# Service Lives and Costs of Local Highway Maintenance and Rehabilitation Treatments

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Reliable estimates of the service life and cost of typical maintenance and rehabilitation (M&R) treatments are very important in the implementation of pavement management systems. The primary objective of this project was twofold: (a) to develop and test a survey questionnaire that may be used to obtain reliable estimates of service lives and costs of maintenance and rehabilitation treatments commonly used on local roads in Massachusetts and other parts of New England, and (b) to use the survey questionnaire to estimate the service lives and costs of such treatments in Massachusetts. Sixty-eight cities and towns in Massachusetts were surveyed. The data were analyzed to estimate the service life and cost of thin overlays, chip seals, and sand seals; they were also used as a basis for developing performance curves.

Capital available for expenditures on local highway improvement projects has steadily decreased over the past decade, as the highway infrastructure continues to age (*1*). Consequently, emphasis has been placed on maintaining that infrastructure. Yet more than 40 percent of U.S. highways may be classified as being in fair to poor condition (*2*). This indicates a need to allocate limited resources for maintenance and rehabilitation (M&R) more efficiently, especially for small cities and towns that constitute a significant proportion of the total paved road mileage in the United States.

High-quality maintenance is an important determinant of pavement performance; it can slow the rate of pavement deterioration due to loads. Many small city and town agencies take a "worst first" approach to their maintenance activities, which often is not cost-effective. Deferred maintenance allows the severity of defects to worsen. Continued deferral of M&R actions can shorten the time between construction and reconstruction and increase the cost of reconstruction by as much as four to five times, thus significantly increasing the life-cycle costs of a pavement (*3*).

Maintenance plans consist of determining not only when an improvement should be made but also what type should be used. More effective decisions about when and which treatment should be applied (a variety of alternative treatments may be used for different types and levels of pavement distress) require good estimates of pavement service lives and costs. These estimates may be used for various activities (*4–7*):

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- Estimating and allocating available funds,
- Identifying cost-effective solutions,
- Anticipating when necessary expenditures will recur, and
- Justifying work plans to elected officials.

State and local pavement maintenance records are not typically well kept (*8*), thus, expected life and cost information is not generally readily available. The best life expectancy information appears to be in the heads (and archaic records) of experienced highway superintendents who have seen many cycles of maintenance activities (*4,9*). This unrecorded information is, however, being lost as these individuals retire. These data would be an invaluable aid to many local highway superintendents in devising maintenance work plans. With regard to the pavement management needs of small cities and towns, FHWA's Rural Technical Assistance Program over the past few years has focused on training and pavement design (*10*). Little if any effort has been made to examine the life-cycle costs of maintenance options typically used by small cities and towns, such as thin overlays, seal coats, slurry seals, and surface treatments.

Several studies have been conducted in recent years to ascertain some usable values that could be used to make better decisions about low-cost pavement maintenance activities. An Ontario survey examined average service lives of maintenance treatments that included crack seals, chip seals, and thin overlays (*11*). An Indiana survey of 33 superintendents and highway foremen examined minimum, average, and maximum service lives for routine maintenance activities on roadways in poor, fair, and good condition (*4*).

Many other factors, however, affect pavement life (*12*). Neither of the studies in Indiana or Ontario included in its analysis many of these important factors. A New Hampshire survey was designed to include present pavement condition, daily truck volumes, drainage, and pavement structures as variables affecting pavement life (*13*). The survey was never carried out, presumably because the questionnaire was too long. Estimates of the lives and costs of maintenance treatments in the New England region considering these other variables would be very useful.

## PROJECT OBJECTIVE

The objective of this project was twofold: (a) to develop and test a survey questionnaire to collect service life and cost data about local pavement M&R practices in Massachusetts and other parts of New England, and (b) to use the questionnaire to estimate the service lives and costs of such practices in Massachusetts.

## SURVEY QUESTIONNAIRE

The general design of the questionnaire reflects what was learned from studying previous efforts just described. The questionnaire is laid out in tabular-matrix format. To reduce the length of time required to gather this type of information, the questionnaire is divided by type of maintenance treatment. Types chosen for inclusion are the ones most often used in New England (*9*) and are described in Table 1.

Several major factors affect the performance of a maintenance treatment. Accordingly, the instrument should be adequate to capture the factors that are most important in determining the life of a particular treatment, including severity and extent of loadings to which the pavement structure will be subjected (truck volumes), general condition of pavement structure, and pavement condition before treatment (*4,11–13*).

### Truck Volumes and Pavement Structure

The effects of truck volume levels on pavement condition are well documented (*14–16*). Since surface treatments provide no structural capacity to the pavement, load levels and the condition of its substructure (see Table 1 for definitions used in this study) have a fundamental relationship with the structure's overall performance and life. For this study, truck volumes were placed into three load levels: light (less than 20 per day), medium (between 21 and 125 per day), and heavy (greater than 125 per day). A truck is defined as any vehicle with a gross vehicle weight greater than 10,000 lb. This was considered adequate, given the low degree of sensitivity that pavement performance exhibits with changes in volume—the functional form of the AASHTO equations is logarithmic,

**TABLE 1 Definition of Survey Questionnaire Variables**

Maintenance Treatments (Seal Types)

| Sand Seal | Chip Seal | Overlay (1.905 cm) | Overlay (2.54 - 3.81 cm) |
|---|---|---|---|
| • Application of low viscosity or moderately diluted asphalt covered with fine (sand gradation) aggregate. Low viscosity and sand combination is designed to fill many small cracks on the existing surface. | • Single application of liquefied asphalt followed by single layer of uniform size aggregate. | • Thin layer of hot mix asphalt concrete. | • Thicker layer of hot mix asphalt. |

Present Pavement Conditions

| Fair | Poor |
|---|---|
| • Moderate to severe ravelling.<br>• Longitudinal and transverse cracks (up to 1.27 cm) show first signs of slight ravelling and secondary cracks. First signs of longitudinal cracks near pavement edge.<br>• Block cracking up to 50% of surface.<br>• Extensive to severe bleeding or polishing.<br>• Some patching or edge wedging in good condition. | • Closely spaced longitudinal and transverse cracks often show ravelling and crack erosion.<br>• Severe block cracking.<br>• Some alligator cracking (<25% of surface).<br>• Patches in fair to poor condition.<br>• Moderate rutting or distortion (2.54 - 5.08 cm deep).<br>• Occasional potholes. |

Pavement Structure Conditions

| Good | Fair | Poor |
|---|---|---|
| • Suitable capacity for anticipated truck volumes. Has good drainage conditions. | • Marginally suited for anticipated truck volumes and/or has fair drainage. | • Inappropriate for anticipated truck volumes and/or has poor drainage. |

Drainage Conditions

| Good | Fair | Poor |
|---|---|---|
| • Ditches, culverts, and inlets are clean. Road shoulders slope away from roadway. | • Ditches, culverts and inlets are fairly clean. Road shoulders slope down and away from roadway. | • Ditches neither function nor exist. Culverts and inlets, if present, are clogged. Road shoulders are often higher than roadway. Extensive frost heaving. |

thus requiring an order of magnitude shift in loadings to affect significantly the pavement's structural capacity and therefore its life.

### Pavement Condition Before Treatment

The positive correlation between maintenance level and maintenance cost is also a well-documented phenomenon (*16*). The condition of the pavement at the time of treatment certainly influences the type of treatment appropriate as well as its expected life (i.e., life-cycle costs). As the benefit derived [i.e., Δ PCI (pavement condition index)] from making an improvement increases, so does its cost (*3*). Quantitative and qualitative estimates of condition were as defined in Table 1.

### Improvement Costs

Highway superintendents are comfortable using unit costs of various maintenance options, both in terms of manpower and materials, and are familiar with variations in costs due to changes in road or climatic conditions. Included on the questionnaire were questions about unit capital costs for each treatment type.

## CONDUCT OF SURVEY

The survey questionnaire was used to interview 68 local highway superintendents in Massachusetts. The commonwealth has two somewhat different geographic areas with regard to both climate and engineering characteristics of pavement substructures. The eastern part of the commonwealth is generally low-lying flatlands with sandy soils, whereas the western part is characterized by rolling hills at higher elevations with gravelly soils. Figure 1 depicts the spatial distribution of cities and towns surveyed, and Tables 2 and 3 provide a list of towns and the treatments used. In choosing superintendents to be interviewed, an effort was made to find a person (or persons) in each agency with sufficient experience regarding the level of truck volumes on local roads, characteristics of pavement substructure material, and other factors examined in the questionnaire.

## SURVEY RESULTS AND ANALYSIS

Data were obtained with the survey questionnaire to estimate the service life and cost of major treatments used in each region, and in selected instances these data were used to develop performance curves.

### Service Life and Cost

The data were tabulated and analyzed using a Microsoft Excel spreadsheet program. For each cell in the questionnaire, all responses were used to estimate the mean service life, in years, and the standard deviation. After this, responses more than two standard deviations from the mean were identified as outliers and removed from the data set. In several cases, the outliers were found to be responses from young and less-experienced personnel.

Tables 4 and 5 present the estimated service lives of 3.81-cm overlays and chip seals in each region for certain conditions. Table 6 gives the estimated service lives of sand seals and 1.91-cm overlays on pavements in fair condition for the combined regions. Because survey response rates were low for these two alternatives, the data from the eastern and western regions were combined. Table 7 summarizes the costs of all four treatments.

### Performance Curves

A variety of curve shapes have been proposed to model pavement performance (*17*). Because it has not yet been shown that the more complicated mathematical forms yield notably better results than the simple mathematical function, it was decided that an exponential function would be used for this study.

The general form of the exponential curve

$$PCI = ae^{bt} + k$$

contains three unknowns: $a$, $b$, and $k$. At least three ordered pairs ($t$ and PCI) are necessary to calibrate this general form to our specific case. Two points are relatively easily and directly obtained. They are

$t_1 = 0$, $PCI_1 = 100$ when pavement treatment is new, and

$t_2 =$ mean age, $PCI_2 = 50$ when pavement is in fair condition.

The value $t$ is the average service life determined from the survey questionnaire. The third ordered pair must be estimated. Point $t_2$, $PCI_3$, represents the time and PCI when the pavement has deteriorated to poor condition. As the interview process progressed and preliminary modeling was being done, it became evident that the location of this third point was necessary in order to estimate performance curves. An additional question was asked of all the later interviewees: "If no maintenance is done, how long will it take for the pavement to deteriorate from fair to poor?" The answer to this question, added to the value of $t_2$, yields $t_3$. The value of PCI (poor condition) was set at 30. With these three data points, calibrating the model and estimating $a$, $b$, and $k$ was a straightforward procedure.

Once the model was calibrated, it was a simple task to generate curves with data from the survey. Pavement structure and pavement condition were held constant (i.e., good and fair), and sets of graphs were prepared for different levels of truck traffic.

## SUMMARY AND CONCLUSIONS

Local pavement management efforts continue to be carried out by cities and towns, so there is a need for good, reliable estimates of service life, cost, and other measures of perfor-

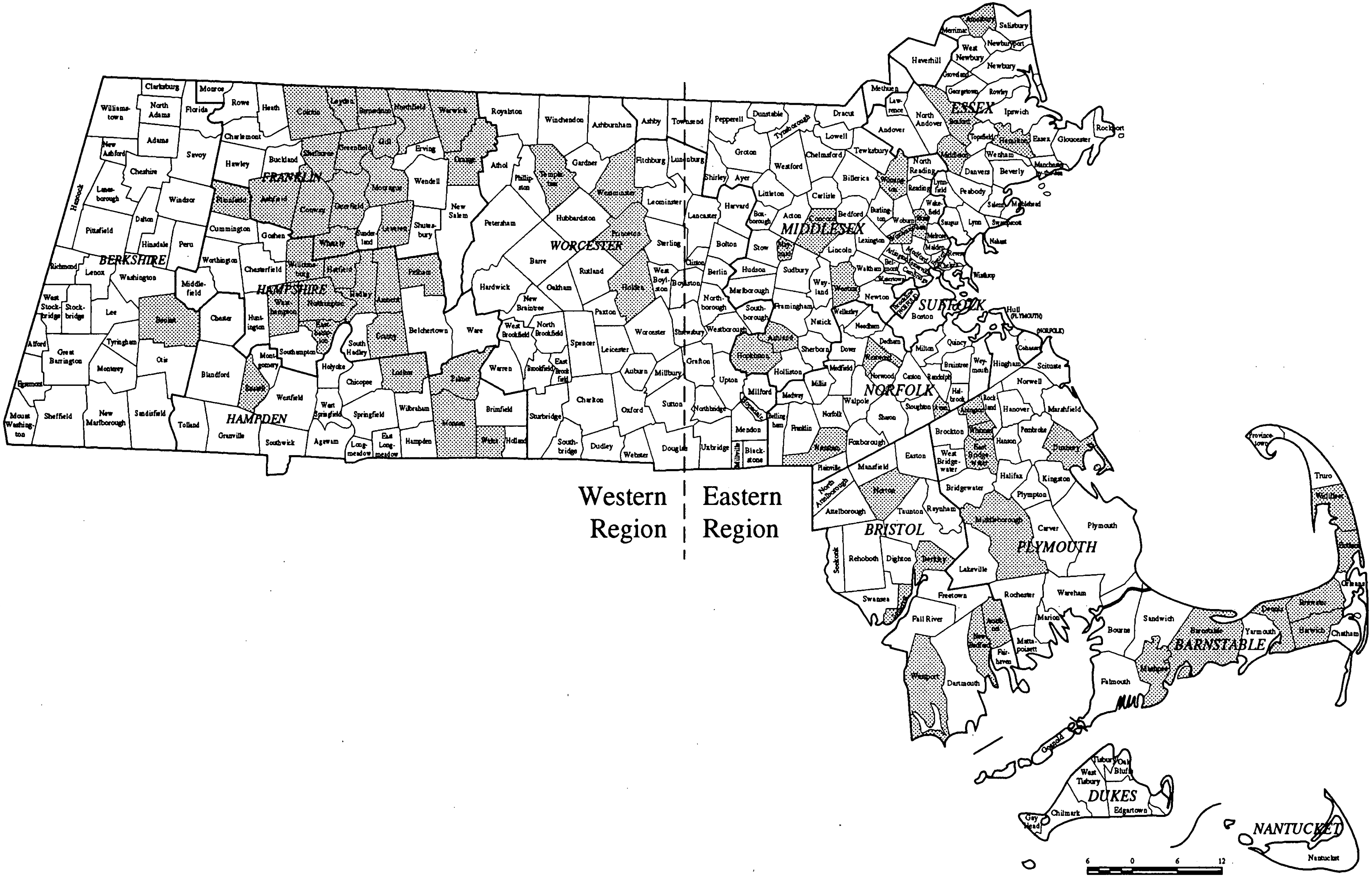


**FIGURE 1 Massachusetts survey sites.**

**TABLE 2 Towns and Treatments, Eastern Region**

| TOWN | population | sand seal | chip seal | overlay 1.905 cm | overlay 3.81 cm |
|---|---|---|---|---|---|
| Abington, MA | 13,810 | | x | x | |
| Acushnet, MA | 8,970 | x | | | x |
| Amesbury, MA | 14,056 | | | | x |
| Ashland, MA | 12,008 | | | | x |
| Avon, MA | 4,770 | x | x | | x |
| Barnstable, MA | 36,431 | | x | | x |
| Bedford, MA | 12,660 | | x | | x |
| Berkley, MA | 3,920 | x | | x | |
| Boxford, MA | 6,449 | x | x | | x |
| Brewster, MA | 7,876 | | | | x |
| Concord, MA | 15,424 | | x | | x |
| Dennis, MA | 13,173 | x | x | | x |
| Duxbury, MA | 14,168 | | x | | x |
| East Bridgewater, MA | 10,640 | | x | | x |
| Eastham, MA | 4,600 | x | | | |
| Hamilton, MA | 7,190 | | | | x |
| Harwich, MA | 10,055 | x | x | | x |
| Hopkinton, MA | 9,150 | x | | | x |
| Mashpee, MA | 9,543 | x | x | | x |
| Maynard, MA | 10,357 | x | x | | x |
| Middleborough, MA | 17,838 | | x | | x |
| Middletown, MA | 5,082 | | | | x |
| Norton, MA | 14,344 | x | x | | x |
| Seekonk, MA | 13,040 | | x | | x |
| Somerset, MA | 17,690 | | x | | x |
| Stoneham, MA | 22,590 | | | x | x |
| Wellfleet, MA | 2,610 | x | | | x |
| Weston, MA | 10,600 | | | | x |
| Westport, MA | 13,241 | x | | | x |
| Westwood, MA | 12,600 | | | | x |
| Whitman, MA | 13,137 | x | | | x |
| Wilmington, MA | 18,070 | | | x | x |
| Winchester, MA | 20,858 | | | x | |
| Wrentham, MA | 8,868 | | | | x |

**TABLE 3 Towns and Treatments, Western Region**

| TOWN | population | sand seal | chip seal | overlay 1.905 cm | overlay 3.81 cm |
|---|---|---|---|---|---|
| Amherst, MA | 31,740 | | x | | x |
| Ashfield, MA | 1,620 | | x | | x |
| Becket, MA | 1,700 | | x | | x |
| Bernardston, MA | 1,820 | | x | | x |
| Colrain, MA | 1,690 | | x | | x |
| Conway, MA | 1,515 | | x | | |
| Deerfield, MA | 4,830 | | x | | x |
| Easthampton, MA | 16,160 | | x | | x |
| Gill, MA | 1,452 | | x | | x |
| Granby, MA | 5,710 | | x | | x |
| Greenfield, MA | 17,950 | | | x | |
| Hadley, MA | 4,300 | | x | | x |
| Hatfield, MA | 3,110 | | x | | x |
| Holden, MA | 14,767 | x | | x | x |
| Leverett, MA | 1,660 | | x | | x |
| Ludlow, MA | 18,146 | | | | x |
| Monson, MA | 8,000 | | x | | x |
| Montague, MA | 8,994 | | x | | x |
| Northampton, MA | 30,384 | | | | x |
| Northfield, MA | 2,600 | | x | | x |
| Orange, MA | 7,346 | | x | | |
| Palmer, MA | 12,120 | x | | | x |
| Pelham, MA | 1,452 | | x | | x |
| Plainfield, MA | 480 | | x | | x |
| Princeton, MA | 3,200 | x | x | x | x |
| Russell, MA | 1,475 | | x | | x |
| Shelburne, MA | 2,000 | | x | | |
| Templeton, MA | 6,408 | x | | x | x |
| Wales, MA | 4,700 | x | | | x |
| Warwick, MA | 600 | | x | | x |
| Westhampton, MA | 1,403 | | x | | x |
| Westminster, MA | 5,870 | x | x | x | x |
| Whately, MA | 1,390 | | x | | x |
| Williamsburg, MA | 2,600 | | x | | x |

**TABLE 4 Pavement Life: 2.54- to 3.81-cm Overlay, Eastern and Western Regions**

EAST

| Present Pavement Condition | Daily Truck Traffic | Pavement Structure Good | Fair | Poor |
|---|---|---|---|---|
| | Low | 14.9 | 11 | 6 |
| F | 0 - 20 | n=26 s=2.4 | n=26 s=3.3 | n=1 |
| A | Moderate | 11.8 | 7.9 | 5 |
| I | 21-125 | n=26 s=3.6 | n=24 s=3.1 | n=1 |
| R | High | 9.4 | 6.2 | 3.5 |
| | >125 | n=20 s=3.4 | n=16 s=2.2 | n=1 |
| | Low | 10.3 | 6 | 6 |
| P | 0-20 | n=3 s=2.3 | n=13 s=2.4 | n=1 |
| O | Moderate | 8.8 | 5.1 | 4.5 |
| O | 21-125 | n=4 s=1.1 | n=12 s=1.8 | n=1 |
| R | High | 6.5 | 4.1 | 2.5 |
| | >125 | n=4 s=1.8 | n=9 s=1.6 | n=1 |

WEST

| Present Pavement Condition | Daily Truck Traffic | Pavement Structure Good | Fair | Poor |
|---|---|---|---|---|
| | Low | 13.2 | 9.4 | 7.2 |
| F | 0 - 20 | n=20 s=3.7 | n=16 s=2.8 | n=9 s=2.0 |
| A | Moderate | 12 | 8.4 | 6.1 |
| I | 21-125 | n=19 s=5.1 | n=18 s=3.8 | n=9 s=2.6 |
| R | High | 7.7 | 5.9 | 4.7 |
| | >125 | n=11 s=2.6 | n=19 s=3.2 | n=5 s=3.0 |
| | Low | 11.2 | 9.8 | 4.6 |
| P | 0-20 | n=10 s=3.6 | n=9 s=5.1 | n=3 s=1.3 |
| O | Moderate | 8.5 | 6.6 | 2 |
| O | 21-125 | n=11 s=3.3 | n=7 s=2.9 | n=2 s=1.0 |
| R | High | 6.4 | 3 | 4.3 |
| | >125 | n=8 s=2.3 | n=3 s=1.1 | n=3 s=2.4 |

**TABLE 5 Pavement Life: Chip Seals, Eastern and Western Regions**

EAST

| Present Pavement Condition | Daily Truck Traffic | Pavement Structure Good | Fair | Poor |
|---|---|---|---|---|
| F | Low | 8.7 | 6.3 | 4.6 |
| A | 0 - 20 | n=17 s=1.5 | n=15 s=1.9 | n=8 s=2.0 |
| I | Moderate | 8 | 4.5 | 3.2 |
| R | 21-125 | n=16 s=2.3 | n=13 s=1.8 | n=6 s=2.2 |
| P | Low | 7.4 | 4 | 2.1 |
| O | 0-20 | n=7 s=2.2 | n=8 s=1.6 | n=5 s=1.2 |
| O | Moderate | 6.1 | 2 | 1.2 |
| R | 21-125 | n=7 s=2.1 | n=6.0 s=0.7 | n=5 s=0.2 |

WEST

| Present Pavement Condition | Daily Truck Traffic | Pavement Structure Good | Fair | Poor |
|---|---|---|---|---|
| F | Low | 6.75 | 4.7 | 3.9 |
| A | 0 - 20 | n=20 s=1.4 | n=15 s=1.1 | n=7 s=1.4 |
| I | Moderate | 5.2 | 3.8 | 3 |
| R | 21-125 | n=15 s=1.2 | n=6 s=1.1 | n=43 s=1.4 |
| P | Low | 5.7 | 9.8 | 3.1 |
| O | 0-20 | n=13 s=1.7 | n=9 s=5.1 | n=7 s=1.7 |
| O | Moderate | 4.8 | 6.6 | 2.3 |
| R | 21-125 | n=10 s=1.5 | n=7 s=2.9 | n=3 s=1.3 |

**TABLE 6 Pavement Life: Fair Condition, Combined Regions**

| | Pavement Structure | |
|---|---|---|
| Daily Truck Traffic | Good | Fair |
| *Sand seals* | | |
| Low | 5.9 | 3.5 |
| 0–20 | $n = 20 \quad s = 2.7$ | $n = 17 \quad s = 1.5$ |
| *1.905-cm overlay* | | |
| Low | 11.7 | 6.1 |
| 0–20 | $n = 11 \quad s = 5.4$ | $n = 9 \quad s = 2.0$ |
| Moderate | 7.4 | 4.3 |
| 21–125 | $n = 12 \quad s = 2.4$ | $n = 9 \quad s = 2.0$ |

**TABLE 7 Costs of Treatments, Combined Regions**

| Treatment | Number of Observations | Cost | Standard Deviation |
|---|---|---|---|
| Sand seal | 8 | \$ 0.43/yd² | \$0.22 |
| Chip seal | 24 | \$ 0.80/yd² | \$0.32 |
| Bituminous overlay[a] | 47 | \$30.36/ton | \$3.88 |

[a]1.905- and 2.54- to 3.81-cm overlays combined.

mance. The survey questionnaire developed and employed in this project serves as a tool to obtain the data required to make these estimates. Such estimates of performance will facilitate the use of personal computer–based pavement management systems and, in turn, provide a decision aid for more efficient and effective allocation of limited pavement maintenance resources.

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