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Evaluation of Highway Maintenance Cost and Organization in Pennsylvania

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The analysis focuses on Pennsylvania's highway maintenance organization in its 67 counties and the cost of five maintenance activities common to all counties: manual patching, mechanical patching, shoulder repair, surface treatment, and snowplowing. In this analysis those counties and groups of counties that produce these activities at either very high or very low total costs relative to one another will be identified. Operational and environmental factors that cause maintenance costs to vary from county to county will be used in multiple regression techniques. Based on the comprehensive nature of the variables used to explain variation in maintenance costs, inferences are made about the relative efficiency of county maintenance organizations according to actual total costs compared to those predicted by the regression equations. These equations were based on data from 1976. The primary source of operational data was the highway maintenance management system developed for the Pennsylvania Department of Transportation. The study compares counties that produce unusually high- or low-cost maintenance and gives possible reasons for unexplained cost variations by examining operational characteristics. On-site management studies are recommended in order to identify areas for efficiency and cost savings.

In the last 30 years Pennsylvania has constructed a vast highway network. In 1977, the total state-maintained system amounted to 72 000 km (45 000 miles). Recently, because of the mounting cost of construction and debt service, the push for construction has diminished and increased emphasis has been placed on maintaining and improving the existing system. This trend is anticipated to continue.

This study was directed toward dealing with the problems of the efficient and effective use of resources in one area of the total highway maintenance operation, specifically, the operations of the 67 highway maintenance organizations located in the 67 counties of Pennsylvania.

The questions that prompted the study concern the comparability of maintenance work done in the county maintenance organizations in terms of cost, quality, quantity, efficiency, and effectiveness. Critical questions addressed concern which factors influence the total cost of various maintenance activities, which counties vary significantly from the statewide norm for costs of producing a particular maintenance activity, and why some counties do vary. It was hoped that identifying these counties would provide the impetus for an in-depth review of maintenance activities in them in order to determine the operational reasons for the variations.

Highway maintenance functions consist of a large number of individual activities. In order to make the study manageable in terms of length, only five maintenance activities were examined: surface treatment, manual patching, mechanical patching, shoulder operations, and snowplowing. They were selected because they represent a major share of the cost and time of highway maintenance and because they represent summer as well as winter maintenance activities.

Hypothesized cost functions, developed for each of the activities listed above, were estimated through the use of multiple regression analysis. The results were then used to determine which counties vary considerably from expected behavior. These counties were then singled out for a special analysis of the possible causes of their deviation.

This study was thus intended to be a first step in an effort to analyze highway maintenance in Pennsylvania and thus to increase efficiency and reduce costs. It did not provide definitive results in itself but did identify counties that may need on-site management studies. It should also be noted that the method employed was intended to be flexible enough to be applied to the management of highway maintenance on a yearly basis. The Pennsylvania Department of Transportation (PennDOT) is now using the study method and two recent years of management data to validate the models and results. This new study could serve to further refine the method and to provide conclusive evidence of the value of initiating management studies in the identified counties.

THEORETICAL CONSIDERATIONS

Economic theory states that the level of output is the major influence on the cost of production. Costs may rise at an increasing, constant, or decreasing rate as output increases. However, when one is examining behavior across many plants or counties it is necessary to consider other influences on costs that become important because of variations in conditions and practices across the counties. Werner Hirsch in his study of urban refuse collection provided a framework for this type of analysis (1).

Hirsch used 1960 cross-sectional data for 24 municipalities in the St. Louis metropolitan area to build an ideal model of the average cost of refuse collection. This model served as a guide in selecting the variables to explain the cost of maintenance activities. The factors that Hirsch used to explain average cost were the amount or quantity of service, the service quality, the service conditions affecting input requirements, the factor price level, and the state of technology and productivity.

The amount- or quantity-of-service variable represents the output of refuse collection. The theory states that average cost should first decrease over a range and then increase as output increases.

The quality-of-service variable refers to factors such as the reliability of service, cleanliness, quietness, and courtesy of the pickup crew. Higher-quality service would be expected to result in higher average costs at any level of output.

The third variable, service conditions, refers to the peculiarities of each community that result in higher or lower collection costs. These factors include the pickup density, average distance to the disposal site, and the method of financing the operation.

The fourth variable, factor price level, is useful for explaining the variation in average costs that result from the different prices municipalities pay for their inputs. Of primary concern to Hirsch were differences in wages.

Finally, if technology and productivity vary across the municipalities this could also push average costs higher or lower. The municipalities with more advanced technologies should be capable of lower average costs.

The theory of cost and Hirsch's work guided the selection of potential variables and the form of equations used to analyze the cost of highway maintenance. Quantity of maintenance was the major explanatory factor. The equations also included variables representing the quality of output, the service conditions, the factor prices, and the state of technology and productivity. In addition, linear, quadratic, and cubic forms of the cost-output relation were examined. The general forms of the models are presented below. The X term represents the non-output influences on costs. These are assumed to be linearly related to costs.

$$\text{Total cost} = a + B_1 \text{ output} + CX \quad (1)$$

$$\text{Total cost} = a + B_1 \text{ output} + B_2 \text{ output}^2 + CX \quad (2)$$

$$\text{Total cost} = a + B_1 \text{ output} + B_2 \text{ output}^2 + B_3 \text{ output}^3 + CX \quad (3)$$

THE MODELS

The hypothesized influences on the cost of producing each of the selected maintenance activities vary across the activities. However, they do correspond to the general categorization proposed by Hirsch, and the discussion below follows his format. The proposed models were not created in a vacuum; they were developed after consultations with PennDOT maintenance engineers whose operational insights were invaluable.

Dependent Variables

For each maintenance activity studied, the dependent variable was the total cost of producing the output associated with the activity during fiscal year 1975/76. The cost data were those reported for each county through PennDOT's highway maintenance management system (HMMS), which was developed by PennDOT to aid the bureau of maintenance in planning, budgeting, and evaluating the maintenance activities of the county maintenance organizations.

The cost data were from the HMMS expenditure analysis report (2), which presents the costs directly associated with the production of the various maintenance activities. The major items reported are wages and salaries paid to workers involved in an activity, payments to outside contractors for performing an activity (which represent at most 4 percent of the statewide cost of any of the examined activities), the cost of materials used in production valued at the price of their most recent purchase, and costs for equipment used on an activity, valued at an hourly rental rate determined by PennDOT.

Independent Variables

Quantity of Output

Of course, each of the maintenance activities was represented by a different output measure. However, there was commonality across these output measures. It was assumed, as was indicated by the theory, that, after controlling for the other influences on costs across the counties, an increase in output would yield an increase in total costs.

The outputs of surface treatment, shoulder operations, and snowplowing were stated in terms of lane kilometers treated, kilometers of shoulders repaired, and lane kilometers plowed. Because output was measured in lane kilometers for these activities, it was necessary to include variables to account for the degree of highway or shoulder deterioration and snow condition severity. This is because greater deterioration or more severe snow conditions should result in higher costs for each kilometer of production. The service-conditions variables include hypothesized variables for highway and shoulder deterioration and snow condition severity.

The outputs of manual and mechanical patching are the kilograms of material applied. Measuring the output of these activities in terms of kilograms of material applied rather than lane kilometers tends to compensate for differences in the conditions of the roads that are patched. However, road-conditions variables were included in the hypothesized service-conditions variables for these activities.

Quality of Output

It cannot be assumed that each county performs each activity in the same way or with the same attention to the quality of their work, so some measure was needed to account for the differences. This measure was provided by the results of a survey of PennDOT's district engineers, each of whom has responsibility for several counties. For each activity, except snowplowing, they were asked to rate, according to stated objective criteria, the performances of maintenance crews in each of the counties under their jurisdictions. It was assumed that the factors affecting higher-quality work would be associated with higher costs. This assumption was made because higher-quality work would consume more time and attention to detail than lower-quality work.

Service Conditions

This group of variables was the largest of the variable categories. The factors measured by the variables are generally beyond the control of the highway maintenance manager. In general, the variables deal with the geography, the weather, the population, and the highway systems in the counties.

Three variables were proposed as potential representations of the physical size of the county and its highway system. The first of these was the land area of a county. It was assumed that larger counties would have higher costs because travel expenses would be greater in physically larger counties than in smaller counties. A second indicator of size was the number of state-maintained lane kilometers. It was assumed that this variable would be positively associated with costs because it is an indication of physically larger counties that have higher travel expenses. The third size variable was road density. For each county this measure was represented by the total linear kilometers of road per land area. For this variable higher values should result in lower costs because there are more roads to less land area and probably lower travel costs.

However, for snowplowing, increased road density should indicate more lane kilometers of production over the existing land area of the county, particularly since each lane kilometer is plowed. Higher road density may indicate more intense production and higher costs. Because of the relations that exist among these three variables, it was assumed that they would probably not enter the equations together. A selection from among the variables was made based on which variable best explained costs.

A variable was also developed that represented the topography of each county. This variable was calculated as the number of 15-m contours per 16 km (50 ft/10 miles) of federally aided primary highway in each county. For each activity, it was assumed that more mountainous areas, other things being equal, would experience higher costs because of difficulties encountered in working there and the greater deterioration of the roads in the mountainous areas. Also, for snowplowing, it was assumed that the mountainous areas have more severe winters, which may add to the cost of snowplowing.

The interaction of an area's population and travel patterns can also affect costs. This was recognized by hypothesizing that average daily traffic or population density might influence the cost of the maintenance activities. It was reasoned that in more densely populated and traveled areas certain support costs such as traffic control should be higher than in other areas and therefore yield higher overall costs. For snowplowing, however, while congestion may hinder plowing, heavy traffic may inhibit accumulation, thereby making plowing easier and resulting in lower costs.

For certain activities, the type of highway repaired may also influence costs. It was hypothesized that this was the case for surface treatment and manual and mechanical patching. This hypothesis was confirmed by an examination of the cost per unit of output for performing these activities on rigid base, flexible base, and rigid pavement roads. Therefore, it was necessary to include a variable to account for variations across the counties in the type of road that was repaired. This variable was calculated as the weighted average of the statewide average cost per unit of output by road type where the weights were the units of output on each type of road by county. Therefore, the more production on an expensive road type, the higher the cost.

For several of the activities—manual patching, mechanical patching, surface treatment, shoulder repairs, and snowplowing—an effort was made to include a variable that would represent the severity of maintenance problems across the state. For manual patching, mechanical patching, and surface treatment a variable for freeze-thaw cycle was included, as was a variable that measures the number of days during which at least 25 mm (1 in) of snow was on the ground. For each of these variables it was assumed that more severe winters and frequent thawing and freezing caused added deterioration. It was assumed that this deterioration, if severe enough, could result in costs that would not be picked up even with production measured in terms of kilograms of patching material.

For shoulder operations, three variables were included as surrogates for severe deterioration. Maximum daily rainfall was included to represent erosion. Severely eroded shoulders should be more difficult and therefore more costly to repair. Also PennDOT's bureau of maintenance calculated by county the percentage of substandard-width roads that have high average daily traffic. It was reasoned that, as this increased, vehicles were more likely to slip off the road and damage the shoulder. Another effort to develop a proxy for shoulder condition was a variable to measure the frequency of shoulder operations. A higher frequency should indicate less deterioration between shoulder repairs and therefore, everything else equal, lower costs. As was the case above, these variables were likely to be interrelated; therefore, the statistically superior explainer of cost was included in a final equation.

In snowplowing, three weather variables were proposed as potential indicators of severe snowplowing conditions. These were number of days with 25 mm of snow on the ground, mean temperature November-March, and total amount of snow during the year. It was hypothesized that more severe weather would increase plowing costs by making difficult conditions such as greater accumulation of snow and packing and freezing of the snow.

Two additional variables were proposed as explainers of the cost of snowplowing. These were the production units of spreading chemicals and abrasives and total meters of snow fence erected. Higher levels of these activities were assumed to be associated with more severe winters and therefore higher costs or could be used as substitutes for plowing and therefore be associated with lower costs. In either case their link to the level of snowplowing may result in the production of a snowplowing variable that adequately explains their influence on costs.

Factor Prices

The production factors of major importance in maintenance are labor, materials, and equipment. Because all the labor is employed by PennDOT and covered by the same pay scales, it was assumed that the price paid for labor would not vary significantly across the counties. Also, because the same equipment rates are charged across the counties, it was assumed that equipment-factor price should not be important except in snowplowing and shoulder operations. In snowplowing, renting equipment was hypothesized to be a significant factor. In shoulder operations, two different types of equipment are used.

Rented equipment is more expensive than department-owned equipment. To account for this, in snowplowing, the ratio of rented equipment cost to total equipment cost was included as an explanatory factor. Higher values of this ratio should be associated with higher costs.

For shoulder operations counties may use a belt loader or a front-end loader. The belt loader was the more expensive piece of equipment. If a county uses a belt loader their costs should be higher. A dummy variable was created where counties with a belt loader were assigned a value of one and counties without a belt loader were assigned a zero.

For the other activities, the factor for price variables attempts to take account of the variation across counties in the price paid for materials used in the activities. For surface treatment, manual patching, and mechanical patching, the material-costs variable was calculated as the absolute difference between the per unit material cost by county and the statewide average unit material cost. It was hypothesized that the larger this difference, the higher would be the cost of the maintenance activity.

An additional material-cost variable was included in the surface treatment function. This was plant mix surface treatment as a percentage of total surface treatment. This was included because the plant mix materials are more expensive than the liquid bituminous materials. As was indicated above, both types of materials are used in surface treatment.

State of Technology and Productivity

To the extent that productivity and technology vary across the counties, they will influence the cost of production. Other factors being equal, counties that use a more advanced technology or have higher output per unit of input should have lower cost than other counties.

For the most part, it was assumed that the level of technology would not vary across the counties, because each county is part of the same larger organization and because they were producing their outputs within the same limited time period. Productivity, which broadly defined is output per unit of an input, may vary significantly across the counties.

For each of the activities, two productivity variables were proposed as possible explanatory variables. These were production hours per production unit and crew specialization. Production hours per production unit is a direct productivity measure. It was calculated by dividing activity hours (working hours spent in production of each activity) by the total output for each activity. Costs should increase when the value of this variable increases.

Crew specialization is a less direct measure of productivity. This variable was calculated by determining how many different foremen were involved in the production of 75 percent of the output of a given activity in a county. The smaller this percentage for an activity in a county, the more specialized was the county in the activity.

Specialization should result in lower costs for the production of a given level of output. Therefore, the higher the value of the variable for an activity, the higher the cost of producing the outputs. Specialized crews should be more proficient at their tasks, should be more familiar with the equipment involved in the production, and should have developed a greater understanding of the skills involved in the production than the unspecialized crews. These crews should be more productive.

For snowplowing, a technology variable was also included that sought to indicate the amount of capital available for snowplowing across the counties. This was measured by the maximum allowance of snowplowing vehicles by county. It was assumed that the larger the number of vehicles available the lower the cost. Counties with more vehicles have more capital available for use by their work force. This, of course, assumes that increasing the amount of capital used for a given level of output reduces the cost of producing the output. This means that there is excess manpower in relation to the available equipment, after controlling for other factors.

RESULTS OF THE ANALYSIS

The discussion above attempted to categorize and outline the hypothesized influences on the cost of producing the outputs of each of the five maintenance activities. This section presents the results of statistically analyzing the relationship between the proposed explanatory variables and the cost of producing the products of the activities. This is done through the use of single-equation ordinary least-squares regression. Also reported are the results of using the regression equations to identify counties that vary significantly from expected behavior.

Regression Results

Table 1 presents the regression coefficients and related statistics for the preferred model for each of the five maintenance activities. These equations were selected from among the several alternate models examined for each activity. For each activity the models consisted of different forms of the cost-output relation, either a linear, a quadratic, or a cubic cost-output relation, and various combinations of the proposed quality, service conditions, factor price, and technology and productivity variables.

The models presented were selected on the basis of their ability to explain the costs of production across the counties, the significance of the regression coefficients, the reasonableness of the signs, and the magnitudes of the regression coefficients. Unless indicated otherwise, all of the regression coefficients and F-statistics listed in the table were significant at the 0.05 level. For each of the explanatory variables both the regression coefficient (B) and the beta coefficient are presented. The regression coefficient indicates the effect on the dependent variable, all else constant, of a one-unit change in the explanatory variable. The absolute size of the beta coefficient indicates the relative strength of each explanatory variable.

Quantity of Output

For each of the five activities, output was the most powerful explainer of the cost of production, as was expected. For manual patching and snowplowing, the linear cost-output relation proved superior, while for surface treatment, mechanical patching, and shoulder operations, the quadratic cost-output relation was superior. In no instance was the cubic cost-output relation a significant explainer of total cost.

Quality of Output

The quality-of-output variable was not a significant explainer of cost for any activity. It could be that the evaluation of quality by the district engineers was not a valid measurement. On the other hand, it is possible that the quality of output does not vary enough across the counties to be a significant explainer of the cost of production. This variable will be examined below in the discussion of those counties that vary significantly from expected behavior. It may be that, although quality of production does not vary to a large extent across the state, it could be an explanatory factor for those counties that deviate sharply from expected behavior.

Service Conditions

As was pointed out above, several variables were proposed as possible representations of special conditions existing in the counties that may influence the cost of production. However, the bulk of the service-conditions variables proposed for each activity proved to be insignificant explainers of the cost of production.

State-maintained lane kilometers appeared as a significant explainer of total cost for manual patching, mechanical patching, and shoulder operations. It was hypothesized that this variable would be positively associated with the cost of production. This prediction proved true. The positive relation indicates that counties that are larger in terms of the size of their highway network tend to have higher costs, other influences being equal. Apparently the travel costs and other factors peculiar to larger counties push up costs.

Road density, which also represents the size of a county's maintenance area, was a significant explainer of the cost of snowplowing. It was found to be positively associated with the cost of snowplowing. For the other activities it was hypothesized that higher road densities would be associated with lower costs. However, for snowplowing, as was discussed above, a positive relation was expected between road density and costs. This was observed.

Also, for snowplowing, total snowfall was found to be significantly related to the cost of plowing. Greater amounts of snow were associated with higher costs. As was argued above, greater amounts of snow result in difficulties with removal and cause higher costs.

The final service-condition variable that entered an equation was population density. This variable entered the equation for surface treatment. However, it showed a negative relation to the cost of production. It was assumed that this variable would be positively related to costs because of the additional support costs involved with working in more densely populated areas. However, it appears that certain economies are associated with production in more densely populated areas and yield lower costs for surface treatment in these areas.

For the service-conditions variables that did not enter the equations, such as average daily traffic, topography, and production by road type, it appears that they were not associated with the cost of production as anticipated. Of course, in any particular county these factors may be important influences on costs, but across the state their effects were not evident. For the freeze-thaw variable and the snow-accumulation variable, both of which were assumed to influence the cost of manual patching, it would seem that the quantity of production, measured in kilograms, explains whatever effect they may have on cost. It also seems to be the case that the quantity of snowplowing explains whatever influence the erection of snow fence or the spreading of chemicals and abrasives would have on cost.

Factor Prices

The material-cost-deviation variable was significant in only the manual patching and mechanical patching equations. Material cost was a major component of the cost of producing these activities. Therefore, it was expected that higher values of the material-cost variable would be associated with higher costs of these activities, and this was observed.

For surface treatment it was surprising that neither the material-cost-deviation variable nor the variable plant mix as a percentage of total production entered the equation. Although these factors were not found to be significant across the state, they were examined as potential explanatory factors for the counties that stray from expected behavior.

A similar situation existed in snowplowing, with the variable that measured the ratio of rented to total snowplowing equipment costs. This variable was also examined as a potential explainer for those counties that vary from their predicted total cost of snowplowing.

State of Technology and Productivity

Only the mechanical-patching equation did not include a productivity variable. This was not unexpected, because mechanical patching is a highly mechanized activity and involves a similar process across the state. Also, the activity is such that it encourages crew specialization across the counties. Production hours per production unit were significant for manual patching, shoulder operations, and snowplowing. In each case, as predicted,

Table 1. Coefficients and statistics for five maintenance activities.

Explanatory Variable (adjusted R^2)	Coefficients and Statistics for Maintenance Activities: Surface Treatment (0.77)	Manual Patching (0.90)	Mechanical Patching (0.86)	Shoulder Repair (0.74)	Snowplowing (0.82)
Output					
B	7 436.00	31.46	16.01	285.00	1.52
Beta	2.02	0.788	1.51	1.95	0.540
Output^2					
B	-33.21		0.000 2	-0.133	
Beta	-1.34		0.783	-1.46	
Population density					
B	-46.68				
Beta	0.176				
Crew specialization					
B	2 978.00	1 845.00			
Beta	0.202	0.122			
State-maintained lane miles[a]					
B		92.77	21.41	27.28	
Beta		0.243	0.12	0.229	
Material cost					
B		999.14	41 948.00		
Beta		0.061	0.085		
Production hours per unit					
B		15 733.00		2 270.00	126 411.00
Beta		0.227		0.444	0.213
Road density					
B					20 532.00
Beta					0.141
Total snowfall					
B					1 069.00
Beta					0.395
Maximum allowed snowplows					
B					711.00
Beta					0.213
Constant	-45 467.00	-253 295.00	-50 995.00	-64 607.00	-72 703.00

[a]The models were run in lane miles rather than in lane kilometers.

higher costs followed higher production hours per production unit.

Crew specialization entered as a significant explainer of costs for surface treatment and manual patching. More highly specialized counties experienced lower costs. The benefits of specialization, a greater familiarity on the part of the crew with the equipment and skills involved in the activity, apparently include lower costs for these activities.

For snowplowing, the maximum allowed snowplows was also a significant explainer of total costs. However, it was positively related to the cost of production, which is contrary to previous assumptions. It was felt that a given work force with more equipment would produce the output at a lower cost. But the equipment-allowance variable was highly related to total lane kilometers with a simple correlation coefficient of 0.95. Therefore, the equipment allowance actually served as a surrogate variable for county size, and larger counties were assumed to experience higher costs, other factors being equal.

Residual Analysis

The five regression equations discussed above were used to generate predicted costs of production for each activity for each county, given the actual values for each of the explanatory variables. For each activity for each county a residual was calculated, which is the difference between the actual total cost and the predicted total cost. The value of the residual was then used to select the counties that varied considerably from expected behavior.

Regression equations are quite appropriate for this process, because the strategy of regression is to select coefficients for the independent variables so that the difference between the actual and predicted values of the dependent variable is minimized.

For each activity, the residuals were standardized by dividing them by the standard error of the regression equations. The results were examined, and those counties that had standardized residuals with an absolute value greater than 0.5 were selected for further analysis. This figure was used as a cutoff because preliminary analysis indicated that the vast bulk of the counties had standardized residuals for each activity that were less than 0.5. Yet enough counties exceeded this value for each activity to provide adequate observations for analysis.

The purpose of the examination of the operations of the counties that deviate more than ±0.5 standard residuals was to attempt to identify general areas of operational difference to which costs higher or lower than predicted could be attributed. It was assumed that those counties that were singled out as spending less than predicted for an activity have achieved some operational efficiencies that permit the county to produce the maintenance activity at lower than predicted costs. On the other hand, it was assumed that those counties that spend more than predicted for an activity have operational inefficiencies.

For the counties that were above or below their predicted costs, three major elements of maintenance operation were examined: labor costs per unit of output, material costs per unit of output, and equipment costs per unit of output. In addition, independent variables that did not enter the total cost equations were examined for the deviating counties. These independent variables were analyzed based on the assumption that they were not significant explainers of total cost for the state as a whole because of a lack of variability in them across the counties. However, the outlying counties may be different from the rest of the state, and thus the variables could provide some insight into why a county had costs substantially higher or lower than predicted. Included in this group of independent variables were the productivity variable, the crew-specialization variable, the quality variable, and the material-cost-deviation variable.

The final area of operation that was examined for the deviating counties was the cost of rented equipment and the cost of contracts and services used in maintenance activities. Significant differences in rented equipment and contracts between the counties that spend more or less than predicted could indicate a need for further study of renting and contracting practices of individual counties.

Surface Treatment

As with all the maintenance activities, there was a great deal of variation among individual counties in the two groups in terms of personnel, material, and equipment costs per unit output. However, when the two groups were examined as a whole, several patterns emerged. The average personnel and equipment costs per unit of output were relatively close for the two groups of counties. Those counties that had higher-than-predicted total costs had average personnel and equipment costs of $1292 and $918, respectively, while the same average costs for the counties with lower-than-predicted total costs were $782 and $560.

The material cost per unit of output appears to be the major area of difference between the two groups. On the average the material cost per unit of output was nearly two times as high for the counties that spent more than expected as for counties that spent less than expected.

A possible explanation for the sharp divergence of material costs per unit of output for the two groups is the distribution of surface treatment between the two possible surface-treatment procedures: plant mix and liquid bituminous. In terms of materials, plant mix surface treatment is more expensive than liquid bituminous surface treatment. The counties that had higher-than-expected costs did, on the average, twice as many lane kilometers of surface treatment with the more expensive plant mix procedure than did the counties with lower-than-expected costs.

Several factors beyond the unit cost of the input factors appear to distinguish the two groups of counties. For instance, those counties that spent more than predicted for surface treatment reported higher expenditures for contracts and services than those counties that spent less than predicted. In terms of the number of counties with contract costs, 5 of the 11 higher-cost counties had contracted costs, while 2 of 9 of the lower-cost counties reported contracted costs. Of the counties with higher-than-predicted total costs, one county stood out with contract and service costs of $255 331. Because of the relatively small number of counties with expenditures on rented equipment, no conclusions could be drawn as to basic differences between the two groups of counties.

There appeared to be no substantial difference between the two groups of counties in terms of the quality of the work. However, there does appear to be a difference in the productivity of the two groups. Those counties that had higher-than-predicted total cost required 181 production hours per production unit of surface treatment, while those counties that spent less than predicted required 161.

Manual Patching

For manual patching it was found that, on the average, those counties that spent more on manual patching than predicted had higher personnel, material, and equipment costs per production unit than those counties whose costs were lower than predicted. In the three general areas of operation, the material costs per production unit were substantially higher for counties with higher-than-predicted costs. Material costs per production unit for the higher-cost counties averaged three times higher than those for the lower-cost counties.

Personnel and equipment costs per production unit were both higher in the higher-cost counties than in the lower-cost counties. The average difference in personnel costs per production unit between the two groups of counties was roughly $9, while the average difference in equipment cost was only $6. Because the charges for personnel and specific pieces of equipment were relatively uniform throughout the state, one can speculate that those counties with high personnel or equipment costs per unit of output were using different combinations and amounts of personnel and equipment.

The final operational factor that appeared to be significantly different for the two groups of counties was the quality of the manual patching operation. Those counties with manual patching costs significantly more than predicted had an average quality score of 4.8 out of 10, and those with costs lower than predicted had an average score of 6.2. This difference indicates generally higher-quality work in those counties that spend less than predicted. Higher quality may be related to better management in the lower-cost counties. The better management in the lower-cost counties is indicated by the lower input costs per unit of output observed above.

Mechanical Patching

For mechanical patching, only eight counties had expected costs that varied from actual costs by more than ±0.5 standardized residual units. The two groups of counties varied substantially in terms of per unit expenditures on personnel and materials. Those counties with higher costs than expected spent a little less than twice as much per unit of output on personnel than did those counties with negative residuals. In materials, the difference was much more dramatic. Those counties that had mechanical patching costs higher than predicted on the average spent four times as much per unit of output as those counties spending less than predicted. This difference occurred after the deviation of each county's raw material cost from the state average had been accounted for in the regression equation.

The material costs must be examined with a jaundiced eye, particularly since there is a high probability that reporting errors exist in the material-cost data. The possibility of reporting errors became evident after comparing the $3.65 mean material cost per unit of output for the counties with lower costs than expected with the $15/900 kg average cost for the material used in mechanical patching. Units of production for mechanical patching were measured in kilograms of material. According to PennDOT's bureau of maintenance personnel, certain economies were possible in the area of material costs, but the costs reported were unrealistically low.

The cost per unit of output of department equipment was virtually identical for both groups of counties. However, there were major differences in the amount of rented equipment used in the two groups of counties. Those counties that spent more than predicted had an average rented equipment cost of $1216, while the counties that spent less than predicted had no rented equipment expenditures.

Along the same lines, the use of contracts and services was much more prevalent among the counties that had costs higher than predicted. The county that had the highest positive residual spent $57 000 on contracts and services for mechanical patching, while no county with a negative residual reported any expenditure for contracted mechanical patching.

Since the productivity variable was not a significant explainer of mechanical patching costs for the state as a whole, it was useful to examine the productivity variable in terms of those counties that deviated the most from the predicted cost of mechanical patching. This examination revealed a significant difference between the two groups of counties. Those counties with costs higher than predicted required an average of 0.84 production hours to produce a production unit. On the other hand, those counties that spent less than predicted for mechanical patching required only 0.31 production hours. This would tend to indicate higher levels of productivity in the latter group of counties.

Shoulder Repair

Fourteen counties had expected costs for shoulder operations that varied by more than ±0.5 standardized residual units from their actual costs. Among the counties there was a great deal of variation in the cost of personnel and equipment per production unit of shoulder operations. The averages revealed, however, that those counties with total costs higher than predicted spent $91 more per unit of output on personnel and $68 more per unit of output on equipment than those counties that spent less than predicted.

The use of rental equipment was somewhat different for the two groups. Those counties with higher costs tended to spend more on rental equipment than did those with lower costs. In particular, one county reported an expenditure of $15 772 on rented equipment, while the highest rented-equipment expenditure for a lower-cost county was $7300.

The difference in the quality of the shoulder repair between the two groups of counties appears to shed more light on possible causes of cost variation. The counties that spent more money than predicted on shoulder operations ranked lower in terms of the quality of their work than the counties that spent less. The score for the higher-cost counties averaged 6.00 out of 10, while the score for the lower-cost counties averaged 6.25. The county that had the highest positive residual received a score of 1 on the quality variable, which was the lowest possible score.

Finally, there were minor differences between the groups of counties in terms of the specializations of crews in shoulder repair. The higher-cost counties averaged 24 percent of crew foremen to do 75 percent of the production, while the lower cost counties averaged 18 percent. It was difficult to draw conclusions on this basis because shoulder operations appear to be equally specialized across the state. However, in one county where 40 percent of the crews were involved in shoulder activities, a lack of specialization could be singled out as a possible cause of high costs. This fact is reinforced by the relatively high cost of personnel per production unit for this county.

Snowplowing

In snowplowing, the 17 counties whose expected costs varied by more than ±0.5 standardized residual units from their actual costs showed considerable differences among their per unit personnel and equipment expenditures.

Because of the nature of some of the variables that entered the total cost equation for snowplowing, such as productivity and maximum equipment allowance, the opportunities for operational analysis were rather limited. Two criteria on which the counties could be analyzed, however, were the personnel costs per unit of output and the equipment costs per unit of output. The positive residual group of counties had a $1.27/km ($2.05/mile) of snowplowing for personnel and a $1.97/km ($3.18/mile) for equipment, while for the same categories of unit costs, the lower-than-predicted-cost counties had costs of $0.70 and $1.36 ($1.13 and $1.35).

The difference in unit costs for equipment between the two groups would appear to be the more significant of the two. To further trace equipment cost, the costs of rented snowplowing equipment were examined. For the counties whose costs were higher than predicted, the average total rented snowplowing equipment cost was $31 676, while for the other group of counties, the same figure was only $9853, a difference of nearly $22 000.

The expenditures for contracted snowplowing were another area of snowplowing operations that indicated basic differences between the two groups of counties. It was difficult to draw any firm conclusions because of the limited number of counties that contracted for snowplowing. However, it was significant to note that no county with a lower-than-predicted cost for snowplowing had any expenditure for contracted plowing. On the other hand, two of the nine counties with higher-than-predicted total costs had significant expenditures for contracts. One of these counties reported an expenditure of $16 000 on snowplowing contracts, while another of these counties reported a $17 000 expenditure.

SUMMARY AND CONCLUSIONS

As was expected, the quantity of output produced was the most important explainer of total cost for each activity. However, the quality of output, as measured in this study, failed to appear as a significant explainer of cost.

The size of the county, as represented by total state-maintained lane kilometers was significant for manual patching, mechanical patching, and shoulder repair. Road density was a significant factor for snowplowing. Except for population density, the variables that were intended to measure traffic congestion did not enter the equations. Population density entered the surface-treatment equation, but with a negative sign, which was not expected.

In general, independent variables that represented the climate of a county did not enter the total cost equations as significant explanatory variables. The one exception was in snowplowing, where the total number of millimeters of snowfall was a significant explainer of the total cost of snowplowing.

Productivity variables were not a factor in explaining the cost of mechanical patching. However, each of the equations contained either or both productivity hours per production unit or crew specialization. This illustrates the importance of productivity in cost containment.

Material costs entered the mechanical and manual patching equations. This was not surprising because materials represent a large part of the costs of these activities.

For those counties that varied considerably from expected behavior, it can be said that the counties with higher-than-expected costs had higher costs of personnel, equipment, and materials per unit output than did the counties with lower-than-expected costs. This indicated a more efficient use of inputs in those counties with lower-than-expected costs than was observed in the counties with higher-than-expected costs.

In addition, further study should be directed toward the practice of contracting for maintenance services and renting equipment. For each of the activities, except manual patching, where the vast bulk of production is done by the state work force, the higher-cost counties spent more for contracts and equipment rental than did the lower-cost counties. It is possible that the discrepancies are justifiable, but they do deserve further study.

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