Pavement maintenance is traditionally the most expensive function of a highway-operating agency. However, the long-term benefits of maintenance strategies are typically not quantified. More is known about the initial, relative improvements associated with a given maintenance strategy than is known about its impact on a pavement's performance and life. This is one of the main reasons given for not integrating maintenance activities into pavement management systems. This paper discusses procedures used to quantify the improvements and costs associated with typical maintenance strategies and activities and demonstrates the benefit of utilizing these relationships in pavement management, specifically the tradeoffs between pavement rehabilitation and maintenance. Iowa Department of Transportation contract maintenance and in-house maintenance records are used to quantify improvements and costs associated with individual maintenance strategies. The authors intend to use the results of this study in a multi-year prioritization program used by the Iowa Department of Transportation as its pavement management system software. The paper demonstrates the benefits of using maintenance data in the pavement management process. Key words: pavement, maintenance, and management systems.

INTRODUCTION

Pavement maintenance is a very crucial component of any highway agency's operation. Highway agencies try to maintain their existing highway network in a state that provides a safe and smooth ride to the travelling public through the application of maintenance strategies.

Research has been conducted at the national level to determine the value of maintenance to encourage highway agencies to adopt sound maintenance practices (preventive maintenance) and understand the benefits of maintaining the highway network. Individual highway agencies need to carry this research further to determine the impact of their own maintenance practices on the condition of their highway network. The results can be incorporated into a pavement management system to conduct resource allocation and project selection.

This paper discusses procedures used to determine the impact of several maintenance strategies on pavement condition for the Iowa Department of Transportation (Iowa DOT). The research described goes through the process of obtaining the data, assessing the impact, and finally determining the benefits of each individual treatment strategy or a combination of strategies. The paper is divided into three major sections. The first section describes the methodology used to acquire the necessary data, maintenance activity identification, data review and validation, and then data integration using a dynamically segmented GIS database. The second section describes the impact assessment of specific maintenance strategies as they were used by the Iowa DOT. This process is completed by determining the change in pavement condition (considering the before and after condition data) as a result of the application of a specific maintenance strategy. Finally, conclusions are made to the value and benefit of maintenance treatments and how that information is incorporated into the Iowa DOT pavement management system.

Another component of the research was to look at the cost of maintenance treatments and determine the feasibility of individual maintenance alternatives. At this point, not enough data were available to allow the researchers to conduct a benefit cost analysis. Instead, cost estimates will be used in the Iowa DOT pavement management system to integrate both pavement management and pavement maintenance in one system.

METHODOLOGY

As noted previously, a primary objective of this research is to quantify the relative improvements to pavement condition resulting from different maintenance activities and the cost of these improvements. The objective of this portion of the research is to perform data integration necessary to accomplish this objective, specifically integrate historic programmed and routine maintenance activities and pavement condition data. This is accomplished through four tasks: 1) data acquisition, 2) maintenance activity identification, 3) data review, and 4) data integration and summary. The following section documents each of these tasks as well as discusses issues encountered during the integration process.

Pavement Condition Data

Pavement condition data were obtained from the Iowa DOT pavement management information system (PMIS). Condition data, which are typically collected biennially, were provided by pavement management section for the years 1992 through 1998. Condition measures include a composite index, ride, friction, cracking, patching, and faulting.

Programmed Maintenance Data

The Iowa DOT Maintenance Division provided records of programmed (contracted) maintenance activities (MP Projects) for the years 1991 through 1998. Of particular interest to this study were the dates during which work was performed, the type(s) and cost(s) of

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work performed, and project location. In many cases, several types of work, designated by work codes, were performed on the same project.

Routine Maintenance Data

Information about routine maintenance activities (in-house maintenance work) was obtained from the Iowa DOT Maintenance Management System (MMS) (Office of Maintenance) for the years 1994 through 1997. Once again, key elements of interest were the dates during which work was performed, the type(s) and cost(s) of work performed, and work location.

For the purposes of this research, maintenance activities of interest were those that directly improved the roadway surface. Furthermore, activities that performed or served the same basic function were grouped together and considered a single activity. All other maintenance activities, although present in the programmed and routine maintenance records, were not considered. Tables 1 and 2 present the programmed and routine maintenance activities of interest.

TABLE 1 Programmed Maintenance Activities

Programmed Maintenance Activities
Joint and crack filling with emulsion (ACC pavement 2-lane)
Joint and crack sealing (ACC pavement 2-lane)
Joint and crack filling with emulsion (ACC pavement 4-lane)
Joint and crack sealing (ACC pavement 4-lane)
Joint and crack sealing (PCC pavement 2-lane)
Joint and crack sealing (PCC pavement 4-lane)
Full-depth patching ACC/PCC ACC partial-depth patching
PCC partial-depth patching
Longitudinal joint repair
Transverse joint repair (per 2-lane width)
Microsurfacing (2-lane)
Microsurfacing (4-lane)
Pavement seal coat (CRS-2P 2-lane)
Pavement slurry seal (ACC pavement 2-lane)
Pavement seal coat (CRS-2P 4-lane)
Pavement slurry seal (ACC pavement 4-lane)
Pavement double slurry seal (ACC pavement 2-lane)
Pavement double slurry seal (ACC pavement 4-lane)
ACC resurfacing (2-lane) 1 inch deep
ACC resurfacing (2-lane) 2 inch deep
ACC resurfacing (2-lane) 3 inch deep
ACC resurfacing (2-lane) 4-5.5 inch deep
ACC resurfacing (2-lane divided) 4-5.5 inch deep
ACC resurfacing (2-lane) 6 inch deep
Adds milling to ACC resurfacing projects (1.5 inch depth)
Intermittent AC resurfacing (spot leveling)

TABLE 2 Routine Maintenance Activities

Routine Maintenance Activities
Spall Patching and Hand Leveling
Machine Surface Restoration and Leveling
Permanent Surface Repair
Joint and Crack Filling
Joint and Crack Routing and Sealing
Strip Sealing – Edge Sealing
Pavement Replacement
Seal Coating – Slurry Sealing – Fog Sealing
Pavement Expansion Relief Joints
Burn/Plane or Mill Surface
Underseal/Raise Pavement

The data review process entailed a more detailed analysis of the component data sets. Data sets were analyzed for consistency, completeness, and potential data integration issues.

Pavement Condition

The pavement condition data are both consistent and complete. Locations of pavement management sections are clearly defined by county, route, milepost, and direction. Modifications to section definitions over time have also been appropriately addressed within the data set. Field collected condition data are provided (for most sections) on a biennial basis. A composite index is often estimated for years in which field data are not collected.

The complete data set, with the exception of a few urban sections, is appropriate for further analysis. Effective use of the aforementioned urban sections is prohibited because of the complex relationship among existing and historic section definitions.

Programmed Maintenance

The majority of the programmed maintenance data is also consistent and complete. Locations of pavement management sections are clearly defined by route and milepost. However, in some instances the milepost information is missing, incomplete, or inaccurate. As a result, these records (projects) can not be used in analysis.

To accurately attribute condition improvements to the appropriate maintenance activity, the data set was initially limited to projects with a single surface improvement work code (i.e., a single maintenance activity was undertaken on a particular section in a given year). This significantly decreased the number of observations for the maintenance activities. Therefore, logical work code (activity) pairs were identified, based on the data provided, for inclusion in analysis. Activity pairs are those surface improvement activities regularly performed in conjunction with each other or one preceding the other, such as patching and resurfacing. The activity pairs are presented in Table 3. Projects are not considered if more than two activities occur on a section.

TABLE 3 Programmed Maintenance Work Code (Activity) Pairs

Programmed Maintenance Activity Pairs	
Full depth patching ACC/PCC	Pavement seal coat (CRS-2P 2-lane)
Full depth patching ACC/PCC	ACC Resurfacing (2-lane) 2 inch deep
Full depth patching ACC/PCC	ACC Resurfacing (2-lane) 3 inch deep
Pavement seal coat (CRS-2P 2-lane)	Joint and crack filling with emulsion (ACC pavement 2-lane)
Pavement seal coat (CRS-2P 2-lane)	Joint and crack sealing (ACC pavement 2-lane)
Pavement seal coat (CRS-2P 2-lane)	Full-depth patching ACC/PCC
Pavement seal coat (CRS-2P 2-lane)	Adds ACC surface patches
Pavement seal coat (CRS-2P 2-lane)	Intermittent AC resurfacing (spot leveling)
Pavement seal coat (CRS-2P 2-lane)	ACC Resurfacing (2-lane) 3 inch deep
Pavement slurry seal (ACC pavement 2-lane)	Slurry leveling
Intermittent AC resurfacing (spot leveling)	Pavement seal coat (CRS-2P 2-lane)
ACC Resurfacing (2-lane) 1 inch deep	Full-depth patching ACC/PCC
ACC Resurfacing (2-lane) 1 inch deep	ACC partial-depth patching
ACC Resurfacing (2-lane) 1 inch deep	Adds ACC surface patches
ACC Resurfacing (2-lane) 1 inch deep	Adds milling to ACC resurfacing projects (1.5” depth)
ACC Resurfacing (2-lane) 2 inch deep	Full-depth patching ACC/PCC
ACC Resurfacing (2-lane) 2 inch deep	ACC partial-depth patching
ACC Resurfacing (2-lane) 2 inch deep	Pavement seal coat (CRS-2P 2-lane)
ACC Resurfacing (2-lane) 2 inch deep	Adds milling to ACC resurfacing projects (1.5” depth)
ACC Resurfacing (2-lane) 2 inch deep	Longitudinal subdrains
ACC Resurfacing (2-lane) 3 inch deep	Full-depth patching ACC/PCC
ACC Resurfacing (2-lane) 3 inch deep	Intermittent AC resurfacing (spot leveling)
ACC Resurfacing (2-lane) 3 inch deep	Adds milling to ACC resurfacing projects (1.5” depth)
Adds heater scarification to ACC resurfacing projects	ACC Resurfacing (2-lane) 1 inch deep

Routine Maintenance

Several aspects of the routine maintenance data from the Maintenance Management System prohibit its use in the analysis. Milepost information is missing, incomplete, or inaccurate (to a much greater extent than programmed maintenance activities.) In addition, the milepost location description is not specific enough to accurately assign activities to the appropriate pavement management section(s). Furthermore, cost information is missing or incomplete in many records, and “miscellaneous” is often assigned to surface maintenance activities.

As noted in the previous section, only the historic programmed maintenance activities and pavement condition data are used to assess the pavement condition improvement associated with specific maintenance activities. Several different tools are utilized to integrate and summarize these data. Primary tools include a geographic information system (GIS) with dynamic segmentation capabilities, Intergraph Corp. MGE, and a relational database management system, Oracle. This section briefly outlines the manner in which the maintenance activity and condition data are integrated as well as how the aforementioned tools are utilized. The procedures necessary to create the GIS environment for dynamic segmentation are not discussed within this context.

Data Validation

The first step of data integration is data validation through use of GIS dynamic segmentation capabilities. Dynamic segmentation provides the ability to create representations of roadway features or events; in this case pavement management sections and maintenance projects, along a GIS representation of the roadway network. Database attributes (county, route, begin and end milepost) describe the location and extent of the pavement management sections and maintenance projects along the network. The objective of the validation is to ensure that the graphic representation of these features accurately represents the feature, specifically the section or project extent, in the field. The length of the graphic representation of the maintenance projects and pavement management sections is calculated using dynamic segmentation and compared to the their field lengths, calculated using other database attributes. If the difference between the graphic distance and field distance is not within a specified tolerance, the project or section is eliminated from further analysis. This difference may be defined as an absolute difference, such as one-kilometer, or a proportional difference, e.g., the graphic distance is 90 percent of the field distance. An absolute difference of one-kilometer was used for all sections in this research; however, use of a proportional difference may be more appropriate for short sections.

Maintenance Activity Identification

The next step of data integration is identifying how many maintenance projects (activities) occurred along a pavement management section during each year of analysis. To accurately attribute condition improvements to the appropriate maintenance activity, the only sections considered are those along which a single project (maintenance activity code) occurred during a given year. If a single maintenance project occurred on the section, the type of activity, or activity pair, is assigned to the section. Dynamic segmentation is utilized to overlay maintenance data and condition data, on a year by year basis, and update the condition data accordingly. Since condition data are not available prior to 1992 or after 1998, this process is repeated for the years of 1993 through 1997 only.

New Record Creation

The previous process yields a year by year account of the number, and type, of programmed maintenance activities occurring on each pavement management section. Type is provided only if a single activity occurred during a given year. The pavement management sections along which this occurs are of primary interest. The third step of the data integration process uses these sections and the maintenance data to generate a new subset of data. Dynamic segmentation is utilized to overlay the aforementioned data sets and create the new record set. This record set represents a union of the pavement management sections and maintenance activities for each year between 1993 and 1997. Data associated with the new record set are its graphic length, the total graphic length and project cost of the maintenance project from which it originated, and the section identifier of the pavement management section from which it originated. The data are used in the subsequent steps to assign a proportion of maintenance activity and cost to each pavement management section.

Maintenance Activity Summary

The next steps in the data integration process involve modifying and aggregating the records contained in the data set created in the previous step. First, the proportional, or weighted, cost of maintenance for each record in the new data set is calculated. This is accomplished by multiplying the total project cost by the graphic length of the new record and then dividing by the graphic length of the entire maintenance project. The new cost represents the cost of the maintenance activity along that portion of the pavement management section. Upon calculating the maintenance activity cost of each new record, all records are summarized by pavement management section identifier and year of maintenance activity. The graphic length and cost (weighted) of all records are summed for each management section and year. This yields the total lane miles and cost of maintenance performed on a pavement management section in a given year.

Combined Maintenance-Condition Summary

The last step in the data integration process is associating the summarized maintenance data with the appropriate pavement management section. The result is a database table containing pavement condition and programmed maintenance activities, by type, cost, and lane mile, on a year by year basis. Another important attribute, derived from this data set, is the proportion of the pavement management section along which the maintenance activity occurred. The proportion is calculated by dividing the total lane miles of maintenance by the length of the pavement management section. This proportion is a primary factor in the analysis that follows, as is the timing of the condition data with respect to a maintenance activity. For example, if a maintenance activity occurred along only 20 percent of a pavement management section, the activity will likely have little impact on the condition of the section as a whole. This will be discussed in more detail in the next section.

IMPACT ASSESSMENT

To assess the impacts of different maintenance activities on pavement condition, two indices were taken into consideration. These were the Pavement Condition Index (PCI) and the International Roughness Index (IRI). PCI is a composite index with a range of 0–100 (zero representing the worst possible condition and 100 representing the best possible condition). The IRI, the International Roughness Index, is a profile index describing road profile roughness that causes vehicle vibrations. Expressed in units of slope (inches per mile and/or meters per kilometer), it can take values of zero or greater (zero representing an absolutely flat profile).

The combined maintenance-condition summary file was reviewed and, following a step-wise procedure, an assessment of the impact of maintenance activities on PCI and IRI values was conducted. The authors identified highway sections in the combined maintenance-condition summary file where:

1. Only one type of maintenance activity was carried out in a year.
2. The activity covered more than 50 percent of the section length.
3. Field measured distress data (PCI and/or IRI) were available before and after the maintenance activity.
4. The PCI and IRI values indicated some improvement in pavement condition due to the maintenance activity.

For example, if a section of highway was resurfaced (ACC resurfacing 2-lane 2-inch deep–WC 42) in 1995 and distress data were measured in 1994 and 1996, then the difference in the before and after distress data indicate the improvement in the section condition due to the application of that maintenance strategy. The process was completed manually by checking each pavement section over the entire analysis period.

Observed improvements to PCI and IRI were noted. However those improvements did not reflect the actual improvements because they did not take into account the deterioration of pavement condition between the treatment time and the time that it was re-observed. A correction was applied to the observed improvements in PCI and IRI values by taking into consideration the deterioration of the pavement between the treatment time and the after observation period. Age-based PCI & IRI equations developed for the Iowa DOT pavement management system were used for this purpose.

Tables 4 and 5 present a summary of the results for improvements in PCI and IRI due to different types of maintenance activities. A brief description of the two tables follows.

· The first two columns in both tables list the work code and its description.
· The third column lists the observed mean difference in PCI and IRI.
· The fourth column lists the mean change in PCI and IRI when deterioration effects between the before and after time period were taken into consideration.
· The last column provides the number of observations.

Some of the results are based on relatively few observations and thus the confidence in the PCI and/or IRI improvements is low. However, in the absence of other information on the improvements

TABLE 4 Impact of Maintenance Activities on PCI Values

Work Code	Description	Mean Observed Change in PCI	Mean Change in PCI After Correction	No. of Observations
WC1	Joint and crack filling with emulsion ACC 2-lane	1.63	6.33	11
WC2	Joint and crack sealing ACC 2-Lane pvt.	2.14	6.31	21
WC3	Joint and crack sealing PCC 2-lane pvt.	0.50	1.66	2
WC6	Joint and crack sealing ACC 4-Lane pvt.	-1.25	1.48	4
WC10	Full depth patching ACC/PCC	1.08	3.50*	23
WC11	ACC Partial depth patching	1.00	5.72	1
WC20	Microsurfacing 2-Lane	2.10	4.76	10
WC21	Pvt. Fog seal ACC 2-Lane	1.00	6.47	1
WC22	Pvt. Seal coat CRS-2P 2-Lane	3.33	5.08	3
WC40	Intermittent AC resurfacing (spot leveling)	5.28	8.60	7
WC42	ACC resurfacing 2-Lane 2” deep	5.67	11.41	3
WC43	ACC resurfacing 2-Lane 3” deep	8.16	11.03	6
			Total	**92**

** This conservative result is based on PCC PCI equation*

TABLE 5 Impact of Maintenance Activities on IRI Values

Work Code	Description	Mean Observed Change in IRI	Mean Change in IRI After Correction	No. of Observations
WC1	Joint and crack filling with emulsion ACC 2-lane	-0.294	-0.432	14
WC2	Joint and crack sealing ACC 2-Lane pvt.	-0.225	-0.340	16
WC10	Full depth patching ACC/PCC	-0.515	-0.570*	8
WC20	Microsurfacing 2-Lane	-0.292	-0.324	15
WC40	Intermittent AC resurfacing (spot leveling)	-0.450	-0.600	3
WC42	ACC resurfacing 2-Lane 2" deep	-1.210	-1.323	4
WC43	ACC resurfacing 2-Lane 3" deep	-0.580	-0.725	4
WC44	ACC resurfacing 2-Lane 4"- 4.5" deep	-2.260	-2.320	1
			Total	**65**

** This conservative result is based on PCC IRI equation*

due to those maintenance activities on distress indices, these are the best estimates. More data are needed to refine the estimates based on relatively few observations.

CONCLUSIONS

The results from the impact assessment section clearly show the benefits of specific maintenance strategies using either the PCI or the IRI condition indicators. As discussed earlier, however, more data are needed so that a more refined benefit analysis can be conducted. As more data are collected, more pavement sections and maintenance strategies can be considered. This will allow the researchers to refine the improvements in PCI and IRI values as a result of applying a specific treatment strategy.

The next step in this process is to integrate the data from this research into the Iowa DOT pavement management system. The Iowa DOT uses a multi-year prioritization program for resource allocation and project selection. So far, the pavement management system only considers rehabilitation and reconstruction strategies. During the current phase of the project (2000), the maintenance data will be integrated into the pavement management system and the impact of doing maintenance will be assessed. This will allow the Iowa DOT staff to better represent their maintenance program and provide with the ability to justify additional budget request for preventive maintenance work.

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