the use of an air compressor requires a larger crew without providing an increase in daily accomplishment, thus resulting in a higher unit cost. To seal cracks properly, however, they must be free of dirt and other debris. Because road conditions vary, the roadway may often be clean and the cracks free of debris, making it unnecessary to blow them clean. It is, however, improbable that this would always be true, and the practice of never using an air compressor would be questionable. Factors such as this can only be identified in a manual review of records or by field inspections. No trends with respect to the use of a tar kettle versus distributor were apparent from the equipment records.

Field Inspections

One prototypical field inspection was made of a sealing crew at work in the Columbus subdistrict which was selected from the low-cost group. The observations were made on US-31 north of Franklin in Johnson County on December 13, 1983. A 10-man crew used two dump trucks, two crew cab pickups, a tar kettle, and an air compressor. A pickup truck pulling the air compressor was first in the process, followed by a dump truck pulling the tar kettle, three workers applying bituminous material to cracks, and three workers squeegeeing the material into the cracks. Next in line was a dump truck equipped with a sand spreader that backed along spreading sand on the sealed surface. Last in line was a pickup truck pulling an arrow board. After observing the operation and condition of the road, the unit foreman decided that it was not necessary to blow the cracks clean; this allowed the compressor to be parked and the crew member operating it to help with the actual sealing.

According to the unit foreman, the bituminous material being used was unusually thick, and he expected the crew's accomplishment to be lower than normal because thick material is slower to pour. The bituminous material is delivered to the subdistrict, and its quality is not under their control. According to the foreman, the daily accomplishment of a crew will vary according to the condition of the sealing material and to the severity of cracking of the roadway. The foreman indicated that US-31 was one of the worst roadways in his area with respect to cracking and needed to be resurfaced. Without an objective statewide standard for determining pavement conditions, what constitutes a "bad" pavement as opposed to a "good" pavement is a subjective judgment. Perhaps roadways in the southern part of the state are in better condition than those in the north. Figure 1 indicates that seven of the eight low-cost subdistricts are in the southernmost districts, Seymour and Vincennes, whereas five of the seven high-cost subdistricts are in the two northernmost districts, Fort Wayne and LaPorte.

CONCLUSIONS

The analysis indicates that higher costs are associated with larger crew sizes, lower average daily accomplishment, and higher rates of material use. Furthermore, the amount of material used per lane mile explains much of the variation in average cost. Most of the high-cost subdistricts are in the two northernmost districts, whereas most of the low-cost subdistricts are in the two southernmost districts. This suggests that there may be a difference in road conditions in the southern versus the northern part of the state, a factor that could be affected by climate. More field inspections are needed to investigate this possibility and to compare the quality of work in various subdistricts.

SUMMARY

The purpose of this study was to provide the Indiana Department of Highways with a systematic procedure to identify maintenance units with low productivity and compare units on a statewide basis. Higher levels of management will be able to relay this information to the individual unit, indicating that unit's production level and how it compares with other units and the statewide average. Providing maintenance unit personnel with a guideline to evaluate their operations, in the form of a checklist of factors found to contribute to low productivity, will help them to identify areas for improvement, resulting in cost savings as well as improvements in the quality of maintenance operations.

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The authors are solely responsible for the contents of this paper.