HWYNEEDS: A Sensitivity Analysis

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County highway needs identified in Iowa's Quadrennial Needs Study are used to determine the amount of funding allocated to each Iowa county for secondary highway improvements. The Iowa Department of Transportation (Iowa DOT) uses a computer algorithm called HWYNEEDS to compute Iowa's secondary highway needs. Several highway operational, safety, and condition elements are collected and entered into HWYNEEDS. Variations in one of the condition elements, the pavement condition rating, were shown to significantly impact the resulting highway needs. Currently, pavement condition ratings are manually collected every ten years during the winter months. The Iowa Pavement Management Program (IPMP) provided a means to improve the condition ratings with improved data collection procedures. The IPMP uses an automated platform to collect pavement condition data at two-year intervals for the entire state during the year when pavement distresses are easier to recognize. A method was developed to compare the secondary highway needs resulting from the manual and automated collection procedures. First, a means to make the pavement condition data collected for the IPMP compatible with HWYNEEDS was needed. HWYNEEDS requires a pavement condition rating on a scale of one to five with five being a pavement showing no deterioration. As a result, the pavement condition data were converted to pavement condition ratings using equations developed through expert opinion. Second, a historical comparison of the highway needs derived from the manual and automated condition ratings was needed to indicate which data provided more consistent and accurate results. However, the IPMP was in its infancy; therefore, a historical database of condition data did not exist. As a result, pavement performance curves were developed for the automated condition data. Having created a historical database of automated condition ratings, the performance curves contained in HWYNEEDS were used to deteriorate the manual ratings. Pavement performance curves for both the automated and manual condition ratings allowed for more realistic comparisons of the data because the condition of the pavements could be deteriorated to common years. Finally, several data sets compiled from the automated and manual pavement condition ratings were entered into HWYNEEDS to compare the accuracy and consistency of the resulting highway needs.

INTRODUCTION

The majority of revenue allocated to Iowa counties for secondary highway improvements originates in Iowa's Road Use Tax Fund (RUTF). A legislatively-determined formula designates 32.5 percent of the fund for secondary highway improvements. The amount of funding allocated to individual counties is largely based on the secondary highway needs of each county. Needs are defined as, "physical work necessary to improve, maintain, and administer roads and streets to standards of service essential to serve present and future traffic" (*1*). Of the 32.5 percent designated for secondary highway improvements, 70 percent of the funds are distributed to each county based on individual county needs relative to the needs of the entire state. The remaining 30 percent is apportioned to each county based on individual county land area relative to the land area of the state.

A method of determining secondary highway needs was necessary if allocations were to be based on needs. As a result, the state legislature required the implementation of the Quadrennial Needs Study as a planning and resource allocation tool (*2*). Iowa's highway needs, as determined by the Quadrennial Needs Study, represent the cost of upgrading all roads, structures, and railroad crossings in Iowa to current system design standards plus the cost of maintenance, administration, and engineering for a given 20-year analysis period (*3*).

Quadrennial Needs Study

The Quadrennial Needs Study consists of a five-step process. The first and second steps deal with functional classification and design guides. Third, inventories of the existing roads, structures, and railroad crossings are taken. This inventory includes such items as lane width, shoulder width, surface type, and traffic. Condition ratings for drainage, pavements, shoulders, and foundations are also included in the inventory (*4*). The data obtained from the first three steps of the process are incorporated into a computer model called HWYNEEDS.

The fourth step in the process involves the determination of costs. Surveys asking for highway-related cost data are sent to all 99 counties, cities with populations over 5,000, and a sample of smaller cities. The information obtained from the surveys, along with information within the Iowa DOT, is used to develop unit costs (*4*). Costs for construction, maintenance, and administration are used to develop total dollar needs, which are computed by HWYNEEDS using the cost information developed by the Iowa DOT (*4*).

The final step in the process is an adequacy appraisal completed by HWYNEEDS. Each highway section, structure, and railroad crossing is compared to design guides to determine existing and accruing deficiencies over a 20-year analysis period (*4*). To determine accruing deficiencies, traffic levels are forecasted, and condition ratings are depreciated in yearly increments. During each five-year period, the operational, safety, and condition elements of the highway sections, structures, and bridges are analyzed for deficiencies (*4*). Certain deficiencies or combinations of deficiencies trigger various improvements. Upon completion of the 20-year analysis, the triggered improvements are evaluated for possible redundancies (*5*). Finally, the second-

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ary highway needs are output in terms of construction, maintenance, and administration costs.

Problem Statement

The RUTF secondary highway distribution process must be consistent and accurate to ensure the routes comprising the secondary system are maintained and continue to serve the needs of the public. However, reports have shown that HWYNEEDS has produced inconsistent and inaccurate results over time making it difficult for counties to maintain and improve the routes on the secondary system they are responsible for (*2*,*6*). Certain counties have experienced shifts in funding between studies in as much as 30 percent (*6*). Engineers in those counties believe the funding shifts are not justified. Because the secondary highway system remains fairly static, and the time interval between studies is only four years, large funding shifts should not be a common occurrence.

Objective

HWYNEEDS uses several inputs relating to the operational, safety, and condition elements of secondary highways to compute the needs for each county. Certain inputs were shown by Iowa Highway Research Board Project HR-363 to significantly impact the results of the model. One of these inputs was the pavement condition rating (*6*). Currently, the pavement condition ratings used as input to the HWYNEEDS model are collected manually on a ten-year cycle. However, the Iowa Pavement Management Program (IPMP) collects pavement condition data using a service provided by Roadware Corporation. Roadware utilizes a mobile data acquisition platform and an automated process to collect pavement distress information on a two-year cycle. The objective of this paper is to explain how pavement condition data from the IPMP were converted to composite pavement condition ratings used by HWYNEEDS as a means to improve the accuracy and consistency of the resulting highway needs.

METHODOLOGY

IPMP Database

The IPMP database is the focal point of the pavement management program. Data are received from numerous sources and entered into the database. The Iowa DOT provides cartography and information from its Base Record Inventory System, which is entered into a set of base record tables. The Base Record Inventory System is the Iowa DOT's statewide highway database consisting of information describing all public roads and structures. The system contains over 150 data fields describing highways; however, only those data fields relating to pavement management are included in the IPMP database (*7*). Counties, cities, and the Iowa DOT provide pavement section history information for facilities they operate. The information includes such data as the pavement surface type, pavement surface thickness, year of construction, traffic volume, and functional classification. This data is entered into a set of pavement history tables. Roadware provides the distress information for each pavement distress section on all Iowa federal aid eligible, non-national highways, many of which are secondary highways. The distress information is entered into a set of pavement distress tables. The pavement distresses collected by Roadware for both asphalt and concrete pavements followed the definitions given by the SHRP *Distress Identification Manual for the Long-Term Pavement Performance Project* for distress severity and extent. Roadware collects the following distresses:

- A measure of ride quality referred to as the international roughness index (IRI) for the left and right wheel paths measured in millimeters of roughness per meter of pavement
- Pavement rutting for the left and right wheel paths measured as the rut depth in millimeters
- Durability cracking measured as the number of pavement joints with durability cracking
- Joint spalling measured as the number of spalled joints
- Transverse cracking measured as the length of the transverse cracks in meters
- Patching measured as the area of patching in square meters and number of patches
- Longitudinal cracking measured both in the wheel path and non-wheel path as the length of the longitudinal cracks in meters
- Block cracking measured as the area of block cracking in square meters
- Alligator cracking measured as the area of alligator cracking in square meters
- Pot holes measured as the number of pot holes

Pavement segments used by the Quadrennial Needs Study are defined at three levels. The highways are first divided into needs routes. The needs routes are then divided into needs sections, which in turn, are divided into needs records. The needs sections are based on construction history, and the needs records are simply the base records maintained by the Iowa DOT. It is the intent of the Iowa DOT to determine highway needs at the section level.

Integrating the pavement distress data with needs study pavement data at the section level was accomplished using the base record, pavement history, and pavement distress tables mentioned above. In theory, the base record and pavement history tables should contain the same information. However, the data comes from different sources, so the information is not always the same. Base record information is integrated to the needs sections and used by the Iowa DOT when running HWYNEEDS. Therefore, the consistency of the information between the base record and pavement history data was investigated. When discrepancies were found between the data sets, the pavement history data were used because it arrived directly from the counties that maintained those highways. Finally, using the dynamic segmentation capabilities of the IPMP's geographic information system (GIS), the needs study section and pavement distress section data were integrated.

Data Conversion

The pavement condition rating associated with each needs section is used by the computer model as input to assist in the determination of highway needs. HWYNEEDS does not allow for use of the raw distress data provided by Roadware as input. Therefore, the distress data must be converted to pavement condition ratings on the same scale used by HWYNEEDS.

Transforming the distress data into pavement condition ratings was accomplished using expert opinion. Members of the Iowa County Engineers Association on the Functional Classification and Highway Needs Committee provided their expert opinions to assign weights to the various distresses. The county engineers agreed that concrete, asphalt, and composite pavements deteriorate differently and should be analyzed separately. Therefore, weights summing to 100 percent were assigned to the distresses of each pavement type. Weights were initially assigned to distress groups and later assigned more specifically to each distress. The distress weights can be seen in column F of Table 1.

Weights were now established for each of the distresses; however, many of the distresses are categorized by distress severity. Factors were applied to the severity levels with the notion that high severity distresses impact pavement quality more than low or moderate severity distresses. Column B of Table 1 shows the severity factors.

Having established distress weights and severity factors, the pavement condition ratings were calculated from the automated condition data. Because ride and rutting values are recorded for each wheel path, average values were calculated for each highway needs section. Next, a single value was obtained for each distress by multiplying the individual severity value by the assigned factor and summing the results. The values are shown in column C of Table 1.

At this point in the condition rating calculation process, the distress values represent the pavement condition of each needs section. However, needs sections vary in length and are comprised of a number of 100-meter distress sections. To provide a common reference, the distress values were divided by the number of distress sections comprising each needs section to obtain an average condition per 100-meter test section. Column D of Table 1 shows the number of distress sections comprising the example needs section. This calculation was not performed on the ride and rutting values because they were already averaged in this way through the dynamic segmentation process.

Distress threshold values, indicating a pavement in poor condition, were determined for the various distresses and are shown in column E of Table 1. Distress values equaling or exceeding the threshold were assigned a value of one and multiplied by the assigned weight since a poor rating is the worst possible pavement rating. In the majority of instances where the distress values did not exceed the threshold, the values were divided by the threshold value and multiplied by the assigned weight. The overall rating per needs section was obtained by subtracting the sum of the weighted distress values from a perfect rating of 100. Finally, to obtain a rating on the one to five scale used by

TABLE 1 Automated Condition Rating Calculations

Pavement Distress	Distress Value A	Severity Factors B	C SUM(A*B)	Distress Sections D	Threshold Values E	Distress Weights F	Results SUM (((C/D)/E)*F)
IRI							
left wheel path	2.04		(2.04+2.60)/2				
right wheel path	2.60						
			2.32		4	35	20.30
Rutting							
left wheel path	4.09		(4.09+4.28)/2				
right wheel path	4.28						
			4.19		15	20	5.59
Alligator Cracking							
moderate severity	0.00	1x	0.00				
high severity	0.00	2x	0.00				
			0.00	64	60	10	0.00
Transverse Cracking							
low severity	442.66 /2.75	1x	160.98				
moderate severity	0.00 / 2.75	1.5x	0.00				
high severity	0.00 / 2.75	2x	0.00				
			160.98	64	15	10	1.68
Longitudinal Cracking							
low severity	144.41	1x	144.41				
moderate severity	0.00	1.5x	0.00				
high severity	0.00	2x	0.00				
			144.41	64	30	5	0.38
Longitudinal Cracking (wheel path)							
low severity	918.40	1x	918.40				
moderate severity	8.81	1.5x	13.22				
high severity	463.98	2x	927.96				
			1859.58	64	30	10	9.69
Block Cracking							
moderate severity	0.00	1x	0.00				
high severity	0.00	1.5x	0.00				
			0.00	64	90	10	0.00
						100	37.64

Condition Rating = (100-37.64)/20
Condition Rating = 3.1

HWYNEEDS, the overall rating was divided by 20. Where the rating fell below 20, a rating of one was assigned as is done in a similar fashion by HWYNEEDS. This calculation is shown at the bottom of Table 1.

Pavement Performance Prediction Equations

Having obtained composite pavement condition ratings, pavement performance prediction equations were derived from the condition ratings and age of the pavements. The performance equations were intended to demonstrate the consistency of the automated pavement condition ratings over time. The equations would also assist in predicting the future condition of the highway needs sections. Finally, the performance equations could be used as a tool to compare the manual and automated condition ratings along with the resulting needs.

Due to the different performance characteristics of asphalt, concrete, and composite pavement, performance equations were developed for each pavement type. Age information was available for 77 asphalt, 64 concrete, and 17 composite pavement needs sections. Pavement age was calculated by subtracting the year of construction or most recent rehabilitation from the last year that the pavement condition was determined. The ages of the needs sections were plotted against the automated condition ratings for each pavement type. Regression was performed to determine the performance trends. Outlying values were eliminated from consideration and the performance trends were reestablished using regression.

Highway needs were calculated using six different pavement condition rating data sets. The first data set consisted of manual pavement condition ratings collected throughout the ten-year period prior to analysis year 1998. The second data set was comprised of the same manual ratings deteriorated to analysis year 1998 using the performance equations. The third data set consisted of automated ratings calculated using the two years of automated distress data collected prior to analysis year 1998. The final three data sets were comprised of the automated condition ratings deteriorated to analysis years 1998, 2002, and 2006 using the performance equations.

ANALYSIS

Pavement Condition Rating Age

A factor found to influence the amount of resulting highway needs was the age distribution of the pavement condition ratings. To determine the impact of utilizing current condition rating information on the resulting highway needs, a comparison was made of the highway needs calculated using the manual condition ratings collected over ten years and the manual ratings deteriorated to 1998. Deteriorated condition ratings increased total needs by over $13.5 million for analysis year 1998. Increases of more than $500,000 occurred in 12 of 36 corridors in the study. While the overall increase in needs was about 8.0 percent, the needs of several individual counties increased considerably. In two instances, the county highway needs increased by over 60 percent. A comparison of the highway needs calculated using the automated condition ratings collected in the two years prior to 1998 and the highway needs calculated from the same automated ratings deteriorated to 1998 revealed the same trend.

When considering that the results represented the highway needs of the pilot study group, the differences in needs were significant. This was especially true when looking at the results from the manual condition ratings with a wider age distribution. The pilot study consisted of about 675 miles of highway, which is slightly more than 5.0 percent of the total paved portion of the secondary system. Expanding the difference in needs obtained from the pilot study group to a level representing the entire paved portion of the secondary system resulted in a difference of about $260 million over 20 years for analysis year 1998.

Consistency of Highway Needs

The consistency of the resulting highway needs was demonstrated using the automated condition ratings deteriorated to analysis years 1998, 2002, and 2006. Having deteriorated the automated condition ratings while holding all other variables constant, the 20-year county highway needs were expected to increase from analysis year 1998 through analysis year 2006. The results confirmed that the total highway needs did increase through the three-year analysis period. The total needs increased by $4 million between the 1998 and 2002 simulated needs studies and by $7 million between the 2002 and 2006 studies. However, continuous increases in highway needs did not always occur at the county level.

The results showed decreasing needs in eight of thirty-six corridors considered. Corridors 6 and 9 experienced significant decreases in needs. Between the needs studies simulated for 2002 and 2006, corridors 6 and 9 experienced decreases in highway needs of $2.7 million and $0.9 million respectively. The results were unusual considering that pavements in worse condition had fewer needs. The resulting highway needs are shown in Figure 1. As a result, a manual analysis was performed on one highway needs section from corridors 6 and 9 to determine how HWYNEEDS was arriving at such unrealistic results.

CONCLUSIONS

The timeliness of the condition ratings had a significant impact on the resulting highway needs. Needs calculated from the deteriorated pavement condition ratings were significantly higher than the needs calculated using the condition ratings distributed over a number of years. For example, the needs resulting from the deteriorated manual surface ratings were $13.5 million higher than the needs calculated using the manual ratings collected over a ten-year period. The automated data has the advantage over the manual data in that the automated data is collected more frequently. However, the advantage could be reduced by manually collecting data more frequently or by using performance prediction curves to simulate pavement deterioration.

Improving the computer model would reduce the inconsistencies in the highway needs. Currently, HWYNEEDS may trigger several improvements for a needs section but always selects the improvement triggered first. Multiple improvements are selected only if subsequent improvements are not redundant. As a result, the selected improvement may not be the most cost effective. For example, the condition of certain elements may trigger a resurfacing improvement at year five and a reconstruction improvement at year ten. The

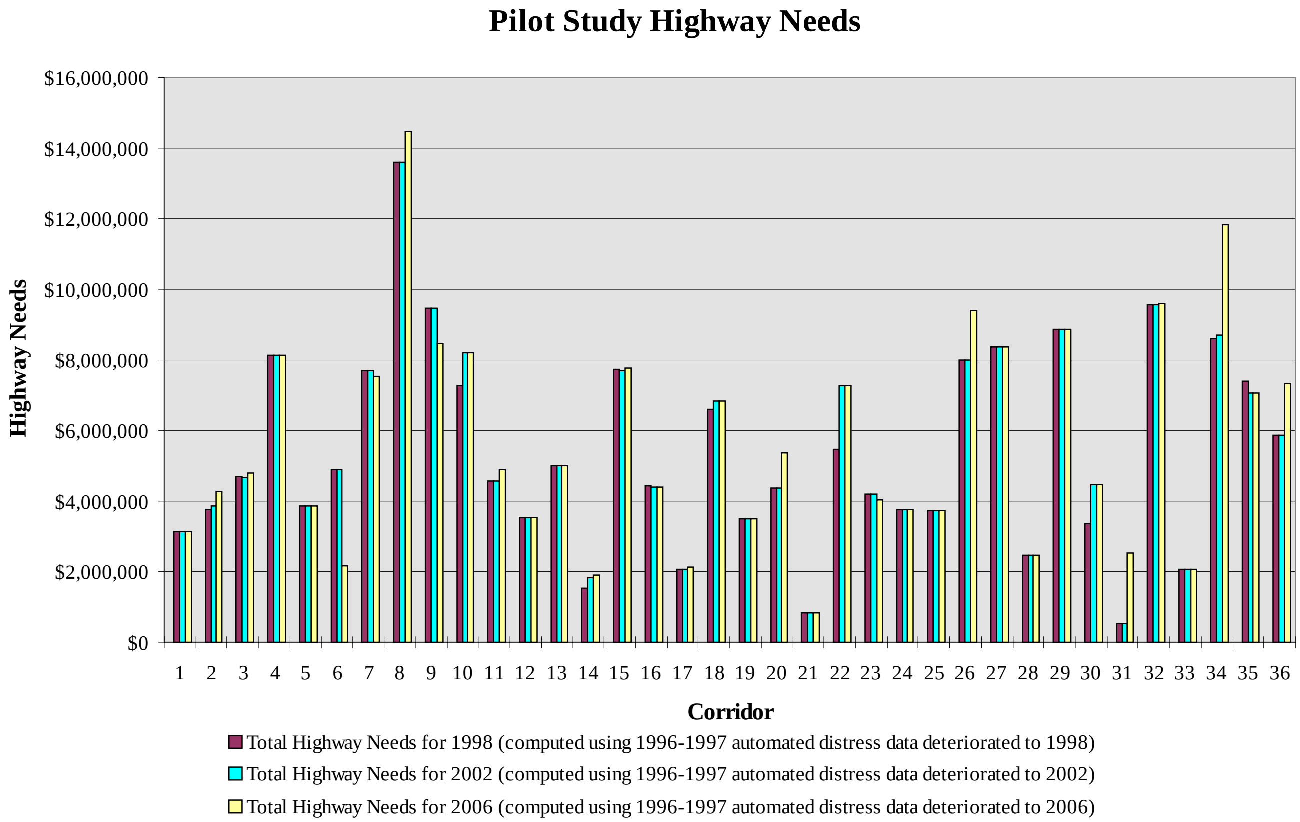

FIGURE 1 Comparison of highway needresulting from deteriorated automated surface ratings

reconstruction improvement would improve the surface among other problems but will not be selected because it was not triggered first. A method is needed that will prioritize all triggered improvements.

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