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Effects of Maintenance Treatments on Asphalt Concrete Pavement Management

Study SD2001-03
Final Report

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16. Abstract

Today's state highway agencies (SHA) are faced with the challenge of maintaining the condition of their highway networks in an environment where funding levels are inadequate to address all of the pavement preservation needs identified. The use of preventive maintenance treatments is one example of a strategy that can be used to optimize the use of available funds. In order to demonstrate the effectiveness of preventive maintenance programs, it is important that the benefits, or effectiveness, of maintenance treatments be incorporated into the agency's pavement management activities. This research study was initiated to improve the integration of maintenance into the pavement management process by addressing the following issues.

- Determine whether the current pavement condition rating procedures are adequate to evaluate the impact of maintenance activities on the various condition indexes.
- Identify feasible condition levels that indicate when various maintenance treatments are viable candidates.
- Develop guidelines to model the impact of maintenance treatments on pavement conditions.
- Develop guidelines to establish feedback loops between maintenance, construction, and pavement management.

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1.0 EXECUTIVE SUMMARY

Today's state highway agencies (SHA) are faced with the challenge of maintaining the condition of their highway networks in an environment where funding levels are inadequate to address all of the pavement preservation needs identified. In light of this fact, agencies have adopted innovative approaches to improve the cost-effectiveness of the decisions being made to preserve the pavement network. The implementation of pavement management systems is one example of a tool that is being used by agency personnel to help identify their needs and optimize the use of available funds to address these needs. The implementation of preventive maintenance programs is another example of agencies trying to optimize the use of available funds. Preventive maintenance programs use a series of planned maintenance activities on pavements that are still in good condition in order to minimize overall life-cycle costs.

The South Dakota Department of Transportation (SDDOT) is striving to continuously improve the effectiveness of its pavement preservation decisions. In 1994, the Department implemented an enhanced pavement management system that is better able to analyze pavement condition information to recommend projects for inclusion in the state's Surface Transportation Improvement Program (STIP). The pavement management system includes pavement performance models that predict the future condition of pavement "families" (pavements with similar characteristics) for specified treatment triggers that indicate when a treatment is considered a viable strategy. Additionally, the pavement management system contains treatment reset values that provide an estimate of the conditions that will exist after a treatment is applied so that the long-term impacts of various programs can be evaluated. One of the benefits to the use of a pavement management system is the ease with which various rehabilitation scenarios can be programmed and analyzed so that agency personnel can determine the most cost-effective set of projects for the STIP.

At the same time, the SDDOT has been active in the use of preventive maintenance treatments as a way of improving the functional condition of the road network in a cost-effective manner. The SDDOT is finding, as are other states such as Michigan and California, that the use of preventive maintenance treatments is an effective means of retarding the deterioration of pavements and thereby delaying the need for rehabilitation actions. This is an important component of the management of assets within a state highway agency. However, preventive maintenance treatments are most effective when they are applied to pavements in relatively good condition as a preventive measure, rather than a reactive measure. Hence, the current mantra for preventive maintenance: use the right treatment, at the right time, on the right road.

Inherent in the use of preventive maintenance treatments is the use of those activities as part of a planned strategy for maintaining the road network at the lowest possible life cycle cost. Since decisions regarding the programming of maintenance activities are normally made at the Region and Area level in South Dakota, rather than in the Central Office as part of the pavement management analysis, there is not always a link between maintenance and rehabilitation planning activities. Further, there may be important differences in the timing of maintenance treatment applications, which have a significant impact on the potential service life of the treatment and the future need for rehabilitation. Complicating the issue even more is the fact that maintenance treatments that are applied by State forces are not directly reported to the Pavement Management Unit as feedback to enhance the analytical models.

Because of the issues described above, the SDDOT is sponsoring this research study to better incorporate chip seals, patching, and crack sealing into its pavement management system. A number of specific issues were addressed as part of this study, including the following.

- An assessment of the current pavement condition rating procedures to evaluate the impact maintenance activities have on the calculation of the various condition indices.

- The identification of feasible treatment triggers that identify when various maintenance treatments are feasible candidates to retard pavement deterioration and the incorporation of those trigger levels into the pavement management system.

- The development of reset values that can be used in the pavement management system to indicate the impact of maintenance treatments on pavement conditions so that the appropriate timing for rehabilitation can be determined.

- The development of guidelines to establish feedback loops between maintenance, construction, and pavement management so that maintenance and construction activities can be incorporated into the pavement management analysis.

The findings and conclusions from the study are summarized in this section of the report. More detailed information from the study can be found in the main body of the report.

1.1 Condition Ratings and Condition Indices

The SDDOT has been using a visual pavement distress survey to assess the condition of its road network since 1995. The manual pavement condition survey includes the identification of pavement distress type, severity, and extent and is based on the procedures outlined in the Strategic Highway Research Program (SHRP) *Distress Identification Manual for the Long-Term Pavement Performance Project* (SHRP 1993). The surveys are conducted by seasonal employees who rate pavement distress information on each 0.250-mile section of road. As part of the manual survey on flexible pavements, transverse cracking, fatigue cracking, patching, and block cracking quantity and severity are reported. In addition to the manual pavement condition surveys, rutting and roughness information are collected on flexible pavements using a South Dakota-type road profiler. For each of the distresses collected, individual condition indices are developed on a 0 to 5 scale, with points deducted from a perfect score of 5 if distresses are present. In addition to the calculation of the six individual distress indices for flexible roads, a composite index, SCI, is developed using the mean of the applicable individual indices and the standard deviation of the mean. In the near future, the

Department intends to collect the pavement distress information automatically using equipment purchased from Pathway Services, Inc.

During the conduct of the study, the research team identified several issues related to the existing distress survey procedures that were hindering the planning and programming of maintenance activities. For the Field Office personnel, the greatest concern regarded the rating of a maintenance patch that covered an entire 0.25 mile survey section section. Under the current procedures, the patch is considered an overlay so the patch itself is not rated but any distress that show through the patch are rated. As a result, not only is the current condition of the road somewhat overestimated (since the patch does not improve the structural integrity of the road), but future conditions are also overestimated.

Various solutions to this issue were investigated. The recommended solution is to have the raters rate the patch based on its condition and extent. Using this approach, a new patch that is in good condition (low severity) that covers the entire sample unit (extreme extent) would result in a patching index of 3.0, rather than the 5.0 rating that would have been given under the existing system. To assist the raters in differentiating maintenance patches and contract overlays, a recommendation to provide a list of contract overlays completed within the last 3 years is included. Guidelines for a quality control check are also provided to query the database for any section in which the condition indices increase by more than two times the standard deviation of the ratings and no contract overlay was flagged. This type of a check would allow the Pavement Management Unit to identify sections that could be verified as maintenance overlays and rated appropriately.

A change to the distress severity definitions for transverse cracking is also included in the recommendations for this project. The recommendation states that all sealed transverse cracks that do not have depressions be recorded as low-severity cracks. This change provides a measurable benefit to a crack sealing program by changing medium- and high-severity cracks to low severity.

Somewhat related to the issues that emerged in the survey procedures for patching is the calculation of the Patching Index and its relationship to the Fatigue Cracking Index. The research team recommends that these two indices be combined into one index that represents structural (or load-related) deterioration. To determine the feasibility of this idea, the APTech research team explored the differences in the deterioration curves for each index, the deduct values used to calculate the two indices, and the treatment rules applied to each index. The team found that the deduct points associated with the two indices are identical. Further, an examination of the treatment triggers and performance models for the two condition indices further support the feasibility of combining the two distresses into one index. Other combined indices are discussed in the report, but are not included in the final recommendations.

Several other issues related to the pavement condition survey and the calculation of condition indices were explored. With regard to the transition from a manual rating process to a process that includes the manual interpretation of distress from video images, some potential discrepancies in the rating of transverse cracking were identified since depression depth will be difficult to observe at a workstation. Other issues regarding the quality of the survey and the possible transition to a survey based on sampling are discussed. A recommendation to conduct a study to evaluate the impact of converting to a sampling-based survey is included.

1.2 Pavement Management Analysis Models

The study also included an investigation of the reasonableness of the current pavement management models, including the pavement performance models, the treatment triggers, and the reset values.

Performance Models

There were two aspects of pavement performance that were investigated during the conduct of this project. First, the APTech research team investigated whether any changes were necessary to the existing pavement performance families to better reflect the effect of maintenance treatments in the optimization analysis. Secondly, the research team investigated whether separate performance models were needed for pavements in each existing pavement family depending on whether maintenance was applied on a regular basis.

The investigation in this area quickly focuses on the performance of chip seals since crack sealing and patching activities are not tracked in the pavement management database (and there are no plans to begin tracking these treatments). The results of the study did not conclusively demonstrate either a significant difference or similarity in deterioration rates between pavements that had received a chip seal and those that had not. However, the research team found that the rate of deterioration after a chip seal has been applied is highest if the pavement sections are rated soon after a chip seal is applied. Immediately after the chip seal application, few distresses can be observed. However, within 1 or 2 years of the chip seal application, any original distress can be seen again so the pavement appears to have a higher rate of deterioration after the chip seal. For that reason, some recommendations were developed to better model this condition using chip seal flags in the pavement management database (similar to the overlay and mill and overlay flags). No new performance models were established for the chip sealed pavements, but a rule was developed that within 3 years of the chip seal application, the pavement condition will return to the condition prior to the chip seal. From that point on, the use of the shifted family modeling curve is recommended.

Treatment Triggers

The research team also investigated the reasonableness of the treatment trigger values for chip seals, patching, and crack sealing. The efforts in this area were to improve the Pavement Management Unit's modeling for budget purposes rather than the programming of maintenance activities, which was to remain in the hands of Field Office personnel.

The development of treatment triggers for chip seals is an important part of this research project. Comments from the Technical Panel indicated that management had a high interest in developing an improved approach to estimating the cost and standardizing the timing of chip seals. Field Office personnel also expressed an interest in obtaining a listing of candidate projects for chip seals based upon the pavement's age and condition. This listing would then serve as a basis for conducting field reviews to verify the suitability of the pavement for a chip seal. As with other maintenance treatments, the Field Office personnel are interested in retaining responsibility for programming chip seals.

Although no changes were recommended for the triggers that are currently being used to trigger crack sealing and patching, several changes were recommended for the chip seal triggers. First, a mechanism is recommended that differentiates in the database whether the first chip seal, the second chip seal, or a subsequent chip seal is being applied. Presently, all chip seals are simply denoted in the pavement management system by "S." Creating rehabilitation categories of S1, S2, and S3 would accomplish this item. Treatments S1 and S2 are used as a preventive maintenance treatment; S3 is most likely considered more of a stopgap maintenance activity.

Second, though a majority of chip seals are applied in year 3, to allow for the range of application years it is recommended that a treatment trigger for the first chip seal be established 2 to 5 years after rehabilitation. This period of time is more reflective of current practice in the state. Triggers for the second chip seal, which is normally scheduled approximately 5 years after the first chip seal, were recommended based on a time-based factor. However, since the pavement is aging by the time the second chip is placed, certain conditions have been flagged to indicate that a chip seal is not considered a viable treatment. A majority of the sections analyzed in this project meet the requirements for the second chip seal. The limitations on conditions vary slightly from those currently used by the SDDOT. The new values were determined based upon an examination of projects in the Yankton Area and were further refined during the meeting with field personnel in October 2001.

Field Office personnel felt that lower limits for many of the distresses should be lower than what the APTech team proposed. In particular, they indicated that the use of roughness (RUFF) should be eliminated as a trigger value. Instead, they supported its use in calculating the cost of a chip seal. They stated that since badly deteriorated or rough areas would be patched before the chip seal was applied, a better strategy was to increase the estimated cost of the chip seal to cover the increased patching costs. The Field Office personnel also recommended lowering the rutting index (RUT) for the second chip seal to 3.5 and 3.0 for the third chip seal.

Original analysis showed the limits for transverse cracking (TRCR) to be similar to the first chip seal with a value of 4.4 or greater. This limit was again based on restricting chip seals to pavements without high severity or medium severity, high extent transverse cracking. Field Office personnel stated that they would apply chip seals on pavements as long as they did not have high-severity transverse cracking. This would allow for a minimum transverse cracking index (TRCR) of 3.5.

Setting trigger values for the third chip seal was more difficult because the third chip may be used in a preventive manner or as a stopgap measure before resurfacing can be applied. For that reason, the period of time between the second and third chip seals may be shorter than the period between the first and second chip seals. As a result, the recommendation for the treatment trigger for the third chip is based on an age limit of 2 years as well as other condition criteria.

To assist the Field Office personnel in selecting pavement sections that are good candidates for chip seals, the Pavement Management Unit agreed to provide a listing of pavement sections that are triggered for chip seals using the treatment triggers in the pavement management system. As the chip seals are applied, the Field Offices would report completed chip seals to the Pavement Management Unit for input into the historical pavement management database.

Reset Values

Perhaps one of the "hottest" topics to emerge from this project is the establishment of reset values for maintenance treatments. The reset values used by the pavement management system have a significant influence on when subsequent treatments are considered in the analysis and should reflect actual conditions as much as possible. Several issues emerged with respect to this topic, including the resets assigned to a patch that covers an entire survey section and the resets for indices after chip seals are recommended for a section.

As discussed earlier, it is important that the benefits associated with a crack sealing program be recognized in the pavement management system. The reasoning for this is relatively simple. In the typical pavement management system, the benefit of each treatment considered in the analysis is reflected by the increase in area under the performance curve generated by the application of a treatment. The costs are calculated on a lineal foot- or square foot-basis. In most cases, the benefit associated with a treatment is caused by an increase in the condition index and/or a shifting of the performance model to reflect a slower rate of deterioration.

If there is no change in the condition index due to the application of a treatment, and there is no change in the performance model after the treatment has been applied, then there is no benefit calculated by the pavement management system for that treatment. If the selection of maintenance and repair projects in the pavement management system is based on a benefit-cost analysis, as exists in the SDDOT, then a treatment with no benefit will not be selected for inclusion in the program. If, on the other hand, the treatment is triggered on a cycle based on timing rather than selected by the benefit-cost analysis, then the lack of benefit will not impact the selection of the treatment in the program.

A second approach to address this issue is to set an absolute reset value for crack sealing in the models, which essentially accomplishes the same thing as recalculating an index based on a change of crack severities to low in a much simpler way. The disadvantage is that an equal reset value is applied to all pavement sections, regardless of the initial value of the transverse cracking index. It represents more of an average increase in condition rather than a section-specific increase in condition. This is the approach that is currently being used in the SDDOT pavement management system.

The usefulness of changing the approach to determine the reset value in South Dakota is debatable. At the present time, crack sealing is triggered based primarily on pavement age rules. However, the most important factor to consider is that the benefit-cost analysis is currently established in such a way that three different budget categories are used for asphalt treatments: a maintenance budget, a resurfacing budget, and a reconstruction budget. Both chip seals and crack seals are included in the maintenance budget. As a result, maintenance treatments are not competing with resurfacing treatments over the analysis period reducing the importance of this issue in the APTech research team's mind. Rather than recommend that the SDDOT develop a routine that would automatically calculate the reset value (based on re-evaluating medium- and high-severity cracks as low severity), the research team recommends a revision to the reset value currently being used. The recommendation included in chapter 6.0 is to set the reset value for transverse cracking at the higher of two values: either the actual rating from the field or a value of 4.5. This latter value of 4.5 is representative of a section with a high extent of low-severity cracks, a value considered a conservative estimate of conditions after a crack seal program has taken place.

Field Office personnel did take exception to the reset value recommendation for the transverse cracking index. They stated that if there were depressions present at the cracks, the chip seal would not improve this condition. While this is a valid point, the recommended trigger limits would not result in a chip seal recommendation on any pavement with a transverse cracking index less than 3.5. As long as the transverse cracking index is greater than 3.5, the depression present at the cracks cannot be greater than 0.25 inches, so the concern of the Field Office personnel may not be as significant as originally thought. The APTech research team recommends that reset values stand as presented in the October meetings.

Since patching is not a treatment included in the treatment set for the pavement management system, no reset values are established for this treatment. Hence, the research team did not explore treatment triggers or resets for patching.

In the current pavement management analysis, the application of a chip seal adds a total of 0.2 points to the transverse cracking, fatigue cracking, patching, and block cracking indices. No change is made to the rutting or roughness indices projected by the pavement management system. Based on a review of South Dakota data and discussions with Field Office personnel, the research team recommends that only the block cracking and transverse cracking indices be reset by the application of a chip seal. For the first chip seal, the reset would be to perfect condition, with a value of 5.0. For the second and third chip seals, the recommended reset values would be based on the higher of either the existing value before the chip seal application or a value based on low severity distress since the cracks would be sealed (block cracking equal to the higher of the actual index or 4.3; transverse cracking equal to the higher of the actual index or 4.5).

1.3 Coordinating and Exchanging Information

One of the benefits to arise from this project has been the opportunity to use the meetings with the Field Office personnel to facilitate the exchange of pavement management information between the Field Offices and the Pavement Management Unit. Based on questions that were asked of the APTech team members during the initial field meetings, there was a general lack of understanding about many aspects of the pavement management system, including how projects are being optimized. Additionally, the Field Office personnel were given an opportunity to participate in the development of recommendations for improving some of the ways maintenance treatments were represented in the pavement management system. This latter opportunity emerged when the Technical Panel approved the change to the scope of work that allowed the APTech research team to test the Train-the-Trainer materials during a series of three meetings around the state. These activities alone have gone a long way towards achieving the Department's objective to strengthen the coordination of information between the Field and Central offices.

One of the things that was emphasized during the Train-the-Trainer sessions was the importance of maintenance treatment information to support the pavement management analysis. If maintenance reports the application of maintenance chip seals then a chip seal flag would allow the Pavement Management Unit to use a different deterioration rate for the first three years after a chip seal had been applied. Similar exceptions are recommended for maintenance patches.

Similarly, the meetings led to a discussion of the value to the Field Office personnel of having the pavement management system print out a listing of pavement sections that would be good candidates for chip seals each year. The Field Office personnel would retain the authority to decide where the chip seals should be applied, but the list would assist them in section selection and familiarize them with the trigger limits that are used to determine feasible candidates in the pavement management analysis. As the Field Office personnel increase their understanding of the pavement management analysis, they will become a valuable resource to the Pavement Management Unit as they continue to update the treatment triggers, performance models, and other components of the pavement management analysis with time.

To share information on the state's pavement management system and implement findings from this research project, Train-the-Trainer course materials on pavement management are included as a project deliverable. The materials were tested on Field Office personnel in October 2001 and were well received by the participants. The course materials include Instructor's Guides and PowerPoint presentations that introduce the objectives of the pavement management system and walk the participant through each of the steps of a pavement management optimization analysis. Members of the Pavement Management Unit participated in the initial demonstration of the Train-the-Trainer course materials and offered suggestions to strengthen the materials. Their comments were incorporated into the final course materials. Regularly presenting these materials to Field Office personnel will help to familiarize new hires with the process as well as to reacquaint experienced personnel with the operation of the system.

One of the issues discussed at the meetings with Field Office personnel that cannot be directly addressed by the pavement management system concerns the trade-off between resurfacing and continued maintenance. The current SDDOT optimization approach weighs the benefit associated with various treatments on the additional performance realized and the traffic levels that will benefit from the treatment. As a result, there are a number of sections in South Dakota that are feasible candidates for resurfacing, but have traffic levels that keep them from being included in the resurfacing program. Instead, the Field Offices are forced to expend maintenance dollars on continued maintenance in order to keep them in serviceable condition. This strategy has a large impact on the maintenance budgets of Regions with lower volume pavements, since a larger proportion of their budget is potentially being spent on these types of needs rather than on preventive maintenance treatments. These stopgap maintenance applications do not fit the criteria for planned maintenance in the pavement management system, so an analysis of the true cost of deferring a resurfacing treatment may not be fully understood.

To address this dilemma, the APTech research team explored the idea of a Maintenance Needs Index (MNI) that would help the Department better understand the cost-effectiveness of maintenance expenditures and that could be used to assist in developing programming strategies. As a programming tool, the MNI could potentially be used to help prioritize treatment needs on low-volume roads, or it could be used to assist in shifting extra maintenance dollars to Regions with roads that are selected for continued maintenance rather than resurfacing (even though resurfacing was determined to be a viable alternative). This tool might also be helpful in estimating the agency's maintenance needs.

1.4 Conclusion

As a result of the work conducted during this project, the SDDOT will be better able to model the use of pavement preventive maintenance treatments in its pavement management system. The updated models will better reflect the maintenance practices being used by the Area and Region Offices throughout the state and the observed performance trends of preventive maintenance treatments such as chip seals. Additionally, through the training and meetings that were conducted during this project, the Field Office personnel have a better understanding of the planning activities that are conducted by the Pavement Management Unit. As a result, the interaction and coordination between the Central Office and Field Offices is likely to be enhanced.

2.0 PROBLEM DESCRIPTION

Today's state highway agencies (SHA) are faced with the challenge of maintaining the condition of their highway networks in an environment where funding levels are inadequate to address all of the pavement preservation needs identified. In light of this fact, agencies have adopted innovative approaches to improve the cost-effectiveness of the decisions being made to preserve the pavement network. The implementation of pavement management systems is one example of a tool that is being used by agency personnel to help identify their needs and optimize the use of available funds to address these needs. The implementation of preventive maintenance programs is another example of agencies trying to optimize the use of available funds. Preventive maintenance programs use a series of planned maintenance activities on pavements that are still in good condition in order to minimize overall life-cycle costs.

The South Dakota Department of Transportation (SDDOT) is striving to continuously improve the effectiveness of its pavement preservation decisions. In 1994, the Department implemented a pavement management system that is capable of analyzing pavement condition information to recommend projects for inclusion in the state's Surface Transportation Improvement Program (STIP). The pavement management system includes pavement performance models that predict the future condition of pavement "families" (pavements with similar characteristics) for specified treatment triggers that indicate when a treatment is considered a viable strategy. Additionally, the pavement management system contains treatment reset values that provide an estimate of the conditions that will exist after a treatment is applied so that the long-term impacts of various programs can be evaluated. One of the benefits to the use of a pavement management system is the ease with which various rehabilitation scenarios can be programmed and analyzed so that agency personnel can determine the most cost-effective set of projects for the STIP. Recent SDDOT research projects have enhanced the reliability of the pavement management models by developing improved pavement performance models based on historical condition information and improving the links between the analysis assumptions used in the pavement management system and those used by design personnel for pavement type selection.

At the same time, the SDDOT has been active in the use of preventive maintenance treatments as a way of improving the functional condition of the road network in a cost-effective manner. For instance, a recent SDDOT research study was aimed at developing guidelines to improve the performance of surface treatments on high volume/high speed asphalt pavements (Wade et al. 2001). An evaluation of current practices and initial indications from the test sites constructed for this project indicated that the performance of chip seals can be improved by adjustments to the aggregate gradation (such as using one-sized aggregate, limiting the amount of fines, and limiting the amount of flat, elongated particles), by adopting a formal design procedure for determining application rates, and by improving construction practices (such as adherence to roller speeds and more timely sweeping) (Wade et al. 2001). The SDDOT is finding, as are other states such as Michigan and California, that the use of preventive maintenance treatments is an effective means of retarding the deterioration of pavements and thereby delaying the need for rehabilitation actions. This is an important component of the management of assets within a state highway agency. However, preventive maintenance treatments are most effective when they are applied to pavements in relatively good condition as a preventive measure, rather than a reactive measure. Hence, the current mantra for preventive maintenance: use the right treatment, at the right time, on the right road.

In order to demonstrate the effectiveness of preventive maintenance programs, it is important that the benefits, or effectiveness, of maintenance treatments be measured. Based on the experience of Applied Pavement Technology, Inc. (APTech) personnel with the SDDOT's current visual condition rating survey procedures, there is little to no impact on the calculation of distress indices due to the application of maintenance activities such as crack sealing. For instance, the current procedures for rating pavement distress identify crack severity based on crack width. A low-severity transverse crack, for example, is defined as a crack less than ¼ inch wide or a routed and sealed crack less than ½ inch. A medium severity transverse crack is defined as a crack between ¼ inch and 1 inch in width and depressions of less than ¼ inch may or may not be present. Under the current rating system, if a pavement rating shows low-severity transverse cracking, there is no way to distinguish whether the cracks are sealed or unsealed. Similarly, a medium-severity crack could be a sealed ¾-inch crack or an unsealed ¾-inch crack. As a result, the Transverse Cracking Index that is calculated after a crack seal program has been applied may not reflect much of a change in the rating. The same is true of the Block Cracking Index, since severity definitions are based on the size of the blocks rather than the condition of the cracks. If this information were entered into the pavement management system, it would indicate that there is no benefit, or improvement, gained due to the application of crack sealing in terms of its effect on the Transverse Cracking or Block Cracking Indices. This is counterintuitive to what pavement engineers understand as an important technique for reducing moisture infiltration and preserving the pavement structure.

Inherent in the use of preventive maintenance treatments is the use of those activities as part of a planned strategy for maintaining the road network at the lowest possible life cycle cost. Efforts have been made within the SDDOT to better coordinate the life cycle cost assumptions made by designers with the preservation activities being recommended by the Pavement Management Unit as part of the STIP. Nevertheless, additional work is needed in the maintenance area since decisions regarding the programming of maintenance activities are normally made at the Region and Area level, rather than in the Central office as part of the pavement management analysis. As a result, there is not always a link between maintenance and rehabilitation activities. Further, there may be important differences in the timing of maintenance treatment applications, which have a significant impact on the potential service life of the treatment and the future need for rehabilitation. Complicating the issue even more is the fact that maintenance treatments that are applied are not directly reported to the Pavement Management Unit as feedback to enhance the analytical models.

Because of the issues described above, the SDDOT is sponsoring this research study. A number of specific issues will be addressed as part of this study, including the following.

- An assessment of the current pavement condition rating procedures to evaluate the impact maintenance activities have on the calculation of the various condition indices.
- The identification of feasible condition levels that identify when various maintenance treatments are feasible candidates to retard pavement deterioration (as opposed to keeping a pavement serviceable until rehabilitation can be applied), and the incorporation of those trigger levels into the pavement management system.
- The development of guidelines that can be used in the pavement management system to indicate the impact of maintenance treatments on pavement conditions so that the appropriate timing for rehabilitation can be determined.
- The development of guidelines to establish feedback loops between maintenance, construction, and pavement management so that maintenance and construction activities can be incorporated into the pavement management analysis.

This report summarizes the results of this research effort to improve the integration of maintenance into the pavement management process.

3.0 OBJECTIVES

The Request for Proposals (RFP) for this project identified three specific objectives to be achieved through the research effort. In this section of the report, each of the objectives is introduced and a summary of the extent to which each objective was accomplished is provided.

Objective 1: Include chip seals, patching, and crack sealing as treatments to be triggered in the SDDOT's pavement management system.

One of the primary outcomes of the project is the establishment of recommendations for adding maintenance treatments such as chip seals, patching, and crack sealing into the pavement management system. The RFP indicated that the recommendations were to include the following: treatment triggers that identified the appropriate time to consider the three maintenance treatments in the pavement management analysis, reset values that indicated the impact of the maintenance treatments on pavement conditions, and performance characteristics that reflected the slowed rate of deterioration expected after maintenance had been applied.

The Technical Panel made it clear to the research team that recommendations for patching and crack sealing triggers were only included in the study for the purpose of predicting overall future maintenance needs in the state rather than for identifying specific locations for patching to be programmed. Through improved models for triggering these treatments, the Pavement Management Unit hoped to better estimate both the level of funding needed for maintenance activities and the future pavement condition of the state's highway network.

The recommendations for treatment triggers were to be based on input from personnel from the Central Office and Field Offices as well as on information obtained from other SHAs. To facilitate this, meetings were held with field personnel throughout the state to discuss current maintenance practices and to determine the timing at which these treatments are being applied. During the project it was determined that the real emphasis of the study was the treatment triggers for chip seals rather than crack sealing and patching. Consequently, a concerted effort was made to improve the chip seal triggers and to determine the impact chip seals have on pavement performance. For instance, it was determined that the first chip seal is generally applied 3 to 5 years after a pavement is constructed or resurfaced. The second chip seal, if it is applied, is usually applied several years after the first chip seal. However, there is a discrepancy in the use of the third chip seal. In some cases, the third chip seal is used as a preventive measure on roads that are still in relatively good condition. More commonly, though, the third chip seal is used on roads with lower traffic volumes that are not receiving resurfacing funds due to budget constraints. In these situations, the chip seal is being applied to pavements in need of resurfacing so the expected performance is much different than that of the first or second chip seal. One of the recommendations from this study involves differentiating between the various chip seal applications so that these variations can be accounted for in the pavement management system.

Objective 2: Improve methods to evaluate applied maintenance treatments during the annual condition survey.

Incorporating the maintenance treatments into the pavement management analysis is only part of accounting for the effects of maintenance into the preservation activities of the SDDOT. While the pavement management system can simulate the impacts of maintenance for the development of future maintenance and rehabilitation programs, a concurrent activity must be initiated to ensure that the pavement condition rating procedures, and the subsequent calculation of condition indices, also reflect the impact of the maintenance treatment.

As part of this research effort, the APTech research team reviewed the existing pavement condition survey procedures and the calculation of the state's various asphalt concrete (AC) pavement condition indices to determine ways that the effects of chip seals, patching, and crack sealing could be more effectively considered. As discussed earlier in this report, one area that was investigated concerned methods to differentiate between sealed and unsealed cracks so that the benefits of a crack sealing program could be better determined. The work also involved a review of the guidelines that had been developed under research project SD1999-09 to determine whether any additional distress types should be added to the survey for better identifying chip seal candidates and an assessment of any changes that might be necessary as the Department transitions from its manual survey to a video-based survey procedure.

The highest priority that emerged during the project, however, was to investigate the way that maintenance patches were being rated during the survey. Field personnel brought this issue to the attention of the research team because the current rating procedures classify patches placed over an entire section as maintenance overlays. As a result, only distresses that show through the patches are rated and no deducts are assigned to the patches. Maintenance personnel disagreed with this procedure because they perceived that they were being penalized for applying maintenance patches to hold pavements in serviceable condition prior to resurfacing activities. The current procedures tended to artificially inflate the pavement condition ratings enough that a project would likely be bumped from the resurfacing list for several years. In reality, maintenance patches do nothing to improve the structural condition of a pavement, yet this was not reflected in the rating process. This issue is addressed in the project recommendations.

Objective 3: Recommend procedures for coordinating decisions made through the formal construction program and annual maintenance programming.

The final step in developing a comprehensive approach for considering the effects of maintenance includes the development of feedback loops that provide for the exchange of information at two levels: from the Pavement Management Unit to the Field Offices and from the Field Offices back to the pavement management system. At the first level, a process was needed to provide the Field Offices with information on pavement sections that might make good candidates for the chip seal program. This information would be needed early on in the programming cycle. At the second level, a process is needed to ensure that the Pavement Management Unit can flag pavement sections where maintenance patches and chip seals have been applied so that the pavement management database can reflect this information. The recommendations for this project assume that the information from the field is provided to the Pavement Management Unit for inclusion in the historical pavement management database.

A double check for this information has been included in the survey recommendations as a safety mechanism. This should help the Department better transition into the new reporting procedures.

One of the modifications to the project scope that was made during the conduct of the project was intended to help facilitate this exchange of information. The original project scope included a series of interviews of individuals from Field Offices across the state to solicit their feedback on the existing pavement management processes. As the interviews were being conducted, the research team provided some clarification on the way the pavement management system actually operated, which helped to dispel some myths that had existed. To further build on the positive momentum that was being generated, the project scope was modified slightly to include another series of meetings to introduce the initial recommendations for the project and to obtain the "buy-in" of the field personnel. The meetings also provided the research team with an opportunity to test the Train-the-Trainer materials that were developed. The Train-the-Trainer materials were designed so the Pavement Management Unit could use them for future networking opportunities with field personnel.

4.0 PROJECT TASKS

The Technical Panel for this project established a total of 12 tasks, which were intended to provide a framework for addressing the research objectives. The project tasks are listed here and are followed by a brief explanation of the accomplishments that were made during each task. In addition, this section of the report identifies the location of any further discussion of these topics in a later section of the report.

Task 1. Review and Summarize Literature Relevant to Incorporation of Maintenance Treatments (Chip Seals, Patches, and Crack Sealing) Within a Pavement Management System

The project work began with the conduct of a literature search to identify any relevant research work that would provide insight into the practices of other transportation agencies that have initiated efforts to integrate pavement maintenance into their pavement management systems. The literature search was conducted using resources available at the University of Illinois' Grainger Engineering Library. The Grainger Library has access to tens of thousands of technical journals and reports through the use of on-line databases, such as the Transportation Research Information Service (TRIS).

In addition to the materials that were identified through the TRIS search, the research team conducted informal phone interviews with individuals in several state highway agencies that have been working in this area over the last several years. The pavement management engineers in several states, including Montana, Utah, Minnesota, Indiana, Michigan, Nevada, New Hampshire, and Virginia (as well as other states), provided valuable information on how certain maintenance activities are accounted for in their pavement management systems. Although no one state had addressed maintenance activities to the extent that South Dakota intended, input from these States was helpful in developing some of the project recommendations and also served as a check on the reasonableness of some of the recommendations.

A third source of information was the SDDOT itself. Individuals from throughout the agency were helpful in providing reference reports and data from the pavement management database that documented existing practice. In addition, information from the Heron Region was provided to assist in tracking the performance of chip seal projects in that Region.

The results of the literature review are summarized in section 5.1 of this report. In addition, most of this information was presented to the Technical Panel during the kick-off meeting.

Task 2. Meet With the Technical Panel to Review Project Scope and Work Plan

A meeting between the research team and the SDDOT Technical Panel took place in Pierre, South Dakota on May 7, 2001. The meeting provided the Technical Panel an opportunity to further clarify the project scope by outlining the Panel's expectations for the project. During the discussions at this meeting it became very clear that certain priorities existed in the project objectives. For instance, the need to develop specific triggers for crack sealing and patching was identified as a low priority of the project, but triggers for chip seals were important. Also important were recommendations for addressing the impact the current patch ratings had on the program results. Similar types of priorities were established in other areas of the project objectives.

Based on the results of the meeting with the Technical Panel and the meetings described in Task 3, the scope of work for the project was modified slightly to reflect the priorities established and to provide an opportunity to test the Train-the-Trainer materials while simultaneously presenting the initial project recommendations. The results of the change are further discussed under Task 10. Minutes from the meeting were provided to the Technical Panel.

Task 3. Interview SDDOT Personnel From the Central Office and 12 Field Offices Involved With the Programming of Rehabilitation and Maintenance of Asphalt Concrete Pavements to Detail How Maintenance and Rehabilitation Decisions Are Made

On May 8 and 9, 2001, immediately following the meeting with the Technical Panel, the research team met with representatives from the Central Office and Field Offices to discuss the current procedures that were being used to program maintenance and rehabilitation activities, and also to identify the issues that arose during the process. To help facilitate the discussion, the APTech research team distributed questionnaires to the expected participants. The questionnaire asked the participants to document their existing practices, such as the identification of the timing for maintenance treatments to be applied. The survey results were summarized prior to the meetings and presented to the participants for verification.

Two separate meetings were held in Pierre and Huron to increase the number of participants. Representatives from the Rapid City and Pierre Regions were scheduled to attend the meeting in Pierre, although no representatives from Rapid City were able to participate. At the Huron meeting, representatives from both the Aberdeen and Mitchell Regions were present.

Several key observations were made at the meetings and summarized in the meeting minutes. Some of the points raised that had a significant influence on the outcome of this project are summarized here.

- Field personnel emphasized that they did not want to lose any freedom in selecting maintenance candidates as a result of this study. They were receptive to obtaining information from the pavement management system to assist them in determining the relative effectiveness of applying maintenance on various road sections.

- The existing procedures for rating long, maintenance patches were negatively impacting the timing of resurfacing activities because of the way the condition indices were being calculated.

- The timing of resurfacing activities was also negatively impacted on projects where maintenance had applied a second or third chip seal to "hold" things together until the resurfacing could be constructed. The pavement management system was overestimating the positive impact the chip seals had on badly deteriorated pavements.

- Field personnel had little confidence in the quality of the pavement condition surveys because seasonal employees were conducting them.

- Historically, maintenance has selected chip seals projects based on pavement age rather than condition ratings.

- First and second chip seals are generally applied as preventive maintenance treatments, but the third applications are generally applied because a pavement was not a high enough priority in the resurfacing program to be funded and something had to be done to the road to keep it in operational condition. In some cases, the same thing occurred with second chip seals, if they were not applied early enough in the pavement life cycle.

- There appeared to be a general lack of understanding of the operation of the state's pavement management system. The participants stated that they had been told the system "optimizes" the state's needs for a certain year and if it is not funded it was placed in a "backlog" category and no longer analyzed by the program. As a result, there were strong, negative connotations to the terms "optimized" and "backlog." The research team attempted to correct these misinterpretations at the meeting, and had an opportunity to further explain the analysis process during the meeting to test the Train-the-Trainer materials.

Task 4. Develop a Method for Incorporation the Effects on Pavement Performance Following Application of a Chip Seal, Patch, or Crack Sealing for Each Pavement Family Based on Historical Data

Originally, the research team envisioned that this task would involve the development of a process for incorporating the effects of chip seals, patching, and/or crack sealing into the pavement performance families used in the pavement management system for modeling pavement deterioration. After the meetings conducted during tasks 2 and 3, it became apparent that patching and crack sealing projects conducted by state maintenance forces would not be tracked in the pavement management history at this point in time. Without access to the historical information, the research team realized that patching and crack sealing could not reasonably be incorporated into the pavement family classifications. For this reason, the research team focused exclusively on chip seals during the conduct of the work for this task.

The work that was conducted during this task focused on whether or not the first two chip seals, which were being applied fairly uniformly across the state, were actually incorporated into the existing performance models or whether another set of family models needed to be developed. The latter recommendation would have resulted in a significant increase in the number of performance models that would have to be maintained in the pavement management system, which would have placed a strain on the Pavement Management Unit.

The research involved efforts to determine whether the existing pavement performance families had been developed based on the assumption that the first two chip seals were a typical maintenance activity performed on all flexible pavements (with the exception of interstates). This assumption seemed reasonable if one further assumed that without the application of the first two chip seals, the pavement would deteriorate much more rapidly than reflected in the existing performance models. In other words, the application of the first two chip seals could be considered a means of keeping the pavement on the family performance model, as shown in figure 4-1.

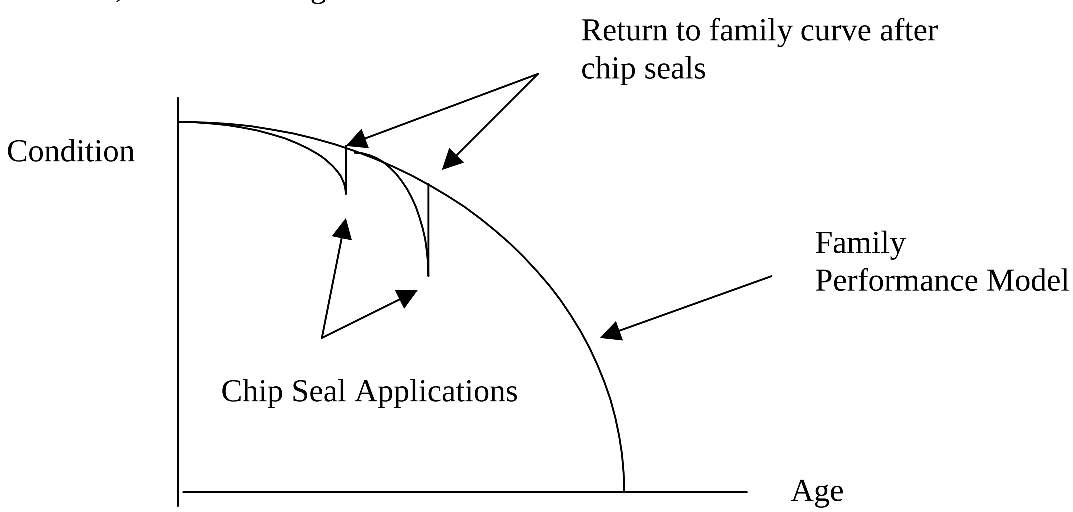


Figure 4-1. Influence of chip seals on family performance models.

Based on the data provided to test this assumption, the research team was not able to confirm its appropriateness. The observations that were made, and the conclusions that were drawn are discussed in more detail in section 5.3 of this report.

Task 5. Define Trigger Limits That Describe When Maintenance Treatments Are Likely to be Applied

As in the previous task, the scope for this task was revised slightly to eliminate patching from the list of maintenance treatments that would be triggered by the system since patching is most commonly used as a “stopgap” treatment rather than a planned activity. To accomplish the goals for this task, the research team reviewed the existing trigger limits that are used in the pavement management system to identify sections that are feasible candidates for crack sealing or chip seals. Based on the input provided by the SDDOT during the project meetings, recommendations were developed for improving the match between pavement management recommendations and actual field practice. Special emphasis was placed on age-based criteria for chip seals to reflect the actual practice of field personnel. The findings from this task are described in more detail in section 5.4 of this report.

Task 6. Determine the Effects of Maintenance Treatments on Existing Families of Pavement Performance Curves and/or Treatment Resets

In a pavement management system, the set of models must include “reset” values that provide a simulation of the performance characteristics that might be expected after the application of each treatment. In most systems, this includes identifying any changes to the condition indices (do they reset to a perfect score?) and performance models that reflect the deterioration patterns of pavements that have been treated. For this task, the research team reviewed the reset values that are currently incorporated into the pavement management system to determine whether any changes were necessary. For instance, in order to differentiate between the performance of a planned chip seal and a “stopgap” chip seal, a series of different reset values are recommended. Section 5.5 of this report describes the work conducted under this task.

Task 7. Investigate Methods Used by the Visual Distress Survey and Recommend Necessary Changes to the Collection of the Data

The data used by the pavement management system to develop improvement programs are, in part, based on the results of a pavement condition survey. For this reason, it is imperative that the survey procedures result in a process that is repeatable and fairly representative of existing pavement conditions. With this in mind, a task was included to recommend any changes to the existing visual distress survey that might enhance the incorporation of maintenance techniques.

The comments that arose in this area have been discussed earlier. The primary concern among field personnel was the procedure for rating full-length maintenance patches. Since no distress could be observed by the survey team immediately after the surveys were placed, these patches were being treated the same as a contract overlay in the analysis. The research team has included a recommendation that addresses this deficiency in the rating process.

Secondly, the research team reviewed the current distress types collected during the survey process to determine whether any additional distress should be included to better trigger a chip seal. Friction was not considered an option since the Department currently has no means of measuring friction and has no immediate plans for acquiring the necessary equipment. Based on the feedback from the field personnel, no additions were made to the distress collected.

Although not specifically outlined in the RFP, the research team also included an assessment of the current condition index calculations in the study. Included in the list of recommendations from this project is a recommendation to reduce the number of condition indices currently being used by combining several distresses together into one index. This recommendation would have a significant impact on reducing the number of performance models in the system.

In the next year or so, the SDDOT will likely be converting from the manual condition surveys that have been conducted since 1995 to the use of a video-equipped van to collect pavement surface information that can then be interpreted at a workstation. Throughout this task, the research team considered whether any additional changes were required to account for the change in rating procedures.

The results of this task are further discussed in section 5.2 of the report.

Task 8. Develop Procedures For Coordinating Decisions and Exchanging Information With the Formal Construction Program and Maintenance Programming

The final component of the integration of maintenance activities with pavement management is the development of feedback loops to link the pavement management recommendations to the individuals responsible for programming the activities and to ensure that the information from the field is provided to the Pavement Management Unit so that the historical database reflects actual practice. The resulting recommendations focus on providing reports to the field personnel that will assist them in identifying chip seal candidates and developing a process that assists the Pavement Management Unit in identifying when chip seals and maintenance overlays have been placed. The results of this task are further discussed in section 5.6.

Task 9. Produce Detailed Guidelines to Change Appropriate Sections of the SDDOT's Pavement Management System

The results from the previous tasks are incorporated into the detailed guidelines and recommendations that have been included in section 6.0 of this report. The recommendations and guidelines provide the basis for assisting the SDDOT with the incorporation of maintenance into its pavement management analysis.

Task 10. Prepare Materials and Conduct a Train-the-Trainer Course to the Technical Panel and Pavement Management Staff on the Overview of the Pavement Management System With an Emphasis on the Effect of Adding Maintenance Treatments

Since field personnel have a substantial role in the programming of both maintenance and resurfacing projects, it is important that they have a good understanding of the planning and programming activities that are conducted by the Central Office. In addition, to facilitate the exchange of information that must take place between the Central Office and the field personnel if the recommendations from this project are to be successful, the type of information needed by pavement management must be identified and understood. A training course is one way of exchanging this information to all of the involved personnel.

With that in mind, the Technical Panel for this project included a task to develop Train-the-Trainer course materials that could be used by the Pavement Management staff to train field personnel on the importance of including maintenance activities in the pavement management analysis. The course materials were to be presented to the Technical Panel and Pavement Management Staff prior to the conclusion of the project.

To strengthen the effectiveness of this project, a scope change was made to this task. The change provided an opportunity for the APTech research team to test the Train-the-Trainer materials in workshops that were delivered to the Region offices within the state. At the same time, these workshops provided the research team with an opportunity to conduct a field validation check of the draft recommendations that were developed. The Technical Panel supported this change and three workshops were held during the week of October 22, 2001. One meeting was held in Rapid City, one in Pierre, and one in Huron (for both the Mitchell and Aberdeen Regions). Overall, the meetings went a long way towards improving the Field Office personnel’s understanding of pavement management systems. The Pavement Management Unit also participated in the series of meetings so they not only had an opportunity to review the training materials, but also had the opportunity to strengthen their relationship with the field staff. A final session with the Technical Panel was conducted in conjunction with the SDDOT Research Review Board presentation at the end of the project. The materials for this task were delivered under separate cover.

Task 11. Prepare a Final Report and Executive Summary of the Literature Review, Research Methodology, Findings, Conclusions, and Recommendations

This report essentially completes the work that was required for this task.

Task 12. Make an Executive Presentation to the SDDOT Research Review Board at the Conclusion of the Project

An Executive Presentation to the SDDOT Research Review Board was made at the conclusion of this project in February 2002.

5.0 FINDINGS AND CONCLUSIONS

In this section of the report, significant findings and conclusions from the study are presented. Findings from each of the major areas of the study are documented separately, as shown in table 5-1. The implementation recommendations that were developed as a result of these findings are presented in chapter 6.

Table 5-1. Organization of chapter 5.

Report Section	**Topic Discussed**
5.1	Review of Current Practice
5.2	Visual Condition Survey and the Calculation of Condition Indices
5.3	Performance Models
5.4	Trigger Limits
5.5	Reset Values
5.6	Coordination and Exchange of Information

5.1 Review of Current Practice

The SDDOT is not unique in its desire to better integrate maintenance and rehabilitation activities into its pavement management efforts. During the last few years, a number of state agencies have adopted similar strategies to improve the cost-effectiveness of their pavement preservation activities; moreover, there has also been an increased focus on pavement preservation activities such as preventive maintenance. These programs promote the use of cost-effective treatments applied early in a pavement's life. Agencies that use a preventive maintenance approach speak of the extension to pavement life realized by applying maintenance treatments on the right road at the proper time. Other benefits can include one or more of the following (Peshkin et al. 1999):

- Higher customer satisfaction.
- Better informed decisions.
- Improved strategies and techniques.
- Improved pavement condition.
- Cost savings.
- Increased safety.

The use of pavement management systems to support pavement preservation efforts is well documented (Peshkin et al. 1999). Pavement management systems provide the analytical tools that can be used to compare a pavement preservation strategy that triggers the worst roads first to another strategy that incorporates the appropriate use of maintenance treatments as a technique to extend a pavement's serviceable life.

The current status of pavement management systems that incorporate maintenance treatments into the analysis spans a spectrum of experiences. For example, the Arizona Department of Transportation (ADOT) is currently in the process of modifying its pavement management practices to incorporate maintenance effects. Due to limitations of its existing pavement management programs, it appears that the state will have to acquire new pavement management software in order to accomplish its goal. Nationally, ADOT is considered a leader in evaluating maintenance effects; having established several maintenance test sites to evaluate the performance of certain maintenance activities used in pavement preservation programs.

Other state highway agencies are also working to accommodate maintenance in their pavement management systems. For example, the New York State Department of Transportation (NYSDOT) initiated efforts several years ago to incorporate crack sealing into its pavement management activities. More recently, Wisconsin has done some work to determine the effectiveness of crack sealing on asphalt concrete (AC) pavements in the state.

One of the challenges to incorporating maintenance into pavement management efforts is the lack of coordination between the individuals responsible for programming maintenance activities and those working in pavement management. This shortcoming has been recognized and many SHA as now working to close this gap. For example, as part of its Pavement Quality Partnership program, Massachusetts started an initiative to bring together the key players in pavement performance (design, materials, maintenance, utilities, and construction) in a partnering effort aimed at improving pavement performance in Massachusetts and improving communication across departmental boundaries.

Based on information provided by the Federal Highway Administration’s (FHWA’s) Office of Asset Management for a presentation made at the First European Pavement Management Conference held in 2000 (Zimmerman and Botelho 2000), over half of the states reported that preventive maintenance activities (such as thin overlays and surface treatments) are integrated into their pavement management activities, as shown in figure 5-1. The figure also indicates that several states reported that this activity is under development, while several indicated that preventive maintenance is not included. As shown in figure 5-2, surface treatments are a common maintenance activity included for asphalt concrete roads (Zimmerman and Botelho 2000). Other treatments such as patching and crack sealing may be categorized under “Other Treatments” in this figure.

One of the factors considered during this study involved the identification of the conditions under which chip seals, patching, and crack sealing on asphalt roads are appropriate treatments to consider. Typically, the treatment selection process is based on the condition of the pavement. Two of the most common tools for aiding in the process of selecting treatments are decision trees and decision matrices. An example of a decision tree that incorporates chip seals and crack sealing is shown in figure 5-3. An example of a decision matrix that incorporates single course surface treatments, such as chip seals, is shown in table 5-2. More examples of these tools and their use are found in Hicks et al. (2000).

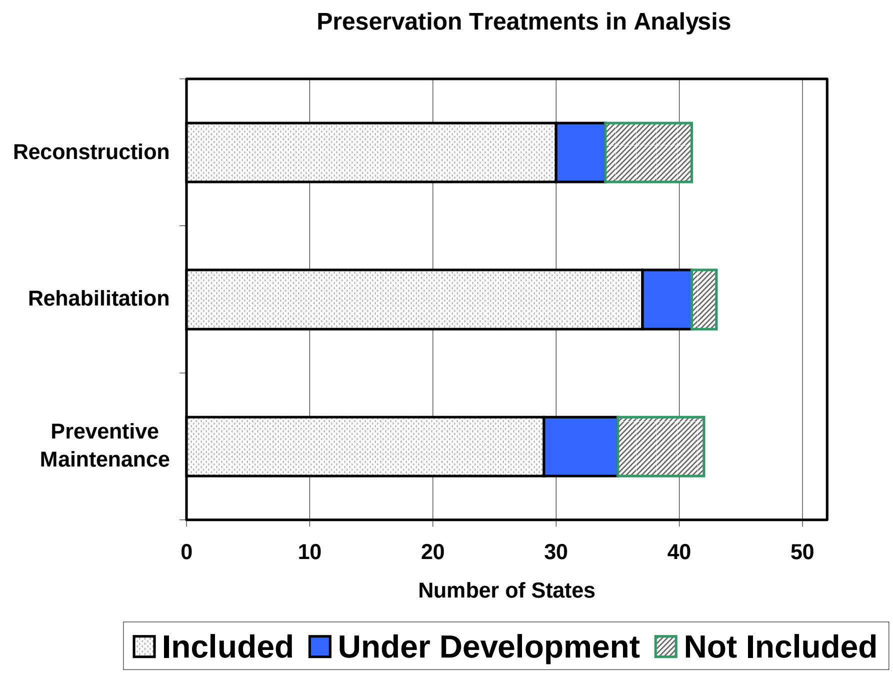


Figure 5-1. Category of treatments included in pavement management (Zimmerman and Botelho 2000).

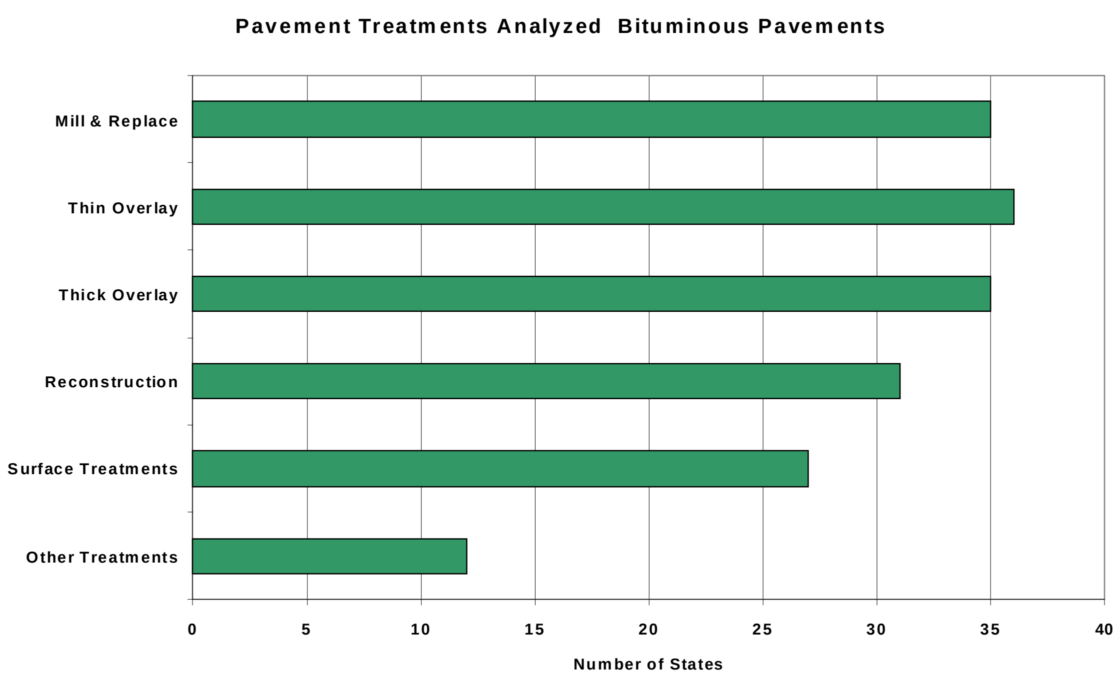
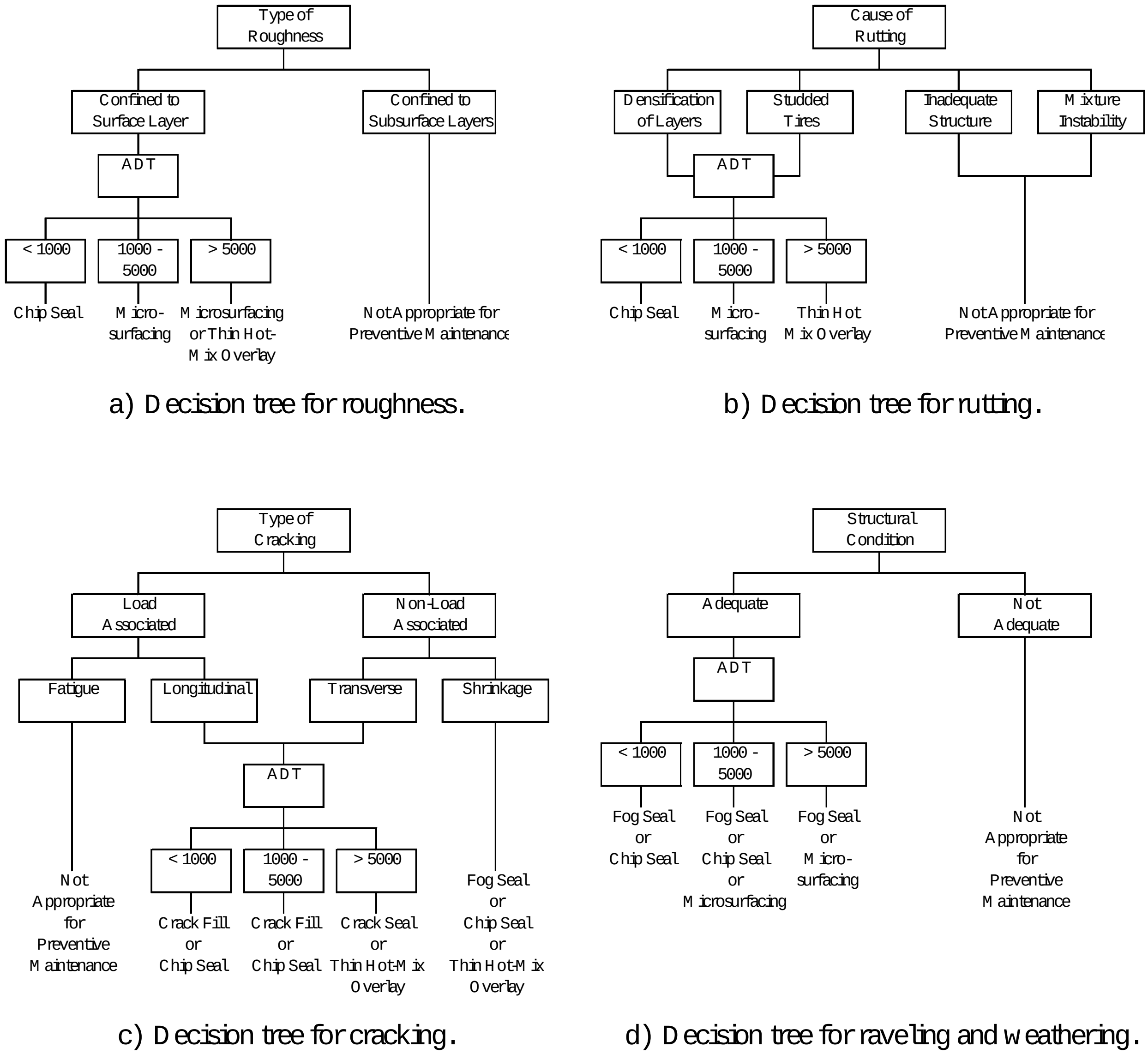


Figure 5-2. Types of treatments considered on asphalt concrete pavements (Zimmerman and Botelho 2000).



a) Decision tree for roughness.

b) Decision tree for rutting.

c) Decision tree for cracking.

d) Decision tree for raveling and weathering.

Figure 5-3. Example decision trees for preventive maintenance considering roughness, rutting, cracking, and raveling/weathering (Hicks et al. 1997).

Starting with the pavement condition and using either a decision tree or matrix often results in the identification of more than one appropriate treatment. These are termed “feasible” treatments, and a more comprehensive evaluation process is used to select the treatment to apply from among the list of feasible treatments. Hicks et al. (2000) describe a selection process in which the following attributes are considered:

- Performance attributes: these include the treatment’s expected life, the effect of the existing pavement condition on performance, the effect of the treatment on the pavement condition, the effect of the climate, and the cost effectiveness of the treatment.

- Constructibility attributes: these include the availability of skilled contractors and suitable materials, and environmental constraints on the placement of the treatments.

- Customer satisfaction attributes: these include traffic disruption, noise impacts, surface friction, and ride quality.

Table 5-2. Alternative preventive maintenance treatments and the conditions for their use by New York State DOT (NYSDOT 1999).

Pavement Maintenance Treatment	Conditions for Use					
	Traffic Criteria		Maximum Pavement Distress Guide*			
	AADT	Trucks	Cracking Severity	Raveling Severity	Rutting Severity	Drop-Off Severity
Single Course Surface Treatment	Less Than 2000	Low – Moderate	Low	Low	Low	—
Quick-Set Slurry	Low Volume	Low – Moderate	Low	Low	Low	—
Micro-Surfacing	No Restriction	No Restriction	Low	Low	Medium	—
Paver Placed Surface Treatment	No Restriction	No Restriction	Low	Low	Medium	—
Hot-Mix Asphalt Overlay (40 mm)	No Restriction	No Restriction	Low	Infrequent	Medium	Medium
Cold Milling with Non-Structural HMA Inlay	No Restriction	No Restriction	Low to Medium	Medium	Medium	Medium
Cold In-Place Recycling (CIPR) with Non Structural HMA Inlay	Less Than 4000	Less Than 10%	Medium	High	High	High

*Note: All treatments (with the exception of CIPR with Non-Structural HMA Inlay) assume infrequent corrugations, settlements, heaves, or slippage cracks.

During the conduct of this project, the focus of the work on determining treatment triggers was concentrated on performance attributes exclusively.

Another consideration that was taken into account during this study was the importance of appropriate timing of maintenance treatments. Figure 5-4 illustrates the concept of identifying the appropriate type of treatment at different stages of a pavement life cycle. Using pavement management to model the effects of maintenance, the appropriate timing for the use of maintenance treatments can be determined.

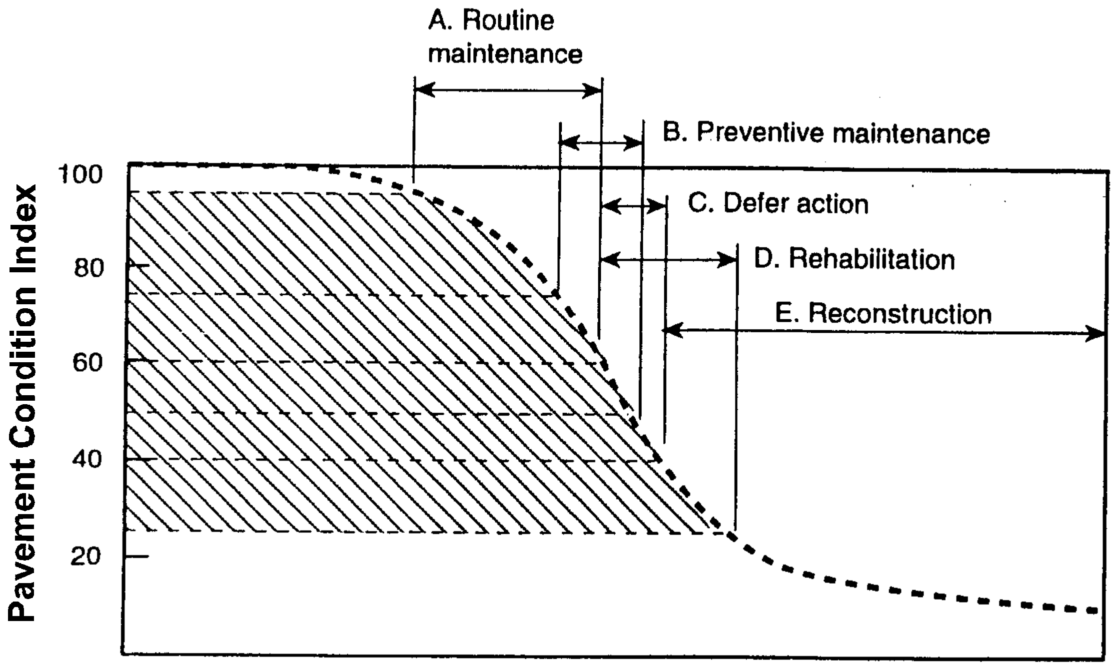


Figure 5-4. Conceptual relationship for timing of various M&R treatments (Cornell 1995).

Determining an appropriate treatment is inextricably linked to the timing of the placement of that treatment since the same treatment performs differently when applied at different times (or conditions) in the life of the pavement. Place the right treatment at the right time, and the maintenance treatment is by definition, cost effective; miss the best timing and the treatment as applied is no longer the best solution.

Studies that document the optimal timing of maintenance treatments also exist, although they are somewhat limited. One study evaluated various application timings of seal coats (including chip and sand seals) to demonstrate the cost-effectiveness of maintenance treatments (Al-Mansour and Sinha 1994). The results of the analysis were evaluated in terms of a comparison of agency costs, user costs, and total costs. It found that to achieve maximum user cost savings at either high or low traffic levels; the seal coat activities could not be postponed beyond a PSI value of 3.0. It further found that if the application of seal coats was deferred, the best strategy in terms of user costs was to conduct annual, routine maintenance until the end of the pavement section's life rather than apply any seal coats. When total uniform annual agency costs were combined with user costs, the study found that when seal coating was performed at or before the pavement reached a PSI of 3.0, the most cost-effective strategy was the application of three consecutive chip seals with routine maintenance. If the seal coat application was deferred under this scenario, the most cost-effective strategy included basic routine maintenance with one chip seal.

Several state highway agencies provided information that was very useful in developing the recommendations and guidelines for this project. In some cases, the information was useful in checking the reasonableness of the proposed recommendations. In all cases, the discussions with state pavement management practitioners confirmed that no state has been able to fully address the integration of maintenance activities into their pavement management system. Several neighboring states, and one midwestern state, can be used to illustrate these points.

5.1.1 Utah Department of Transportation

Just two years ago, the Utah Department of Transportation (UDOT) went through a process to update the analysis models in its pavement management system to better account for factors contributing to pavement deterioration. As part of the process, new pavement condition indices were developed, along with new pavement deterioration models and treatment rules. The process they followed is documented in the literature (Neeley et al. 2001).

Included in the development of their treatment rules for asphalt pavements were treatment rules for surface rejuvenation and surface seals (chip seals, slurry seals, fog seals, and open graded friction courses). Routine maintenance activities such as crack sealing and patching were not included in the pavement management models. Trigger values for surface rejuvenation were based entirely on age and no reset values were developed. For surface treatments, the following types of distress were identified as being important trigger factors to consider in determining the feasibility of surface seals.

- Environmental cracking (including both longitudinal and transverse cracking).
- Fatigue cracking (load-related cracking in the wheelpath).
- Raveling.
- Rutting.
- Ride.

Although raveling was identified as a key factor in determining the applicability of a surface seal, Utah did not develop a condition index for that distress. As a result, it was not used in developing the treatment triggers for surface seals. Interestingly, treatment triggers for this particular treatment were not set for either rutting or ride. In other words, the Department assumed that surface seals were feasible treatments regardless of the rutting or ride index values.

In general, Utah's treatment triggers for surface seals apply to pavements in good condition (between 70 and 90 on a 100-point scale) but it allows for a wider application range on lower volume roads (55 to 90). This is similar to South Dakota's use of surface treatments on low volume roads that are not included in the resurfacing program. The state's life cycle cost cycle shows surface seals being applied on a 6-year cycle following resurfacing for interstates and low volume roads. High volume roads are sealed on an 8-year cycle.

In addition to setting treatment triggers, the Utah DOT also established reset values for the various treatments that are included in their pavement management analysis. For surface seals, the environmental cracking index was reset to 100 after the application of the treatment in the analysis. No change was made to the wheelpath cracking index to reflect the lack of structural improvement provided by surface treatments. Similarly, no change was made to

Utah's ride index or Years to Fatigue Failure index. A relative increase was recommended to the rut index following the application of a surface seal. The recommendation from the team developing the models was to increase the rut index by 10 points, regardless of the value at the time the treatment was triggered.

In addition to establishing reset values for the condition indices, the team developed rules that indicated how future performance should be modeled after the application of the various treatments. No changes to the performance model were recommended for the wheelpath crack index, the rut index, the ride index, or the Years to Fatigue Failure curve. The only change was to the environmental cracking performance model. The recommendations indicate that although the cracking index is reset to 100, the group felt that within 4 years the condition would be back to the original condition before the treatment was applied. This recommendation reflects a higher rate of deterioration after the application of the surface seal, which is indicative of the fact that cracking patterns are observable shortly after the sealcoat has been applied.

5.1.2 Montana Department of Transportation

The Maintenance Division of the Montana Department of Transportation (MDT) identifies and programs projects for both preventive and reactive maintenance on an annual basis. This process involves two steps, both of which are performed by Central Office staff. First, candidates for maintenance treatments are identified using the state's pavement management system. Then, projects are selected from the list of candidate projects in accordance with the funding levels available for maintenance activities. The Maintenance Division is also responsible for identifying the projects that will be contracted out and those that will be done by state maintenance forces. The projects are then administered by each of the eleven field Maintenance Divisions.

For this project, the most relevant aspects of the maintenance programming involve the use of the pavement management system for programming maintenance activities. Information was provided by MDT to better familiarize the APTech team with the process (MDT Pavement Analysis and Research 2000).

The MDT collects pavement condition information using two different rating procedures. Visual condition surveys are performed by employees who identify the distresses located in the first 200 feet of each mile, in the direction of increasing mile markers. In addition, information is obtained from a South Dakota-type Road Profiler to collect pavement rut and ride information. Using the information obtained from these surveys, five condition indices are calculated, as shown below.

- Ride index
- Rut index
- Alligator cracking index
- Miscellaneous cracking index
- Overall performance index (OPI)

The ride index is calculated using the International Roughness Index (IRI) in inches per mile and converting it to a 0 to 100 scale. The other indices are also rated on a 0 to 100 scale, with rut measurements taken every foot and then averaged over 0.1-mile sections. Cracking information is used to calculate either the alligator cracking index or the miscellaneous cracking index, depending on whether the cracking is load-related or not. The OPI is calculated by combining the other indices according to weighting factors. The OPI is similar to South Dakota's Composite Index (SCI) since it is used to report the overall network conditions and is used in the prioritization analysis. MDT is somewhat unique in that it also reports a Structural Capacity Index (SCI) that is calculated from data collected and analyzed by the Non-Destructive Testing (NDT) Unit. The condition indices are calculated for each data sample and averaged over the management sections used in pavement management.

As with most pavement management systems, decision trees are used to identify feasible treatments for each management section in the analysis. In addition to condition variables, traffic, system functional classification, and pavement type/structure are used to determine feasible treatments. Besides determining rehabilitation treatment needs, the MDT analysis also determines when crack seals and/or crack seals with seal coats are appropriate treatments. The crack sealing treatment is selected if a sufficient quantity of cracking is evident; however, the crack seal with a seal coat is selected if the pavement has a sufficient amount of cracking and is of an age that warrants a seal coat. Although not listed in the report, individuals in Montana say that there are also chip seal decision trees that trigger chip seals based on friction levels.

To determine the program each year, MDT runs the pavement management system for the entire pavement network by identifying first all of the maintenance needs (run 1) and then the capital improvement needs (run 2). The maintenance needs for each of the Divisions in the state and are then totaled to determine the total maintenance need for the state. Based on the distribution of need within each Division to the total state need, maintenance funds are allocated to each of the Divisions. Divisions then have the latitude to select the projects they want from the list of eligible projects. Guidelines are provided to assist the maintenance personnel in selecting the appropriate treatment.

5.1.3 Minnesota Department of Transportation

The Minnesota Department of Transportation (Mn/DOT) is in the process of trying to integrate preventive maintenance treatments into its pavement management system. The Department has successfully incorporated some preventive maintenance treatments into its decision trees, but has not been able to incorporate the change in performance characteristics due to maintenance into its pavement performance models. Instead, one curve is used to represent the performance of all preventive maintenance treatments. Mn/DOT intends to study the performance of its preventive maintenance treatments in the next year or so. Mn/DOT is at a slight advantage in that individual performance models are developed for a section if three to five survey points are available. The default models built into the system are only used on sections that do not meet this criterion.

Minnesota uses three indices to rate pavement characteristics: a Pavement Serviceability Rating (PSR), a Surface Rating (SR), and a composite index called the Pavement Quality Index (PQI). The PSR is an indicator of smoothness and the SR is a distress index. A number of different maintenance treatments are considered in the analysis, including chip seals, microsurfacing, crack seals, crack repair, and rut filling. Rather than reset the condition indices after crack sealing is applied in the analysis, the Minnesota system calculates the change in deduct points associated with the application of a treatment. Using the change in deduct points, the condition index after treatment is calculated. For instance, cracks that are medium or high severity before a crack-sealing program are reduce to low severity after crack sealing has been selected for the program. After a chip seal, the SR index increases back to a perfect score of 4 in the pavement management analysis. The PSR does not change for either crack sealing or chip seals. Patching is not included as a treatment but is counted as a distress type in the pavement condition survey.

Minnesota's process for distributing preventive maintenance funds is similar to the process used by Montana. All pavement sections that could benefit from preventive maintenance are identified and the ratio of the District's need to the total statewide need is used to distribute the available funding. District personnel are not required to use the treatment recommended by the pavement management system, but the decision trees provided by pavement management help the maintenance personnel determine when certain treatments are appropriate. The Central Office signs off on the treatments recommended by District personnel. It took Mn/DOT approximately 2 years to develop this system. Previously, the Central Office provided the Districts with the list of projects for programming. Today, the Central Office merely provides an indication of the funding levels that should be spent on preventive maintenance.

The decision trees used by Mn/DOT are fairly extensive, with a total of 25 treatments for bituminous pavements alone (Mn/DOT 2001). The decision tree user starts by evaluating whether a pavement has a good ride or bad ride. From there, the tree begins to branch based on whether the ride value is accompanied by a good SR rating or a bad SR rating. In general, treatments such as crack sealing and chip seals are applied to pavements with a good ride and a good SR value. Higher volume roads (> 10,000 AADT) tend to be recommended for microsurfacing rather than chip seals in the current decision trees. Table 5-3 summarizes the trigger values that are used to distinguish between the good and bad ride and SR values (on a 0 to 4 scale). The trigger values differ based on functional classification and rural/urban classifications.

Figure 5-5 summarizes a portion of the Mn/DOT decision trees for bituminous pavements to reflect one of the branches of the decision tree that leads to the selection of crack sealing and chip sealing as a treatment option. This example illustrates only one branch of a decision tree and is not intended to be all-inclusive (the full decision tree is considered too voluminous for this report).

Table 5-3. Trigger values for bituminous pavements (Mn/DOT 2001).

Pavement Classification	PSR	SR
Rural Principal Interstate	3.0	2.7
Rural Principal Arterial	3.0	2.7
Rural Minor Arterial	2.8	2.5
Rural Major Collector	2.8	2.5
Rural Minor Collector	2.8	2.5
Rural Local	2.7	2.4
Urban Interstate	3.1	2.7
Urban Principal Arterial Freeway	3.1	2.7
Urban Principal Arterial	2.8	2.5
Urban Minor Arterial	2.7	2.4
Urban Collector	2.6	2.4
Urban Local	2.5	2.4

1. Is PSR > Trigger value? If yes, continue.
2. Is SR > Trigger value? If yes, continue.
3. Is there any load-related cracking? If no, continue.
4. Is rutting > 10%? If no, continue.
5. Is there any severe transverse cracking? If yes, perform crack sealing. If no, continue.
6. Is the slight + medium transverse cracking > 25%? If yes, go to 7. If no, go to 8.
7. Is Age > 5 years? If yes, select chip seal for pavements with AADT < 10,000. Select Microsurfacing for pavements with AADT > 10,000. If no, go to 9.
8. Is Age > 8 years? If yes, select chip seal for pavements with AADT < 10,000 and Microsurfacing for pavements with AADT > 10,000. If no, go to 10.
9. Is Last Rehab = Crack Seal or Crack Repair? If yes, do nothing. If no, go to 11.
10. Is Age > 2 years and Last Rehab = Overlay or Reconstruction? If no, do nothing. If yes, crack seal.
11. Is longitudinal cracking > 10%? If no, do crack sealing. If yes, select chip seal for pavements with AADT < 10,000 and Microsurfacing for pavements with AADT > 10,000.

Figure 5-5. Sample decisions leading to the selection of crack sealing or chip seals in Mn/DOT's pavement management system (Mn/Dot 2001).

5.1.4 Indiana Department of Transportation

The Indiana Department of Transportation (InDOT) recently began conceptualizing the integration of preventive maintenance into a pavement management analysis and the results are documented in a paper submitted for presentation at the January 2002 Transportation Research Board (TRB) Annual Meeting (Weaver and Piane 2002). The analysis was primarily established to demonstrate the effectiveness of preventive maintenance treatments and to help InDOT establish its budget for preventive maintenance.

A limited number of treatments were considered in the analysis, which focused only on Interstate pavements. In addition to the traditional rehabilitation treatments, crack sealing, mill and inlays, and thin surface treatments were considered for asphalt-surfaced pavements. InDOT typically conducts crack sealing using in-house forces but other maintenance activities are conducted under contract.

Indiana uses pavement roughness, distress, and rutting as the main indices for reporting pavement condition, modeling pavement deterioration, and identifying feasible treatments. Roughness is reported in terms of the IRI and summarized on a per-mile basis. Distress data are used to calculate a Pavement Condition Rating (PCR). The PCR is calculated using a deduct system, with deducts subtracted from a high score of 100. Distresses are collected in the first 500 feet of each mile in the system. Distress are measured from a videotape of the pavement surface and converted into severity and extent to determine the PCR value. Rutting is collected in conjunction with roughness and reported in terms of an open-ended rutting index that increases in value as rut depth increases.

Treatment trigger values were established for each of the preventive maintenance treatments. Crack sealing was triggered on a 3-year cycle rather than on a condition-based cycle. To model deterioration, it was assumed that the number of cracks increases by 10 to 20 percent for each 3-year cycle. In other words, if there were “X” number of cracks in the first 3-year cycle, the number of cracks in the second 3-year cycle was estimated to be “X+20 percent.”

Thin surface treatments were triggered based on the three performance indicators: ride, surface condition, and rutting. If any of the three ratings fell within the thresholds for this treatment, a surface treatment was triggered in the analysis. No information was provided to document the performance models or reset values that were utilized in the analysis.

The example is presented because InDOT uses the same pavement management software as the SDDOT. To demonstrate the effectiveness of preventive maintenance, InDOT chose to use the treatment strategy option available in dTIMS so that a series of treatments could be evaluated instead of evaluating each treatment individually. The APTech research team felt this was an interesting application of the pavement management software that would allow an agency to compare the effectiveness of various age-based cycles for crack sealing and chip sealing.

5.1.5 Nevada Department of Transportation

The Nevada Department of Transportation (NDOT) has recently adopted a time-based approach for triggering resurfacing and preventive maintenance applications. NDOT currently has a backlog of resurfacing and reconstruction projects amounting to $337 million (NDOT 2001). In order to reduce the backlog and maintain the network of pavements that NDOT manages, NDOT has adopted the program shown in table 5-4. For NDOT’s moderate and higher volume routes, its strategy revolves around constructing an adequate pavement, performing adequate maintenance, and applying overlays prior to a high concentration of distress.

Table 5-4. Repair strategy determination for moderate- to high-volume routes based on pavement age in years (NDOT 2001).

Route (by Functional Classification)	Pavement Type	Preventive Maintenance	Corrective Maintenance	Overlay	Reconstruct
Principal Arterials - Interstate	Asphalt	≤ 4	> 4, < 8	8	> 8
	Concrete	≤ 10	> 10, < 18	N/A	≥ 18
Principal Arterials - Non-Interstate	N/A	≤ 4	> 4, < 10	10	> 10
Minor Arterials	N/A	≤ 4	> 4, < 12	12	> 12
Major Collectors	N/A	≤ 4	> 4, < 15	15	> 15
Minor Collectors & Local	N/A	≤ 4	> 4, < 20	20	> 20

5.2 Visual Condition Survey and the Calculation of Condition Indices

The SDDOT has been using a visual pavement distress survey to assess the condition of its road network since 1995. The survey includes the identification of pavement distress type, severity, and extent and is based on the procedures outlined in the Strategic Highway Research Program (SHRP) *Distress Identification Manual for the Long-Term Pavement Performance Project* (SHRP 1993). The surveys are conducted by seasonal employees who rate pavement distress information on each 0.250-mile section of road. As part of the survey on flexible pavements, transverse cracking, fatigue cracking, patching, and block cracking quantity and severity are reported. The severity and extent classifications for each distress type are provided in the SDDOT *Visual Distress Survey Manual* (SDDOT 2001).

In addition to the manual pavement condition surveys, rutting and roughness information are collected on flexible pavements using a South Dakota-type road profiler. For each of the distresses collected, individual condition indices are developed on a 0 to 5 scale, with points deducted from a perfect score of 5 if distresses are present. The deduct values for each distress are documented in a reference by SDDOT (2000).

After each individual 0.250-mile section is rated, the sections are then aggregated into analysis units. Analysis units vary in length depending upon their location and the original construction sequence. As a general rule the segments are shorter in urban areas and much longer in the rural portion of the state. The average analysis segment is a little less than 3 miles long. The six distress indices are then computed for the analysis segment based on the weighted average of values for each of the six indices. In addition to the calculation of the six individual distress indices for flexible roads, a composite index, SCI, is developed using the mean of the applicable individual indices and the standard deviation of the mean. The calculation of the composite index is also documented in a reference by SDDOT (2000).

The SDDOT is taking steps to modify its current survey procedures to enable them to collect the pavement distress information using automated equipment that has been purchased from Pathway Services, Inc. The Department's plan is to run the Pathway vehicle over each road in the pavement network to automatically record rutting and roughness on flexible roads while also digitally video recording the pavement surface. The video will then be viewed at a workstation where raters will identify distress type, severity, and extent in accordance with the same procedures that are now being used in the field.

During the conduct of this project, there were several specific areas that the APTech research team focused on:

- Issues Concerning the Existing Visual Distress Survey Procedures
- The Calculation of Condition Indices
- Other Issues in This Area

Each of these areas is listed below and described in more detail in a subsection of this portion of the report. The findings and observations from this topic area are incorporated into the recommendations and guidelines presented in the next chapter.

5.2.1 Issues Concerning the Existing Distress Survey Procedures

Patching

During the meetings with the Technical Panel and the Field Office personnel, several issues emerged concerning the current visual distress survey procedures. The greatest concern existed in the current procedures for rating a patch, especially maintenance overlays (also known as a skin patches) that cover the entire length of the inspection section. Participants in the meeting reported that skin patches are usually placed to keep a road section in serviceable condition until a more substantial treatment, such as resurfacing, can be applied. During the rating process, these patches are examined by the raters in accordance with the *Visual Distress Survey Manual* (SDDOT 2001), as shown in figures 5-6 and 5-7. Figure 5-6 illustrates two possible field scenarios; one in which the patch is only a small part of the 0.25-mile section and another where a more substantial area is patched, but the total area is less than half of the section area. In both instances, the patches are rated according to the condition of the patch and the amount of area that is covered. No problems were reported with these two scenarios.

Figure 5-7 reflects scenarios 3 and 4. In scenario 3, more than half of the section area is patched. Under this scenario, the raters rate the condition of the patch but also rate the individual distress that show through the patch. In other words, the procedure recognizes that the patch itself is a distress, but the other distress in the pavement section still exist and should be counted towards the section's deteriorated condition.

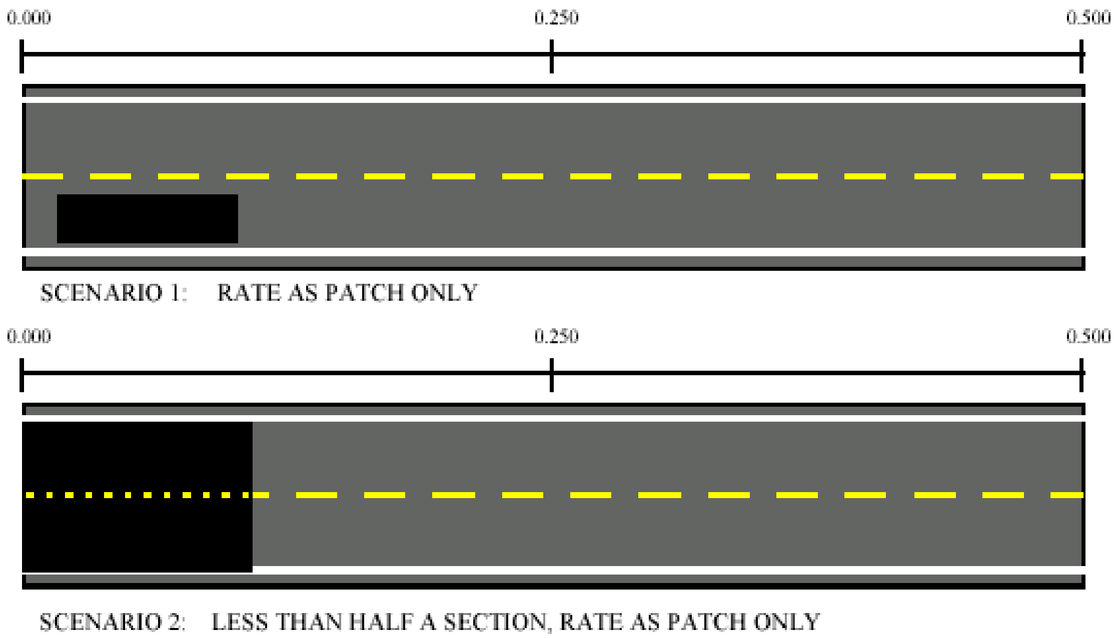


Figure 5-6. Patch scenarios 1 and 2.

In scenario 4, the entire section is patched. Under these conditions, the raters are instructed to rate the distress that show through the patch, but they do not also rate the condition of the patch. As a result, the raters report the patch index as a perfect score of 5.0. Additionally, immediately after a maintenance patch has been applied, no surface distresses are visible so the road section is rated in the same condition as a newly constructed road. The problems arise when the Field Office personnel patch a poorly performing section when a resurfacing project is needed. During the summer, the rating crews rate the pavement in near perfect condition and when the program is run through the pavement management system, the project falls out of consideration for resurfacing. Since a maintenance patch does nothing to address the structural integrity of the pavement, treating it in the same manner as an overlay or resurfacing treatment led to problems in the analysis.

An example of this analysis situation is shown in figures 5-8 and 5-9. In this example, the reported fatigue cracking indices are plotted over time in figure 5-8. The patch deterioration index over time is reflected in figure 5-9. All ratings prior to 1995 should be ignored since the survey approach only began being used in 1995.

During the timeframe from 1995 to 1997, it is fairly clear that the section experienced some fatigue cracking since the fatigue cracking index dropped from a value of 5.0 to a 2.0. A rating of a 2.0 is reflective of a high extent of medium-severity fatigue cracking or a moderate extent of high-severity fatigue cracking. At the point the fatigue cracking index dropped below a value of 3.5 (as represented by the dashed horizontal line) it became a candidate for the resurfacing program.

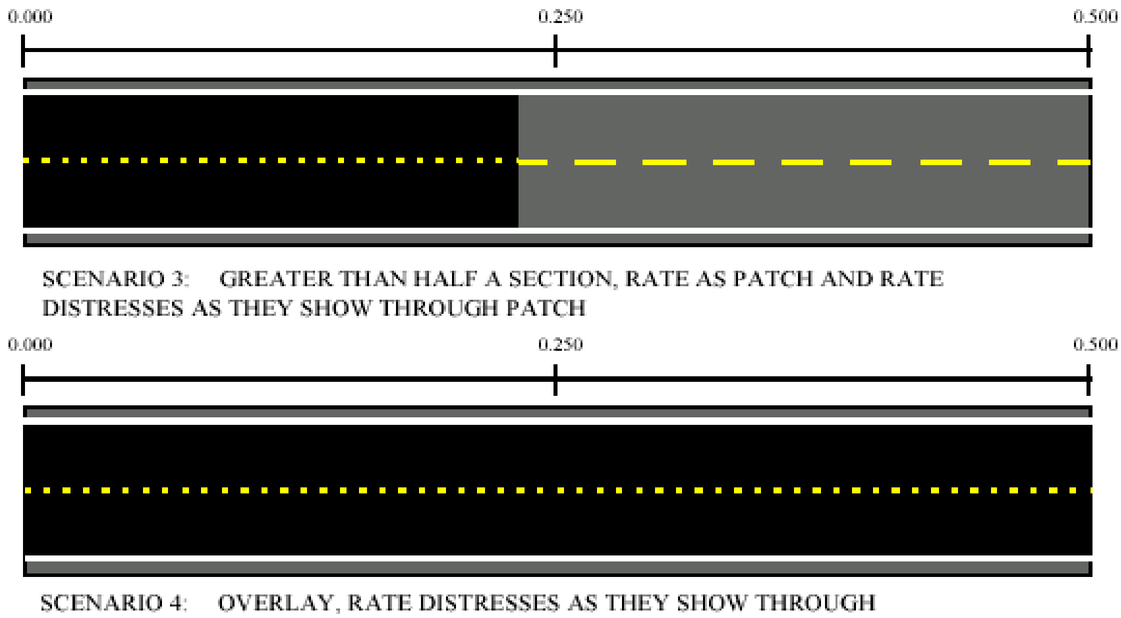


Figure 5-7. Patch scenarios 3 and 4.

A similar review of the patching index shows that in 1997 some patching occurred, as reflected in the decrease in the patching index (it further indicates that the entire section was not patched or the rating would have stayed at a 5.0). At the same time, a corresponding jump in the fatigue cracking index can be seen. As a result, in 1998 and 1999 both the fatigue cracking index and the patching index are above the criterion for the resurfacing program. Although not shown, if the deterioration curves for each section had been overlaid on the graph it would be apparent that the predicted conditions are not reflective of the rapid return of the fatigue cracking soon after the patch was applied.

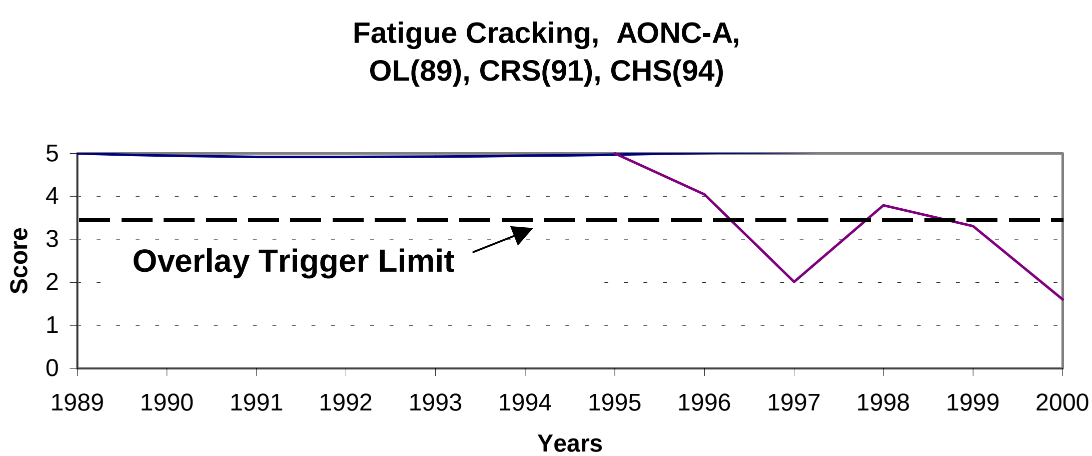


Figure 5-8. Fatigue cracking index over time.

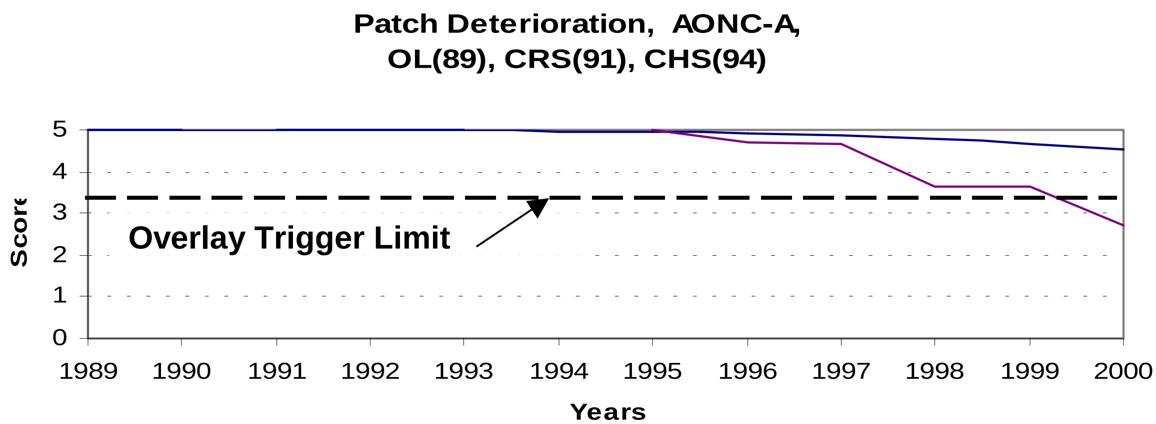


Figure 5-9. Patching index over time.

Other states have recognized similar problems in their rating system. The Texas DOT (Stampley 2002) reported to the APTech research team that it utilizes a rule that the patch must be at least 500 feet in length before being considered an overlay. Even though this is considered an overlay no flag is set for the pavement section identifying it as such. Full width patches less than 500 feet in length are treated as a patch.

Representatives of Washington DOT (WSDOT), on the other hand, stated that they have a 0.5-mile length limit before classifying a treatment as an overlay (Sivaneswaran 2002). Raters are trained to identify patches by the methods used to taper the new pavement into the existing. Raters are also given a list of paving projects completed in the last 3 years. In the past, maintenance was restricted from lengthy patches for financial reasons, but presently they are constructing 2-mile long chip seal patches. Maintenance supplies a listing of the patches and why they were constructed. For example, if the patch was placed to improve friction then it is not counted as a patch by the PMS. Conversely, if the patch was placed due to fatigue cracking then it is rated as a patch. If no reason is supplied by maintenance for placing the patch, then once again it is listed as a patch and appropriate deducts are calculated. WSDOT has a significant deduct in their system for patching. The implementation of this system by the WSDOT has resulted in better acceptance of the PMS and its recommendations from field personnel.

The implication of the rating assigned to a pavement with a maintenance patch is far reaching. Not only is the current condition of the road somewhat overestimated, but the future conditions are also overestimated. One solution to the problem of the raters assigning a high rating to a survey section is to have the raters alter their rating procedure in some way. For example, the rater could consult the previous year’s rating before a section is rated to check if the section has greatly improved from the previous year. The concern with this is that this information may bias the rating of that section. To maintain the integrity of the system, it is important that these types of exceptions not be incorporated into the process, and the raters should be consistent in rating what they see in the field. To help with this, a flag could be inserted into the pavement management system (similar to an overlay flag) on projects that have received a maintenance overlay to trigger a more rapid rate of deterioration than that of an overlay. Then, during the pavement survey, the patch itself would be rated based on its severity level and extent should be rated as extreme, resulting in a patching index of 3.0 or less. Additionally, any distresses that are observed through the patch should also be rated as is done under the other scenarios.

To implement this strategy there are two alternatives to consider. First, field personnel could annually report where maintenance overlays had been placed. Pavement Management could then incorporate this information into the rating forms provided to the rating teams. For patches applied in the spring or summer, a box on the rating form would be available for the rater to indicate a patched section. The second alternative is to provide the raters with a list of all contract overlays completed in the last 3 years. When the raters come upon a section of pavement that appeared fairly new, they would check the contract overlay listing. If the section did not appear on the listing it would be assumed to be a maintenance patch and the appropriate box on the rating form would be checked.

Due to the amount of paperwork involved in instituting the first option, the latter option appears a more implementable solution. A quality control check could then be implemented to check for sections that have had increases in the distress indices that exceed two times the standard deviation of the ratings and no contract overlay was flagged. This type of a check would allow the Pavement Management Unit to identify sections that could be verified as maintenance overlays and rated appropriately.

Transverse Cracking

A second consideration in modifying the existing rating procedures is to change the definition of low-severity transverse cracking to include all sealed cracks. In the current rating procedure, a low-severity crack is reported if the crack width is less than ¼-inch or if a crack that is less than ½-inch wide has been routed and sealed. All other cracks are reported as medium- or high-severity cracks. Under the existing approach, a pavement section will likely have the same transverse cracking index whether or not it has been crack sealed, since only sealed cracks that are less than ½-inch in width are considered low severity. Although this is not a significant issue in the condition rating procedure itself, and is of minor importance to the Field Offices, it has implications in the pavement management analysis if crack sealing is included as one of the treatments that is triggered in the pavement management system and competes with other treatments on a benefit-cost basis. This issue is further discussed in section 5.5.1, Crack Sealing Resets, of this report. The importance of the change to the rating procedure is to better match practices in other states, to address a minor omission in the rating process itself, and to incorporate into the rating process a method for easily assessing the value of a crack seal program. The Field Office personnel were not entirely supportive of this recommendation since crack sealing programs do not eliminate depressions at cracks. The ability to measure the depression at transverse cracks may become more of an issue as the use of video ratings is introduced. This topic will be discussed in further detail later in this report.

Longitudinal Cracking

When this project began, the SDDOT pavement condition rating procedure did not include longitudinal cracking as one of the distress types collected on flexible pavements. During the summer of 2001, a change was made to incorporate longitudinal cracking into the severity descriptions for block cracking. As the distress description for block cracking currently reads, random longitudinal cracks between the wheel paths or interconnected transverse and longitudinal cracks that form blocks greater than 6 feet per side are considered low-severity block cracks. No differentiation is made for the severity of the longitudinal cracks in the existing descriptions.

The APTech research team found that a number of states, including Virginia and Montana, use a composite cracking index that includes some combination of the following distress types: transverse cracking, longitudinal cracking (non-wheelpath), reflection cracking, and block cracking.

Although the change to incorporate longitudinal cracking into the survey procedure is appropriate, the better fit is likely with transverse cracking. However, the current method of rating transverse cracking (based on crack spacing) does not easily allow the incorporation of longitudinal cracking into the existing distress definition. But, longitudinal cracking does not fit well with block cracking either, in that respect, because the extent of block cracking is based on area rather than linear feet.

The advantage of linking longitudinal cracking with transverse cracking is that the severity level of the crack can be incorporated into the rating procedure. Severity level descriptions similar to those for transverse cracking are appropriate. Changes to the condition index that would be associated to this change in procedures are discussed in the next section of the report.

Incorporating Other Distress Types into the Procedure

During the past 2 years, the SDDOT sponsored a research project that resulted in the development of guidelines for improving the performance of chip seals within the state (Wade et al. 2001). One of the products of the research study was a table that outlined guidelines for the use of chip seals on various types of pavements within the state. The APTech research team reviewed the guidelines to determine whether any additional distresses should be added to the survey procedures to better assist in triggering chip seals as a preventive maintenance activity.

The guidelines included in the draft Final Report for the chip seal project listed the following distresses as significant factors in determining the use of an appropriate surface treatment. These distresses, shown in order of importance to identifying the appropriate treatment, are listed below:

- Rutting
- Bleeding
- Roughness
- Cracking
- Poor surface friction
- Raveling
- Oxidation

Several of the distresses listed, including rutting, roughness, and cracking, are already included in the SDDOT survey procedures. Surface friction is not likely to be collected in the near future since the Department currently owns no working equipment for measuring friction and repairs on the existing equipment do not appear to be a high priority. As a result, only bleeding, raveling, and oxidation remain as possible considerations to be added to the pavement condition survey procedures. In order to determine whether any of these distresses should be added, the APTech research team evaluated the way chip seals are triggered in the existing pavement management system.

It is important to distinguish that the pavement management system is using treatment triggers to determine whether a pavement section is a candidate for a chip seal. It is not using treatment triggers to distinguish whether a chip seal or a scrub seal is the better choice for a particular section. With this in mind, it does not appear that either raveling or oxidation is needed in the rating procedure. Raveling is most valuable for distinguishing between the type of surface treatment to be used and oxidation can be approximated through an age calculation.

Bleeding, on the other hand, is probably a little more significant in determining the appropriateness of a chip seal on a pavement section. Bleeding is included in a number of statewide pavement condition surveys, but is not a major trigger for treatment decisions. In Georgia, the maximum number of deduct points associated with bleeding or flushing is 15 points (on a 100-point scale) for areas with more than 30 percent of the area covered in high severity. Virginia also records the presence of bleeding, but includes it in its non-load related index. Delaminations, which could include raveling, are also incorporated into the non-load related index for Virginia.

Based on these findings, and the fact that chip seals are predominantly triggered on age criteria in South Dakota, it is not a high priority to add bleeding (or any other distress) to the survey procedure to trigger chip seals. However, if the SDDOT elects to develop composite indices (as discussed in the next section of the report), then bleeding could easily be incorporated into the index so it is available for triggering chip seals in the future.

5.2.2 The Calculation of Condition Indices

Patching Index

Somewhat related to the discussion of how patching should be rated in the field is the recognition of the link between patching and other distress. In several pavement condition survey procedures, alligator cracking and patching are combined into one structural distress index. Handled in this way, the presence of the distress causes the index to drop in value but when a patch replaces the distress, there is no discontinuity in the overall rating. This importance of rating the patch as a distress is discussed in the Virginia DOT's rating manual (McGhee 1998) for ratings conducted using video images. In it, the following discussion is included.

> *Raters should be especially cautious about surface patching of asphalt pavements. The color change between the asphalt concrete and the patch may be so subtle that this type of patching is often missed in the pavement view but is usually visible in the forward view. Because skin patching almost always covers a serious distress it is important that every effort be made to detect its presence so the rater should carefully scan the forward view for upcoming patching. The number of surface patches and square feet of surface patching for the section should be reported.*

For this reason, the APTech research team investigated the feasibility of combining the fatigue cracking index and the patching index into one index that represents structural (or load-related) deterioration. To determine the feasibility of this idea, the APTech research team explored the differences in the deterioration curves for each index, the deduct values used to calculate the two indices, and the treatment rules applied to each index.

The team found that the deduct points associated with the two indices are identical, so the SDDOT currently considers the two distresses equivalent. In practice, the SDDOT could continue to use the existing deduct model but change the distress category to fatigue cracking and/or patching. Using this approach, if the example provided earlier in figures 5-8 and 5-9 had been reflective of a pavement section with a high extent of medium-severity fatigue cracking immediately prior to the patching, the rating after the patch had been applied would have been similar to the prior value. Assuming that no distress showed through the patch after it was applied in 1998, the rater would have likely rated the section with a high extent of low-severity fatigue cracking and patching. Instead of a section with two ratings (a fatigue cracking index of 3.9 and patching index of 3.7), the section would have a load-related index of 3.6. The difference in the ratings would be even more dramatic in a section that had been patched over the entire section, where both the patching index and the fatigue cracking index would have been reset to 5.0 under the current procedures. Under the proposed approach, the section would have been rated as an extreme patch with low severity. The deduct points associated with that combination would have rated that section no higher than a 3.0 so the pavement section would have remained eligible for an overlay in the resurfacing program.

An examination of the treatment triggers for the two condition indices further support the feasibility of combining the two distresses into one index. For flexible pavements, there are very few situations in which only one of the two indices is used to trigger a treatment. Specifically, this occurs for Mill and Overlay triggers on Full Depth, Rural Thick, and Urban AC pavement families as well as for Process-In-Place (PIP) Recycling on Full Depth pavement families. All other treatments are triggered by either the fatigue cracking index or the patching index and the same value is used for either. This includes PIP on Rural Thick, Rural Thin, and Blotter Roads as well as Overlay triggers for Rural AC, Rural Thin, Blotter, and Urban AC pavements.

The final item involves the performance models for each of the indices. The APTech research team found that for the 15 family combinations that utilize these indices (5 families with 3 flags each) there were a total of 4 instances where the models were nearly identical (less than 1 year difference in terminal age), 6 instances where the differences were between 2 and 6 years, and 5 instances where the difference in terminal age was more than 6 years. Although this appears to be a substantial difference, it is likely that some of the differences reflect the inherent variability that is expected when combining vastly different conditions in the same family.

This approach is further supported in the literature. Based on the condition survey manuals available to the APTech research team, a total of 13 states utilize a load-related condition index rather than separate fatigue cracking and patching indices. Several states also incorporate rutting into the index. An additional benefit that would be realized by combining these two distresses into one index is the reduction in pavement performance models that would occur. Instead of having separate fatigue cracking and patching curves for each family, a combined deterioration model would be developed, somewhat simplifying the maintenance of the pavement management system.

Other Combined Indices

When the SDDOT initiated development of its pavement management system, the trend in pavement condition ratings was to develop individual indices for each distress type that was an important part of the treatment selection process. This trend represented a deviation from the prior practice in which multiple distress were combined into a single composite index, such as the Pavement Condition Index (PCI) developed by the Corps of Engineers. The change was instituted because pavement management engineers were concerned that a composite index tended to mask individual problems that were important in identifying treatment needs. For instance, a pavement section that had rutting, but no other distress, might have a fairly high rating that wouldn’t necessarily indicate the need for rut filling. By keeping the rutting index separate, the need for a rut treatment is obvious. On the negative side, the use of individual indices increased the complexity of pavement management systems because performance curves, treatment rules, and treatment resets were needed for each of the various indices that were used.

Recently, however, pavement management practitioners have somewhat modified their approach to the use of individual indices. Now, instead of having six to eight indices for each pavement type, agencies are reducing the number to three or four indices by combining certain distress types together. As discussed earlier, several states have developed a load-related index that is a combination of fatigue cracking, patching, and possibly rutting (although the APTech research team prefers keeping rutting separate). This change is being made in an attempt to simplify the pavement management analysis somewhat and to recognize that certain distresses trigger very similar treatments. South Dakota's treatment triggers and distress deducts for fatigue cracking and patching are excellent examples of the types of distresses that could be combined with little to no negative impact on the system.

There are other examples of combined indices that South Dakota could consider. It was mentioned previously that several states have combined distresses to form a non-load related cracking index that might include transverse cracking, longitudinal cracking (non-wheelpath), reflection cracking, and block cracking. Longitudinal and transverse cracking could easily be grouped together into a longitudinal and transverse (L&T) cracking index or longitudinal, transverse, and block cracking could possibly be combined into a non-load related cracking index. Additionally, bleeding could be added to a composite index if it becomes more important in triggering chip seal projects. Since a study of the impact of these changes was not included in the scope of this project, a recommendation was not made to institute the changes. However, the APTech research team did recommend the combination of fatigue cracking and patching as first step in this direction, while also eliminating one of the major complaints with the system from the Field Office personnel's point of view.

5.2.3 Other Issues in This Area

In the near future, the SDDOT will be transitioning from a manual rating process to a process that includes the manual interpretation of distress from video images. There may be some discrepancies in the data obtained from the new rating process and the Department seeks to minimize the impact of these changes as much as possible. The change in procedures provides the Department with an excellent opportunity to make other changes to the rating process, should that be necessary.

The Commonwealth of Virginia recently went through a similar change and used that opportunity to revise its rating process and condition indices. Virginia's distress manual (McGhee 1998) lists several differences in procedures when the survey process changed to include the interpretation of video images. For instance, the *Guide* states that with a manual survey a rater can directly measure crack widths in the field. However, at a workstation, crack widths can only be estimated. Therefore, distress interpretation procedures were developed in Virginia to focus more on qualitative issues in distress interpretation rather than the quantitative approaches that were used in earlier references.

Based on the work of the research team, and the experience of the APTech team members doing condition ratings at workstations, the only concern with the conversion to a workstation-based rating is with transverse cracking. Presently, SDDOT determines the severity of transverse cracking based upon the crack width and the depth of the depression at the crack. The width of cracks can be estimated on the video screen but the rater will not be able to determine the depth of the depression on a two-dimensional video screen. This may force a modification to the severity ratings for transverse cracking in the near future.

That said, the APTech research team encourages the SDDOT to take steps to ensure the quality of the distress data regardless of the manner in which it is collected. The recommendations that emerge from the pavement management system are largely dependent on the quality of the data collected during the pavement condition surveys. As an agency, the SDDOT made some decisions early on in its pavement management process regarding the balance between reliability, affordability, and appropriateness of the data that have governed the conduct of the ratings to this point in time. Decisions were made to use seasonal staff to conduct the surveys and to perform continuous surveys rather than use a sampling technique. With the upcoming changes in the rating procedure, it is an opportunity for the Department to evaluate the balance between these three factors.

For instance, there are a number of options available to the Department when the distress surveys can be conducted at workstations. Some of the options involve the number and type of personnel who are responsible for performing the surveys. Some examples of state practices are provided below to illustrate the point.

- Several states contract directly with the provider of the data collection equipment to conduct the surveys and deliver a data file containing the distress information at the end of the contract period. This is most common among agencies that lease the data collection equipment rather than own it. Indiana, Oklahoma, and Virginia are all examples of states that use this procedure. This approach is not a sure-fire solution to ensure the quality of the distress interpretation because the state has little control over the training of the raters or the delivery schedule of the contractor. A quality assurance program by the agency is vital to ensure that quality data is accepted and input into the pavement management system.
- In Illinois, where the equipment is state-owned, the state has placed workstations in each of the Districts as well as in the Central Office. The Districts are responsible for rating the condition of the non-Interstate network. One District rater and one Central Office rater rate the condition of the Interstates in each District together. This provides the Districts an opportunity to rate their pavement network, but requires adequate staffing levels to ensure that the work is done on a timely basis.
- Applied Pavement Technology, Inc. (APTech) has conducted several pavement condition surveys using the same type of equipment that South Dakota acquired. The first time APTech conducted this type of survey for its clients, in-house engineers were responsible for the distress interpretation. To put it mildly, the job was repetitive and boring. During the last round of surveys APTech conducted in this manner, summer engineering interns were trained to conduct the surveys and a QC/QA program was put in place. Every day during the first few weeks of their work, APTech's engineers reviewed the interns' ratings to evaluate accuracy and consistency. After several weeks, a QC/QA check was performed on a weekly basis from that point on until the job was completed. The process proved to be very effective.

There are several keys to ensure the quality of the distress identification process. First, the distress interpretation procedures should be clear and rules should be established that outline in detail how certain activities will be conducted. Secondly, the raters should be trained and tested to ensure consistency in the ratings conducted by each rater. Additionally, schedules should be developed for the raters that prevent any one rater from spending more than one-half a day at the workstation, with breaks every 2 hours at a minimum. This increases the number of raters that must be hired, or lengthens the period of time over which the ratings will be conducted, but helps prevent the raters from being fatigued and ineffective. Finally, a strong QC/QA process should be established to check the ratings regularly and help ensure that the raters are following the rating rules consistently. The advantage of conducting the ratings at workstations in the office, rather than in the field, is that any questions on distress calls can be quickly resolved by the pavement management staff.

It is also time for the Department to revisit its decision to continue the use of continuous surveys rather than implement a sampling process. The initial decision to use a continuous survey can easily be justified. However, the Department now has several years of data available that would allow it to conduct a separate research study to compare the reliability between the continuous survey currently being conducted and a sample survey process. If the Department finds that there is a strong correlation between the two data sets, then the Department could move to a sampling process with confidence in the ratings. If the correlation does not exist, then the Department could be confident that it was pursuing the path that provides it with the greatest probability of quality data.

5.3 Performance Models

There were two aspects of pavement performance that were investigated during the conduct of this project. First, the APTech research team investigated whether any changes were necessary to the existing pavement performance families to better reflect the effect of maintenance treatments in the optimization analysis. Secondly, the research team investigated whether separate performance models were needed for pavements in each existing pavement family depending on whether maintenance was applied on a regular basis. If there was a clear indication that regularly maintained pavements in each family were performing better than pavements that were not maintained, the development of new performance models might be warranted. However, since crack sealing and patching applications are not tracked in the database, it quickly became evident that the effects of these treatments on pavement performance could not be measured. For that reason, the APTech research team concentrated on the performance issues related to the application of chip seals.

The SDDOT's dROAD™ database contains information on chip seals applied to a pavement section, but the database does not distinguish whether the chip seal is the first, second, or subsequent application. This information was believed to be important since chip seals that are applied early in a pavement life cycle are not expected to perform in the same manner as chip seals that are applied later as a stopgap measure. In the absence of this information, the APTech research team made use of a paper record from the Yankton Area that listed pavement resurfacing activities over the last several years. From the records that were provided, it was easy to distinguish between resurfacing projects and chip seals. It was also easy to determine subsequent treatments, so the chip seal number could be determined. This paper record, which was converted to an Excel spreadsheet by the APTech research team, is included as Appendix A to this report. Combined with the pavement condition information that was extracted from dROAD™, the research team investigated the various performance issues.

During the initial meeting with the Field Office personnel, and the kick-off meeting with the Technical Panel, the group discussed the assumptions made in developing the current pavement performance models, which are based on historical condition information. As those models were being developed, pavement condition information for each family was plotted against pavement age for each pavement section. Because of the existing family groupings, pavement performance models were differentiated by pavement type (such as full-depth asphalt or thin hot-mix asphalt on a weak base) and a treatment code. The treatment code allows the Department to differentiate between original pavement types (O), those that have been milled and overlaid (M), and those that have received an asphalt overlay (A). During the development of the models that are based on historical ratings, it was assumed that regular maintenance was applied to the pavements in each family. Inherent in this assumption was the presumed application of chip seals, crack sealing, and patching.

The group reported that if maintenance activities were constrained, or if regular maintenance was not applied, the performance period for each pavement family would be shorter than the time reflected in the historical pavement performance models. This situation is reflected in figure 5-10, which shows that the application of chip seals actually helps pavements remain on the family deterioration model over time.

As shown in the figure, without the application of the first two chip seals, it was assumed that pavement deterioration would accelerate faster than the rate reflected in the family model. The figure also shows that immediately after the application of the first and second chip seals, the performance of the pavement section might be somewhat better than that reflected in the performance model, but overall the family model was representative of the average conditions over time.

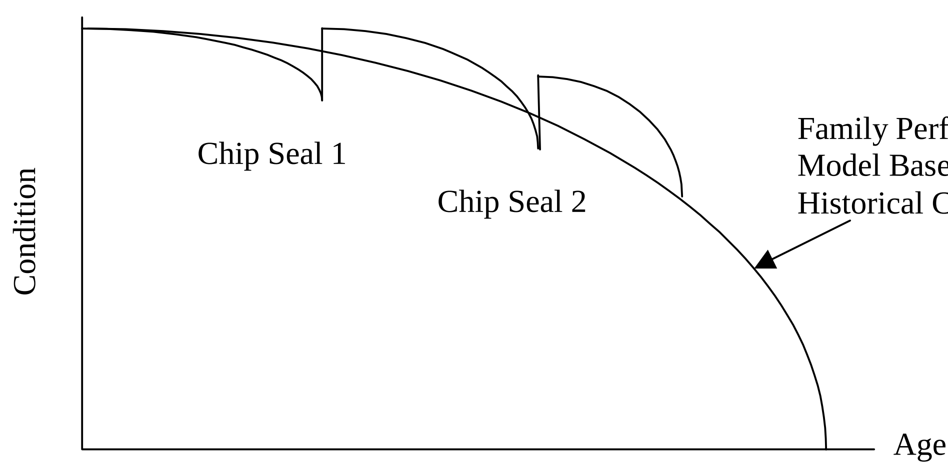


Figure 5-10. Simulated pavement performance models with maintenance assumed.

With this in mind, the APTech research team set out to demonstrate the reasonableness of this assumption using the chip seal information provided by the Yankton Area and the condition information extracted from dROAD™. For the more populated flexible performance families, the performance trends of individual families were overlaid on plots of the overall family curve to see if the assumptions could be proven with actual data. Unfortunately, the actual performance trend lines for pavement sections where chip seals had been applied did not resemble the family performance models, as shown in figure 5-11. Although this figure reflects only one family, similar findings were observed for the other families. The amount of scatter in the data prevented the research team from obtaining any meaningful results from this investigation. The difficulty in finding any one pavement that followed the family performance trend, regardless of whether a chip seal had been applied or not, led the research team to determine that it would not be worthwhile to develop additional performance models for pavements where chip seals had been applied. Therefore, the shifting of the performance curve that takes place in the pavement management analysis adequately addresses the variation in performance from the family model.

Another way of looking at the data was to see if the average rate of deterioration for pavement sections where chip seals had been applied was similar to that of the family model. Using the data from the Yankton Area again, the analysis of the data included pavement sections in the following families.

- Thin on Weak – Asphalt Overlay (TONW-A) (1 section and 1 subsection).
- Thin on Strong – Original (TONS-O) (1 section and 2 subsections).
- Thick – Original (THK-O) (1 section).
- Thick – Asphalt Overlay (THK-A) (3 subsections).

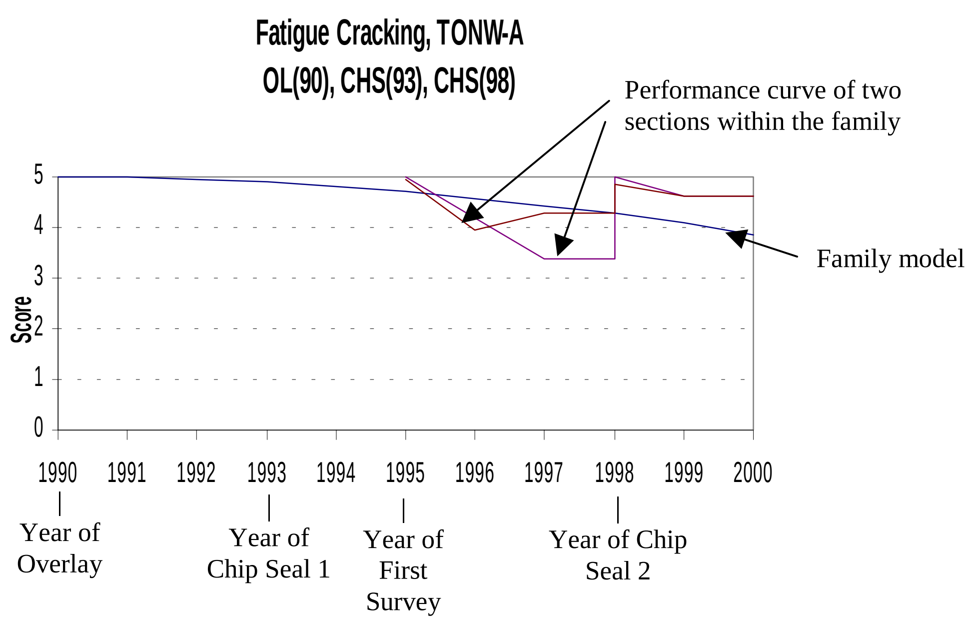


Figure 5-11. Pavement section plots overlaid on family models for fatigue cracking on TONW-A pavements.

The results did not conclusively demonstrate either a significant difference or similarity in deterioration rates. In general, the results demonstrated that for each family, the rate of deterioration after a chip seal had been applied was at least equal to, or greater than, the rate of deterioration reflected in the family performance curve. In effect, this finding may be reflective of the trend shown previously in figure 5-10. As shown in the figure, the family performance model represents the average deterioration of pavement over time. On a yearly basis, the performance of a section is rarely that smooth, with maintenance treatments applied periodically. In actuality, the performance is made up of a series of treatments that increase the conditions above the family curve, deteriorate rapidly, and then are applied again. The APTech research team hypothesizes that because chip seals are applied so regularly in South Dakota, the average deterioration rate reflected in the family models is lower than it would have been if chip seals had not been applied. The rapid deterioration rate immediately after a chip seal is highest if the pavement sections are rated soon after a chip seal is applied. Immediately after the chip seal application, few distresses can be observed. However, within 1 or 2 years of the chip seal application, any original distress can be seen again so the pavement appears to have a higher rate of deterioration <u>after</u> the chip seal. For that reason, some recommendations were developed to better model this condition using chip seal flags in the pavement management database (similar to the overlay and mill and overlay flags). No new performance models were established for the chip sealed pavements, but a rule was developed that within 3 years of the chip seal application, the pavement condition will return to the condition prior to the chip seal. From that point on, the shifted family modeling curve will be used, as shown in figure 5-12. This approach has the advantage of better simulating the actual conditions in the field without requiring that any additional performance curves be developed and maintained over time.

The roughness and patching indices proved to be exceptions to the general observations. For several of the sections, the roughness index was found to increase slightly after the chip seal rather than deteriorate. Similarly, the patching index on some sections did not deteriorate over the analysis period, indicating that no patches were present in the section. Obviously, neither of these situations reflected the average rate of deterioration found in the family model. Neither of these exceptions was thought to be due to problems with the performance modeling, so no variations to the recommendations were made.

5.4 Trigger Limits

Task 5 of the Request For Proposals called for defining "trigger limits that describe when maintenance treatments are likely to be applied." During the meeting with the Technical Panel in task 2 this item was defined to focus on the use of treatment triggers to improve the budget estimates for preventive maintenance treatments and to develop lists of possible candidate projects for use by Region personnel. The focus was not on dictating the practices of Field Office personnel.

One of the first steps in developing treatment triggers is to look at the history of this treatment by the Department. This issue is complicated due to the lack of available history for maintenance treatments. Since many routine maintenance activities are not reported to the Pavement Management Unit, there is no comprehensive record of these activities in the

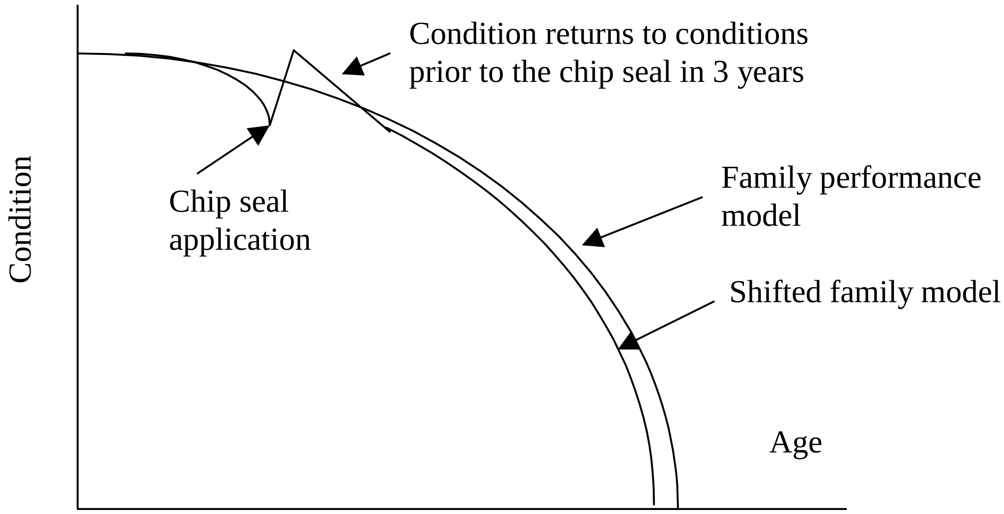


Figure 5-12. Pavement performance immediately after a chip seal.

Central Office. It was determined that it would not be easy for the pavement management system to track this information due to the way it is reported in the Department's accounting system. For instance, crack sealing is reported in terms of material quantity used over a length of pavement rather than length of cracks sealed in each pavement section.

The consensus of the participants in the early project meetings was that the first crack sealing is performed within approximately 2 years after the original construction (after the second winter). The first chip seal is normally applied 1 year after the crack sealing is performed. Field Office personnel also reported that they preferred leaving the second chip on at least 3 to 5 years before overlaying the section so they could get the full value out of the chip seal. Field Office personnel also indicated that the third chip seal is generally only used if a pavement section is not included in the resurfacing program and some type of treatment is needed to keep the pavement operational until the resurfacing can be scheduled.

The specific treatment triggers to be discussed in this report include:

- Crack sealing.
- Patching.
- Chip seals.

5.4.1 Crack Sealing Treatment Triggers

Existing Trigger

The current pavement management system includes Improvement Codes for "Route and Seal Cracks" in both Urban and non-Urban areas. Treatment triggers for the activity indicate that crack sealing is considered feasible approximately 2 years after rehabilitation has been applied.

The existing treatment triggers for Route and Seal are set to trigger this treatment in the first 2 years after a new pavement surface has been established due to resurfacing, reconstruction, or some other major work, provided that it has been 2 years since the last rehabilitation treatment has been applied or the pavement age is 2. This trigger is reasonable based on the information obtained during meetings with SDDOT Field Office personnel and is in line with the practice documented by the Yankton Area. No further changes to this treatment trigger appear to be needed.

Superpave PG Binders

One item that was discussed in the meeting with Field Office personnel is the introduction of Superpave Performance Graded (PG) binders. Anecdotal comments by Field Office personnel pointed out that projects paved with PG binders graded for South Dakota's climate are taking 3 or more years to develop sufficient thermal cracks to warrant crack sealing. Continued use of PG binders may warrant a revision to this trigger for projects using PG binders.

5.4.2 Patching Treatment Triggers

Patching is not an improvement type that is listed in the pavement management system. It is considered to be a periodic treatment that can be applied to a pavement section any time after 1 or more years since the last rehabilitation. Trigger limits have been established for a routine asphalt maintenance activity for the purpose of budgeting.

The APTech research team agrees that the use of the Routine Asphalt Maintenance treatment trigger is an acceptable approach to estimate the funding needs for patching. This seems reasonable since Pavement Management is not trying to identify sections that are candidates for patching, but is only trying to improve the accuracy of their planning and budgeting activities.

As it is currently modeled, the treatment trigger flags routine asphalt maintenance for each section in each year, except when rehabilitation is being applied or was applied in the prior year. The maintenance cost for a pavement section is based on average mainline maintenance costs over the past 3 years. This value is then increased by $166.68 per mile per year to account for the increased cost of maintenance over time. Rehabilitation treatments reduce the annual maintenance costs by a fixed percentage. Reconstruction resets the annual maintenance costs to $0. After resetting, the annual costs are then increased again by $166.68 per year.

The method described above is probably underestimating the true maintenance expenditures for a pavement section. In some cases, maintenance work is added to existing construction projects by change orders, especially for the purpose of placing extensive patches. These funds are not presently coded back to the correct segment of road as a maintenance cost. To accurately estimate the maintenance costs for a section, all maintenance costs need to be coded to the segment.

Another comment from field personnel was that the 3-year period is not long enough to cover peaks and valleys of maintenance spending on a particular section. As an example, it was stated that in some cases maintenance on lower volume roads is deferred until the road becomes almost impassable and then a large amount of maintenance work will be scheduled for 1 year to bring the roadway up to an acceptable level.

The historical cost record is also not representative of the maintenance need for each section, since expenditures are influenced by maintenance funding levels, snow and ice removal requirements during the winter, and other factors. A cost value that is more representative of need than expenditures is a better budget tool, but is more difficult to obtain.

An accurate representation of this cost is important for a number of reasons. One item that is presently missing is the tradeoff of maintenance costs versus rehabilitation. First, the cost of maintenance is not a direct factor in the determination of the need to rehabilitate a given segment of roadway. Second, maintenance funding is presently divided among the regions on a more or less “equal” basis based on mileage of the roadway system. Due to population and traffic levels, some areas of the state may be receiving a higher percentage of rehabilitation and reconstruction funds than others because the prioritization approach used in pavement management is weighted towards sections with higher volumes. This is turn may be creating higher maintenance needs in the areas with lower traffic volumes or populations.

Pavement maintenance costs could be used to determine the maintenance cost both to a Region and to the Department when rehabilitation is deferred or not programmed. For example, the Department should consider the level of maintenance funding that must be allocated to a pavement that is eligible for resurfacing to determine whether adequate financial support is being provided. The Maintenance Needs Index discussed in section 5.6 attempts to address these points.

5.4.3 Chip Seal Treatment Triggers

The development of treatment triggers for chip seals is an important part of this research project. Comments from the Technical Panel indicated that management had a high interest in developing an improved approach to estimating the cost and standardizing the timing of chip seals. Field Office personnel also expressed an interest in obtaining a listing of candidate projects for chip seals based upon the pavement’s age and condition. This listing would then serve as a basis for conducting field reviews to verify the suitability of the pavement for a chip seal. As with other maintenance treatments, the Field Office personnel are interested in retaining responsibility for programming chip seals.

Existing Triggers

The existing treatment triggers for chip seals have three provisions that are considered. All three provisions require that pavement sections meet certain distress criteria. The first criterion is solely based upon the condition of the pavement. The listed conditions for consideration of a chip seal are:

- Transverse Cracking Index equal to or above 3.5.
- Fatigue Cracking Index equal to or above 3.3.
- Patching Index equal to or above 2.3.
- Block Cracking Index equal to or above 3.4.
- Roughness Index equal to or above 4.0.
- Rutting Index equal to or above 4.0.

The other two trigger equations for chip seals include time based values. The first states that a chip seal may be applied 1 year after crack sealing is completed if the Transverse Cracking Index is equal to or greater than 4.0 and all the other condition values listed above are met. The other provision states that if a chip seal has been applied 6 years prior, the Transverse Cracking Index is equal to or greater than 4.0, and the other condition criteria listed above have been met, the section will be considered for a chip seal.

Field Practice

Early in the project a written survey was distributed to field personnel to obtain information regarding current chip seal practices. The survey was prepared by the APTech research team and distributed to the four Regions and Central Office personnel. Twenty-four responses were received to the survey. A copy of the survey form and the results are contained in Appendix B. Key findings from the survey include the following.

- First chip seals should be placed between 2 to 7 years after initial construction.

- Second chip seals should be placed 4 to 7 years after the first chip seal.

- Third chip seals should be placed 4 to 7 years after the second chip seal.

- No more than three chip seals should be placed on an HMA pavement as they become less cost effective from a preventive maintenance viewpoint.

- There should be a minimum of 3 to 5 years between chip seal applications in order for them to be cost effective.

- Nineteen of twenty-four respondents reported that chip seals were not cost-effective on roads in poor condition.

- The most effective application of a maintenance strategy was to first crack seal a pavement and then apply a chip seal at the reported intervals.

In task 3, meetings were held with field personnel in Huron and Pierre on May 8, 2001 and May 9, 2001, respectively. After a discussion of the use of pavement management in South Dakota and the practices of other states in the areas of pavement management and maintenance, the groups were then asked for feedback on current practices in the state. The results of the above survey were used as the basis for this discussion.

The discussions indicated that Field Office personnel are primarily using time-based criteria for determining the appropriate time for triggering a chip seal. In practice, the first chip seal is applied 3 to 5 years after resurfacing and a second chip is normally applied approximately 5 years after the first chip seal. The application of the third chip seal seems to vary across the state. The third chip seal is used sparingly and then only if funding for rehabilitation is not available. A third chip seal is more likely to be applied in the eastern half of the state.

As a follow up, the Yankton Area provided a paper ledger of 83 pavement sections (Appendix A). This ledger lists location, pavement type, construction or rehabilitation type and date, and major maintenance work completed since 1970. Chip seals first appeared on the ledger in the mid 1980s. Since chip seals have become a more common practice in the Yankton Area, they have been applied on the 2 to 7 year cycle on most sections.

Tables 5-5 through 5-8 are the result of a group activity that was conducted during the meetings. Participants were asked to describe the treatments over the total life cycle of different pavement types, road functional classifications, and different rehabilitation strategies. The tables present an idealized, time-based approach to pavement preservation.

Funding

Funding of chip seals is another item of concern to both the Regions and the Central Office. The first chip seal is considered part of the construction project and funded out of the construction budget in the year the chip seal is applied. Second and subsequent chip seals are funded from the Region’s maintenance budget. There is no distinction if subsequent chip seals are applied as a preventive maintenance measure or as a stopgap treatment.

Analysis

In order to meet the needs of the Central Office and the Regions, several changes are needed to the existing treatment triggers. First, it is important that a mechanism be created that indicates whether the first chip seal, the second chip seal, or a subsequent chip seal is being applied. Presently, all chip seals are simply denoted in the pavement management system by “S.” Creating rehabilitation categories of S1, S2, and S3 would accomplish this item. Treatments S1 and S2 are used as a preventive maintenance treatment; S3 is most likely considered more of a stopgap maintenance activity.

Table 5-5. Pavement life cycle for new HMA pavements by functional class (SDDOT Field Office personnel, Mitchell and Aberdeen Regions)

New HMA	**Category**			
Year	**Interstate**	**Major Arterial**	**Minor Arterial**	**Secondary**
1				
2	Crack Seal	Crack Seal	Crack Seal	Crack Seal
3	Chip Seal	Chip Seal	Chip Seal	Chip Seal
4				
5				
6				
7	Crack Seal	Crack Seal	Crack Seal	Crack Seal
8	Chip Seal	Chip Seal	Chip Seal	Chip Seal
9				
10				
11				
12		Crack Seal		
13		Chip Seal	Crack Seal	Crack Seal
14			Chip Seal	Chip Seal
15	Overlay			
16				
17	Crack Seal	Overlay		
18	Chip Seal			
19		Crack Seal		
20		Chip Seal	Overlay	Overlay

Table 5-6. Pavement life cycle for HMA overlaid pavements by functional class (SDDOT Field Office personnel, Mitchell and Aberdeen Regions).

Overlay	Category			
Year	Interstate AC over PCC	Major Arterial	Minor Arterial	Secondary
1				
2	Crack Seal	Crack Seal	Crack Seal	Crack Seal
3	Chip Seal	Chip Seal	Chip Seal	Chip Seal
4				
5				
6				
7	Crack Seal	Crack Seal	Crack Seal	Crack Seal
8	Chip Seal	Chip Seal	Chip Seal	Chip Seal
9				
10				
11				
12	Overlay	Overlay	Overlay	Overlay
13				
14				
15				
16				
17				
18				
19				
20				

Table 5-7. Pavement life cycle for new HMA pavements by pavement type (SDDOT Field Office personnel, Pierre Region).

New HMA	**Category**				
Year	**BLOT** Blotter Pavement	**FD** Full-depth HMA Pavement	**THK** Thick HMA Pavement	**TONS** Thin on Strong Base HMA Pavement	**TONW** Thin on Weak Base HMA Pavement
1					
2			Crack Seal	Crack Seal	Crack Seal
3			Chip Seal	Chip Seal	Chip Seal
4	Re-Blotter				
5					
6					
7					
8	Re-Blotter		Crack Seal	Crack Seal	Crack Seal
9			Chip Seal	Chip Seal	Chip Seal
10					
11					
12	Do something				
13					Overlay
14			Overlay due to transverse cracking		
15				Overlay due to transverse or fatigue cracking	Crack Seal
16			Crack Seal		Chip Seal
17			Chip Seal	Crack Seal	
18				Chip Seal	
19					
20	Overlay				

Table 5-8. Pavement life cycle for HMA overlaid pavements by pavement type (SDDOT Field Office personnel, Pierre Region).

Overlay	**Category**				
Year	**AONC** HMA on PCC Pavement	**FD** Full-depth HMA Pavement	**THK** Thick HMA Pavement	**TONS** Thin on Strong Base HMA Pavement	**TONW** Thin on Weak Base HMA Pavement
1		Crack Seal			
2	Crack Seal	Chip Seal	Crack Seal	Crack Seal	Crack Seal
3	Chip Seal		Chip Seal	Chip Seal	Chip Seal
4					
5					
6					
7		Crack Seal			
8	Crack Seal		Crack Seal	Crack Seal	Crack Seal
9	Chip Seal		Chip Seal	Chip Seal	Chip Seal
10					
11		Overlay			
12					
13					
14	Overlay				
15			CIP	Overlay	PIP
16					
17					
18					
19	Possible Overlay				
20	Overlay				

Second, since chip seals are not automatically applied in year 3, it is suggested that a treatment trigger for the first chip seal be established 2 to 5 years after rehabilitation. A treatment trigger such as the one listed in chapter 6 should be considered. It is recommended that in addition to setting the trigger for the time since crack sealing, the time since rehabilitation be included since the Field Office personnel report that some of the newer asphalt materials are not cracking in the first few years. In addition, it is recommended that basic checks on pavement condition be applied to ensure that the pavement is not suffering from premature distress. These limits were established based on the deduct points allowable for low- and medium-severity distress combined with low- and medium-extents.

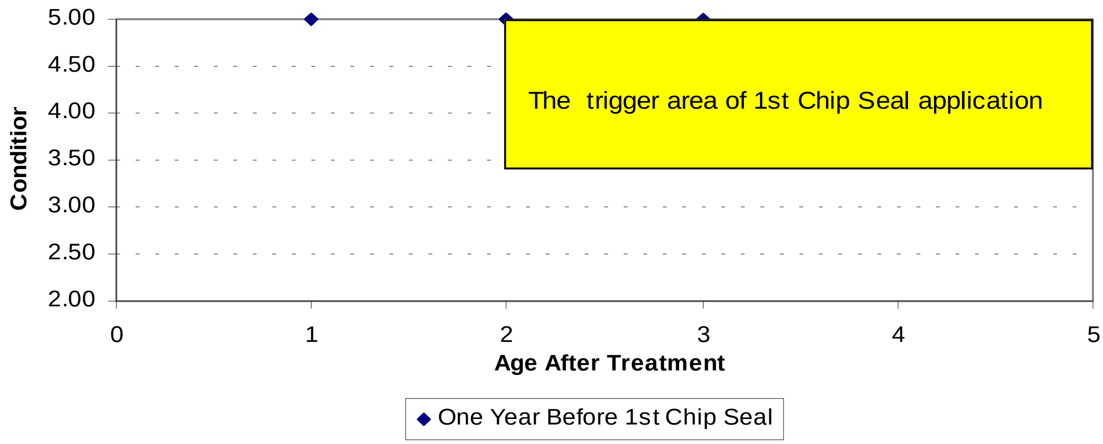
Third, the second chip seal, which is normally scheduled approximately 5 years after the first chip seal, could also be based on a time-based trigger to put it on the schedule. However, since the pavement is aging, certain conditions have been flagged to indicate that a chip seal is not considered a viable treatment. The limitations on conditions vary slightly from those currently used by the SDDOT. The new values were determined based upon an examination of projects in the Yankton Area and were further refined during the meeting with field personnel in October 2001. Figures 5-13 through 5-15 displays the results of this analysis.

These figures show pavements in the Yankton Area that have had one or more chip seals applied. The pavement condition data were plotted in the year before the chip seal was applied to verify the appropriateness of the proposed trigger ranges. The year before chip seal application was used to assure that a rating was used before chip seal application. The shaded boxes in figures 5-13 through 5-15 represent the new recommended treatment triggers.

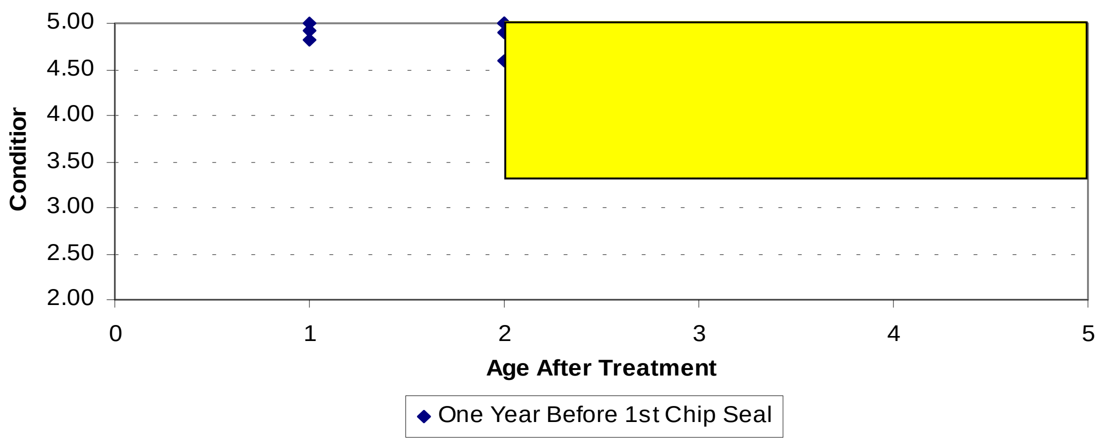
Field Office personnel felt that lower limits for many of the distresses should be lower than what the APTech team proposed. In particular, they indicated that the use of roughness (RUFF) should be eliminated as a trigger value. Instead, they supported its use in calculating the cost of a chip seal. They stated that since badly deteriorated or rough areas would be patched before the chip seal was applied, a better strategy was to increase the estimated cost of the chip seal to cover the increased patching costs.

Original analysis showed the limits for transverse cracking (TRCR) to be similar to the first chip seal with a value of 4.4 or greater. This limit was again based on restricting chip seals to pavements without high severity or medium severity, high extent transverse cracking. Field Office personnel stated that they would apply chip seals on pavements as long as they did not have high-severity transverse cracking. This would allow for a minimum transverse cracking index (TRCR) of 3.5.

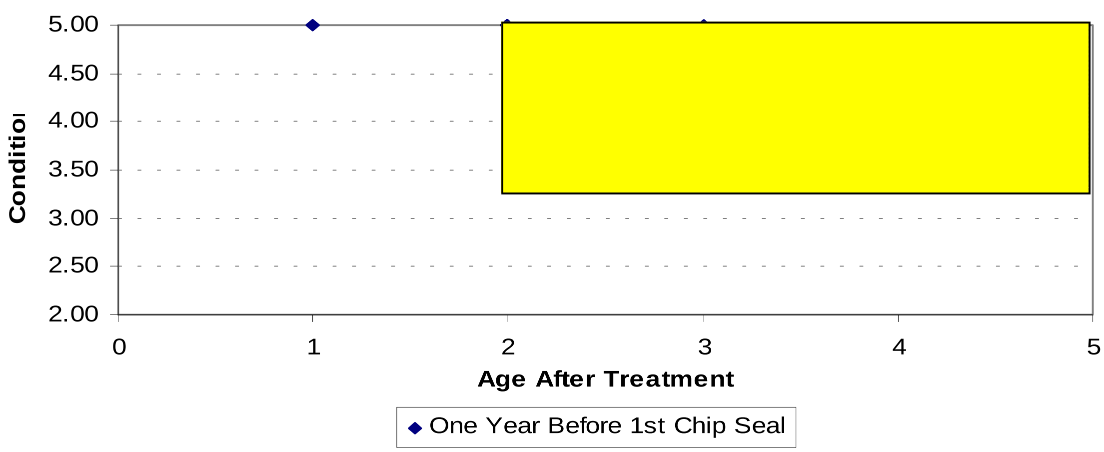
Participants also felt that an average rut depth of greater than 0.25 inches would be tolerable for chip seal applications. This lowers the rutting index (RUT) for S1 and S2 to 3.5 and S3 to 3.0.



a) Block Cracking

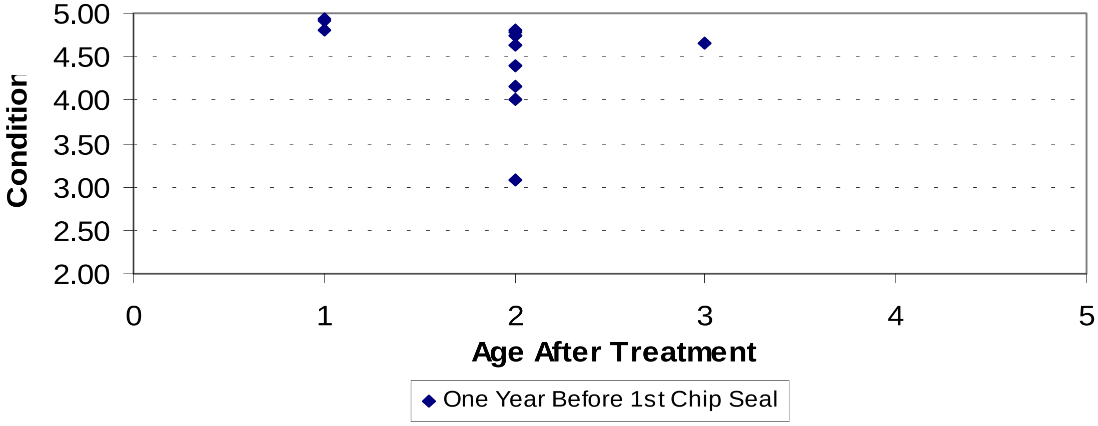


b) Fatigue Cracking

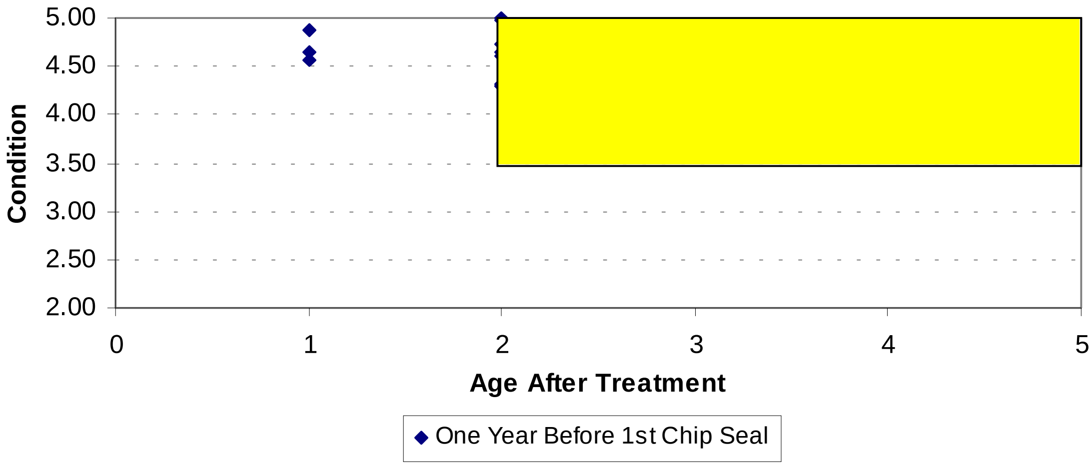


c) Patch Deterioration

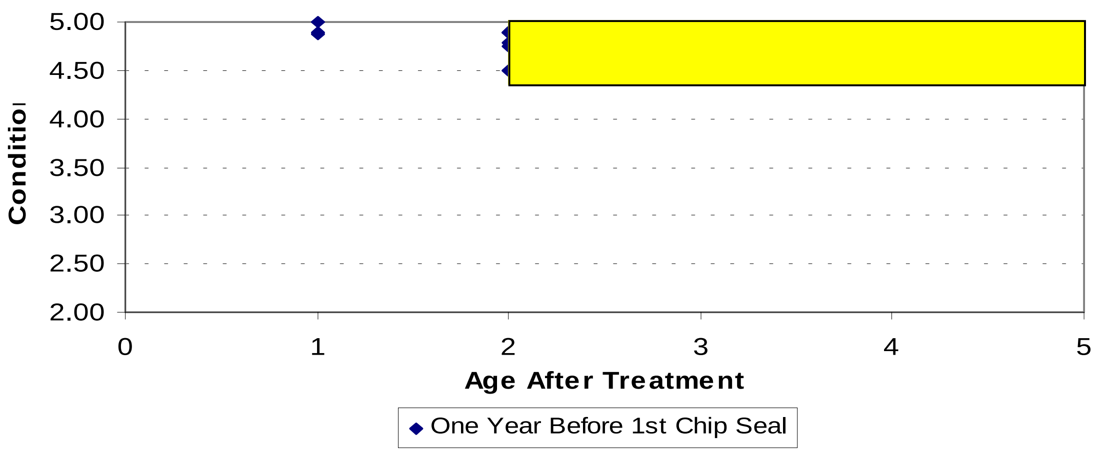
Figure 5-13. First chip seal candidates in the Yankton Area.



d) Roughness

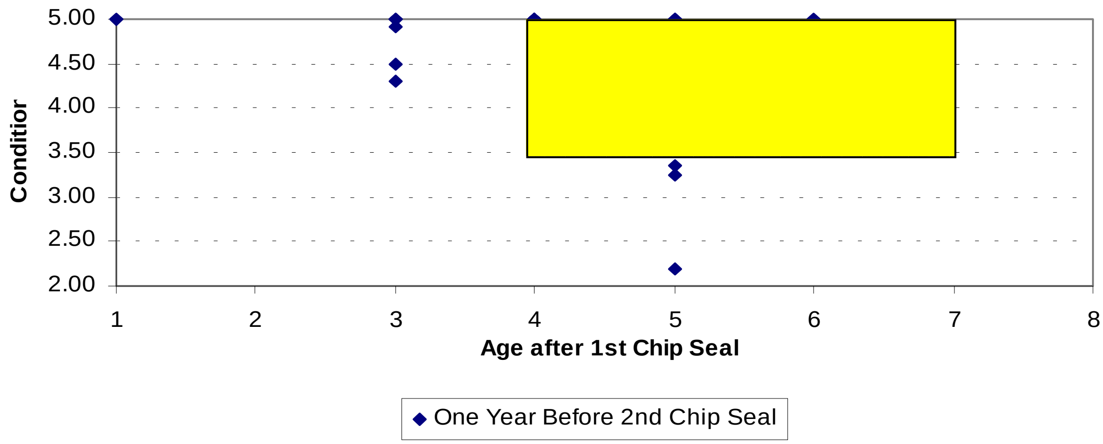


e) Rutting

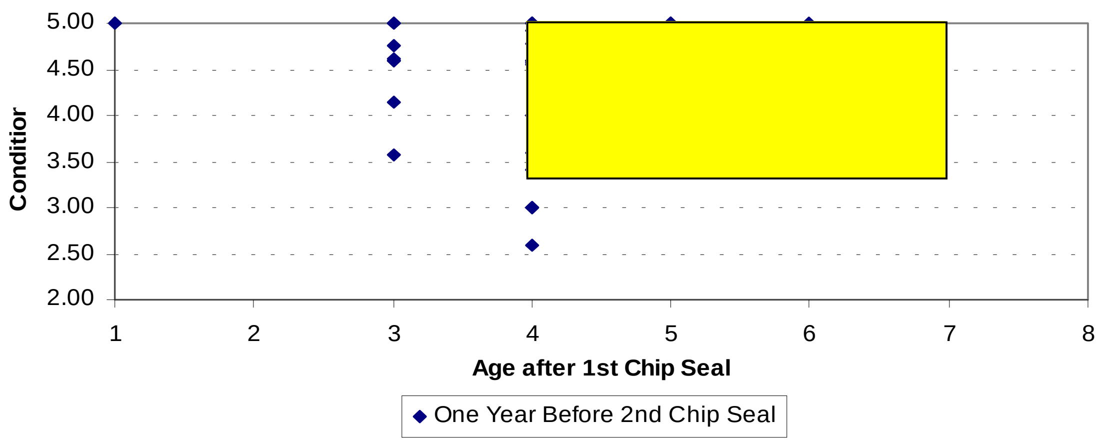


f) Transverse Cracking

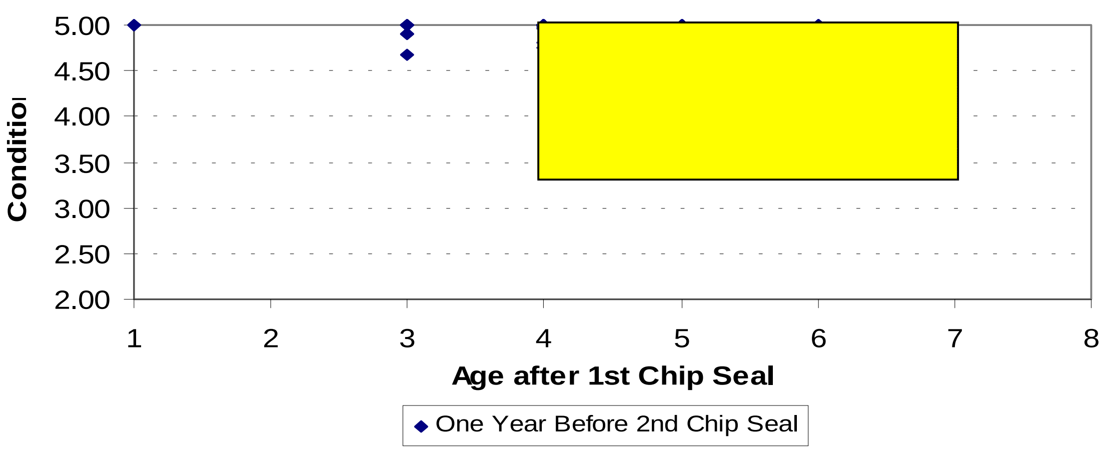
Figure 5-13. First chip seal candidates in the Yankton Area (continued).



a) Block Cracking

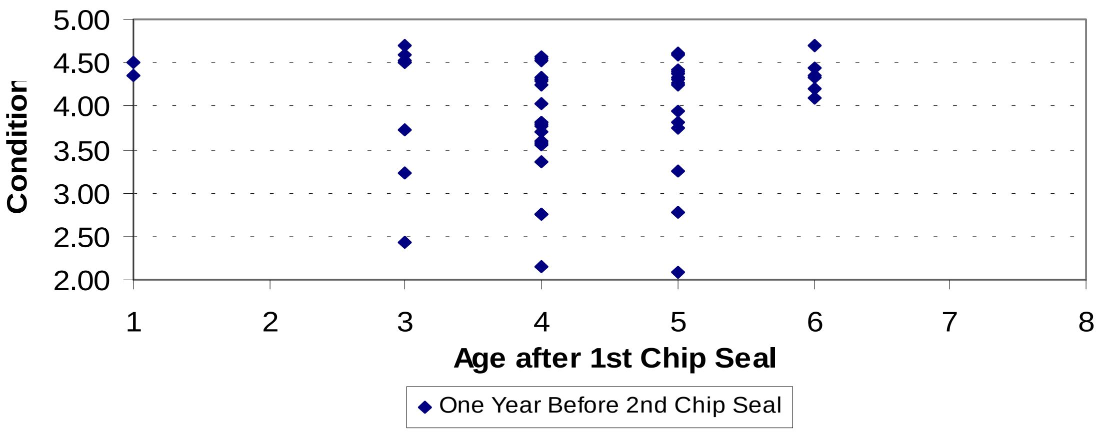


b) Fatigue Cracking

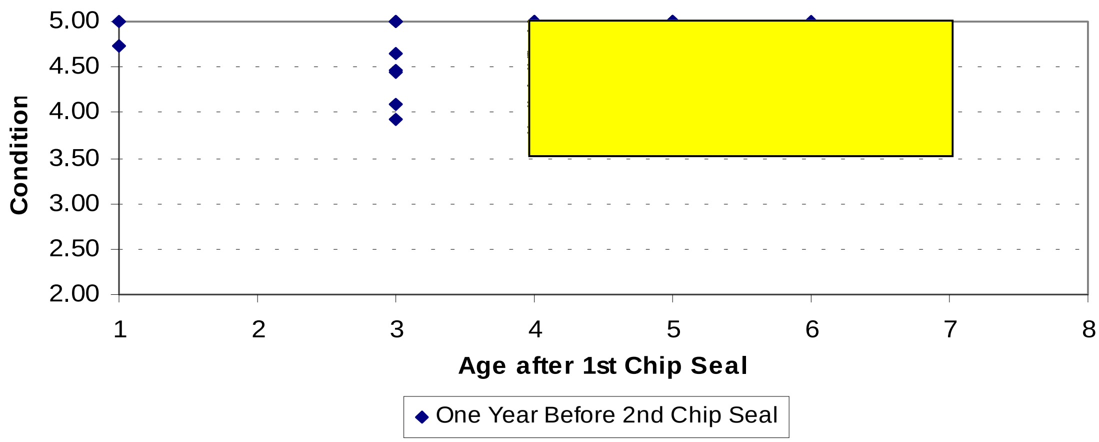


c) Patch Deterioration

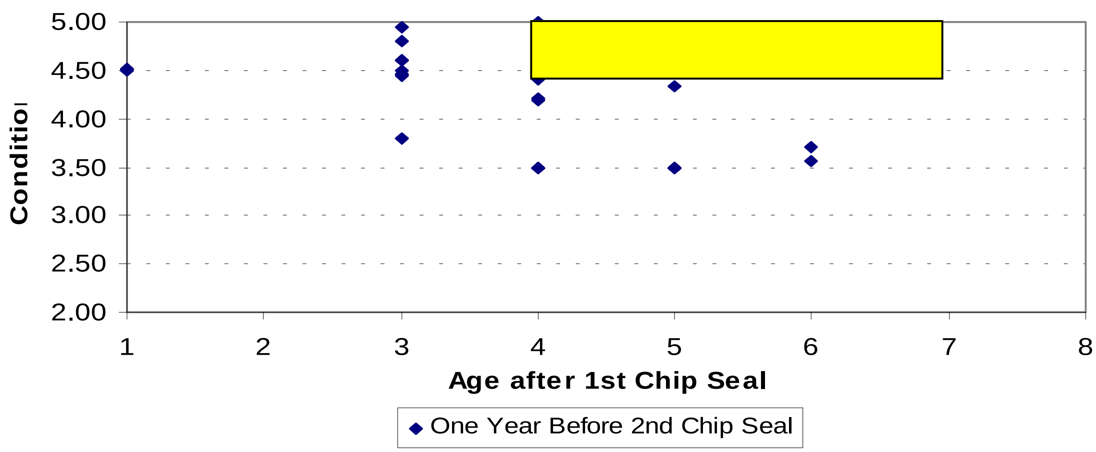
Figure 5-14. Second chip seal candidates in the Yankton Area.



d) Roughness

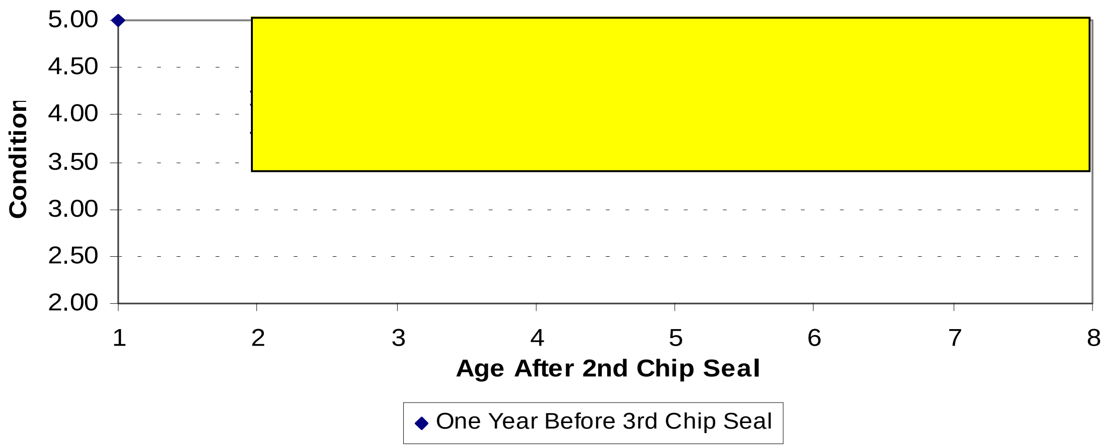


e) Rutting

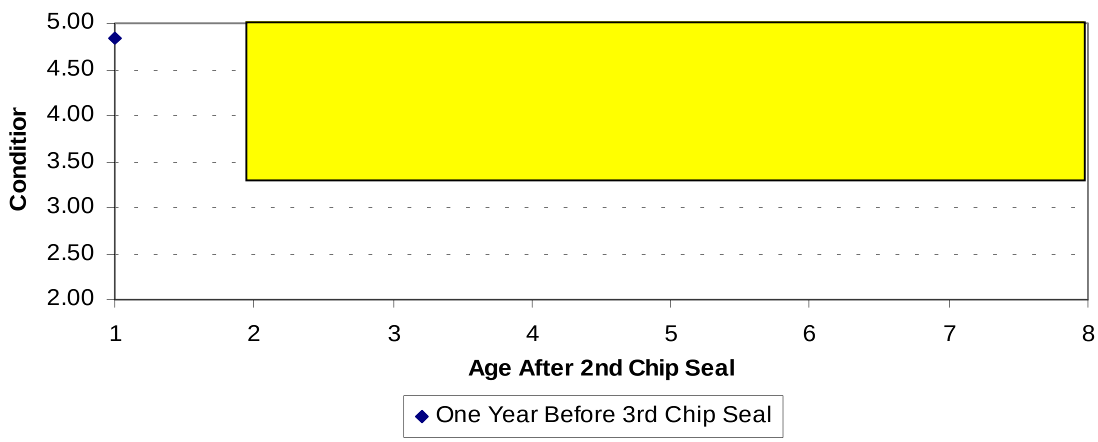


f) Transverse Cracking

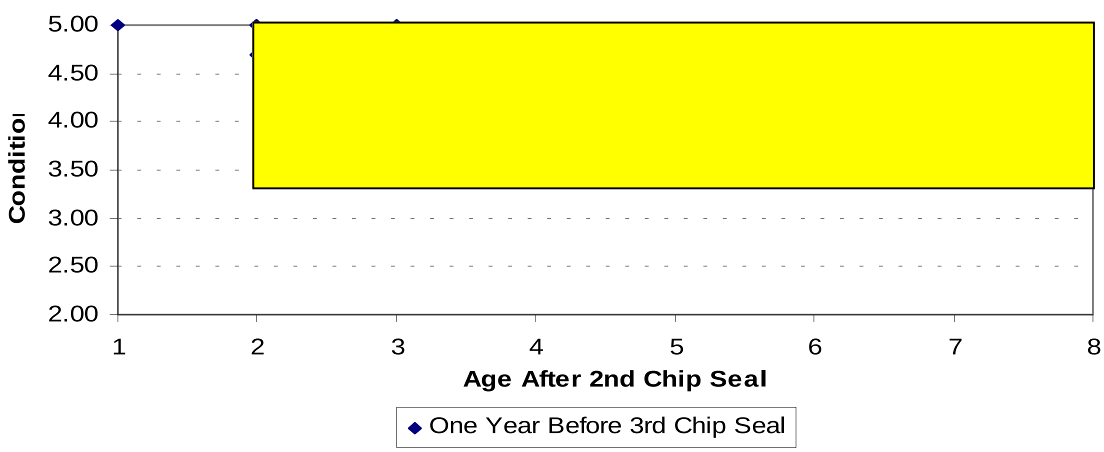
Figure 5-14. Second chip seal candidates in the Yankton Area (continued).



a) Block Cracking

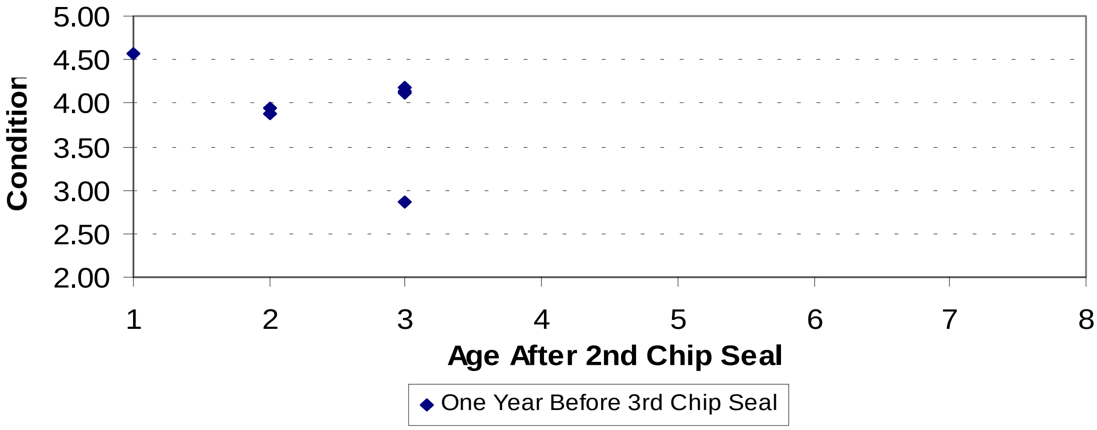


b) Fatigue Cracking

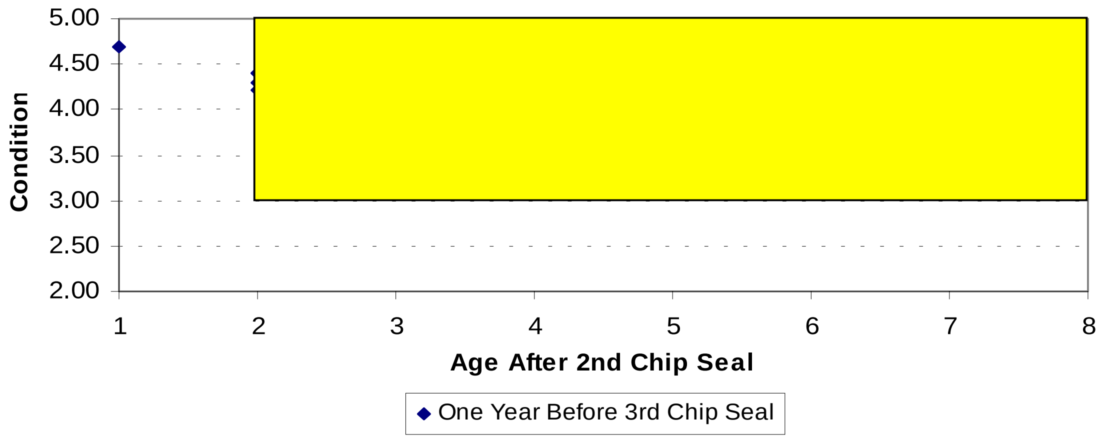


c) Patch Deterioration

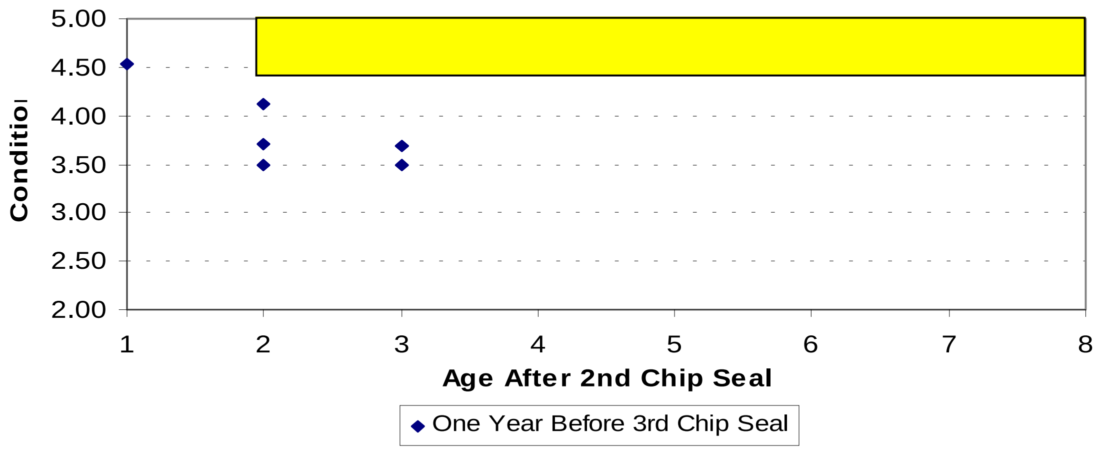
Figure 5-15. Third chip seal candidates in the Yankton Area.



d) Roughness



e) Rutting



f) Transverse Cracking

Figure 5-15. Third chip seal candidates in the Yankton Area (continued).

In examining the Yankton Area data it also became apparent that the third chip seal is applied after less time than the second. This is probably due to the faster deterioration rate of aged pavement. Based on these data and discussions with Field Office personnel at the October meeting, the APTech research team revised the earliest recommendation for the third chip seal to 2 years after the previous chip seal application.

The lowered limits are representative of the factors considered before applying chip seals by Field Office personnel. Field Office personnel listed the following items as objectives influencing the decision to apply chip seals.

- First and second chip seal.
    - Seal surface.
    - Retard surface oxidation.
    - Increase skid resistance.
    - Improve nighttime visibility.
- Third and subsequent chip seals.
    - Seal surface.
    - Retard surface oxidation.
    - Increase skid resistance.
    - Improve nighttime visibility.
    - Hold pavement condition until rehabilitation is programmed.

It is particularly interesting to note that although field personnel are applying chip seals to increase skid resistance, no friction-measuring device is currently operated by SDDOT.

These changes for chip seal triggers will provide the basis for reporting to the Field Office personnel the pavement sections that are eligible for chip seals in a preventive maintenance application. An annual list of “Chip Seal Eligible Pavements” will be generated by the Pavement Management Unit and provided to the Field Offices. Any pavement sections flagged as candidates for chip seals in the first year of the analysis could be provided to the Field Offices for consideration in their maintenance program. As the chip seals are applied, the completed chip seals should be reported to the Pavement Management Unit for input into the pavement management database.

Finally, a third trigger for chip seals is required for the pavement management system to consider preventive maintenance applications of chip seals for pavement sections that are good performers. These are sections that have exceeded the expected performance period and can be maintained at a relatively low cost through the application of a chip seal. The Department may wish to consider developing a special funding category to apply preventive maintenance treatments to those pavement sections that are eligible under this trigger.

If SDDOT revises the condition indices as discussed elsewhere in this report, the treatment triggers discussed above will require revision also.

Impact

Another consideration in adopting the proposed strategy of preventive maintenance is the cost to the Department for the multiple applications of chip seals. Table 5-9 presents the results of a series of simulations based upon an average paving cycle for flexible pavements, excluding Interstate pavements. Paving cycle is defined as the time between overlays of flexible pavements. Figure 5-16 illustrates the effect of paving cycle on the cost of construction and maintenance chip seal for the entire state.

With the passage of TEA-21 and other funding changes, SDDOT has increased the funding for overlays throughout the State thus increasing the number of miles overlaid each year and shortening the paving cycle. Funding for chip seals has not been increased during this same period, creating a potential backlog of needed chip seals.

5.5 Reset Values

For any pavement management system to be able to determine the benefit of a treatment and to accurately model its benefit to the pavement network, the proper reset of the condition indices must be included in the system. As an example, when a flexible pavement is overlaid in South Dakota all the condition indices return to a perfect rating (5.0) and the pavement is flagged as an overlay so that the proper deterioration curves are selected to project its future condition.

Perhaps one of the "hottest" topics to emerge from this project is the establishment of reset values for maintenance treatments. The reset values used by the pavement management system have a significant influence on when subsequent treatments are considered in the analysis and should reflect actual conditions as much as possible. Several issues emerged with respect to this topic, including the resets assigned to a patch that covers an entire survey section and the resets for indices after chip seals are recommended for a section.

Agencies using the Deighton & Associates' software packages have four options to choose from for treatment resets:

1. Absolute Reset: this approach resets the new index to a specified value.

2. Percentage Reset: this approach specifies a percent of the original index value to obtain the reset index value.

3. Relative Reset: this approach specifies a plus or minus value that will be added to the current index value to obtain the reset index value.

4. Expression Reset: this approach specifies an expression to obtain the reset index value.

Table 5-9. Estimated costs for chip seals based on paving cycle (estimated cost of $8000 per two-lane mile).

	Region				
	Aberdeen	**Mitchell**	**Pierre**	**Rapid City**	**Total**
Non-Interstate Asphalt Mileage	1685	1419	1853	1868	6824
Paving Cycle (years)	8	8	8	8	8
Annual miles paved	211	177	232	234	853
Annual miles chip sealed	211	177	232	234	853
Annual cost of construction funded chip seals X 1000	$1,684	$1,419	$1,853	$1,868	$6,824
Annual cost of maintenance funded chip seals X 1000	$0	$0	$0	$0	$0
Paving Cycle (years)	13	13	13	13	13
Annual miles paved	130	109	143	144	525
Annual miles chip sealed	259	218	285	287	1050
Annual cost of construction funded chip seals X 1000	$1,036	$873	$1,140	$1,150	$4,199
Annual cost of maintenance funded chip seals X 1000	$1,036	$873	$1,140	$1,150	$4,199
Paving Cycle (years)	18	18	18	18	18
Annual miles paved	94	79	103	104	379
Annual miles chip sealed	281	237	309	311	1137
Annual cost of construction funded chip seals X 1000	$748	$630	$823	$830	$3,033
Annual cost of maintenance funded chip seals X 1000	$1,499	$1,261	$1,647	$1,660	$6,066

In 2001, Deighton upgraded their software to dTIMS™CT. This change impacts reset values in that only option 4 is available in the newer version of the software. The SDDOT Pavement Management Unit has not yet completed their plans for the implementation of the new Deighton PMS software nor evaluated how this change will affect their reset values.

This section of the report discusses reset values for crack sealing, patching, and chip seal applications.

5.5.1 Crack Seal Reset Values

As discussed in an earlier section of this report, it is important that the benefits associated with a crack sealing program be recognized in the pavement management system. The reasoning for this is relatively simple. In the typical pavement management system, the benefit of each treatment considered in the analysis is reflected by the increase in area under the performance curve generated by the application of a treatment. The costs are calculated on a lineal foot- or square foot-basis. In most cases, the benefit associated with a treatment is caused by an increase in the condition index and/or a shifting of the performance model to reflect a slower rate of deterioration, as shown in figure 5-17.

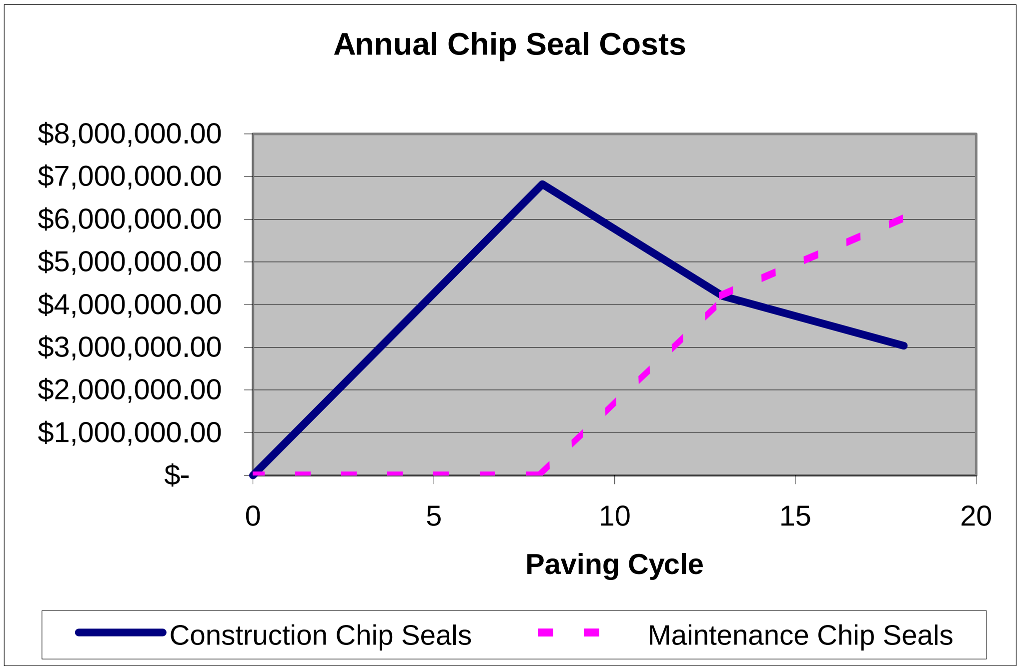


Figure 5-16. Projected statewide annual chip seal costs based on paving cycle.

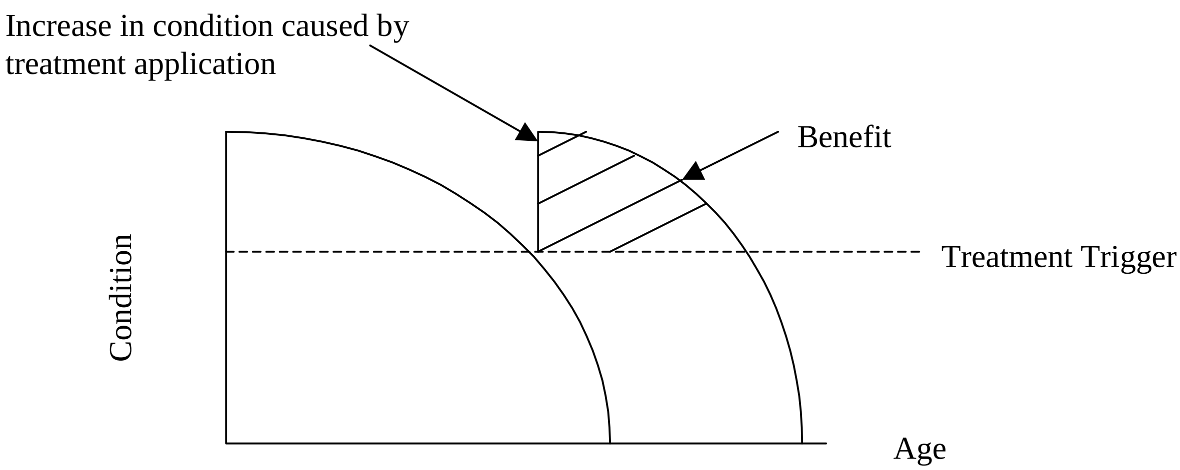


Figure 5-17. Illustration of benefit.

If there is no change in the condition index due to the application of a treatment, and there is no change in the performance model after the treatment has been applied, then there is no benefit calculated by the pavement management system for that treatment. If the selection of maintenance and repair projects in the pavement management system is based on a benefit-cost analysis, as exists in the SDDOT, then a treatment with no benefit will not be selected for inclusion in the program. If, on the other hand, the treatment is triggered on a cycle based on timing rather than selected by the benefit-cost analysis, then the lack of benefit will not impact the selection of the treatment in the program.

There are at least two ways to address this. One approach is to develop a routine that automatically recalculates the transverse cracking index based on the change of all medium- and high-severity cracks (without depressions and regardless of width) to low-severity cracks. This change would correspond to the recommended change in the rating procedure to rate all sealed and routed cracks without depressions as low severity. Depending on the amount of transverse cracking present, this could increase the transverse cracking index by as little as 0.1 point (if medium severity and low extent) or as much as 4.5 points (if high severity and high extent). This approach would provide enough of a difference in the transverse cracking index to provide a benefit to be associated with the treatment in a benefit to cost analysis, but would make the current system a little more complicated.

A second approach to address this issue is to set an absolute reset value for crack sealing in the models, which essentially accomplishes the same thing as recalculating an index based on a change of crack severities to low in a much simpler way. The disadvantage is that an equal reset value is applied to all pavement sections, regardless of the initial value of the transverse cracking index. It represents more of an average increase in condition rather than a section-specific increase in condition. This is the approach that is currently being used in the SDDOT pavement management system.

The usefulness of changing the approach to determine the reset value in South Dakota is debatable. At the present time, crack sealing is triggered based primarily on pavement age rules. However, the most important factor to consider is that the benefit-cost analysis is currently established in such a way that three different budget categories are used for asphalt treatments: a maintenance budget, a resurfacing budget, and a reconstruction budget. Both chip seals and crack seals are included in the maintenance budget. As a result, maintenance treatments are not competing with resurfacing treatments over the analysis period reducing the importance of this issue in the APTech research team's mind. Rather than recommend that the SDDOT develop a routine that would automatically calculate the reset value (based on re-evaluating medium- and high-severity cracks as low severity), the research team recommends a revision to the reset value currently being used. The recommendation included in chapter 6.0 is to set the reset value for transverse cracking at the higher of two values: either the actual rating from the field or a value of 4.5. This latter value of 4.5 is representative of a section with a high extent of low-severity cracks; a value considered a conservative estimate of conditions after a crack seal program has taken place.

5.5.2 Patching Reset Values

Patching is not an operation that is programmed or recommended by the pavement management system. Patching location and quantities are also not reported to the pavement management system. For these reasons, there is presently no reset value for patching included in the system. No change is recommended in this area.

5.5.3 Chip Seal Reset Values

Existing Reset

In South Dakota's present pavement management system, whenever a chip seal is applied a total of 0.2 points are added to the transverse cracking, fatigue cracking, patching, and block cracking indices. No change is made to the rutting or roughness indices projected by the pavement management system. When these sections are rated the following year in the field, the raters often see an almost perfect pavement with little, if any, distress visible after the first or second chip seal.

Analysis

The Yankton Area data was again used to evaluate the effects of chip seals on the ratings recorded in the pavement management database. In this case the rating of the pavement 1 year before and 1 year after the chip seal was applied is used to ensure that the rating actually took place before/after the chip seal was applied. The disadvantage to this approach is that it is possible that more than 1 year passed between the time the chip seal was applied and the rating is recorded. Table 5-10 displays the average rating for pavement segments the year before and after chip seals were applied. Table 5-11 displays the average values from performance curves for the six distress indices in years 3, 8 and 13, the recommend time of application for the three chip seals. These two tables show that the effect of chip seals on the distress indices is significant when the third chip seal is applied to pavements with low condition ratings, when the chip seal masks certain distresses. The other observation is that there is more variation in pavement conditions prior to the third chip seal application. In some cases these may be stopgap applications, not indicative of the reset that would be warranted in a preventive maintenance application.

Based on a review of the Yankton Area data and discussions with Field Office personnel, only the block cracking and transverse cracking indices would be reset by the application of a chip seal. For the first chip seal, the reset would be to perfect condition, with a value of 5.0. For the second and third chip seals, the recommended reset values would be based on the higher of either the existing value before the chip seal application or a value based on low severity distress since the cracks would be sealed (block cracking equal to the higher of the actual index or 4.3; transverse cracking equal to the higher of the actual index or 4.5). This assumption matches the stated purpose of chip seal applications by Field Office personnel discussed in the previous section.

Table 5-10. Average field rating for pavements one year before and one year after chip seal applications in Yankton Area.

Index	Average Field Rating First Chip Seal		Average Field Rating Second Chip Seal		Average Field Rating Third Chip Seal	
	1 Year Before	**1 Year After**	**1 Year Before**	**1 Year After**	**1 Year Before**	**1 Year After**
Block Cracking	5.00	4.79	4.60	4.45	4.24	4.18
Fatigue Cracking	4.92	4.89	4.47	4.41	4.21	4.53
Patching	5.00	5.00	4.92	4.86	4.97	4.98
Roughness	4.49	4.54	3.92	3.95	3.34	3.65
Rutting	4.61	4.57	4.59	4.51	4.29	4.50
Transverse Cracking	4.78	4.46	4.41	4.20	3.62	4.11

Field Office personnel did take exception to the reset value for the transverse cracking index. They stated that if there were depressions present at the cracks, the chip seal would not improve this condition. While this is a valid point, the trigger limits discussed in the previous section would not result in a chip seal recommendation on any pavement with a transverse cracking index less than 3.5. As long as the transverse cracking index is greater than 3.5, the depression present at the cracks cannot be greater than 0.25 inches. The APTech research team recommends that reset values stand as presented in the October meetings. Recommended reset values are listed in chapter 6.

5.6 Coordination and Exchange of Information

5.6.1 Project Meetings

One of the benefits to arise from this project has been the opportunity to use the meetings with the Field Office personnel to facilitate the exchange of pavement management information between the Field Offices and the Pavement Management Unit. Based on questions that were asked of the APTech team members during the initial field meetings, there was a general lack of understanding about many aspects of the pavement management system, including how projects are being optimized. Additionally, the Field Office personnel were given an opportunity to participate in the development of recommendations for improving some of the ways maintenance treatments were represented in the pavement management system. This latter opportunity emerged when the Technical Panel approved the change to the scope of work that allowed the APTech research team to test the Train-the-Trainer materials during a series of three meetings around the state. These activities alone have gone a long way towards achieving the Department's objective to strengthen the coordination of information between the Field and Central offices.

Table 5-11. Average of distress indices prediction of all flexible pavement types in the typical year of chip seal applications.

Index	Predicted Index Value		
	Year 3	**Year 8**	**Year 13**
Block Cracking	4.90	4.38	3.23
Fatigue Cracking	4.86	4.15	2.72
Patching	4.96	4.56	3.47
Roughness	4.79	4.45	3.32
Rutting	4.75	3.87	2.22
Transverse Cracking	473	4.21	3.10

One of the things that was emphasized during the Train-the-Trainer sessions was the importance of maintenance treatment information to support the pavement management analysis. If maintenance reports the application of maintenance chip seals then a chip seal flag would allow the Pavement Management Unit to use a different deterioration rate for the first three years after a chip seal had been applied. Similar exceptions are recommended for maintenance patches.

Similarly, the meetings led to a discussion of the value to the Field Office personnel of having the pavement management system print out a listing of pavement sections that would be good candidates for chip seals each year. The Field Office personnel would retain the authority to decide where the chip seals should be applied, but the list would assist them in section selection and familiarize them with the trigger limits that are used to determine feasible candidates in the pavement management analysis. As the Field Office personnel increase their understanding of the pavement management analysis, they will become a valuable resource to the Pavement Management Unit as they continue to update the treatment triggers, performance models, and other components of the pavement management analysis with time.

5.6.2 Train-the-Trainer

To share information on the state's pavement management system and implement findings from this research project, Train-the-Trainer course materials on pavement management are included as a project deliverable. The materials were tested on Field Office personnel in

October 2001 and were well received by the participants. The course materials include Instructor's Guides and PowerPoint presentations that introduce the objectives of the pavement management system and walk the participant through each of the steps of a pavement management optimization analysis. Members of the Pavement Management Unit participated in the initial demonstration of the Train-the-Trainer course materials and offered suggestions to strengthen the materials. Their comments were incorporated into the final course materials. Regularly presenting these materials to Field Office personnel will help to familiarize new hires with the process as well as to reacquaint experienced personnel with the operation of the system.

5.6.3 Maintenance Needs Index

One of the issues discussed at the meetings with Field Office personnel that cannot be directly addressed by the pavement management system concerns the trade-off between resurfacing and continued maintenance. The current SDDOT optimization approach weighs the benefit associated with various treatments on the additional performance realized and the traffic levels that will benefit from the treatment. As a result, there are a number of sections in South Dakota that are feasible candidates for resurfacing, but have traffic levels that keep them from being included in the resurfacing program. Instead, the Field Offices are forced to expend maintenance dollars on continued maintenance in order to keep them in serviceable condition. This strategy has a large impact on the maintenance budgets of Regions with lower volume pavements, since a larger proportion of their budget is potentially being spent on these types of needs rather than on preventive maintenance treatments. These stopgap maintenance applications do not fit the criteria for planned maintenance in the pavement management system, so an analysis of the true cost of deferring a resurfacing treatment may not be fully understood.

To address this dilemma, the APTech research team explored the idea of a Maintenance Needs Index (MNI) that would help the Department better understand the cost-effectiveness of maintenance expenditures and that could be used to assist in developing programming strategies. As a programming tool, the MNI could potentially be used to help prioritize treatment needs on low-volume roads, or it could be used to assist in shifting extra maintenance dollars to Regions with roads that are selected for continued maintenance rather than resurfacing (even though resurfacing was determined to be a viable alternative). This tool might also be helpful in estimating the agency's maintenance needs.

Although only developed as a conceptual idea since it is outside the scope of this project, a brief overview of the concept is presented in figures 5-18 and 5-19. As shown in figure 5-18, there is a point in a pavement life cycle in which maintenance is no longer as cost-effective as resurfacing as a treatment. Logically, a pavement would reach this point when the sum of annual maintenance needs are more than the cost of resurfacing. Just as trigger values for resurfacing change based on road classifications, the level at which maintenance is considered cost-effective could also vary based on similar types of features. Note that the index would likely be the inverse of a traditional condition index, with a higher value meaning that a road had a higher maintenance need than a road with a lower index.

The MNI value would likely be tied to the cost of maintenance needs for a mile of pavement based on the number of years since the road was resurfaced. This number would be different than the amount of money actually spent on a road since the actual expenditure is based on available funding, the amount expended for snowfall in a year, and/or the philosophy of the Area Engineer. The use of a dollar amount that is reflective of the needed maintenance would be more applicable in this situation. The increasing cost of maintenance since last surfacing is reflected in figure 5-19. Since maintenance expenditures often vary by functional class, different graphs would likely be developed for each functional classification. The cost calculations would likely be a function of the amount of fatigue cracking, patching, rutting, and depressions that are present in a pavement section over time and the frequency with which they must be addressed. The MNI would be based on keeping the pavement above the minimum acceptable level for that functional class.

The MNI would have to be linked to a maintenance cost per mile, perhaps using other condition indices that have a significant impact on maintenance expenditures as the basis for the calculation. For instance, roughness alone does not often trigger a maintenance treatment. However, a section with a lot of patching will likely need maintenance to keep the patches in serviceable condition. The tool could then be used in a number of different ways, as explained below.

As a Treatment Trigger

The MNI has the potential to be used to supplement the treatment trigger values currently being used in the pavement management system. For instance, a pavement that has condition indices that trigger resurfacing in the pavement management system but still has a relatively low maintenance needs index might be triggered for an overlay rather than a mill and overlay.

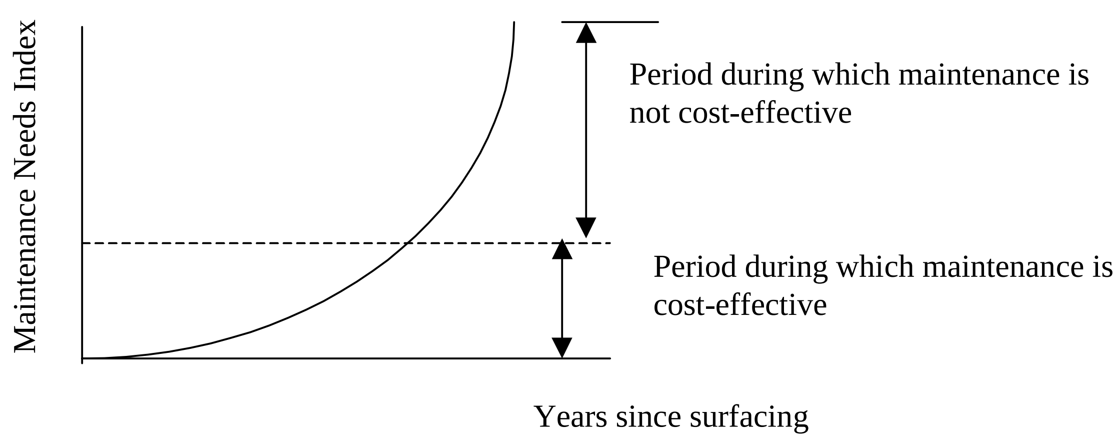


Figure 5-18. Cost-effectiveness of maintenance

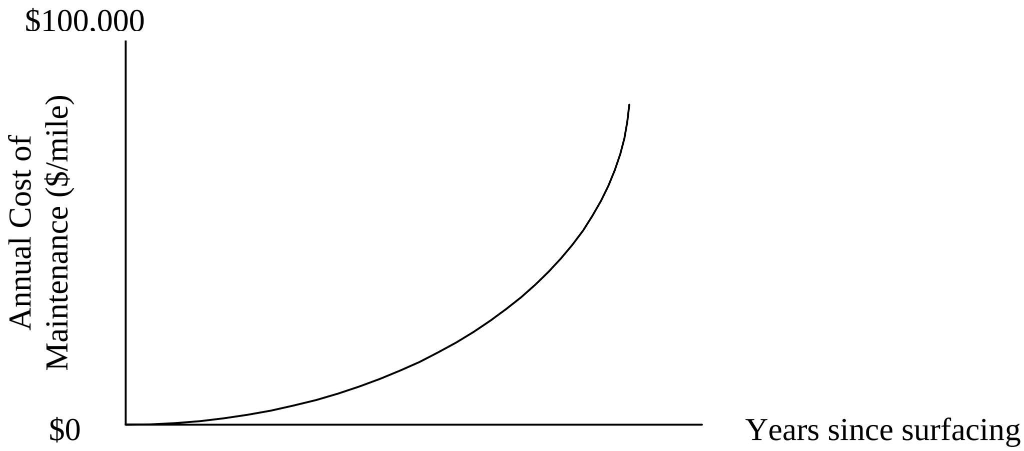


Figure 5-19. Annual cost of maintenance over time.

As a Cost Calculator

Historically, the resurfacing program has had inadequate funding levels to support all of the needs within the State. As a result, a prioritization routine is used to determine the best sections to spend the money on using traffic levels as one of the factors, and consequently, many low-volume roads are not included in the resurfacing program on a timely basis. This has a significant impact on the Regions who are charged with maintaining roads that are not in the program. However, to date the SDDOT has not distributed maintenance funds based on the needs within each Region so the Regions with lower volume pavements are forced to spend a greater percentage of their maintenance budget on stopgap treatments due to the longer resurfacing cycle in their region.

The use of the MNI could assist the agency in better estimating the maintenance needs within each Region, perhaps to better distribute available maintenance funds. In this instance, if an overlay is triggered by the pavement management system but not programmed due to traffic volumes, the MNI could be used to estimate the annual cost of maintaining that section. This information could then be used to allocate additional maintenance dollars for these sections or could be used to distribute maintenance funds, as the Montana and Minnesota DOTs do. At a minimum, the index would provide an excellent indication of the unfunded maintenance levels within the Department. To date, this number has proven to be difficult to obtain.

As a Prioritization Tool

Another potential use of the tool is to support the prioritization analysis in the pavement management system. Just as the traffic level is used to prioritize pavement sections in the analysis, the MNI could be used in a similar way. For instance, if the MNI is greater than a particular value, a resurfacing project might be moved up in the priority because maintenance is no longer cost-effective. Various approaches to incorporating the MNI into the benefit/cost analysis could be explored.

If there is enough interest within the Department, this number could be explored further through a separate research project. If explored further, it may provide the missing piece to the analysis of cost-effective maintenance and resurfacing activities.

6.0 RECOMMENDATIONS AND GUIDELINES

The previous chapter presented the findings and conclusions that were generated from the research work on this project. In this chapter, the research team presents the resulting recommendations and guidelines that will guide the SDDOT through the implementation of the research results. The following recommendations are presented for consideration by the Technical Panel.

Condition Ratings and Condition Indices

1.0 Revise the current condition rating process to incorporate the following modifications. These changes address the problems that have occurred in the rating of maintenance patches and recognize a benefit associated with crack sealing.

1.1 For pavement sections that are patched over the entire 0.25-mile survey section, institute a flag in the pavement management database that indicates the pavement is a maintenance patch rather than a resurfacing overlay.

1.2 For sections that are flagged as a maintenance patch, rate the patch by its severity level. Record the extent of the patch as extreme. Also rate any distresses that show through.

1.3 Institute a process that provides the pavement condition raters with a listing of all contract overlays for the previous 3 years prior to the conduct of the surveys. If a section appears to be overlaid, but it is not on the contract overlay list, it should be treated as a patch.

1.4 Consider a QC check that evaluates whether the current condition indices for a 0.25-mile survey section reflect an increase from the previous year's ratings that is greater than two times the standard deviation of the ratings with the maintenance patch flag off. If any pavement sections fall within this category, they should be checked to see if a maintenance patch has been applied. Once a patch flag has been set it will remain in place until a rehabilitation treatment is applied.

2.0 For transverse cracking the current rating method should be modified to incorporate two changes that will facilitate the use of video workstation distress collection.

2.1 Change the distress severity definitions for transverse cracking to include all sealed cracks without depressions as low-severity cracks, rather than limit the low severity definition to cracks that are less than ½ inch in width.

2.2 When the conversion to conducting surveys at the workstation is made, revise the *Visual Distress Survey Manual* to reflect the fact that depressions at cracks will not be able to be viewed by the raters.

3.0 In addition to the recommendations to revise the rating of maintenance patches, the following recommendation is included to help further reduce the problems associated with maintenance patches. This recommendation addresses the gradual transition that occurs when fatigue cracking progresses to the point at which it is patched and represents that transition through a single index. The change will have the added benefit of reducing the number of performance models that must be maintained in the pavement management system.

3.1 Combine the patching and fatigue indices into one index that represents a structural condition index.

4.0 Although not important to achieving the objectives for this research program, another recommendation is provided to help reduce the maintenance requirements for the pavement management system. The effect of this change could be evaluated through the use of existing database information from previous surveys. It is probably best achieved through the conduct of a research project.

4.1 Evaluate the impact of converting to a sampling basis for determining the fatigue cracking, patching, transverse cracking, and block cracking indices. This change would reduce the amount of data storage required for historical information and shorten the length of time required to conduct the surveys.

Pavement Management Analysis Models

5.0 The research found that for the first 3 years after a chip seal had been applied, the pavement deterioration rate was much higher than was typically reflected by the family performance models. The following recommendations address this issue.

5.1 A flag should be added to the database indicating that a pavement has received a chip seal. If the recommendation to change the treatment codes in the historical database to S1, S2, and S3 is accepted, then it is not necessary to add anything to the flag indicating the chip seal number that has been applied.

5.2 Modify the performance model for a pavement with a chip seal so that within 3 years after the chip has been applied, the deterioration rate is accelerated so that it returns to the condition before the chip seal within that timeframe (see figure 5-12). After 3 years, the pavement section should follow the original family model shifted to the apparent age of the pavement. This change should be implemented when the Department converts to the new version of dTIMS™ (dTIMS™ CT) since the newer version of the program allows the user to query the year and type of last treatment applied. The same change should be made in the treatment reset values for chip seal treatments.

To implement this recommendation within the dTIMS™ software detailed recommendation can be found at http://www.deighton.com/tips_dt.htm, dTIMS Tip #19.

5.3 Rename the rehabilitation code for chip seals to include the chip seal number. For instance, the first chip seal should be coded S1, the second chip S2, and the third (or any subsequent) chip should be coded S3.

5.4 The treatment triggers for chip seals should be modified to reflect new age and condition criteria, as shown below.

Chip Seal 1 (S1):

REHAB="" and GAGE_REH≥2≤5 and FTCR≥3.3 and TRCR≥4.4 and BLCR≥3.4 and PTCH≥3.3 and RUT≥3.5

REHAB=C and GAGE_PER=1 and FTCR≥3.3 and TRCR≥4.4 and BLCR≥3.4 and PTCH≥3.3 and RUT≥3.5

Chip Seal 2 (S2):

REHAB=S1 and GAGE_REHAB ≥4≤7 and FTCR≥3.3 and TRCR≥3.5 and BLCR≥3.4 and PTCH≥3.3 and RUT≥3.5

Chip Seal 3 and Subsequent Seals (S3):

REHAB=S2 and GAGE_PER ≥2 and FTCR≥3.3 and TRCR≥3.5 and BLCR≥3.4 and PTCH≥3.3 and RUT≥3.0

REHAB=S3 and GAGE_PER ≥2 and FTCR≥3.3 and TRCR≥3.5 and BLCR≥3.4 and PTCH≥3.3 and RUT≥3.0

5.5 Modify the reset value for transverse cracking to reflect a value of 4.5 after crack sealing has been applied.

5.6 The recommended changes to the reset values for chip seals are included in table 6-1.

Table 6-1. Recommendations for changes to chip seal resets.

Condition Index	**Chip Seal 1 (S1)**	**Chip Seal 2 (S2)**	**Chip Seal 3 and Subsequent Chips (S3)**
Transverse cracking	5.0	Higher of actual value or 4.5	Higher of actual value or 4.5
Fatigue cracking	No change	No change	No change
Patching	No change	No change	No change
Block cracking	5.0	Higher of actual	Higher value of

		value or 4.3	actual value or 4.3
Roughness	No change	No change	No change
Rutting	No change	No change	No change

Figure 6-1 provides a graphical example of applying the resets from recommendation 5.6 and the performance curves described in recommendation 5.2.

5.7 The treatment triggers and reset values should be reviewed regularly to ensure that actual performance trends are being reflected in the models. One possible modification that could be investigated is the influence of PG binders on cracking. Field Office personnel reported that the new binders are showing reduced cracking so the triggers for some maintenance treatments could be revised to reflect this change if a statistical analysis of the data over time warrants it.

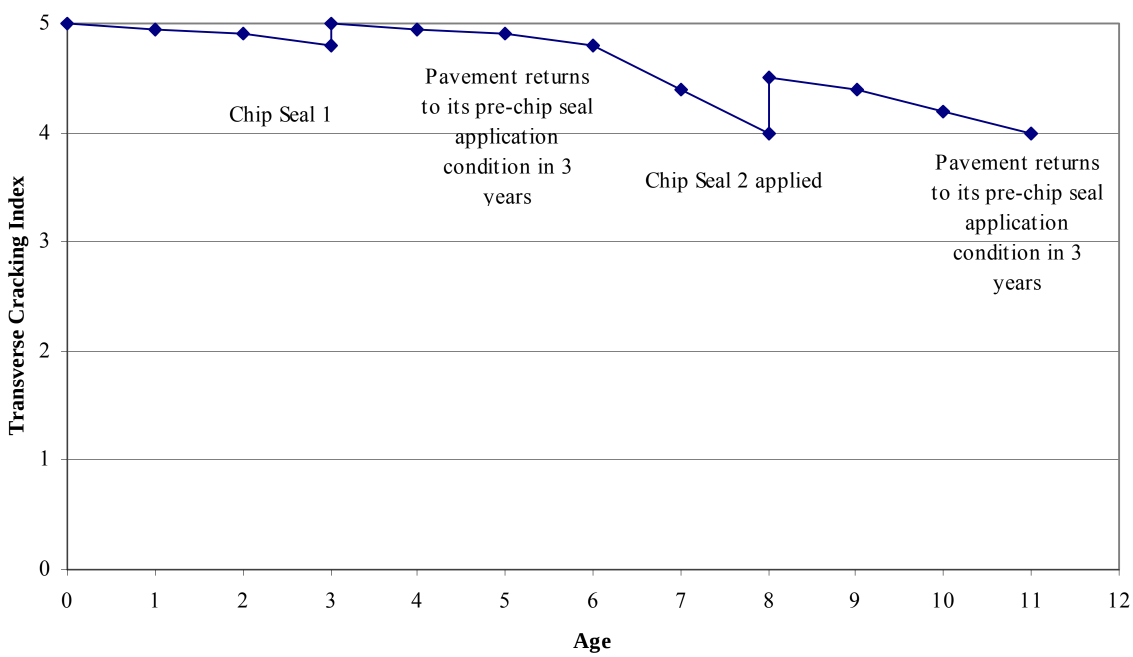


Figure 6-1. Example of application of reset values and performance curve modeling from recommendation 5.6 and 5.2 respectively.

Coordinating and Exchanging Information

6.0 As an agency, the SDDOT should initiate a study to reconsider its funding allocation for maintenance to be based more on a needs basis. This would allow the Department to address the increasing maintenance needs of those Regions with lower volume roads that are not getting into the resurfacing program. It could also be used as a strategy to encourage preventive maintenance activities such as the timely application of third chip seals on pavements that are performing well, which might not be addressed if maintenance funding is tight. Items to consider include:

  6.1 Use of a Maintenance Needs Index as a tool to help determine the cost-effectiveness of maintenance activities on low volume pavements, to help prioritize resurfacing needs within the State, or reallocate funding for maintenance based on need.

  6.2 Establishment of a separate funding source to program third chip seals that meet the trigger criteria to preserve pavements that are performing better than average.

7.0 Have the Pavement Management Unit provide to the Field Office personnel a list of chip seal candidate projects for use in their maintenance programming activities to supplement the map that is currently distributed showing date of last seal.

8.0 Implement a process for Field Office personnel to report to the Pavement Management Unit all maintenance patch locations and lengths and chip seal projects.

9.0 Provide a brief overview of the pavement management system on an annual basis to individuals from the Field Offices. Solicit comments and suggestions from them that might improve the analysis models or the condition rating procedures based on actual data and/or current procedures. The Train-the-Trainer course materials provided as part of this project should satisfy the need for the next year or two.

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YANKTON AREA RESURFACING LOG

ROUTE	LOCATION	From: MiPo	To: MiPo	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2009	2009	2010	ADDITIONAL NOTES:
11		8.500	14.100																					OL			CR S	CH S	CH S			CH S													
11		23.460	34.512															OL						CR S	CH S					CH S															HOLD FOR OVERLAY 2003
11		34.512	39.500																								OL		CR S	CH S				CH S												
11		39.500	48.500								OVERLAYED IN 1975																																							GRADING 2004
18		373.940	387.700										OL							CH S													OL		CH S												
18		387.700	389.510													OL												CH S					CH S														HOLD FOR RECONSTRUCTION 2005
18		389.510	402.770													OL												CH S					CH S														HOLD FOR RECONSTRUCTION 2005
18		402.770	403.760										OL										CH S										OL													
18		403.760	419.820										OL										CH S										OL													CHIP SEAL 2002 (MAINT ?)
18		419.820	420.810																					OL		CR S	CH S					CH S														CHIP SEAL 2002 (MAINT ?)
19		0.000	5.29 (?)																																OL										NEW MAT 2001
19		4.500	4.730				OL																																								RECONSTRUCT
19		4.730	5.822				OL														CH S																										MRM 4-16 2003
19		5.822	18.400				OL														CH S																										MRM 16-25 2003
19		18.400	25.280				OL														CH S																										
19		31.260	33.123																				OL		CR S		CH S					CH S														OVERLAY W/ S. FALLS
19		33.123	43.260																				OL		CR S		CH S					CH S														OR CHIP 2003
19A		25.280	27.630																OL				CR S	CH S						CH S																	LET GO FOR OVERLAY?
19A		27.630	33.438																OL				CR S	CH S						CH S																	
25		7.500	10.150																			OL						CH S				CH S		CH S											OVERLAY OR CHIP
25		10.150	21099.000																			OL						CH S				CH S														2003
25		21.990	27.029																			OL						CH S				CH S														
29 Loop		6.500	8.900																					OL		CR S		CH S						CH S										
29 N	SHOULDER	0.050	2.220											JR					CH S													OL														SEAL SHOULDERS 2003
29 S	SHOULDER	0.050	2.220											JR					CH S														OL	RECONSTRUCTED 98-99										
29 N	SHOULDER	2.220	4.640											JR					CH S													OL														
29 S	SHOULDER	2.220	4.640											JR					CH S														OL													
29 N	SHOULDER	4.640	9.510																										?																	CRC 2005
29 S	M.L.	4.640	9.510																										?					M											RESURF L.R.
29 N	SHOULDER	9.510	15.114																										?																	CRC 2005
29 S	M.L.	9.510	15.114																										?					M											RESURF L.R.
29 N	SHOULDER	15.114	21.291																										?																	CRC 2005 TO EXIT & 2006 TO 19
29 S	M.L.	15.114	21.291																										?					M											RESURF L.R.
29 N	SHOULDER	21.291	27.436											OL								JR						OL		JR,G			E											CRC 2006+
29 S	SHOULDER	21.291	27.436											OL								JR						OL		JR,G			E											CRC 2007+
29 N	SHOULDER	27.436	37.320																								JR		G																	CRC 2002
29 S	SHOULDER	27.436	37.320																								JR		G																	CRC 2001
29 N	SHOULDER	37.320	45.303																							JR	OL				JR,G														CRC 2007+
29 S	SHOULDER	37.320	45.303																							JR	OL				JR,G														CRC 2006+
29 N	SHOULDER	45.303	47.310																					JR	OL						JR,G														
29 S	SHOULDER	45.303	47.310																					JR	OL						JR,G														
29 N	SHOULDER	47.310	55.325																					JR		OL							OL		MAINLINE OVERLAY										CRC L.R.
29 S	SHOULDER	47.310	55.325																					JR		OL							OL											
29 N	SHOULDER	55.325	59.340																					JR		OL							OL											
29 S	SHOULDER	55.325	59.340																					JR									OL											
37		0.000	5.000																													OL		CR S	CHS									
37		5.000	10.300																													OL		CR S	OL									NEW ALIGNMENT 2000 & NEW MAT 2001
37		10.300	20.440																								OL		CR S	CHS				CHS										
37		24.440	36.400															OL					CHS							CHS			CHS*	CHS										
37		36.400	39.071															OL					CHS							CHS				CHS										OVERLAY?
37		39.071	41.630															OL					CHS							CHS				CHS										
44		348.600	362.566																				CR S				OL		CR S	CHS					CHS									
44		362.566	377.890																				CR S					OL		CR S	CHS				CHS									
44		377.890	378.890																									OL		CR S	CHS				CHS									
44		378.890	385.943																									OL		CR S	CHS				CHS									
44		385.943	392.225																			OL				CHS				CHS			CHS												OVERLAY?
44		392.225	392.801																	OL						CHS				CHS			CHS												
44		392.801	395.820																					OL		CR S	CHS					CHS														CHIP 2003
46		297.270	298.510																			OL		CHS						CHS															OVERLAY 2003
46		298.510	305.600																			OL		CHS						CHS															
46		305.600	318.500																					CHS						CHS															HOLD FOR OVERLAY
46		318.500	322.440																											OL				CHS										CHIP 2005
46		322.440	325.220																											OL				CHS										
46		325.220	334.560																			OL							CHS				CHS		CR S									NEW BRIDGE 2002
46		334.560	346.630																									CHS					CHS		CR S									
46		346.630	350.640												OL												CHS							OL	OL									
46		350.640	356.600												OL												CHS							OL	OL									
46		356.600	364.590										OL																		OL				CHS									
46		364.590	365.580										OL																					JR											NEW PCCP 2000
5 (Concrete Benesford)		365.580	366.574																															JR											
46		366.574	382.673																						OL		CR S		CHS				CHS											
48		371.890	384.234																OL						CHS				CHS				CHS										

YANKTON AREA RESURFACING LOG

ROUTE	LOCATION	From: MiPo	To: MiPo	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2009	2009	2010	ADDITIONAL NOTES:
50		337.660	343.051																						OL			CHS					CHS		CR S										
50		343.051	343.520															OL					CHS					CHS					CHS	OL											CRACK SEAL 2002
50		343.520	354.301															OL					CHS						CHS					OL											
50 (Concrete)		354.301	355.810																					JR,G																					
50 (Concrete)		355.810	357.140																					JR,G																					OVERLAY 2003
50		357.140	368.121																					JR,G																					
50		368.121	370.800																							JR								OL											
50		370.800	378.350																							JR								OL											
50 (Concrete)		378.350	381.502																							JR								OL											CRACK SEAL 2002
(*note 382.92 = US81)		381.520	383.830																					JR		JR																			
50		383.830	385.790																JR																										
50	SHOULDER	385.790	386.779																															OL											CRACK SEAL 2002
50	SHOULDER	386.729	388.240									OL															JR,G							OL											
50 E	SHOULDER	388.240	389.024									OL															JR,G							CHS											
50 W	SHOULDER	388.240	394.135									OL															JR,G							CHS											
50 E	M.L.	389.024	391.752																						OL				CHS					CHS											RECONSTR.
50 E	SHOULDER	391.725	392.785																								JR,G							CHS											
50 E	M.L.	392.785	396.040																						OL		CR S		CHS					CHS											RECONSTR.
50 W	SHOULDER	394.084	396.040																						JR,G		OL							CHS											
50 E	SHOULDER	396.040	400.894																						JR,G	OL								CHS											OVERLAY 2003
50 W	SHOULDER	396.040	396.589																						JR,G		OL							CHS											
50 W	M.L.	396.589	405.965																						OL		CR S		CHS					CHS											RECONSTR.
50 E	SHOULDER	400.894	406.672																						JR,G	OL																			OVERLAY 2003
50 W	M.L.	405.965	406.384																						OL		CR S		CHS					CHS											RECONSTR.
50 E	SHOULDER	406.672	407.100													OL																													
50 W	SHOULDER	406.384	407.100													OL																													REHAB OR
50		407.100	407.975					CONCRETE																																					OVERLAY 2001
50		407.975	408.619					CONCRETE																																					
50		408.619	410.170					CONCRETE																																					
50 E		410.810	416.170																										OL	CR S	CHS														
50 W		410.810	416.170											OL				CHS																OL											RECONSTRUCT 2006+
50 E		416.170	416.670																										OL	CR S	CHS			OL											
50 W		416.170	416.670											OL															OL	CR S	CHS			OL											
50		416.670	416.965																										OL	CR S	CHS			OL											
50		416.870	423.590					CONCRETE																	417.31-417.55 = NEW CONCRETE 1990								OL	CR S											CHIP SEAL 2003
50		423.590	426.423																					OL			CR S	CHS				CHS													
50 LOOP W		406.170	407.300																						OL		CR S	CHS						CHS											
50 LOOP E	M.L.	406.650	407.300																						OL			CHS						CHS											CHIP SEAL 2005
50 LOOP	M.L.	407.300	408.430																						OL			CHS						CHS											
50 LOOP		408.430	409.920											OL											RECONSTRUCTD IN 1997 (407.8-408.5 +OR-)																				
50 LOOP		409.920	411.180					CONCRETE																																					OVERLAY IN 2003?
50 LOOP E	M.L.	411.180	411.480																										OL	CR S	CHS														
50 LOOP W	SHOULDER	411.180	411.480											OL																															
52		315.000	327.320					OL																			CHS						OL												NO CRACKS 7/13/00
52		332.240	337.300																			OL					CHS					CHS													
52		337.300	342.460																			OL					CHS					CHS													RECONSTRUCT 2005
52		342.460	342.960																			OL													CHS										
52		342.960	343.762					CONCRETE																																					
81		4.224	6.285											OL								CHS																							RECONSTRUCT 2001
81		6.285	12.360																										OL	CR S	CHS														CHIP SEAL M.L. AND SHLDRS 2002
81		12.360	15.449					CONCRETE																																					PCCP 2001
81		15.449	21.480					CONCRETE																						JR															
81		21.480	23.659					CONCRETE																						JR															
81		23.659	30.157					CONCRETE																					JR																
81		30.157	35.276					CONCRETE																									JR												
81	SHOULDER	35.226	46.410					CONCRETE																					OL																CHIP SEAL SHLDRS 2001
81	SHOULDER	46.410	49.292					CONCRETE																					OL																
105		2.480	3.460					CONCRETE																																					
105		3.460	3.640					CONCRETE																																					
105		3.640	5.606																				OL		CR S			CHS																	
105		5.606	5.940																				OL		CR S			CHS				TRANSFERRED TO COUNTY 1998													
105		5.940	10.360																				OL		CR S			CHS																	RECONSTRUCT 2003
105		10.360	11.074																				OL					CHS																	
153		1.250	3.619																											OL	CR S			CHS											CHIP SEAL 2005
314		378.330	382.447			OL																												OL											CRACK SEAL 2002

LEGEND

NEW CONCRETE OR REPAIR	JR , G
OVERLAY	OL
CRACK SEAL	CR S
CHIP SEAL	CH S
MICROSURFACING	M
EVERYTHING BUT MICRO	*E*

* DENOTES SHOULDERS ONLY