Network Condition Analysis for Pavement Program Development: A Case Study

DIMITRI A. GRIVAS, B. CAMERON SCHULTZ, AND GEORGE H. TANNER

The ability to describe roadway network condition properly is an essential requirement for pavement management. The methodology employed to develop and use condition measures for pavement network characterization as part of a broader effort to develop and implement a pavement management system for the New York State Thruway Authority is presented. The methodology uses a distress index as the criterion for evaluating pavement network condition. Specific intervals of the index scale are mapped to qualitative condition classes through a series of interactions with field engineers. The resulting condition classes are used in a process that relates network condition to needs and facilitates development of the annual and multiyear highway capital improvement and maintenance programs. A distinction between pavement and highway needs is necessary to accommodate Thruway-specific program development and budgeting practices. Two types of network-level analysis are implemented. In the first, the network is characterized using uniform sections based solely on pavement condition, and analysis is limited to short-term pavement needs. In the second, the network is characterized using planning sections, and analysis includes the broader long-term highway needs. It is concluded that pavement condition characterization provides an objective basis for program development but that it must be supplemented by additional highway information. This is because treatment needs for specific projects cannot always be determined solely on the basis of characterized pavement condition.

Once a novel concept, pavement management systems (PMSs) are now an established tool for the preservation and improvement of existing pavements (*1*,*2*). The New York State Thruway Authority (NYSTA) and Rensselaer Polytechnic Institute (RPI) have been cooperating since 1988 to develop a PMS for the authority. The PMS is based on experience with local conditions, materials, and pavement performance. It uses modern decision-making procedures and state-of-the-art technology to record, store, and analyze information. Technical details are documented elsewhere (*3–8*).

This paper provides a case study of the process through which a specific component of the developed PMS is being integrated into the operations of the NYSTA. The study outlines the use of a distress index as a criterion for network condition evaluation and pavement program development. The distress index is also used in other development methodologies—such as economic analysis, prioritization, and optimization—that constitute distinct components of the authority's PMS.

D. A. Grivas, B. C. Schultz, Department of Civil and Environmental Engineering, Rensselaer Polytechnic Institute, Troy, N.Y. 12180. G. H. Tanner, New York State Thruway Authority, 200 Southern Boulevard, P.O. Box 189, Albany, N.Y. 12201.

Integration of the distress index with project programming activities was advanced through a series of interactions with the field engineers and headquarters personnel responsible for managing the highway maintenance and rehabilitation program. Three specific objectives were accomplished during this study: (a) evaluation of the condition of NYSTA pavements using a PMS methodology, (b) initiation of a process that can convert network condition into a scope of work and establish an annual and multiyear highway program, and (c) identification of needed enhancements to developed PMS methodologies, based on feedback from experiences to date.

OVERVIEW OF NYSTA PMS

Operational Perspective

NYSTA was established in 1950 to construct, maintain, and operate a limited-access toll road spanning the state of New York. The Thruway currently consists of 1030 km (640 mi) of Interstate-type highways, administered as four divisions. The pavement was originally constructed of reinforced portland cement concrete (PCC). Typical slabs are 30.5 m (100 ft) long and 23 cm (9 in.) thick and have expansion joints with load transfer devices. The original slabs were constructed on 30.5 cm (12 in.) of granulated subbase course, with no provision for subsurface drainage.

As the original pavements deteriorated over the years, approximately 90 percent of the entire network was overlaid with asphalt concrete. Underdrain has been installed in conjunction with many rehabilitation projects. Shoulders were originally constructed of chloride-treated granulated material or sod. All have since received at least a thin asphalt overlay, and some have been fully reconstructed with asphalt concrete.

In 1986, with 10 years remaining under the initial organizing legislation and with increasing problems brought about by a chronic shortage of funds, a $1.7 billion infrastructure improvement program was developed for the period 1988 to 1996. The highway component ($500 million) of this long-term program was based on generalized pavement surface condition ratings obtained by a windshield survey. The PMS research and development effort was initiated in 1988 in response to the need to improve the information basis and decision methodologies used for highway program development and monitoring.

Analytical Methodologies

A methodology has been developed for visually evaluating surface distress on asphalt overlaid and PCC pavements in an objective and reliable manner (*3*). Individual distress magnitudes are assessed using linguistic scales that consider distress type, severity, and extent along nominal lengths of pavement. The survey that collects this information has been applied annually to the driving lanes and shoulders of all Thruway pavements since 1989. A 3-week rater training and testing program has been held annually to ensure the quality of the collected data.

A set of project- and network-level methodologies has been developed as part of NYSTA's PMS (*6–8*). It includes condition analysis, project definition, categorization, treatment selection, life-cycle cost analysis, project ranking, optimal project scheduling, and optimal program development. The methodologies were initially developed using a series of spreadsheets and stand-alone computer programs. They are being enhanced and integrated under a prototype windows-based program manager, and linkages are being developed to a centralized relational data base.

TABLE 1 Aggregate Change in Thruway Condition (1990–1991)

	Pavement Type	
Summary	OVL	PCC
Total Number of Rated Segments in Both Years	8,546	693
Number of Rated Segments with an LDI Change of <5 Points	2,758 (32.3%)	84 (12.1%)
Number with LDI Increase	1,989 (23.3%)	155 (22.4%)
Number with LDI Decrease	6,557 (76.7%)	538 (77.6%)
Net (increase - decrease)	- 4,568 (53.4%)	- 383 (55.2%)
Approximate Mean Increase	12.2	16.7
Approximate Mean Decrease	- 12.6	- 23.2

CONDITION ASSESSMENT

The distress data collection activity generates eight distress ratings for each 160.9-m (0.10-mi) nominal segment of road surveyed (*3*). In essence, these data represent localized assessments of pavement condition at discrete points in time and space. Detailed information of this type is essential for refined project-level analysis, but pavement condition must also be expressed in a more aggregate manner to support network-level activities. This synthesis is accomplished through a methodology that combines distress data from individual segments into indexes that represent the aggregate condition of each pavement project. Thus, distresses reflecting the condition of a specific pavement component, such as slab, joint, shoulder, or the entire pavement surface, are combined into indexes descriptive of the specific component (*5*).

The indexes are produced by a calculation method that accounts for the relative significance of each individual distress through the use of appropriate weighting factors. Index values are scaled proportionately to the maximum possible value and are reported on a 100-point scale. The scaled value denotes the calculated cumulative distress condition relative to the maximum value that a given distress index may receive. Thus, distress indexes can range from 0 to 100, with 100 representing a condition of no surface distress. Details of the calculation method are provided by Grivas et al. (*5*).

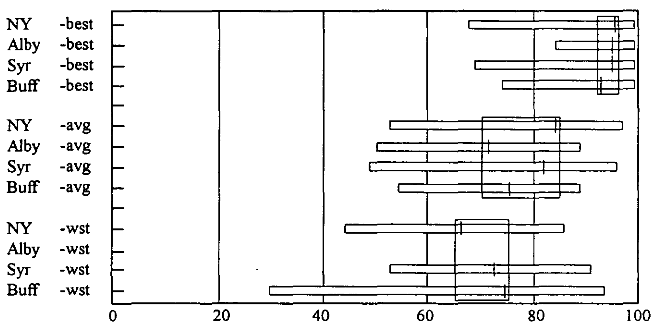
Consideration of the decision support potential offered by each of the developed indexes led to the designation of the lane distress index (LDI) as the condition measure to be used for pavement network characterization. It is anticipated that LDI will also be used to monitor surface condition over time. This is illustrated in Table 1, which presents the change of the pavement network condition from 1990 to 1991, exclusive of those sections undergoing rehabilitation or reconstruction during that period. The aggregate change in condition is summarized for all overlaid (OVL) and concrete (PCC) pavement meeting previous criteria. The reported values represent net condition changes, including effects of both deterioration and maintenance work. It can be seen that on average, overlaid pavements declined by 0.4 points, and concrete pavement declined by 6.5 points over the 1-year period. As more data become available, a capability will be developed to predict trends on the basis of past performance.

NETWORK CONDITION EVALUATION

NYSTA field engineers have accepted the LDI for a wide range of uses, including comparison of projects on the basis of exhibited surface distresses and characterization of system condition. Soon after acceptance of the LDI, the need was identified to use the quantitative values of LDI as the criterion for evaluating network condition—that is, to establish what constitutes excellent, good, fair, and poor pavement. This was achieved by a series of interactions with field engineers and a sensitivity analysis of the boundary values for the resulting condition classes.

First Iteration

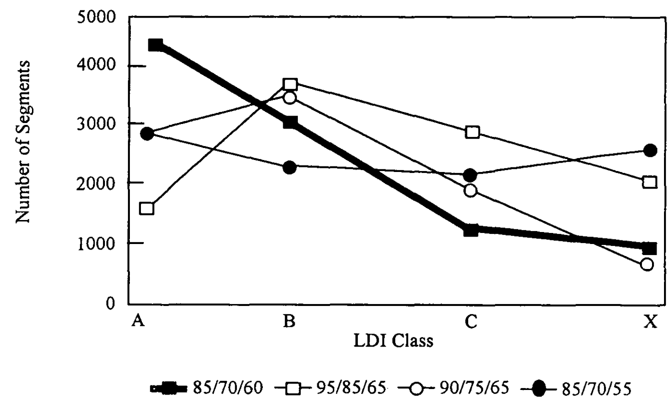
In the first iteration of this study, engineers from each of the four divisions were asked to subjectively identify sections of pavement that exhibited the best, average, and worst condition. The responses characterized 22 sections, totaling 234.6 km (145.8 mi) of pavement. The LDI for each 160.9-m (0.10-mi) interval of these sections was calculated, and the mean and range of the LDI for each category of pavement in each division were compared. The results for overlaid pavement are summarized in Figure 1, where the bars indicate the range and the tick marks on the bars indicate the mean value of LDI determined for each category. This study suggested that



Engineers' Assessment	Division	LDI Values Min	Mean	Max
Best	New York	68.2	95.7	99.4
	Albany	84.3	95.3	99.4
	Syracuse	69.6	95.2	99.4
	Buffalo	75.3	93.5	99.4
Average	New York	53.5	83.7	97.3
	Albany	50.7	71.0	88.9
	Syracuse	50.0	81.7	96.0
	Buffalo	55.0	75.0	88.9
Worst	New York	44.4	64.8	84.3
	Albany	*	*	*
	Syracuse	53.6	71.8	89.3
	Buffalo	30.6	74.6	92.8

* not reported

FIGURE 1 Ranges of LDI for overlaid pavement sections identified as representing best, average, and worst condition in each division.



LDI Class	No. of Segments	Rel. Freq.	Rel. Cum. Freq.
A > 90 - 100	2859	0.29	0.29
B > 80 - 90	2344	0.24	0.53
C > 70 - 80	2168	0.22	0.75
X ≤ 70	2452	0.25	1.00
A > 95 - 100	1629	0.17	0.17
B > 80 - 95	3574	0.36	0.53
C > 65 - 80	2685	0.27	0.80
X ≤ 65	1935	0.20	1.00
A > 90 - 100	2859	0.29	0.29
B > 75 - 90	3465	0.35	0.64
C > 65 - 75	1564	0.16	0.80
X ≤ 65	1935	0.20	1.00
A > 85 - 100	4488	0.46	0.46
B > 70 - 85	2886	0.29	0.75
C > 60 - 70	1339	0.14	0.89
X ≤ 60	1113	0.11	1.00
A > 85 - 100	4485	0.46	0.46
B > 70 - 85	2886	0.29	0.75
C > 55 - 70	1642	0.17	0.92
X ≤ 55	810	0.08	1.00

FIGURE 2 Sensitivity of overlaid pavement network characterization to selection of LDI intervals.

LDI was a meaningful basis for developing qualitative condition classes. It also provided an early indication of the need to resolve differences between individuals for such subjective assessments.

Second Iteration

From the results of the first iteration, four preliminary condition classes, referred to as A (excellent), B (good), C (fair), and X (poor), were proposed. Field engineers were asked to assign each section under their jurisdiction to one of the qualitative classes. The mean values and ranges of LDI of sections in each class were compared as before. The obtained results confirmed the findings of the first iteration, namely, that each individual showed a consistent trend of assigning sections with lower LDI to poorer condition classes, and that subjective assessments by different individuals were not always consistent.

Sensitivity Analysis

The demonstrated lack of consistency between individuals emphasized the need to relate qualitative characterizations to a relatively objective measure such as LDI. This was accomplished by defining intervals of the 100-point LDI scale to correspond to each of the four condition classes. Figure 2 illustrates the sensitivity of the characterization of system condition to the boundaries of the LDI intervals for each class. For example, it can be seen from Figure 2 that if Class A (excellent) is defined by 95 < LDI ≤ 100, then 17 percent of the overlaid pavement in the system is characterized as excellent. However, if Class A is defined by 85 < LDI ≤ 100, then 46 percent of the overlaid pavement is considered excellent. The heavy line corresponds to the limiting values between LDI classes that were eventually selected.

Results

The resulting network characterization based on the selected LDI intervals is presented in Tables 2 and 3. In Table 2 it can be seen that the percentages of pavement considered excellent and good have increased for overlaid pavement, and decreased for concrete pavement, between 1990 and 1991. Table 3 provides a summary of 1991 pavement condition for the four Thruway divisions. Constraints imposed by variations in geographic and demographic characterization across the state, in combination with historically different approaches to pavement maintenance, result in distinctly different characterizations between divisions. It can be seen, for example, that the Syracuse division is composed entirely of asphalt overlaid pavement and has the highest percentage of excellent pavement and the lowest percentage of poor pavement among all divisions. Interpretation of such observations must of course be tempered by consideration of past maintenance practices and other factors such as climate, soil, and traffic that affect pavement performance across the state.

PRELIMINARY PROGRAM DEVELOPMENT

The developed PMS uses a staged approach to program development, one in which defined projects are screened to identify feasible scopes of work before proceeding with an economic analysis of alternatives, scheduling, and optimization (*6,8*). The relationship between LDI, which is used for network characterization, and a project scope of work, which is determined during preliminary program development, provides an important link between project- and system-level methodologies.

TABLE 2 Characterization of Thruway Network Condition

Condition Class (LDI)	Overlaid 1990	Overlaid 1991	Concrete 1990	Concrete 1991
A ("Excellent") LDI > 85 - 100	42.4% 630.0 km	45.7% 722.3 km	1.1% 1.9 km	1.2% 3.4 km
B ("Very Good") LDI > 70 - 85	25.6% 380.4 km	29.4% 464.4 km	5.2% 9.3 km	2.6% 7.4 km
C ("Good") LDI > 60 - 70	18.4% 273.4 km	13.6% 215.5 km	4.8% 8.7 km	3.7% 10.5 km
X ("Poor") LDI 0 - 60	13.5% 200.5 km	11.3% 179.1 km	88.9% 159.8 km	92.6% 264.7 km
Length Surveyed (km)	1484.3	1581.3	179.7	286.0

1 km=0.6 mi

TABLE 3 Comparison of Division Network Characterizations

Division	Pvt Type	LDI Condition Class (%) A	B	C	X
New York (492.3 km)	Overlaid	30.1	10.5	9.1	4.3
	Concrete	0.3	1.0	2.0	42.7
Albany (440.5 km)	Overlaid	40.5	20.3	14.1	14.4
	Concrete	0.1	0.1	0.1	10.5
Syracuse (450.6 km)	Overlaid	50.6	30.3	13.0	6.1
	Concrete	0.0	0.0	0.0	0.0
Buffalo (483.9 km)	Overlaid	34.7	38.6	10.4	13.8
	Concrete	0.4	0.4	0.1	1.7

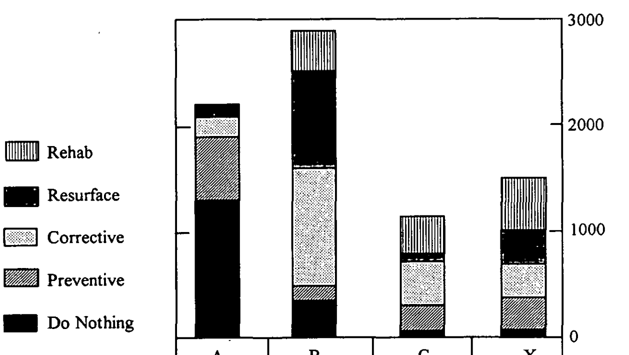
1 km = 0.6 mi

Uniform Sections

The developed PMS defines uniform sections on the basis of LDI values and construction and maintenance history. When defined in this manner, each payment section has needs distinct from those surrounding it. This facilitates economic programming, as treatments can be tailored to each project, thus minimizing occurrences of inappropriate treatment. Figure 3 shows, for the case of three divisions, how the scope of work applied to each uniform section in 1991 compares with the condition class characterization. It can be seen that the more involved scopes of work tend to be applied to sections in worse condition. It is also observed that about a fifth of the pavements in poor condition are receiving preventive maintenance. This apparent inconsistency is due to the attempt to maintain pavement sections in serviceable condition until programmed rehabilitation or reconstruction is performed. Similarly, sections in excellent condition may be resurfaced if, for example, roughness is outside acceptable limits. Clearly, in some cases the condition characterization must be supplemented with other engineering parameters to provide a comprehensive evaluation.

Planning Sections

Early in the process of integrating the PMS with existing project programming procedures, it became clear that a distinction had to be made between condition-generated "pavement" projects, which are the focus of the developed PMS, and "highway" projects, which include items such as guiderails, lighting, interchanges, ramps, toll plazas, signs, and slopes, in addition to pavement lane and shoulder improvements. The distinction between pavements and highways was introduced because (a) the condition and requirements of nonpavement items can significantly affect the scope and cost of work re-



	A	B	C	X
Rehab	0	374	260	505
Resurface	104	854	64	286
Corrective	196	991	462	327
Preventive	652	202	298	312
Do Nothing	1,279	432	42	38

FIGURE 3 Comparison of implemented scope of work with condition class for 1991 uniform sections (New York, Albany, and Buffalo divisions).

quired at a given location, and (b) for multiyear planning, it is prudent to coordinate work on adjacent highway sections, bridges, and bridge approaches to achieve economies of scale and scope and minimize inconvenience to users.

Uniform sections are accepted as useful for planning and assessing annual maintenance activities. However, because they are defined without consideration of highway characteristics, they are considered to be of limited use for long-term capital programming. Therefore, the concept of planning sections was introduced to improve the process of program development and monitoring. Planning sections are used primarily for long-term capital programming and may incorporate several uniform sections in addition to bridges, ramps, toll plazas, slopes, and so on. Figure 4 illustrates the difference between uniform and planning sections. Whereas the boundaries of uniform sections may change from year to year, the boundaries of planning sections are structured to be fixed for long periods to facilitate coordination between related projects in different years.

Table 4 provides an example of the annual (1992) and multiyear (1993–2000) programs for one division (Buffalo) that corresponds to the condition classes determined on the basis of the 1991 condition survey data. The number of miles and the percentage of the division network that are programmed for each treatment type are also provided.

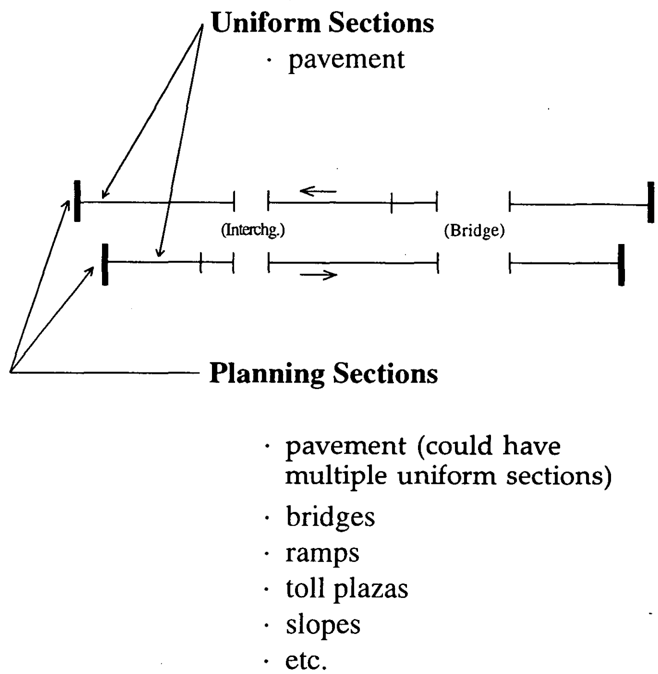


FIGURE 4 Relationship between uniform sections and planning sections.

TABLE 4 Annual and Multiyear Capital Program for a Division

	1992			Future M&R		
Condition Class (1991)	Scheduled Work	Length (in km)[a]	Percent of Class	Next Major Work	Length (in km)	Yr.
	Do nothing	34.0	28%	Mill and pave	8.9	'96
	Preventive mtce.	48.3	40%	Mill and pave	25.3	'98
A	Prevent. & correct. mtce.	4.2	4%	Paving (scope unknown)	4.2	'97
(119.4 km)	Pave (selected portions)	16.3	14%		38.3	
	Mill and pave (DL only)	15.1	13%			
	Mill and pave	1.6	1%			
	Do nothing	21.6	8%	Mill and pave (DL only)	10.5	'93
	Preventive mtce.	5.8	2%	Mill and pave (DL only)	34.3	'94
B	Prevent. & correct. mtce.	88.7	32%	Mill and pave (DL only)	7.4	'95
(273.4 km)	Corrective mtce.	55.2	20%	Mill and pave (recycle)	49.7	'93
	Mill and pave (DL only)	72.7	27%	Mill and pave	5.8	'96
	Mill and pave	29.5	11%	Mill and pave	1.9	'98
				Mill and pave	20.0	2000
				Paving (scope unknown)	4.7	'97
				Rehabilitation	20.3	2000
				Rehab/reconstruct	8.5	'94
				Rehab/recon.-add lane	3.2	'94
					166.2	
C	Preventive mtce.	6.9	15%	Mill, rubblize, and pave	6.9	'93
(46.5 km)	Prevent. & correct. mtce.	29.3	63%	Rehabilitation	27.7	'93
	Mill and pave (DL only)	10.3	22%		34.6	
X	Preventive mtce.	42.8	64%	Rehabilitation	42.8	'92
(67.3 km)	Prevent. & correct. mtce.	5.5	8%	Reconstruction	10.9	'93/'94
	Interim pave	19.0	28%	Reconstruction	13.5	'95/'96
					67.3	

1 km = 0.6 mi

FUTURE DEVELOPMENTS

Enhancements to the developed PMS are being pursued jointly by the NYSTA and RPI. Activities focus on

- Expanding pavement condition assessment procedures to provide additional quantitative measures such as roughness, rutting, and transverse profile;
- Automating pavement image analysis;
- Refining the decision methodologies to reflect improvements suggested from operational use of methods and products; and
- Integrating the component stand-alone application programs and the centralized relational data base into a networked computer system.

SUMMARY AND CONCLUSIONS

This paper presented the process through which a distress index was integrated into the NYSTA's project programming operations. The index has been examined and used to provide classification structures for network characterization and to support preliminary program development. Field assessments of pavement quality were associated with distress index values to provide a basis for network characterization. These characterizations were compared with the defined scope of work for programmed projects using 1991 data.

On the basis of the achievements and findings presented in this study, the following conclusions may be drawn:

- The participation of PMS users in the development of criteria for network characterization is essential for acceptance and integration into the project programming processes.
- Though network characterization provides a basis for objective pavement programming, it alone does not represent a comprehensive view of roadway condition. The needs of nonpavement components of the roadway (ramps, bridges, rock slopes, etc.) must also be accommodated during program development.
- The relationship between the characterization of pavement condition and the treatments applied to specific projects can be a very complex one. Treatments cannot always be determined solely on the basis of characterized pavement condition.

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