Network-Level Performance Evaluation of Asphalt-Rubber Pavement Treatments in Arizona

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The disposal of waste tires is an important and unresolved problem in the United States. The addition of crumb rubber modifier to asphalt paving materials is a feasible solution for the disposal of scrap tires. For more than 25 years the Arizona Department of Transportation (ADOT) has been using asphalt-rubber materials in the construction and rehabilitation of pavements. Asphalt-rubber has been placed on more than 1360 km (850 mi) of the state system. The performance of various asphalt-rubber treatments was evaluated using the data available in the ADOT pavement management system data base. The performance of stress absorbing membranes (SAMs) and stress absorbing membrane interlayers (SAMIs) is analyzed considering treatment service life, survival curves, roughness, and cracking. Survival curves show that SAMs on Interstate highways have significantly shorter average service life than on state and U.S. routes. SAMs on state and U.S. routes show approximately the same roughness progression pattern. Interstate SAM sections show the fastest roughness increase. SAMs on Interstate sections also show higher rates of crack development than on state and U.S. routes. SAMIs on Interstate, state, and U.S. routes have approximately the same service life. SAMIs on Interstate sections show faster increases in roughness and cracking than on U.S. and state routes. Three-layer systems and asphalt-rubber asphalt concrete friction courses have performed satisfactorily for several years. No conclusion can be drawn about the performance of dense graded asphalt-rubber until more performance data are available.

The disposal of waste tires is an important and unresolved problem in the United States. Each year approximately 285 million tires are discarded. The Environmental Protection Agency (EPA) estimates that currently a backlog of 2 to 3 billion scrap tires requires disposal throughout the United States (*1*). One use for scrap tires that is thought to have an important potential is to incorporate their rubber into asphalt paving materials. The binder obtained by mixing scrap tire rubber, asphalt cement, and frequently a diluent is called asphalt-rubber.

The Arizona Department of Transportation (ADOT) has been using asphalt-rubber materials in the construction and rehabilitation of pavements for more than 25 years. These materials have been used in various types of treatments, prepared and applied following various techniques. Asphalt-rubber has been placed on more than 1360 km (850 mi) of the ADOT system. The main applications of asphalt-rubber rehabilitation treatments have been on state and U.S. routes.

Michael Heitzman of FHWA in a State of the Practice report on asphalt-rubber technology identified two principal unresolved engineering issues related to the use of asphalt-rubber in asphalt paving materials (*2*):

- At the national level, the ability to recycle these materials, and
- At the state and local levels, the evaluation of the performance of the materials in the field.

This paper focuses on finding answers for this last issue by analyzing the performance of pavement treatments involving asphalt-rubber in Arizona. Knowing the actual performance of the various asphalt-rubber treatments allows ADOT to determine which treatments have performed best and what treatments are the most appropriate.

The network-level pavement management system data base was used to statistically analyze performance of asphalt-rubber pavements. Using these data for the analysis did not provide the level of detailed performance information that normally would be used for the evaluation of various pavement treatments. However, using the pavement management data base allowed analysis of all of the pavement sections in the state. Furthermore, these data are the basis for pavement management in the state and therefore represent a real-world evaluation of the performance of the treatments. The network-level analysis included the evaluation of performance of the following asphalt-rubber pavement treatments: stress absorbing membranes (SAMs), stress absorbing membrane interlayers (SAMIs), three-layer systems (TLS), asphalt-rubber asphalt concrete friction courses (ARACFC), and dense-graded asphalt-rubber concrete (DGAR).

LITERATURE REVIEW

General Background

Crumb rubber modifier (CRM) for asphalt paving is one possible solution to the disposal of scrap tires. However, currently less than 1 percent of the tires discarded annually is used as CRM for paving purposes (*1*). The incorporation of CRM in asphalt surfacing materials can be done using two different processes. The wet process consists of blending the rubber with asphalt cement before incorporating the binder into the process. The dry process mixes the rubber with the aggregate before the mixture is charged with asphalt. Although, the dry process is limited to hot-mix asphalt concrete (HMAC) applications, the wet process has been applied to crack sealants, surface treatments, chip seals, and HMAC (*2*). Arizona uses asphalt-rubber prepared using the wet process. This

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process mixes 70 to 80 percent asphalt with 20 to 30 percent scrap tire rubber at high temperature (160°C to 200°C). Frequently a low percentage of diluent (4 to 6 percent) is also required.

The main factors that affect the properties of the asphalt-rubber binder are rubber type and gradation, rubber concentration, asphalt type and concentration, diluent concentration and type, cure time, and reaction temperature (*3*). The main reasons for adding rubber to asphalt are to improve binder properties and to dispose of waste material (*4*). On the other hand, the main barriers to the development of the asphalt-rubber technology are the following (*3*):

1. Asphalt-rubber treatments have approximately twice the initial cost of conventional treatments, insufficient life-cycle cost data, and high capital cost required for equipment; and
2. Lack of complete long-term testing, conflicting test results, bad information transference, lack of material specifications, and patents.

The long-term performance of asphalt-rubber treatments in ADOT is discussed.

Historical Development

The modem concept of using wet process CRM in paving materials was developed primarily by Charles McDonald, Materials Engineer for the City of Phoenix, in the early 1960s. He developed an asphalt-rubber patching material called "Band-Aid." On the basis of the success of this material, the use of asphalt-rubber was expanded to surface treatments for entire projects. The resulting asphalt-rubber surface treatment is commonly referred to as SAM. ADOT placed its first experimental SAM on the frontage road of Interstate 17 in 1968 (*5*).

In 1972 ADOT placed its first experimental SAMI. This consisted of an asphalt-rubber membrane placed on an existing asphalt concrete surface before a conventional asphalt concrete overlay. The purpose of the membrane is to delay reflection cracking through the overlay and reduce pavement permeability. SAMI further evolved into a TLS as a solution for overlaying portland cement concrete pavements (PCCP). In the TLS the application of asphalt-rubber is placed between two asphalt concrete courses.

Further development resulted in asphalt-rubber binder use in hot asphaltic mixes. The first applications of asphalt-rubber as a binder in a hot-mix asphaltic concrete was in open-graded ARACFC. ADOT's first experimental ARACFC was placed in 1975. The first experimental section with DGAR was placed in 1986 (*6*).

Previous ADOT Reports

Gonsalves (*5*) presented the first comprehensive performance evaluation of asphalt-rubber treatments in ADOT. The principal applications by that time were SAMs and SAMIs. The analysis of pavement performance included surface condition, skid resistance, and roughness. The following were the main conclusions of the study:

1. Surface cracking was reduced by the use of rubberized asphalt and
2. Roughness is not adversely affected by rubberized asphalt.

Zaniewski (*4*) reported a review of the status of the research and performance of asphalt-rubber in Arizona. This report analyzed previous laboratory results, field experiments, and performance of highway sections containing asphalt-rubber treatments versus conventional treatments using ADOTs pavement management system (PMS) data bases. Comparisons between pairs of sections, where the only difference in construction history was that one received a SAM or SAMI and the other of the pair received a conventional treatment, showed mixed results. Finally, Zaniewski's report included a life-cycle cost analysis that concluded that if a conventional chip seal lasts 5 years a SAM application should last at least 10 years to be cost-effective. A 10-cm (4-in.) conventional overlay resulted in similar initial construction cost to a 5-cm (2-in.) SAMI treatment, but the conventional overlay had a lower life-cycle cost.

Scofield (*6*) presented a network level performance evaluation of SAMs, SAMIs, and asphalt-rubber membranes for pavement encapsulation, and a detailed project level analysis of eight experimental projects that included 47 test sections. Scofield concluded the following:

- SAMs had an average service life of 5.3 years on Interstate highways, 10.0 years on state routes, and 8.2 years on U.S. routes.
- SAMIs had an average service life of 9.0 years on Interstate highways, 9.5 years on state routes, and 7.8 years on U.S. routes.

The sections analyzed within each route class had different traffic, environmental, and support conditions. Therefore, the average service lives obtained represent average values for the entire route class. It will not be possible to accurately predict the service life of a particular section, but these average values can be used for network-level pavement management analysis.

NETWORK-LEVEL ANALYSIS USING ADOT PMS DATA BASE

The main body of the research consisted of an analysis of the performance of the various asphalt-rubber treatments using the information available in the ADOTs PMS data base. ADOT has constructed more than 1360 two-lane roadway km (850 mi) of pavement treatments containing asphalt-rubber. Usage consists of approximately 628 km (390 mi) of SAM, 476 km (296 mi) of SAMI, 13 km (8 mi) of TLS, 159 km (99 mi) of ARACFC, and 84 km (52 mi) of DGAR. The analysis concentrates on SAMs and SAMIs because more historical information is available relative to these treatments.

Asphalt-Rubber Membranes

A list of SAM and SAMI projects was obtained from the ADOT PMS data base. This list was compared with that from two previous reports (4,5) to prepare a comprehensive list of projects. For each of the identified projects, the pavement age at the time of the treatment and the time to the first rehabilitation treatment applied after the SAM or SAMI was extracted from the data base. In addition, pavement condition (surface distresses and roughness), traffic volumes, and maintenance costs were extracted from the main PMS data base. This information is available by mile-

TABLE 1 Descriptive Statistics for SAM Service Lives

Statistic	Total	Interstate	State	US. Routes
Mean	8.77	6.36	10.33	8.90
Standard Error	0.61	0.53	1.12	0.99
Standard Deviation	4.19	1.75	4.34	4.55
Coeff. of Variation	48	27	42	51
Range	17	6	14	16
Minimum	3	4	3	4
Maximum	20	10	17	20
Number of Sections	47	11	15	21

post, but average values for each section were computed for the analysis.

SAM Performance

There are 51 homogeneous SAM sections, 11 on Interstate highways, 18 on state routes, and 22 on U.S. routes. Four of these sections were experimental projects and were excluded from this analysis.

Service Life The service life for SAM sections was analyzed considering all route classes together and grouped by route class. Service lives were computed using ADOT's project data base by extracting the date of construction of the treatment and the date of application of the first rehabilitation treatment (mainly overlay or seal coat). However, three sections showed distress patterns (roughness and cracking), which indicated that a maintenance treatment was applied previous to the date shown in the data base. The date of rehabilitation was modified in all three cases. The statistics that describe SAM service lives are shown in Table 1. Survival curves were constructed by plotting the cumulative percentage of projects that have received major maintenance or rehabilitation (mainly seal coat or overlay) versus age of the pavement. The survival curves for Interstate, state, and U.S. routes are shown in Figures 1 through 3, respectively. For each survival curve a linear regression was fitted using the least-squares method. The corresponding fitted line, the coefficient of correlation, and the standard error of estimate are shown on each figure. Figure 2 shows that 50 percent of the SAM sections placed on state routes survived more than 10 years, and only approximately 25 percent were in service for more than 14 years.

Four fitted lines, corresponding to survival curves for all route classes, Interstate, state, and U.S. routes, are plotted in Figure 4. The Interstate sections have a significantly higher slope than the state and U.S. sections. Therefore, Interstate sections have significantly shorter average service life (in years) than state and U.S. routes. These results are consistent with those reported by Scofield (*6*) and can be explained by the fact that the Interstate sections receive, on average, approximately ten times more traffic than the others.

State sections performed slightly better than U.S. sections although they have approximately the same traffic load. This can be because the U.S. sections were significantly older at the time of construction of the SAM. The difference in performance on the two route classifications is less than was observed in 1989.

The average service lives and coefficient of variations of SAMs on each route class are as follows:

Route Class	*Average Service Life (years)*	*Coefficient of Variation (%)*
Interstate	6.4	27
State	10.3	42
United States	8.9	51

The service lives obtained were in all cases longer than those obtained in 1989. This is not surprising because in both cases

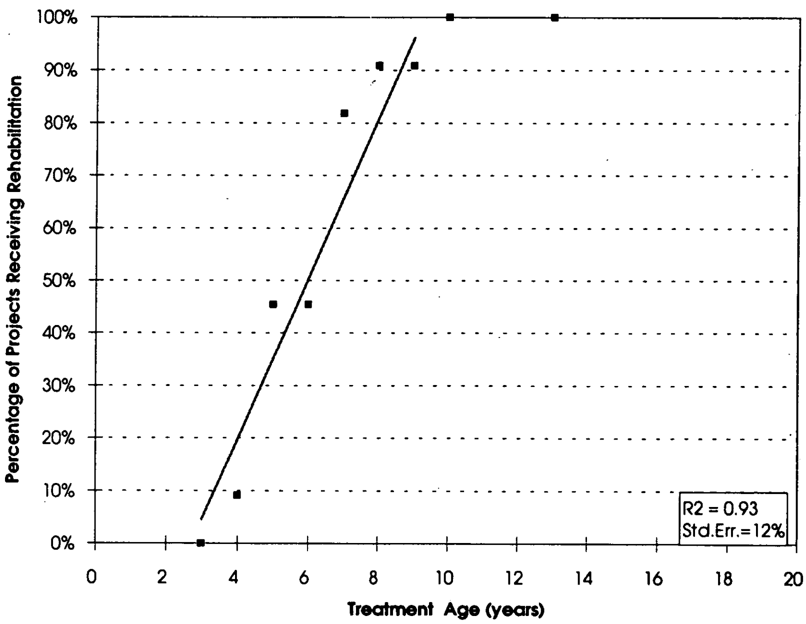

FIGURE 1 Survival curve for SAMs applied on Interstate routes.

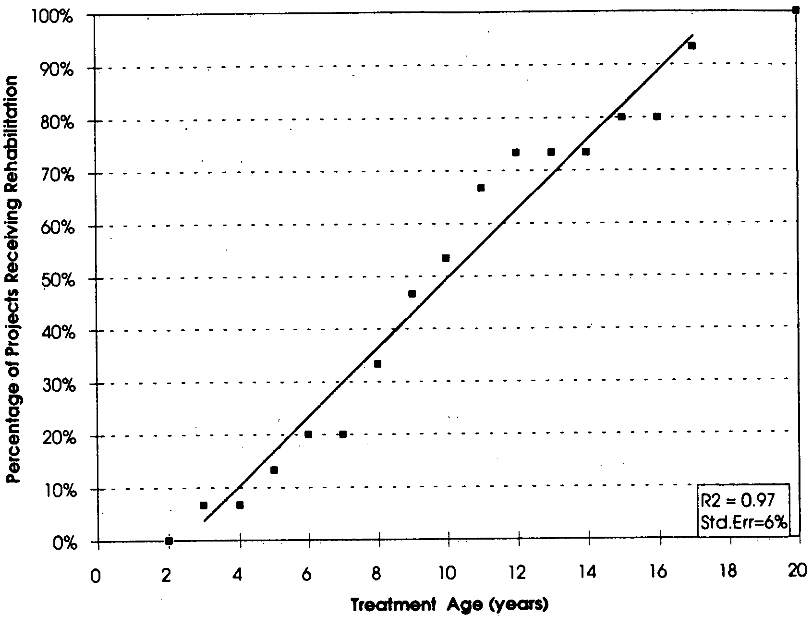

FIGURE 2 Survival curves for SAMs applied on state routes.

several sections have not received rehabilitation treatments and they are older now. The average service life has increased by 20 percent for Interstate, 3 percent for state and 9 percent for U.S. routes.

Roughness ADOT's PMS data base has annual roughness, expressed in inches per mile (in Maysmeter units), for every milepost of their highway network, starting in 1972. For every section considered, the average roughness values for the entire section were computed for the year before SAM placement and for each year of the SAM's service life. The average roughness of all sections and the corresponding standard deviation were computed for the year before SAM and for each year after SAM construction. Figure 5 shows a graphical representation of the average roughness progression with time and a 95-percentile band.

The average annual change in roughness was computed for each section by fitting a linear regression of the form

$$\text{Roughness} = m * \text{Age} + b \pm \epsilon \quad (1)$$

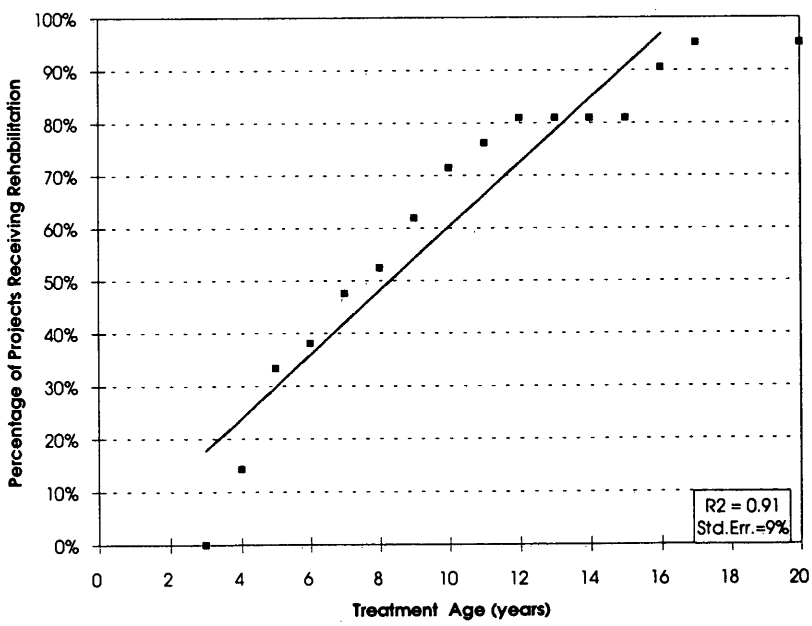

FIGURE 3 Survival curve for SAMs applied on U.S. routes.

The slope of this line (m) represents the average change in roughness for the roadway section. A line with slope equal to the overall average annual change in roughness (m) is shown superimposed on the average roughness plot in Figure 5. This line shows a relatively good fit until a pavement life of 12 years. Beyond that point it departs from the average roughness plot that indicates a reduction of roughness with age at the largest pavement ages. Two explanations are offered for this. First, only the sections that performed the best would survive beyond the 12-year horizon, and it could be expected that they had the lowest roughness. Second, fewer sections were used to compute the average roughness for the larger ages. Therefore, these averages are less representative. If the sections that lasted more than 14 years are analyzed separately, the overall average annual change in roughness (m) is only slightly different. However, in this case, a line with slope equal to the overall average m has a better fit with the plot of annual roughness averages. The averages for the older ages are higher, and therefore closer to the overall average roughness line, than are the averages that consider all sections.

SAM sections on state and U.S. routes show approximately the same roughness progression pattern. Therefore, they were grouped together for further analysis. Interstate sections show a faster increase in roughness probably because they carry heavier traffic load. Figure 6 shows the average roughness pattern for Interstate and state plus U.S. routes.

The performance equations that describe the average roughness for the two route classes are as follows:

$$\text{Average roughness} = 58 + 7.6 * \text{Age} \quad \text{for Interstate} \qquad (2)$$

$$\text{Average roughness} = 88 + 5.5 * \text{Age} \quad \text{for state and U.S. routes} \qquad (3)$$

The results reported by Zaniewski (*4*) are similar. However the values can be compared only after making an adjustment because ADOT has changed the calibration of the Maysmeter.

Cracking A problem was faced while analyzing cracking of SAM sections. Although a large percentage of sections were constructed in the mid-seventies, cracking data were available only starting in 1979. Consequently, the cracking data before SAM that would be expected to significantly affect the crack development are available only for a few sections. Therefore, the accuracy of the analysis is relatively poor because of the incomplete data in the early ages. The top portion of Figure 7 displays the annual percentage of cracking for all sections with a line that indicates the average of all sections for each year. A careful analysis of the cracking data showed that six SAM sections have particularly high percentages of cracking. Available information about these sections is limited to a few years close to the end of their service lives. Analyzing these sections separately reduces the dispersion, as shown in the bottom portion of Figure 7. Figure 8 shows the average percentage of cracking for Interstate, state, and U.S. routes. Interstate sections show a much higher rate of cracking development (1.7 percent per year) than state and U.S. routes (0.6 percent per year, and 0.4 percent per year, respectively).

SAMI Performance

Approximately 400 mi of SAMIs has been placed in Arizona. The analysis identified 77 homogeneous SAMI sections, 17 on Interstate highways, 25 on state routes, and 35 on U.S. routes. Nine of these sections were experimental and were not included in these analysis. Additionally, data for one of the sections analyzed previously was not in the current data base.

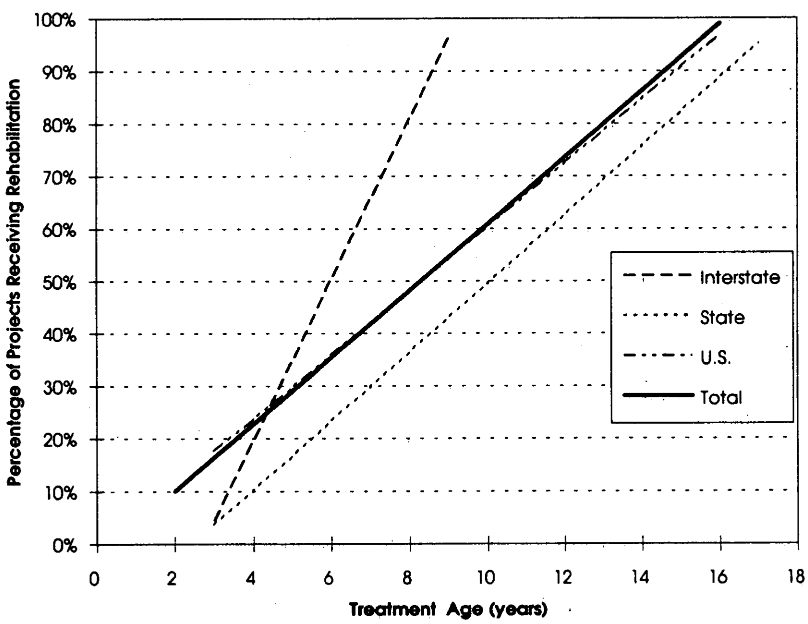

FIGURE 4 Comparison of fitted survival curves for SAMs on various route classes.

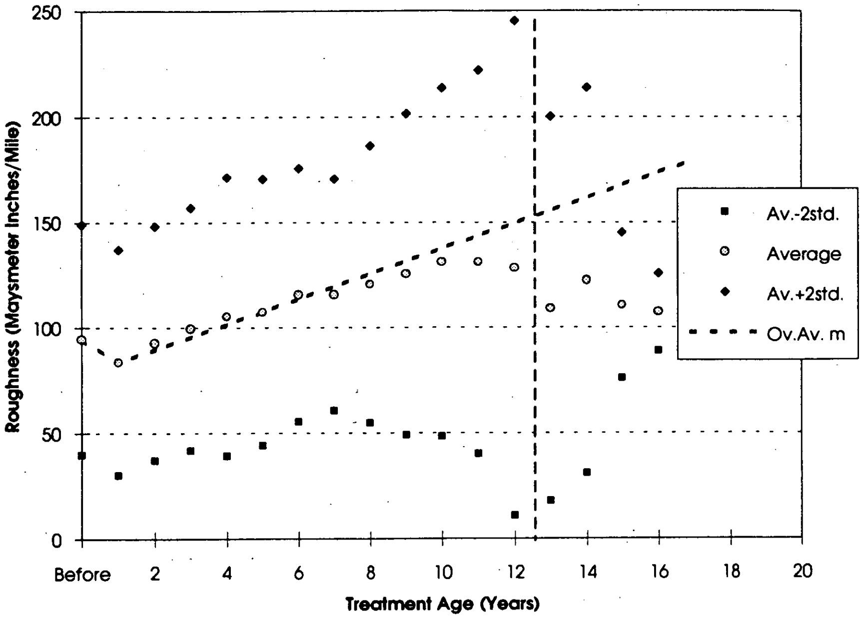

FIGURE 5 Average roughness progression for all SAM sections.

Service Life Service lives for SAMI sections were analyzed by considering all route classes together and grouped by route class. Service lives were computed on the basis of information stored in the PMS project data base. The statistics that describe SAMI service lives are shown in Table 2.

Survival curves for SAMIs on all route classes—Interstate, state, and US. routes—were constructed similar to that for SAM's sections. A linear regression was fitted for each curve. All regression lines showed good fit with coefficients of correlation (R^2) larger than 0.90.

The average service lives obtained for each route class are as follows:

Route Class	*Average Service Life (years)*	*Coefficient of Variation (%)*
Interstate	10.7	35
State	9.5	54
United States	10.7	42

Except for state routes that stayed the same, service lives were in all cases longer than those obtained in 1989. The average service life has increased by 19 percent for Interstate and 37 percent

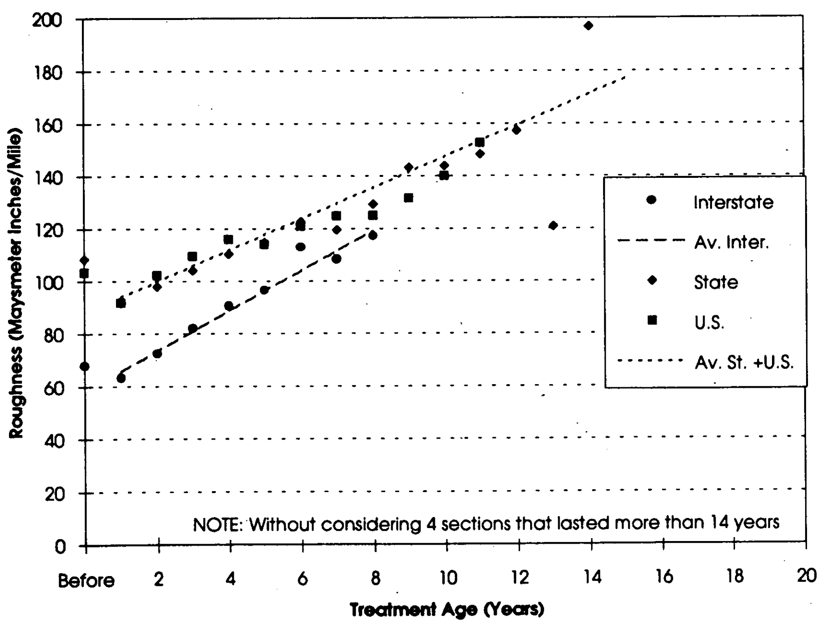

FIGURE 6 Average roughness progression for SAMs on various route classes.

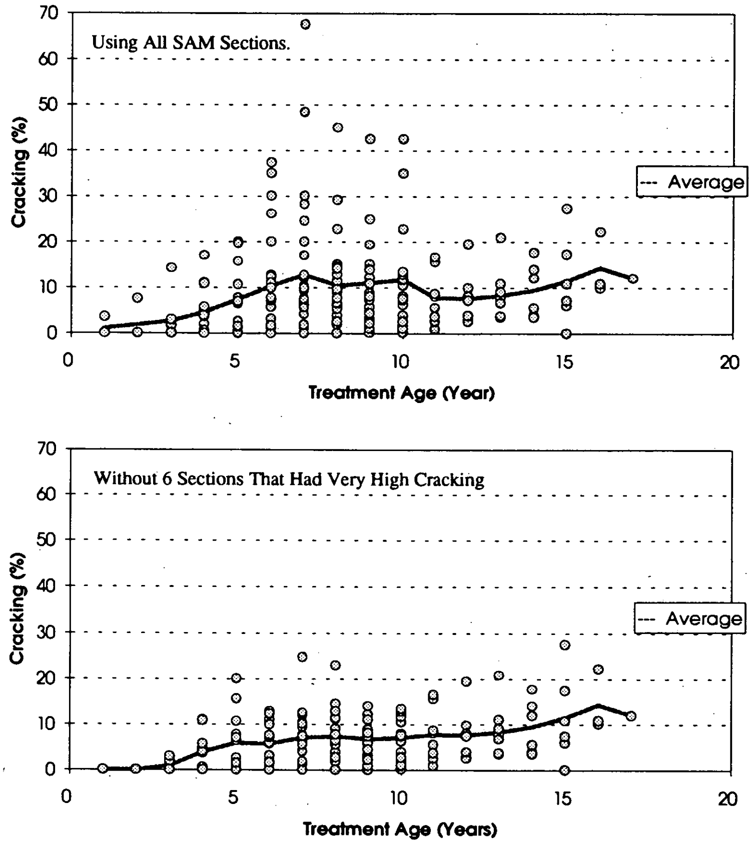

FIGURE 7 Average cracking development for SAM sections by year.

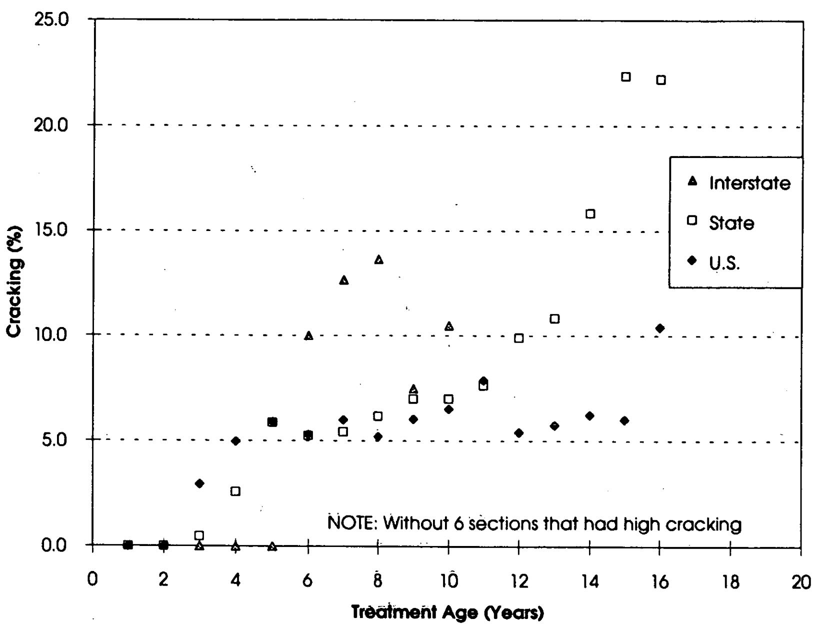

FIGURE 8 Average annual cracking for SAM sections grouped by route classification.

TABLE 2 Descriptive Statistics for SAMI Service Lives

Statistic	Total	Interstate	State	US. Routes
Mean	10.3	10.7	9.5	10.7
Standard Error	0.56	1.08	1.10	0.79
Standard Deviation	4.59	3.73	5.16	4.52
Coeff. of Variation	44%	35%	54%	42%
Range	14	11	14	14
Minimum	52	5	2	2
Maximum	16	16	16	16
Number of Sections	67	12	22	33

for U.S. routes. This increase is explained by the fact that several sections that were in service in 1989 have become older without being rehabilitated.

The four fitted lines obtained by linear regression show similar behavior (Figure 9). Consequently, SAMIs on Interstate, state, and U.S. routes have approximately the same service life. Because Interstate routes carry significantly higher traffic than the others, a shorter service life could have been expected. However, Interstate highways usually receive thicker overlays and in general are in better condition at the time of rehabilitation.

Roughness Roughness data were processed in the same way as those for the SAMs. The average roughness of all sections and the corresponding standard deviation were computed for the year before the SAMI construction and for every year of the treatment's service life. Figure 10 shows a graphical representation of the annual average roughness progression and a 95-percentile band. The average annual change in roughness was computed for each section using linear regression analysis. The overall average annual roughness changes for all sections by route classification are shown in Table 3. A line with slope equal to the overall average annual change in roughness shows a good fit with the annual average values, as shown in Figure 10.

Average roughness pattern for Interstate, state, and U.S. routes were compared. Interstate sections show the fastest increase in roughness probably because they carry a significantly heavier traffic load. Variations in annual roughness change (m) are very high. Performance equations for the average roughness are provided.

$$\text{Average Roughness} = 50 + 5.4 * \text{Age} \quad \text{for Interstate} \tag{4}$$

$$\text{Average Roughness} = 58 + 3.1 * \text{Age} \quad \text{for state routes} \tag{5}$$

$$\text{Average Roughness} = 58 + 2.3 * \text{Age} \quad \text{for U.S. routes} \tag{6}$$

These values are lower than those reported by Zaniewski (*4*) because in the previous report only the sections with high coefficient of correlation ($R^2 > 0.7$) were used to compute the average annual change in roughness.

Cracking Cracking data were evaluated following the same procedure described for SAM sections. Interstate sections show a much higher average rate of cracking development (0.5 percent per year) than sections on state and U.S. routes (0.2 percent per year). This rate can be caused by the heavier traffic load of Interstate highways.

TLS Performance

One section of Interstate Route 17 near downtown Phoenix (both roadway directions) had a TLS placed over PCCP in service for

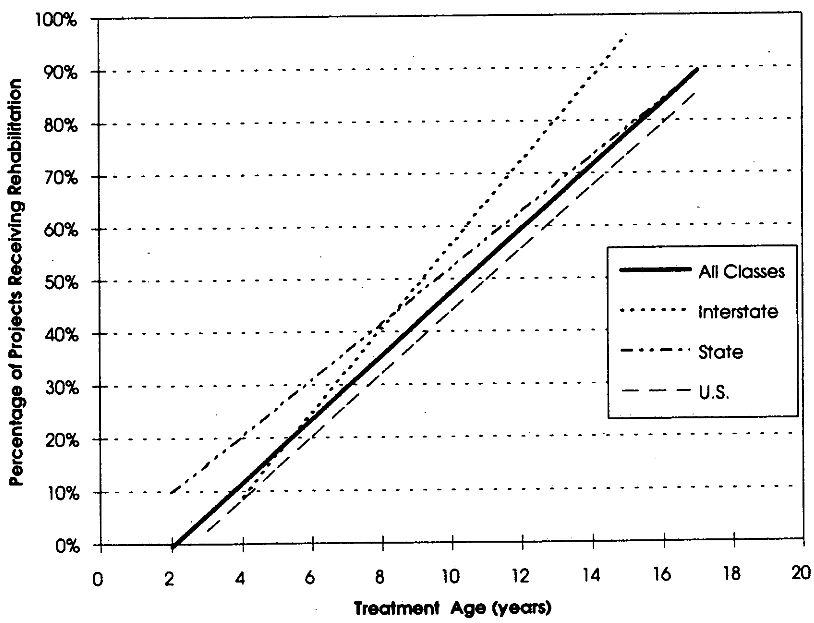

FIGURE 9 Comparison of survival curves for SAMIs on different route classes.

TABLE 3 Average Roughness Values for all SAMI Sections

Route	Roughness Before SAMI			Annual Roughness Change			Initial Roughness After SAMI		
Class	Av.	St.Dev.	Obs. #	Av.	St.Dev.	Obs. #	Av.	St.Dev.	Obs. #
Interstate	106.6	34.5	12.0	5.4	3.8	12.0	50.5	20.8	12.0
State	96.4	52.9	19.0	3.1	4.9	19.0	58.2	20.6	19.0
U.S.	117.7	38.2	31.0	2.3	3.0	31.0	57.8	17.2	31.0
Total	114.2	43.0	62.0	3.2	3.9	62.0	56.5	18.9	62.0

8 years, from 1985 until its rehabilitation in 1993. This section received approximately 7 to 8 million equivalent single axle loads during this period. The distress analysis showed the following:

- The average roughness was drastically reduced by approximately 120 in./mi (Maysmeter units) by applying the TLS.
- Average roughness showed almost no change through the 8 years of service life.
- Cracking developed during Year 4, reaching 3.5 percent in 1991. The average annual rate of crack development was 0.6 percent, similar to the average for SAMIs.

The section was performing satisfactorily at the time of rehabilitation but was removed as part of a larger rehabilitation project on the Interstate. The performance of this treatment is considered good. However, there are not enough statistical data to make strong conclusions about the long-term performance of TLS.

Asphalt-Rubber Concrete

ADOT has constructed several pavement sections using asphalt concrete mixes with asphalt-rubber binder. A brief description of the performance of these treatments is reported.

ARACFC Performance

ADOT's project data base includes 29 sections that have or had ARACFC treatments. Several of these are short experimental sections. Only eight of the ARACFC sections identified were constructed more than 3 years ago. One of these eight sections was a short experimental section and was reconstructed the year following construction, probably as part of a larger rehabilitation project. The average service life of the other seven sections is 10 years. However, only two of these sections have been rehabilitated: one at Year 5 and the other at Year 11. Therefore, the average service life of this treatment cannot be reliably estimated at this time, but it could be expected to be longer than 10 years.

DGAR Performance

A total of 24 sections that have DGAR in their structure were identified in ADOT's project data base. Several are short experimental sections, and only one section is older than 3 years. This section, constructed in 1986, is in service and, as of 1992, has not developed cracks. The roughness has only slightly increased from 1986 to 1992.

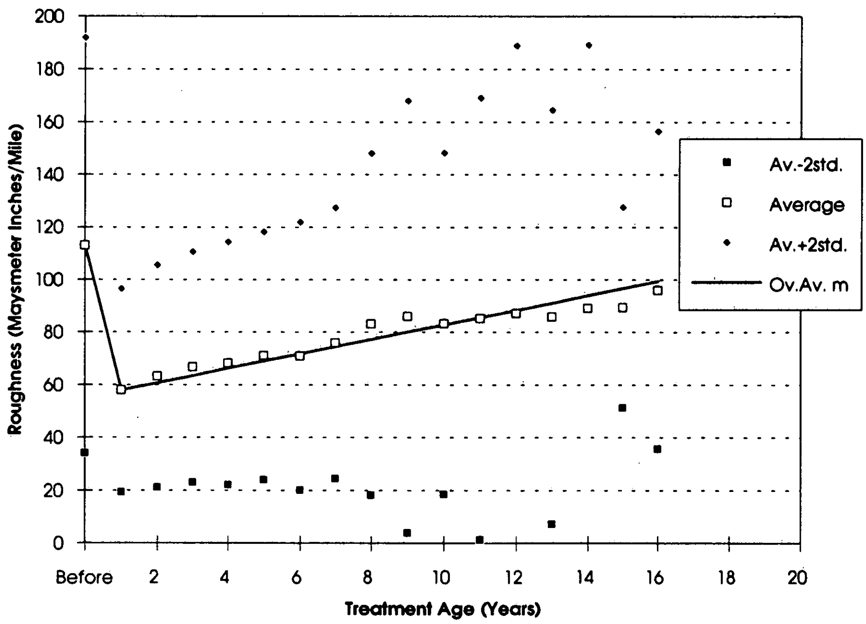

FIGURE 10 Average roughness progression for SAMI sections.

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

The main asphalt-rubber applications in ADOT have been in SAMs, SAMIs, DGAR, and ARACFC. Network-level evaluations of the first two treatments were not conclusive about the relative effectiveness of the asphalt-rubber treatments with respect to conventional treatments. Experiences from other states and national studies also show mixed results.

The average service life for SAM sections on Interstate highways is significantly shorter than the average service life on state and U.S. routes. The average annual change in roughness was computed for each section using linear regression analysis. SAM sections on state and U.S. routes show approximately the same roughness progression. Interstate sections show a faster increase in roughness, probably because of heavier traffic loads. Additionally, SAMs on Interstates also exhibit a higher rate of crack development.

SAMIs on Interstate, state, and U.S. routes have approximately the same service life. Because Interstate routes carry significantly higher traffic than the others, a shorter service life is expected. However, Interstate highways usually receive thicker overlays and, in general, are in better condition at the time of rehabilitation. Interstate sections show the fastest increase in roughness probably because they carry significantly heavier traffic. Interstate sections also exhibit a higher average rate of crack development than state and U.S. routes.

A TLS placed over PCCP was in service under heavy traffic for 8 years until its rehabilitation in 1993. The section had a drastic decrease in roughness with the treatment and was still performing satisfactorily at the time of rehabilitation. ADOT has constructed several ARACFC sections. The average service life of this treatment cannot be reliably estimated as this time, but it could be expected to be longer than 10 years. No conclusion can be drawn about the performance of DGAR until more performance data are available.

To evaluate the effectiveness of using paving treatments that contain asphalt-rubber, their performance should be compared with the performance of conventional treatments of similar characteristics. A close long-term follow-up of treatments using asphalt-rubber concrete should be conducted to evaluate its effectiveness with respect to conventional asphalt concrete treatments.

REFERENCES

1. *Markets for Scrap Tires.* EPA/530-SW-90-074A. Environmental Protection Agency, Washington D.C., Oct. 1991.
2. Heitzman, M. *State of the Practice: Design and Construction of Asphalt Rubber Paving Materials with Crumb Rubber Modifier.* Report FHWA-SA-92-022. FHWA, U.S. Department of Transportation, Washington D.C., 1992.
3. Epps, J. A. *Uses of Recycled Rubber Tires.* (NCHRP Project 20-5, Topic 22-02), TRB, National Research Council, Washington, D.C., 1992.
4. Zaniewski, J. P. *Summary of Arizona Department of Transportation Experience with Asphalt Rubber.* State of the Art Report. Report FHWA-AZ88-818, Arizona Department of Transportation, Phoenix, 1988.
5. Gonsalves, G. F. D. *Evaluation of Road Surfaces Utilizing Asphalt Rubber.* Report 1979-663. Arizona Department of Transportation, Phoenix, 1979.
6. Scofield, L. *The History, Development, and Performance of Asphalt Rubber at ADOT.* Special Report. Report AZ-SP-8902. Arizona Department of Transportation, Phoenix, 1989.

Publication of this paper sponsored by Committee on Pavement Monitoring, Evaluation, and Data Storage.