KICEM Journal of Construction Engineering and Project Management
Online ISSN 2233-9582

www.jcepm.org
http://dx.doi.org/10.6106/JCEPM.2017.3.30.030

# Practical Approach for Pavement Treatment Decisions for Local Agencies

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***Abstract: Most local agencies such as counties and small cities continuously express difficulties in making technically and financially defensible decisions on their pavement infrastructure maintenance and rehabilitation. Unlike pavement systems managed by state highway agencies, the total lane-miles of many local pavements are significantly short and they are managed by a limited number of staff who typically have multiple responsibilities. Most local agencies also do not have historical pavement performance data and the lack of a systematic decision making framework exacerbates the problem. A structured framework and an easily accessible decision support tool that reflects their local requirements, practices and operational conditions would greatly assist them in making consistent and defensible decisions. This study fills this gap by developing a systematic pavement treatment selection framework and a spreadsheet based tool for local agencies. It is expected that the proposed framework will significantly help local agencies to improve their pavement asset management practices at the project level.***

***Keywords: Pavement maintenance, Local agencies, Pavement management, Project level management, Treatment selection***

## I. INTRODUCTION

The American Society of Civil Engineers (ASCE) estimates that $170 billion in capital investment is needed annually to improve the nation's roads infrastructure which are graded with poor grade D [1]. Thus, state highway agencies (SHAs) need to work diligently to smartly manage their pavement assets under strict and constrained funding availability. Local agencies are even facing more challenges since 75% of the nation's roadways are owned by those agencies [2]. This simple fact drives the need for developing tools and methods that should be specifically designed to meet local agencies' needs and requirements. However, due to relatively small sizes of pavements managed by local agencies and lack of resources, local pavements have been seriously neglected from the application of optimized pavement treatments over their life cycle. The federal highway administration [2] also points out that local agencies have limited resources and the standards used for assessing the performance of local pavements are different and vary across local agencies, hence, a different management approach is much needed.

During the decision making process, local agencies need to have a defensible framework to select the most appropriate treatment for a pavement under consideration. The selected treatment option must be technically feasible, cost effective, and it should offer the highest possible return on investment (ROI) among the feasible group of treatments. Many departments of transportation (DOTs) have developed some matrix-based tools and computerized decision tools to identify feasible treatment options when the pavement conditions are given [3, 4 and 5]. However, these tools fall short of fulfilling the needs and limitation of local agencies. State highway agencies (SHAs) are far advanced in terms of implementing pavement asset management systems when compared to local agencies because of the data collected over the past years, financial resources, and continuous asset management implementations. Additionally, many local agencies are different as most of them do not collect pavement condition data regularly and have limited experience with a limited number of staff.

This study aims at developing a practically working approach to pavement treatment decision for local agencies by addressing their critical needs and requirements. The study has been conducted with local agencies in Iowa but the framework and the tool developed in this study can be adapted by any local agency with reasonable adjustments to reflect the agency's unique business environment and practices. This framework is expected to greatly assist local agencies in enhancing their pavement asset management to achieve the agency's long term goal of implementing a comprehensive asset management.

## II. PRIOR STUDIES

There are rich domestic publications in the areas of pavement management systems, pavement treatments, decision support models for pavements, pavement deterioration process, and life cycle cost analysis. However, there are few publications on these topics for local agencies.

Early in the nineties, researchers recognized the importance of pavement management systems for local governments and small communities. Tavakoli et al. [6] developed a user-friendly pavement management system for small communities that consists of seven modules that cover inventory data, condition data, maintenance and

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rehabilitation strategies, cost data, and deterioration rates. The maintenance and rehabilitation module uses the pavement condition index to establish the appropriate strategy such no maintenance, routine maintenance, preventive maintenance. Afterward, Lee and Deighton [7] developed an infrastructure management system for small public agencies “dROAD” that accommodates different types of infrastructure assets such roads, railways, or network of pipes. dROAD can also provide agencies with a methodology to determine the most cost effective maintenance and rehabilitation strategies.

Additionally, it is found that some local agencies have developed their own programs and approaches to managing their pavement assets. For example, the Cole County, Missouri considered using a commercial asset management program because of the agency’s dependence on the experience of its personnel and to comply with the provisions of GASB statement 34. However, adopting a commercial software package would be costly and require periodic staff training. As a result, the County decided to develop a simple and easy to use spreadsheet model to evaluate upcoming maintenance needs by reviewing the pavement condition data and performance predictions curves [2]. Similarly, the City of Redmond, Washington developed an asset management system that includes streets, signs, curbs and gutters, and right of way using a geographic information system. The City of Redmond conducts condition assessment every two years using visual inspection to capture different distresses such as potholes, alligator cracks, and other types of cracks [2].

In Utah, Cottrell et al. [8] developed a transportation infrastructure maintenance management system that uses the Utah DOT’s preventive maintenance strategy for low volume roads for a small city. However, the maintenance strategy adopted is rigid and limited since the system recommends specific treatments at a predetermined age such as applying a structural overlay at year 23. The Utah Local Technical Assistance Program (LTAP) center developed a pavement management system to support local agencies to manage their road networks [9]. The Utah LTAP helps Cities and Counties implement pavement management systems by providing GIS-based inventory, condition survey of the road network, and treatment costs [9]. The Utah LTAP also collects the severity and extent levels for potholes, utility cuts, rutting, transverse cracking, longitudinal cracking, block cracking, edge cracking and alligator cracking for asphalt pavements. Afterward, a governing distress is determined based on the severity and extent levels to select an effective treatment.

In Wisconsin, the DOT officials help local agencies to manage their roadway assets by creating a web-based geographic information system that would provide local agencies with accurate pavement condition data [10]. Local agencies that used the web-based system reported some barriers such as lack of training, road segment divisions, and poor internet connection were reported [11]. In Michigan, Silva et al. [11] recognized that local government agencies faced different challenges and they developed deterministic pavement performance models for local agencies.

Wolters et al. [12] developed a pavement management systems implementation guide for local agencies in Illinois. It is found that agencies select pavement treatments based on treatment rules, triggers such as pavement age or cyclical treatment application. Wolters et al. [12] also reported that Champaign County uses a treatment matrix based on the Pavement Condition Index [PCI] and Rolling Weight Deflectometer (RWD) to select an effective treatment method such crack sealing, chip seal, microsurfacing, asphalt overlay and reconstruction while the City of Macomb uses a customized rating system to select the appropriate maintenance or rehabilitation strategy. Similarly, Douglas [13] developed a pavement management system for local governments that overcomes local issues such as data collection limitation and lack of expertise.

At the state highway agency level, many DOTs have developed and used a decision aid tool such as decision tree or a matrix-based method to facilitate the decision making process including some computerized tools as well. Hicks et al. [14] provided a set of examples of those decision tree and matrix-based methods for flexible pavements used by various state DOTs. Jahren et al. [4] developed a decision matrix for flexible pavement preservation treatments for Iowa DOT. Similarly, Michigan DOT [15] developed a capital preventive maintenance manual that helps select the appropriate preventive maintenance treatment method which considers several factors such as remaining service life and distress index, and international roughness index (IRI). Minnesota DOT [16 and 17] developed decision trees for rigid and flexible pavements that offer one of four decisions, which are preventive maintenance, rehabilitation, reconstruction, or do nothing. Illinois DOT [3] developed a decision making matrix for treatment selection to preserve the pavement investment and to maintain a high level of service. Feasible preservation treatments are identified based on the gathered pavement information, such as pavement type, pavement age, design life, traffic, and pavement materials. The selection of the most appropriate treatment is subject to several constraints such as the availability of qualified contracts, initial costs, facility downtime, and availability of quality materials. Similarly, South Dakota DOT [18] developed treatment selection guidelines for rigid and flexible pavements that is based on the type of distress, severity of distress and its extent.

It is concluded that the frameworks and methodologies used by DOTs are different from local agencies. Additionally, each agency has developed its own tools to fit their requirements and needs. As such, local agencies need to have their own tools that incorporate their needs and requirements as well.

## III. Research Methodology and Framework

A systematic research methodology is adopted to create the treatment selection tool. This methodology can be easily adopted and modified so other local agencies can develop their own frameworks. First, a statewide questionnaire survey is distributed among local agencies personnel to document their experience, needs and capabilities. The second step is to develop a logical and sequential process that recommends technically feasible treatment when the existing conditions are known. This logical process can be in a form of a decision tree, decision matrix or any other decision support tool. Then, a process of evaluating the economic and non-economic factors is developed in order to achieve the highest ROI. Finally, the aforementioned steps are augmented in one spreadsheet tool and validated by using case studies and expert panel reviews.

Based on the proposed methodology, a treatment selection spreadsheet tool that mainly contains four modules is developed as shown in Figure 1. The first module aims at assessing a treatment's technical feasibility to address specific distresses. The technical feasibility data is gathered by scanning the practices of neighboring agencies. Additionally, the life expectancies and cost data reported by local agencies are also archived in the spreadsheet tool. Afterward, a statewide questionnaire survey is conducted to determine the common existing distresses and treatments applied by the Iowa local agency to reflect their needs, requirements and experiences on the treatment selection tool. Follow-up phone and email interviews are then conducted with local agencies to gather information about their pavement treatment decision making processes. Treatment selection decision trees for both asphalt and concrete pavements are developed and embedded in the spreadsheet tool. The second module aims at evaluating the cost effectiveness of technical feasible treatments by examining the life cycle costs and estimating the ROI for each decision. The third module aims at evaluating non-economic factors such as user experience, ride quality and environmental effects in the decision making process. The non-economic evaluation of treatments uses the Analytical Hierarchy Process (AHP) or the Multi Attribute Utility Theory (MAUT) to determine the weight of importance for each selection parameter. Finally, the fourth module is focused on gathering information and analysis results from the other modules to generate a summary sheet that local agencies can use to document and defend their decisions if necessary. Finally, the aforementioned procedures are combined to form a user-friendly spreadsheet-based treatment selection tool. The tool developed is validated using case studies and thorough expert panel reviews during and after the framework development.

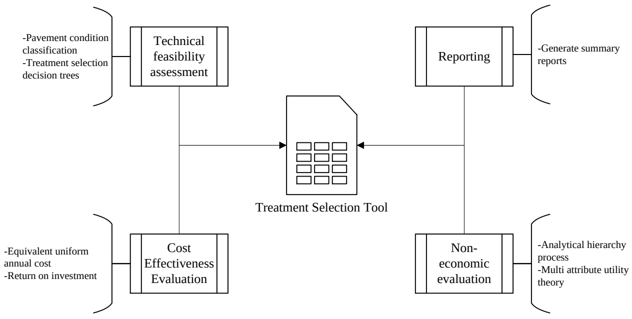



FIGURE I
PAVEMENT TREATMENT SELECTION TOOL MODULES

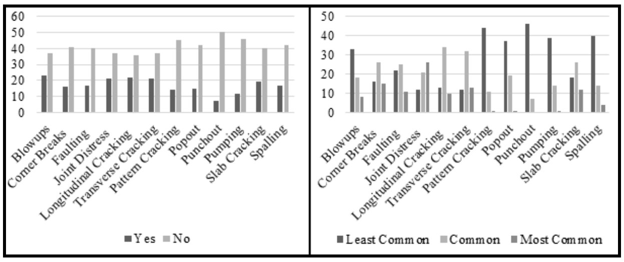
## IV. QUESTIONNAIRE SURVEY

An electronic questionnaire survey is conducted to understand the locals' practices, needs, and determine the most prevailing pavement distresses in Iowa. The survey consisted of fifteen questions related to pavement distress data collection, common preservation and rehabilitation treatments applied, and decision making processes. The survey was distributed to City and County engineers. The total number of responses were 74. However, the responses were mainly from Cities and Counties that cover the majority of the local pavement network in Iowa.

In terms of distress data collection, participants were asked to report data collection processes and existing common distresses. It is found that on average, 70% of the respondents do not collect distress data. The distresses included in the questionnaire were based on the common distresses found in Iowa and other generally common distresses. Ten types of Asphalt Concrete (AC) distresses were included while 14 types of Portland Cement Concrete (PCC) distresses were included in the survey. Figures 2 and 3 show the pavement distress data collected and the least common, common, and the most common pavement distresses for rigid and asphalt pavements. The survey respondents indicated that longitudinal cracking, joint distress, and blowups were the most common pavement distress data collected. At the same time, the respondents indicated that joint distress was the most common pavement distress while punch-out was the least common pavement distress. Similarly, respondents indicated that transverse cracking, longitudinal cracking, rutting, and alligator cracking were the most common pavement distress data collected for flexible pavements, while friction, flushing/bleeding, oxidation, and roughness were the least. The survey also revealed that transverse cracking was the most common flexible pavement distress while flushing/bleeding was the least common (Figure 3).

Participants were also asked to indicate the use of different treatments for rigid pavements to assess the familiarity of local engineers to different treatments to integrate those treatments in the decision support tool. Figure 4 shows common rigid pavement treatment applications as reported by survey respondents. Five preservation/maintenance treatments for rigid pavements were included in this survey. The respondents indicated that crack sealing and joint sealing were the most used preservation treatments for rigid pavements. Also, among seven rehabilitation treatments included in this survey, local agencies indicated that full depth repairs, hot mix asphalt [HMA] overlay with crack and seat, slab stabilization, and unbonded concrete overlay were the most commonly used rigid pavement rehabilitation treatments.

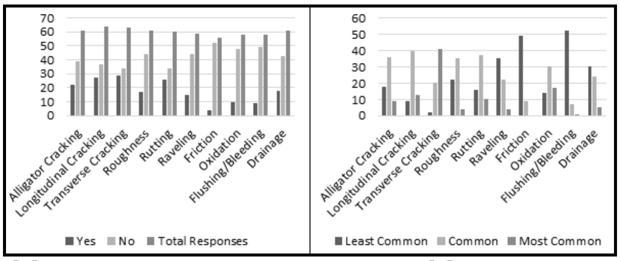
Similarly, twelve AC preservation and maintenance treatments were included in the survey [see Figure 5]. Respondents indicated that crack filling, crack sealing, chip seal, and slurry seal were the most commonly used flexible pavement preservation and maintenance treatments. On the other hand, responses showed that chip seal over textile, open graded friction course, microsurfacing, fog seal, scrub seal, sand seal, and cape seal were not widely used by local agencies in Iowa. Additionally, seven AC rehabilitation treatments were included in the survey. HMA overlay, cold milling with an HMA overlay, whitetopping, and cold in-place recycling were the AC rehabilitation treatments most applied. On the other hand, Novachip and hot in-place recycling were the least used.




[A] DISTRESS DATA COLLECTION [B] LOCAL AGENCIES FAMILIARITY WITH DISTRESSES

FIGURE II

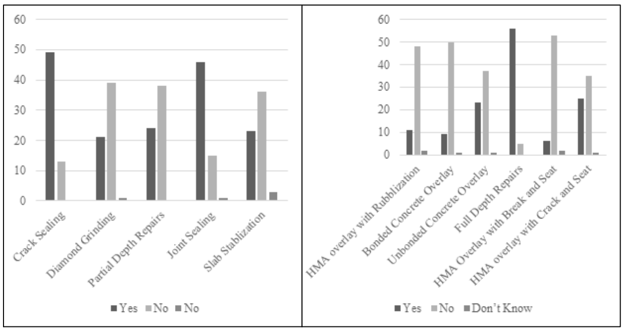
RIGID PAVEMENT DISTRESS DATA COLLECTION AND FAMILIARITY




[A] DISTRESS DATA COLLECTION [B] LOCAL AGENCIES FAMILIARITY WITH DISTRESSES

FIGURE III

ASPHALT PAVEMENT DISTRESS DATA COLLECTION AND FAMILIARITY

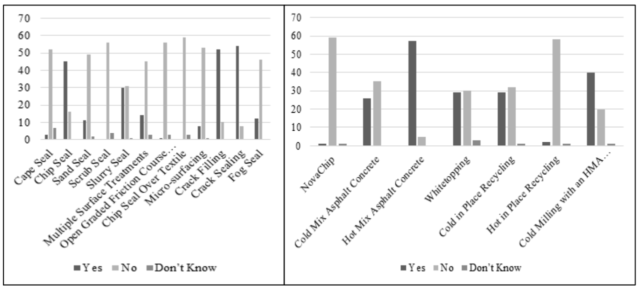



[A] MAINTENANCE TREATMENTS [B] REHABILITATION TREATMENTS

FIGURE IV

APPLICATION OF MAINTENANCE AND REHABILITATION TREATMENTS FOR CONCRETE PAVEMENTS

One of the objectives of the survey was to investigate the current usage of decision support systems or procedures adopted by local agencies. Thus, participants were asked to indicate if any level of service indicators [LOS] or decision-making procedure was used. The majority of the respondents indicated no use of LOS indicators while 21% of the respondents indicated the use LOS indicators. Additionally, 49% of the respondents indicated the utilization of a decision-making procedure to select the most appropriate treatment method. A follow-up survey was conducted with those respondents to examine the use of decision support systems and LOS indicators. One County indicated that pavement condition index (PCI) was used to prioritize pavement rehabilitation work. Additionally, visual inspection was typically used to determine which preventive maintenance should be applied for older pavements. Finally, a simple weighted scoring method that considers PCI, traffic and pavement age was used to select candidate roads for rehabilitation. Another county reported the use of a weighted scoring method to prioritize road segments for full overlay or resurfacing needs. The county used indicators such as structural condition, surface condition, traffic volume, truck volume, federal aid eligibility, total project cost per mile, nearest alternate road, current total thickness, age of current surface in the decision making process. Other counties reported that they relied on visual inspection on semi-annual bases, personal experience and cyclical treatment application.




[A] MAINTENANCE TREATMENTS [B] REHABILITATION TREATMENTS

FIGURE 5 APPLICATION OF MAINTENANCE AND REHABILITATION TREATMENTS FOR ASPHALT PAVEMENTS

## IV. ASSESSMENT OF TECHNICAL FEASIBILITY

The technical feasibility module is developed based on the survey results and practices of neighbouring agencies. Figure 5 shows a worksheet to select technically feasible treatments for flexible pavement. First, existing distresses for the pavement under study are collected and identified. This step includes collecting distress severity, and extent level data for each distress. For the treatment selection tool, four major distresses for flexible pavements are considered while five distresses for rigid pavements are considered. Alligator cracking, longitudinal cracking, transverse cracking, and rutting are the flexible pavement distresses considered in the proposed tool. On the other hand, the rigid pavement distresses considered for the analysis are longitudinal cracking, transverse cracking, D-cracking, joint spalling, and faulting. Additionally, roughness and friction condition data are considered in the treatment selection process. The collection of the friction data is expensive and many local agencies do not have friction data available. As a result, friction data is considered a secondary input in the process. This means that agencies can assume good/bad skid resistant and still use the proposed tool.

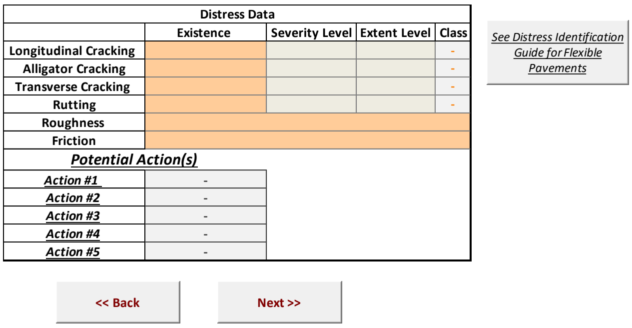



FIGURE V
Selection of technically feasible treatments for flexible pavements

For the aforementioned distresses, three levels of quantitative and qualitative severity and extent levels are identified. The qualitative identification is intended to be used by local agencies that do not collect pavement distress data and heavily rely on visual inspection. As for agencies that collect pavement distress data, quantitative measures are identified based on the Long Term Pavement Performance (LTPP) distress identification manual [21]. However, the quantitative measures are modified after discussions with an expert panel that consists of City and County engineers to reflect their experiences. As for roughness and friction data, only two qualitative levels are identified. It is found that ride quality expectation varies from one agency to another and hence it is decided to use qualitative measures for ride quality.

After determining distresses under consideration and their threshold values, pavement condition needs to be classified to facilitate the treatment selection process for local agencies. Pavement condition is classified into three classes. The first class indicates a highly deteriorated pavement that requires a rehabilitation treatment or reconstruction. The second class indicates a moderately deteriorated pavement that may require a rehabilitation or routine maintenance treatment to address the existing distresses. Finally, the third class indicates a slightly deteriorated pavement that may not require immediate action. However, it is preferred to apply a maintenance or a preservation treatment to extend the pavement service life.

The treatment classification is used along with pavement roughness and friction condition to develop the systematic treatment selection decision trees. A total of six treatment selection decision trees are developed for both flexible and rigid pavements to help local agencies select the technically feasible treatments. The proposed decision trees for rigid pavements consider the type of pavement whether it is jointed plain concrete pavement or continuously reinforced concrete pavement. Additionally, the decision trees consider whether the existing distresses are localized or uniformly distributed through the pavement section under consideration. For localized distresses, the tool recommends localized treatments such as patching instead of surface treatments.

## V. Assessment of Cost Effectiveness

The next stage after determining a set of feasible treatments is to evaluate the cost effectiveness for each treatment (see Figure 6). The assessment of the ROI for each treatment is essential to evaluate the economic effectiveness for competing alternatives. In this study, the ROI is calculated by comparing the Equivalent Uniform Annual Cost (EUAC) of the alternative to the EUAC of the do nothing alternative which is a pavement reconstruction or major rehabilitation in the near future. The calculation of the EUAC is given in equation 1

$$EUAC = P \times \frac{i(1+i)^n}{(1+i)^n - 1} \qquad (1)$$

where P is the total treatment cost at the year of application, i is the discount rate, and n is the extended pavement service life. Local agencies should use their historical cost data to accurately estimate the treatment costs.

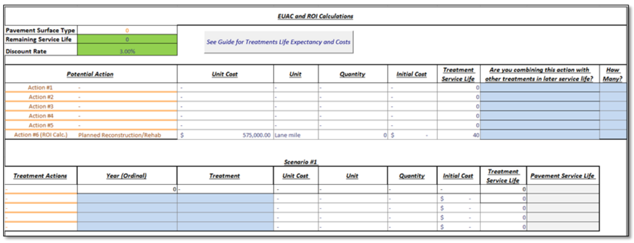



FIGURE VI
Assessment of cost effectiveness

The EUAC is used to evaluate the cost effectiveness There is no clear consensus on how to determine the analysis period for a life cycle cost analysis [22]. It could be the shortest service life among treatments, the longest service life among treatments, the least common multiple of the lives of the treatments, standard analysis period, or infinite long. As such, the tool uses the EUAC to evaluate the cost effectiveness of different treatments as it presents a fair comparison between different alternatives with different service lives.

Next, local agencies need to specify a Discount rate to calculate EUAC for the alternatives under study. A discount rate of 3.5 percent as a default is recommended to calculate the EUAC based on other highway agencies' practices and studies. However, the discount rate may vary from one agency to another as evidenced by several studies [23] and [24]. The treatment selection tool allows the users to specify the desired discount rate that conforms with the agency's policies. Additionally, local agencies can run a sensitivity analysis to evaluate the effect of different discount rates on the overall economic effectiveness in the tool.

After calculating the EUAC for each alternative, the ROI is calculated. The ROI of preservation or maintenance treatments can be estimated by calculating how much the local agency would save by delaying the road rehabilitation or reconstruction compared to a do nothing alternative. A decision based on the EUAC and ROI can be made by ranking the alternatives with the ROI values.

The assessment of cost effectiveness module also allows users to build future treatment application scenarios on applying maintenance or rehabilitation treatments in the future after addressing the existing distresses. This allows users to realize the benefits of a long range life cycle cost analysis on the pavement section. The assessment of cost effectiveness module is linked with a spreadsheet that contains the expected service lives and treatments costs. The service life and cost data can be adjusted to accommodate the escalation of prices or reflect the agency's experience regarding the performance of treatments. This module also allows users to define new treatments that are not originally included.

## VI. ASSESSMENT OF NON-ECONOMIC FACTORS

In some cases, local agencies may consider other non-economic factors and hence the economic evaluation may not be sufficient. As such, there is a need to include a non-economic selection process to enhance the capabilities of the proposed tool. Treatment performance, user satisfaction, procurement and contracts, and environmental sustainability are the non-economic factors considered in this study. A scoring method is developed to differentiate between the non-economic values of the technically feasible treatments. The selection factors to consider are determined based on the treatment selection framework developed by Hicks et al. [16] and Caltrans [25].

The performance category includes pavement structure improvement, performance under heavy traffic loading, and performance under average daily traffic. For example, treatments with positive impact on the pavement structure would be more favourable over other treatments. User satisfaction is the second selection category in the scoring process that includes facility downtime, road closure, or traffic disruption, impact on roughness, impact on friction, and tire/road noise. The facility downtime, road closure, or traffic disruption factor have an impact on user satisfaction. For example, treatments that require less closure time may be favourable over other treatments to minimize extra travel time due to detours.

The third category in the scoring process is procurement and contracts, which includes availability of qualified contractors and availability of quality material. In some cases, the availability of qualified contractors or quality construction materials is limited and a local option might be more favourable. The last category in the scoring process is environmental sustainability which considers greenhouse gas emissions and other negative environmental impacts.

A score and a weight have to be assigned to each selection parameter to calculate the overall score for each alternative. The importance for each factor is subjective to each agency's policy. As a result, a structured process for determining the weights for each selection factor is needed.

The AHP developed by Saaty [26] has been widely used in many decision-making applications. The AHP is characterized by providing a consistent decision-making process [27] that can help decision makers set priorities and select the best decisions. The AHP is designed to represent complex models in a hierarchical structure. Additionally, the AHP is able to handle both quantitative and qualitative attributes [28]. Therefore, the scoring system uses a two-staged AHP. The first AHP stage is used to determine the weight of each of the aforementioned categories while the second AHP stage is used to determine the weight of each factor under each category. The use of the two-staged AHP facilitates the process of developing a pairwise comparison between similar criteria while maintaining an acceptable level of consistency.

The assessment of non-economic factors module allows users to conduct a pair-wise comparison easily as shown in Figure 7. A drop-down list is embedded in the spreadsheet to allow users to specify the level of importance of one category relative to another category using a scale from one to nine where one represents the lowest level of importance and nine represents the highest level of importance. For example, if "Performance" is considered seven times more important than "Procurement and Contracts" in terms of selecting the right pavement treatment on a specific project, the user would select a score of seven from the dropdown list.

*1. High Level Weighing Process*

| Category | Performance | Procurement and Contracts | Environmental Sustainability | User Satisfaction |
|---|---|---|---|---|
| Performance | | | | |
| Procurement and Contracts | | | | |
| Environmental Sustainability | | | | |
| User Satisfaction | | | | |
| | | | | |
| Overall Consistency | - | Review pair wise comparison | | |

FIGURE VII
Categories of pair-wise comparison

Afterward, the module checks the overall consistency of the pair-wise comparison and warns the user if the input values are inconsistent. Additionally, the module allows up to three users to conduct the pair-wise comparison and then calculates the average weight for each factor. Users are then asked to assign scores for all the decision parameters and then the module calculates an overall score for each maintenance/rehabilitation alternative. In some cases, users may prefer to assign their weights directly without using the AHP. The tool allows users to manually assign the weights and checks if the total assigned score is 100%.

## VII. LIMITATIONS

The proposed tool is intended to be used by local agencies in Iowa. As such, the tool may not be directly suitable for use by other agencies. However, the overall methodology used to build the proposed tool can be utilized to develop similar tools for local agencies in other states. This tool is a building block in an asset management system as it does not consider optimizing fund allocation or future performance prediction. This tool is a project level decision support tool that should serve as a strong connection between the network level and project level planning and programming.

## VIII. CONCLUSIONS AND FUTURE WORK

This study developed a practical and working framework and its tool to help local agencies to consistently make decisions on pavement treatments utilizing their business practices, experience, requirements and limitations. Due to limited resources available in local agencies, a simple but structured spreadsheet decision making tool might be the most practical approach for enhancing their asset management practices. A questionnaire survey targeting the local agencies was conducted to determine common distresses, common treatment methods, the use of LOS indicators, and investigate the use of pavement management systems. It is found that most local agencies do not collect pavement condition data. Additionally, local agencies depend on personnel experience to decide which treatment should be applied, and there are only few LOS indicators used by local agencies.

A treatment selection framework is developed using data and input from local agencies. The decision support tool classifies pavements according to the existing deterioration level. Based on the pavement condition classification approach, the study developed six decision trees for rigid and flexible pavements. Each decision tree corresponds to the level of pavement deterioration. As such, the tool recommends the appropriate treatment strategy based on the existing distresses.

The validation of the proposed treatment selection framework is conducted using expert panel reviews and one case study with satisfactory results. The tool is expected to help local agencies select technically and economically most attractive treatment options for their pavements. As for future research, the proposed tool will be linked to the local agencies' pavement assets to develop network planning and budgeting.

## ACKNOWLEDGEMENT

The researchers would like to acknowledge the Iowa Highway Research Board for sponsoring this research

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