Cost-Benefit Analysis of Preventive Maintenance Treatments for Semi-rigid Base Asphalt Pavement in Jiangsu, China: A Pilot Study

Submitted by

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Submitted on July 31, 2013, for consideration for presentation and publication at the 93rd Transportation Research Board Annual Meeting, January 2014

Word Count: 3217+ Figures (11×250) + Tables (6×250) = 7467
ABSTRACT

The Jiangsu provincial highway network consists of 4121 km of asphalt pavement which includes a semi-rigid base at the end of 2012. Currently, a maintenance decision support system which includes detection, analysis, decision-making, implementation, and evaluation is being established and updated.

In this research, a preliminary study of preventive maintenance treatment dealing with the implementation and evaluation stages, focused on cost-effectiveness assessment and function validity by comparing various rut preventive maintenance treatments included microsurfacing, ultra-thin overlay, hot in-place recycling and thin hot mix overlay, etc. The Jiangsu provincial highway network status and major distress were studied based on the statistical analysis of the performance data and maintenance history which was collected from the Pavement Management System (PMS). The determination method of Extended Service Life (ESL) index of the different preventive maintenance treatments was recommended according to the rut depth used as the control performance indicator. Combined with the ESL value, the Benefit-Cost Ratio (BCR) value using Life Cycle Cost Analysis (LCCA) method was calculated with different rut preventive maintenance treatments, and their effectiveness was compared.

The results indicated microsurfacing has the highest cost-effectiveness, ultra-thin overlay and HIR have similar cost-effectiveness level, while thin hot mix overlay has the lowest BCR value compared with other treatments. Furthermore, in terms of the different rut depths, preservation treatments are recommended in Jiangsu Province. The findings will support for the PMS updating for maximize both project and network level benefits, combined the preventive maintenance management system in the near future.

**Keywords:** Semi-rigid base asphalt pavement, rut, preventive maintenance, extended service life, benefit-cost ratio, pavement management system.
INTRODUCTION

Highway agencies are facing a challenge to sustain their highway infrastructure. It is vital for highway agencies to prioritize resource allocations among different assets and balance available funding and the user expectations (1). Like all highway agencies, one of the major tasks of Jiangsu Department of Transportation (JSDOT) is to preserve the existing provincial highway network. At present, the Jiangsu provincial highway network has been basically formed and pavement maintenance has become the most important and urgent task for JSDOT. At the end of 2012, Jiangsu highway mileage exceeded 4121km of asphalt pavement which were all applied with a semi-rigid base.

The Jiangsu “Twelfth Five-Year Plan” (2010-2015) targets that “Transport infrastructure construction and maintenance technology upgrades, and pavement preventive maintenance to the leading domestic level”. It focuses on research and development direction in the area of “highway maintenance” goals, which includes Jiangsu provincial highway maintenance. This will initially form a modern maintenance system during “Twelfth Five-Year” period, to achieve the maintenance scientific decision-making and management information technology (2).

Over the past 20 years, many preventive maintenance treatments have been developed and used in Jiangsu highway network. The treatments have included microsurfacing, fog seal, ultra thin-overlay, thin hot mix overlay, hot in-place recycling, and the like. Currently, due to limited funds and increasing maintenance mileage, especially the requirements of energy saving and low-carbon green maintenance technology by China government, innovative and cost effective pavement solutions are being implemented by JSDOT. For example, reclaimed asphalt pavement (RAP), rubber asphalt (RA) and warm mix asphalt (WMA) is being included in preventive maintenance treatments.

Currently, many researchers studied the cost-effectiveness and treatment timing of pavement maintenance measures. Wei et al. developed preventive maintenance decision trees of the Ontario road network based on cost-effectiveness analysis (3). Mamlouk et al. analyzed the effectiveness of pavement preventive maintenance strategies for both low and high volume roads (4). Morian (5), Eltahan (6), and Shirazi (7) have analyzed the Specific Pavement Studies-3 (SPS-3) data, concluding that the thin overlay is an effective treatment with respective to rut treatment. Liu et al. studied the cost-effectiveness of modified slurry seals and ultra-thin bonded bituminous surface using the Pavement Management Information System from the KDOT (8). Yue et al. evaluated the effectiveness of 2 inch HMA overlay and crack sealing. The timing of maintenance treatment is critical to the cost-effectiveness analysis (9).

The methodology for estimating the optimal timing has been addressed in several studies (10-16), especially for NCHRP report 523, which developed a methodology for determining the optimal timing for the application of preventive maintenance treatments to flexible and rigid pavements to achieve the greatest performance increase at the least cost.
Preventive maintenance treatments have been widely used in the Jiangsu province, while its cost-effectiveness hasn’t been analyzed in detail before. It is important to address the cost-effectiveness and effectiveness of preventive maintenance treatments used for semi-rigid base asphalt pavement in Jiangsu. A clear BCR calculation process did not exist in past Jiangsu research findings.

**OBJECTIVE**

The objective of this study is to identify the current pavement status and summarize the results of preventive maintenance treatments for rutted pavements and to determine the Extended Service Life (ESL) index of preventive maintenance treatment based on the rut depth indicator, and to study a reasonable Benefit-Cost Ratio (BCR) model using Life Cycle Cost Analysis (LCCA) method. Furthermore, based on the identification of the cost-effectiveness of pavement preventive maintenance treatments, the best treatments for rutted pavements are recommended for semi-rigid base asphalt pavement performance in Jiangsu Province.

**METHODOLOGY**

The status of asphalt pavement condition was analyzed based on the PMS data and pavement maintenance history. The critical or combined pavement performance index was selected as the indicator according to the survey results. In this case, rut depth was only selected as the indicator based on highway network status in Jiangsu Province. The ESL index of preventive maintenance treatment was determined based on the critical indicator of the pre- and post-treatment inspection results. Combined with LCCA method, the cost-effectiveness of pavement preventive maintenance treatments was calculated. As to the benefit calculation, the negative benefit was firstly indicated in the Preventive Benefit Index (PBI). Figure 1 shows the BCR calculation flow chart of preventive maintenance treatment.

**PAVEMENT PERFORMANCE**

**Pavement Network Status**

JSDOT monitors pavement performance using a semi-annual condition survey. The pavement indexes include Pavement Structure Strength Index (PSSI), Pavement Surface Condition Index (PCI), Riding Quality Index (RQI), Rut depth Index (RDI), and Skid Resistance Index (SRI) obtained using an automated pavement condition vehicle to inspect the outside lane of all freeways.

According to the inspection performance results at the end of 2012, which included pavement deflection value, Damage Ratio (DR), International Roughness Index (IRI), Rut Depth (RD), and Side-way Force Coefficient (SFC), performance of the Jiangsu provincial highway network using statistical analysis is shown in Figure 2.
The statistical results indicated that each performance index of Jiangsu provincial highway is at a higher level. Especially, the four performance indexes including pavement damage, roughness, deflection and friction is no less than 99%. Only the rut depth index is lower. The good rate means the percent mileage of the performance index value which is no less than 80 by the total of highway mileages.

Figure 1 The Benefit-Cost Ratio calculation flow chart.
Typical Pavement Distress

Based on the previous pavement maintenance experience before 2012, the statistical results of the treatments used for treating pavement distress are shown in Figure 3. The results indicate that the total percent of pavement rut and distress (reflective cracking and patching) account for more than 97% in Jiangsu Province. Recently, rut has become the major distress to be solved in pavement maintenance due to high temperature in summer and heavy load traffic. Because semi-rigid base asphalt pavement was the primary pavement structure used in Jiangsu highway network, reflective cracking once was the obvious distress. In recent years, however, the usage of anti-cracking cement stabilized macadam base, low-dosage cement stabilized sub-base, polymer modified asphalt SBS SMA and Superpave mixtures, reflective cracking is no longer the major distress in the pavements.
Causes of Rut

Figure 3 shows the rut changing tendency of six highways within eight to ten years inspection in Jiangsu Province. The highways are all semi-rigid base asphalt pavement structure. As expected, the rut experiences three stages. At the first stage, the rut depth rapidly increases between 3mm and 5mm at the first three years since traffic opening. Secondly, the rut depth is slightly increased at the second stage within the next two years. Finally, the average rut depth is increased to 8mm at the third stage. The field inspection results are similar to the theoretical rut formation process.

![Figure 4 Rut development tendency since traffic opening.](image)

Two representative highways were selected to investigate the rut formation of each asphalt course. The depth of coring samples was compared to the original depth during the paving process. It should be noted that the rut is only developed in asphalt layers for semi-rigid base asphalt pavement due to sound semi-rigid base. The asphalt layer has three asphalt courses, including surface course, middle course and base course. The rut contribution of each asphalt course is shown in Table 1. The rut contribution means the percent of the rut depth of each course by the total rut depth.

**Table 1 The Results of Rut contribution of Each Asphalt Course**

<table>
<thead>
<tr>
<th>Highway</th>
<th>Coring section</th>
<th>Rut depth (mm)</th>
<th>Rut contribution of each asphalt course (%)</th>
<th>Total contribution of middle and base (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Surface</td>
<td>Middle</td>
</tr>
<tr>
<td>Hu Ning</td>
<td>K157+560</td>
<td>13</td>
<td>16.7</td>
<td>50</td>
</tr>
<tr>
<td></td>
<td>K93+535</td>
<td>12</td>
<td>24.6</td>
<td>35.2</td>
</tr>
<tr>
<td></td>
<td>K92+500</td>
<td>17</td>
<td>28.9</td>
<td>68.6</td>
</tr>
<tr>
<td>Guangjing</td>
<td>K370+020(1#)</td>
<td>21</td>
<td>9.8</td>
<td>4.9</td>
</tr>
<tr>
<td>Xicheng</td>
<td>K370+020(2#)</td>
<td>8</td>
<td>18.8</td>
<td>37.5</td>
</tr>
</tbody>
</table>
According to Table 1, it is found that the rut mainly occurs in the asphalt middle and base course. The total rut contribution of middle and base course is between 71.1% and 90.2%. There are many factors affected the high temperature stability of asphalt pavement, such as pavement structure, traffic load, temperature, asphalt mixture type, additive and rainfall, etc. Since similar structure and materials was used in Jiangsu, the previous findings showed that the major factors affect rut is traffic load.

Rut depth Distribution

The results of current rut depth distribution are shown in Figures 5. Figure 6 shows the timing of the treatments is generally applied correlated with the Rut Depth (RD) according to previous pavement maintenance experience. In recent years, the preventive maintenance treatments are implemented when the rut depth exceeds 10mm. Due to the limited maintenance funds and increasing maintenance mileages, the pavement is normally preserved when the rut depth reaches 15mm. As shown in Figure 4, the majority treated timing of RD is in the range of 10 to 18 mm.

![Rut depth distribution in Jiangsu provincial highway network.](image)

Figure 5 RD distribution in Jiangsu provincial highway network.
CURRENT RUT TREATMENT PRACTICES

As mentioned earlier, rut is the major pavement distress with reflective cracking and patching distresses in some local sections in Jiangsu Province. Therefore, the objective of pavement maintenance treatments is to correct rut and these treatments have been implemented since 1995. Table 2 shows the application development trend for treating rut. Milling and overlay treatment was always applied in Jiangsu freeway network, especially for heavy and extra heavy traffic levels.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>Microsurfacing, Thin overlay</td>
<td>Microsurfacing, Ultra-thin overlay, Thin overlay</td>
<td>Microsurfacing, Ultra-thin overlay, Thin overlay, Hot in-place recycling</td>
<td>Ultra-thin overlay, Hot in-place recycling, Thin overlay</td>
</tr>
</tbody>
</table>

The ultra-thin overlay has been performed with different types of hot mix asphalt mixture. In addition, Easy Compacted Asphalt (ECA 6.7 and ECA 10), Stone Mastic Asphalt (SMA 9.5), Open-Graded Friction Course (OGFC 13), and Multiple-efficient Asphalt Concrete (MAC 10 and MAC 13) have been used in pavement preventive maintenance projects. In particular, ECA is the most widely applied for rut filling and repair as an effective preventive maintenance treatment. ECA consists of polymer modified asphalt SBS PG76-22, warm-mix agent (Evotherm), and the specific aggregate gradation. Hot in-place recycling (HIR) technology using the remix method is another widely used rut treatment where the treated types of asphalt mixtures include SBS modified asphalt AC 13 and SMA 13.
Recycling agents, new asphalt (if needed, and new asphalt mixture are added in the recycled mixture. Microsurfacing was widely used for rut filling and repair before 2010. However, due to its noise pollution and riding discomfort, microsurfacing has seldom been used since 2010.

Table 3 shows the some of the rut treatment history in Jiangsu. In addition, asphalt emulsion Cold In-place Recycling (CIR) and MAC 10 is now being used in pavement maintenance and its effectiveness will be verified according to the long-term inspection results.

Table 3 Rut Treatment History in Jiangsu Province

<table>
<thead>
<tr>
<th>Highway</th>
<th>Opening time</th>
<th>Microsurfacing</th>
<th>Ultra-thin overlay</th>
<th>HIR</th>
<th>CIR</th>
<th>Milling &amp; overlay</th>
<th>Thin Overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Novachip ECA 10 SMA 9.5 OGF C 13 MAC 10</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hu Ning</td>
<td>1997</td>
<td>2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Airport highway</td>
<td>1997</td>
<td>2010</td>
<td></td>
<td></td>
<td></td>
<td>2012</td>
<td></td>
</tr>
<tr>
<td>Ning Gao</td>
<td>2006</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yan Jiang</td>
<td>2004</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Xi Yi</td>
<td>2003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2010 2011</td>
<td></td>
</tr>
<tr>
<td>Su Jia Hang</td>
<td>2002</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2010</td>
<td></td>
</tr>
</tbody>
</table>
TREATMENT COST-EFFECTIVENESS ANALYSIS

Extended Service Life (ESL)

As shown in Figure 7, the Extended Service Life (ESL) index can be estimated using two approaches (17). In fact, preventive maintenance treatments mostly are implemented before the accepted terminal threshold. Therefore, ESL is determined based on the equivalent pavement performance condition of pre-treatment and post-treatment as indicated by approach A.

Rut is the major distress on the basis of the analysis of typical pavement distress and the pavement maintenance history. In this study, the rut depth (RD) was selected as the pavement performance indicator. Then, ESL was identified as time taken for the rut depth to the level it was at immediately prior to the preventive maintenance treatment. RD data was collected according to the long-term pavement performance index survey in the Pavement Management System (PMS).

![Figure 7 ESL determination of preventive maintenance treatment.](image)

The ESL values of each preventive maintenance treatments were determined based on the RD index. As shown in Figures 8, 9 and 10, the RD value gradually increased after microsurfacing, HIR, and ECA treatments. ESL values of 3.5, 4.7 and 4.4 years were calculated based on the RD value, respectively.
Yan, Zhang, Ding, and Li

Figure 8 Rut development trend of post-microsurfacing treatment.

Figure 9 Rut development trend of post-HIR treatment.
Figure 10 Rut development trend of post-ECA treatment.

Analysis of Cost Benefit

Preventive Benefit Index (PBI)

The Preventive Benefit Index (PBI) model of multi-index is shown in Figure 11. The effect of the preventive maintenance treatments is focused on the following performance indicators including rut, roughness, and skidding. The PCI, RQI, and BPN indexes are used as performance indicators in the cost-effectiveness calculation process. However, it is found that PCI indicator does not reflect the real pavement status in Jiangsu Province. In order to compare the cost-effectiveness for each preventive maintenance treatments, the absolute values of RD, SFC, and IRI were selected as condition indicators in this research. The weighting coefficients based on actual engineering applications were adjusted accordingly as shown in Table 4.

As to the calculation of PBI, the baseline of the PBI calculation curve was the same as ESL determination method. The RD indicator was considered as the control index as expressed in the ESL calculation process. The RD value increased to the level of pre-treatment as the acceptable trigger point. As shown in Figure 11, if IRI or SFC value surpassed to the original level of pre-treatment during the ESL period, the negative benefit should be included in the PBI calculation of implementation of preventive maintenance treatment. The analysis of PBI was more practical and reasonable to be consistent with the actual pavement status.
As shown in Figure 11, the absolute benefits of do nothing option and preventive maintenance treatment performance curves are calculated with the Equations 1 and 2.

\[ S(i) = \int_{0}^{T_1} [(y_3(i) - y_1(i))]dx \] (1)

Where,
- \( S(i) \), do-nothing condition area associated with a condition indicator.
- \( T_1 \), implementation timing of preventive maintenance treatments.
- \( y_1(i) \), equation defining the do-nothing condition indicator relationship.
- \( y_3(i) \), upper benefit cutoff value associated with the rut depth indicator.
- \( i \), the number of condition indicators; \( i=1, 2, 3 \).

The rut depth index was determined as the control condition indicator. Therefore, the PBI value of rut depth performance curves for post-preventive treatment was positive as shown in Equation 2. While the SFC or IRI value maybe surpassed its original level during the ESL period, and its negative area will be produced and should be considered as shown in Equation 3.

\[ S(i)' = \int_{T_1}^{T_2} [(y_3(i) - y_2(i))]dx \] (2)

Where,
- \( S'(i) \), post-treatment area associated with a condition indicator.
- \( y_2(i) \), equation defining the post-treatment condition indicator relationship.
- \( T_2 \), overall post-treatment analysis period; \( T_2 - T_1 \) is ESL.

\[ \Delta S(i) = S(i)' - S(i)'' = \int_{T_1}^{T_2} [y_3(i) - y_2(i)]dx - \int_{T_1}^{T_0} [y_2(i) - y_3(i)]dx \] (3)

Where,
\( \Delta S(i) \), individual absolute benefit area associated with a given condition indicator.

\( S(i)'' \), negative area associated with the SFC or IRI indicators.

\( T_0(i) \), period of the SFC or IRI indicators curve intersects the upper RD benefit cutoff value.

The relative benefit and the PBI value of preventive maintenance treatment are calculated according to Equations 4 and 5.

\[
E(i) = \frac{\Delta S(i)}{S(i)} \\
PBI = \sum k(i) E(i)
\]

Where,

- PBI, preventive benefit index, %.
- \( E(i) \), relative benefit corresponded to individual condition indicators.
- \( k(i) \), weighting coefficients of individual condition indicator.

**Equivalent Uniform Annual Costs (EUAC)**

Life Cycle Cost Analysis (LCCA) has been widely used to evaluate the cost-effectiveness of preservation maintenance treatments (18-20). With the aim to absolutely compare the effectiveness of each preventive maintenance treatments, only once rut preventive treatment was analyzed in LCCA method. The equivalent uniform annual cost (EUAC) was calculated according to Equations 6 and 7.

\[
PW = \frac{C}{(1 + d)^{T_1}} \\
EUAC = PW \times \left[ \frac{d(1 + d)^{T_2}}{(1 + d)^{T_2 - 1}} \right]
\]

Where,

- \( PW \), present worth value of preventive treatment, ¥/lane/km.
- \( C \), preventive maintenance cost, ¥/lane/km.
- \( d \), discount rate (6.5%) expressed as a percentage, %.
- \( T_1 \), the age of preventive treatment application since opening time, year.

**Benefit-Cost Ratio (BCR)**

The Benefit-Cost Ratio (BCR) was computed using Equation 8. The most cost-effective preventive treatment has the largest BCR ratio to prolong the pavement longer service life.

\[
BCR = \frac{PBI}{EUAC}
\]

Where,

- BCR, the treatment benefit-cost ratio, % / (¥/lane/km).

**Comparison of Rut Treatments: Project Case Study**

According to the survey results and project records of each rut preventive treatment.
maintenance treatments collected from the PMS, Table 5 shows the results of ESL, PBI, EUAC and BCR index based on typical rut preventive maintenance treatments. It can be concluded that microsurfacing has the highest BCR value which indicated the best choice for rut treatment, and thin hot mix overlay has the lowest BCR values. HIR and ultra-thin overlay have similar effectiveness level, while Novachip has a litter higher BCR value and HIR has a litter lower BCR value compared with the other ultra-thin overlay treatments.

During the BCR calculation process, it should be noted that the project cases are selected from the PMS. Due to different application timing of the preventive maintenance treatments, the present value of cost maybe different. The preventive project case was selected for the same year. Since the critical factor of the ESL value was the traffic load level, it was not considered in this research due to current limited samples. In future studies, the traffic level and pavement structure (especially surface asphalt layer) and different lanes will be correlated with the determination of ESL and BCR values.

### Table 5 Cost-effectiveness Results of Preventive Maintenance Treatments

<table>
<thead>
<tr>
<th>Performance indicators</th>
<th>Microsurfacing</th>
<th>SMA-9.5</th>
<th>ECA-10</th>
<th>Novachip</th>
<th>HIR</th>
<th>Thin overlay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative Benefit Index $E_1(\text{RD})$</td>
<td>0.626</td>
<td>0.621</td>
<td>0.715</td>
<td>0.738</td>
<td>0.712</td>
<td>0.697</td>
</tr>
<tr>
<td>$E_2(\text{SFC})$</td>
<td>0.128</td>
<td>0.490</td>
<td>0.359</td>
<td>0.514</td>
<td>0.362</td>
<td>0.374</td>
</tr>
<tr>
<td>$E_3(\text{IRI})$</td>
<td>0.208</td>
<td>0.471</td>
<td>0.529</td>
<td>0.757</td>
<td>0.481</td>
<td>0.471</td>
</tr>
<tr>
<td>PBI, %</td>
<td>0.4010</td>
<td>0.5498</td>
<td>0.5880</td>
<td>0.6989</td>
<td>0.5727</td>
<td>0.5646</td>
</tr>
<tr>
<td>EUAC, ¥/lane/km</td>
<td>12669.04</td>
<td>24655.18</td>
<td>26280.04</td>
<td>27926.78</td>
<td>26409.80</td>
<td>41227.49</td>
</tr>
<tr>
<td>BCR $(10^{-5})$, % / (¥/lane/km)</td>
<td>3.1652</td>
<td>2.2300</td>
<td>2.2374</td>
<td>2.5026</td>
<td>2.1685</td>
<td>1.3695</td>
</tr>
</tbody>
</table>

In summary, microsurfacing, ECA and HIR treatments have been widely implemented in Jiangsu highway to treat rutted pavements. Microsurfacing has been seldom used since 2010. However, with new developments with modified asphalt emulsion technologies and equipment, durable and low noise microsurfacing is expected in the near future. According to previous rut preventive maintenance experience, Table 6 provides the rut treatment plan as a function of rut depth. In general, microsurfacing and ultra-thin overlay are suggested for treating rut depths from 5 to 10mm, while ultra-thin overlay and HIR are recommended for treating rut depths from 10 to 15mm. For rut depths between 15 to 25mm, HIR and milling and overlay are suggested. If rut depths exceed 25mm, traditional rut treated measure milling and overly was the only recommended measure.
### Table 6 Rut Treatment Plan with Different Rut Depth

<table>
<thead>
<tr>
<th>Rut depth (mm)</th>
<th>Recommended plans</th>
<th>Asphalt mixture types</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-10</td>
<td>I Ultra-thin overlay (2cm)</td>
<td>ECA-6.7, MAC-10</td>
</tr>
<tr>
<td></td>
<td>II Microsurfacing</td>
<td>Durable, low-noise microsurfacing</td>
</tr>
<tr>
<td>10-15</td>
<td>III Ultra-thin overlay (2-2.5cm)</td>
<td>ECA-10, MAC-13</td>
</tr>
<tr>
<td></td>
<td>IV Hot in-place recycling (4cm)</td>
<td>AC-13, SMA-13, with warm-mixed agent, recycled agent (if needed)</td>
</tr>
<tr>
<td>15-25</td>
<td>V Hot in-place recycling (4cm)</td>
<td>AC-13, SMA-13, with added new asphalt mixture, warm-mixed agent and recycled agent (if needed)</td>
</tr>
<tr>
<td></td>
<td>VI Milling and overlay (4cm)</td>
<td>SMA-13</td>
</tr>
<tr>
<td>&gt;25</td>
<td>VII Milling and overlay (10cm or 18cm)</td>
<td>SMA-13, Sup-20, and Sup-25, milling and overlay two or three asphalt layers,</td>
</tr>
</tbody>
</table>

### CONCLUSIONS

This research studied the Jiangsu province highway network status, and identified major distresses based on the statistical analysis of the performance data and maintenance history which was collected from the PMS. Rut depth was used as the control index to calculate the ESL and BCR of each preventive maintenance treatments based on the recommended determination method from the practical point of view. Based on the findings, the following conclusions were drawn.

1. Rut was the major distress in Jiangsu current highway network based on the pavement maintenance history and performance data collected from the Pavement Management System.
2. The extended service life of preventive maintenance treatment determination method was recommended according to the rut depth used as the control indicator from a practical point of view.
3. Combined with ESL and LCCA, the cost-effectiveness calculation method of preventive maintenance treatments was suggested. The BCR values indicated that microsurfacing has the highest cost effectiveness, ultra-thin overlays and HIR have almost the same cost-effectiveness level, while thin hot mix overlays have the lowest BCR value compared with other treatments.
4. According to Jiangsu Province experience, the rut treatment plan with different rut depth was recommended using the following measures including preventive maintenance treatments durable and low noise microsurfacing, ECA, HIR, and MAC with energy saving and low-carbon green technology.
ACKNOWLEDGEMENTS

This study was supported by Jiangsu Provincial Transportation Science and Technology Project (2011 1/02-G1-6). We would like to thank Mr. Yu Jia, Professor Fujian Ni and Dr. Lan Zhou who accommodated the help with pavement preservation datum, original performance data and maintenance history of Jiangsu Province, thanks are especially extended to Professor Gary Hicks for his revisions, edits and comments. The authors also appreciate the comments of the peer reviewers and editors.
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