Determination of Pavement Distress Index for Pavement Management

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A methodology is presented for determining a pavement distress index (PDI) needed for pavement management purposes. It involves a Delphi-like process for the acquisition of expert opinion through a series of questionnaires and the derivation of weighted average condition measures. Emphasis is placed on making the methodology useful for a wide range of pavement preservation decision-making purposes. The index formulation is based on two types of information, namely, (a) individual distress ratings along nominal lengths of pavement, and (b) a set of weighting values associated with the various distress types and severity-extent combinations. The PDI is used as a condition measure in various other analytical methodologies within the pavement management system of the New York State Thruway Authority. Important aspects of the methodology are discussed and the index calculation technique is demonstrated in an illustrative example. It is concluded that the developed index is a viable single measure of pavement surface condition useful for pavement management purposes.

The New York State Thruway Authority (NYSTA) and Rensselaer Polytechnic Institute (RPI) are cooperating to develop a pavement management system (PMS) for the authority's network, which consists of 641 centerline-mi (2,763 lane-mi) of Interstate-type highway. More than 90 percent of the network is composed of asphalt overlay pavement (AC). The rest is primarily the original jointed mesh–reinforced portland cement concrete (PCC). Throughout the system, shoulder surfaces are built of asphalt cement concrete.

Since 1989, NYSTA's PMS distress survey has been applied to the system annually. The survey technique (*1*) involves three personnel making visual distress estimates of the driving lane and shoulder from a vehicle driven on the shoulder at slow speeds. The distress types measured vary with pavement type. This intensive data collection activity results in eight distress ratings for each 1/10 mi of road surveyed. Table 1 summarizes the distress types and their possible ratings. The ratings are coded to represent linguistic assessments of distress severity and extent. The first letter S,M,L, or T denotes small, medium, large, or total level of severity, respectively; the second letter G or L denotes general or local extent. Thus, rating ML indicates medium severity and local extent, and rating TG indicates total severity and general extent. The code N stands for no distress.

Data collected by the distress survey represent measures of specific pavement surface features taken at regular intervals. The availability of such detailed data is essential for many pavement management tasks, but there is also the need to characterize pavement distress condition in a more aggregate manner. This is accomplished by combining individual distress data into indexes that summarize the condition of each pavement segment or project. Thus, distresses reflecting the condition of a specific pavement component such as slab, joint, shoulder, or an entire lane are combined into indexes descriptive of the condition of the specific component. The resulting indexes are referred to as slab distress index, joint distress index, shoulder distress index, and lane distress index. Consideration of all distresses on a given pavement segment produces a single index called the pavement distress index (PDI).

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TABLE 1 POSSIBLE DISTRESS STATES (1990)

Distress Type	Valid Ratings
Asphalt Pavement (Overlaid)	
Centerline cracking	N, SL, SG, ML, MG, LL, LG, TL, TG
Other types of lane cracking	N, SL, SG, ML, MG, LL, LG, TL, TG
Surface defects	N, SL, SG, ML, MG, LL, LG
Rutting	N, LL, LG, TL, TG
Transverse cracking	N, SL, SG, ML, MG, LL, LG, TL, TG
Edge cracking	N, SL, SG, ML, MG, LL, LG, TL, TG
Shoulder	
Shoulder defects	N, SL, SG, ML, MG, LL, LG
Lane/shoulder displacement	N, SL, SG, ML, MG, LL, LG
Concrete Pavement (Original)	
Loss of transverse joint seal	N, LL, LG
Transverse joint spalling	N, SL, SG, ML, MG, LL, LG, TL, TG
Transverse joint faulting	N, LL, LG
Longitudinal joint spalling	N, SL, SG, ML, MG, LL, LG, TL, TG
Slab surface defects	N, SL, SG, ML, MG, LL, LG, TL, TG
Slab cracking	N, SL, SG, ML, MG, LL, LG, TL, TG

OBJECTIVES

The availability of an appropriate PDI is considered an important requirement of NYSTA's PMS. Specific objectives in developing the PDI are to (a) combine distress data in a manner that reflects NYSTA maintenance practices and that is meaningful to field personnel and middle and upper management, and (b) create a sufficiently responsive condition measure that can be used for network-level analysis.

Like the PMS itself, the PDI is developed through a staged process. Desirable early products included tabular and graphical summaries of the surface condition of defined pavement segments. Other uses of PDI include the following:

- Monitor pavement surface condition over time.
- Define uniform condition sections for project-level analysis.
- Compare condition of candidate projects.
- Assist in project priority ranking for budgeting purposes.
- Conduct correlation analysis with other engineering parameters.

METHODOLOGY

It is well recognized that each individual distress type contributes in a distinct manner toward the aggregate pavement condition. For each distress type, relative severities are not equivalent (e.g., the difference between small and medium transverse crack may not be the same as the difference between small and medium surface defect). Thus, determination of an overall distress index must accommodate the relative significance of each distress type and magnitude (severity and extent).

The approach followed in this study to calculate PDI values uses weights determined on the basis of expert opinions. In general, each weight value represents the importance that maintenance personnel give to the task of correcting a specific pavement deficiency identified through surface distresses. This approach also enabled the capture of existing maintenance practices and the use of generated information to improve consistency of judgments throughout the network.

Use of Expert Opinion

Opinions were solicited from experienced maintenance personnel using a technique derived from the well-known Delphi method (*2*). The applied technique involved mainly a series of questionnaires, to which responses were solicited anonymously so that conformity pressure and individual domination would be minimized.

The task of soliciting expert opinion was accomplished through a series of three questionnaires. These involved multiple-choice questions, a modification of the "traditional" open-ended Delphi format. This modification helped expedite the completion of the questionnaires and facilitate quantification of responses.

The first questionnaire was distributed to 25 agency-designated pavement maintenance experts. Questions focused on repair priorities for isolated distress states; an example of the questions might be this: "When deciding on the need for maintenance work, how much importance do you assign to alligatored edge cracks?" Participants were asked to choose one of the following responses:

- Condition does not warrant repair;
- Very low priority repair;
- Low-priority repair;
- Medium-priority repair;
- High-priority repair; and
- Condition is critical; repair is of highest priority.

Questions about the relative significance of roadway components (e.g., concrete slab versus joint) and of the various distress types were phrased in a similar manner. Information on current maintenance practices was also collected. Generally, opinions expressed by maintenance personnel tended to confirm the severity progression of the distress scales.

After completion of the initial study, 9 personnel were selected from the original pool of 25 to participate in further refinement of the responses, as well as in other knowledge-acquisition activities. Logistics necessitated the reduction in the original number of participants.

In the second questionnaire, the nine participants' original responses to each question were summarized graphically. Participants were asked to review the group response and indicate whether they agreed with the majority opinion. Those who disagreed were asked for a brief written explanation. The results of the second questionnaire indicated that consensus was improved in almost every question. Furthermore, consistency was verified in the use of the distress scales; for example, participants assigned higher repair priorities to increasing severities of a given distress.

Finally, the third questionnaire aimed to achieve two objectives, namely, (a) review and confirm responses to questions that were asked for the first time in the second questionnaire and (b) refine the relative significance of each distress type.

Data Reduction

The information generated through the series of questionnaires was used to establish (a) the relative significance (for maintenance decision making) of each distress type and (b) the repair priority of each distress type–severity combination. Consensus on distress type–severity priorities was easily established, but the obtained responses were not consistent about the relative significance of each distress type. Thus, the effort of deriving a composite index for pavement surface condition had to address two major issues, namely, (a) accounting for repair priority of distress extents and (b) resolving inconsistency about the relative significance of each distress type.

The opinions on repair priorities were quantified by mapping the responses into integers (Table 2), the mean values of which were taken as the needed priority values. For example, for a particular distress state, if seven respondents

TABLE 2 INTEGER MAPPING FOR QUANTIFYING REPAIR PRIORITY

Repair Priority	Value
Condition does not warrant repair	0
Very low priority repair	1
Low priority repair	2
Medium priority repair	3
High priority repair	4
Condition is critical; repair is of highest priority	5

indicated a high priority and two indicated medium priority, then the resulting priority value was 3.78. Priority values generated in this manner are summarized in Tables 3 and 4 for overlaid and concrete pavements, respectively.

Values of the relative significance (significance score) of each distress type were proportionally scaled so that those corresponding to major significance, minor significance, and insignificant would be assigned scores of 100, 50, and 0, respectively. The significance score for each distress type was determined as the mean value of the significance scores provided by the nine participants. The resulting values for each distress type are given in Table 5.

Significance scores were interpreted as representing the relative importance of each distress type and priority values as representative of the cells associated with the general extent of various distress type–severity combinations.

Weight Determination

The values of the weights associated with each distress state are determined using the priority values and significance scores. The applied procedure involves the following steps.

1. Record the significance scores and priority values in a blank weight table. If two or more surface conditions are combined in one level of the scale, the priority values associated with each of the conditions are averaged and the average value is recorded.
2. Identify the "anchor cell" in the table. To do this, consider (only) those distresses that have a "total" scale. The TG cell of the distress that has the highest significance score will be the anchor cell. Assign this cell the arbitrary weight of 10.
3. Calculate weights for the other TG cells in the table on the basis of the ratio of the significance scores as follows:

$$(W_{\mathrm{TG}}) = \frac{(SS_{\mathrm{TG}})}{(SS_a)} \times (10) \tag{1}$$

where

W_{TG} = weight for a given TG cell,
SS_{TG} = significance score associated with the column that holds the given TG cell, and
SS_a = significance score associated with the column that holds the anchor cell.

4. Calculate weights for all the remaining "general" cells in the columns that contain a TG cell. For each column, use the ratio of priority values as follows:

$$W_{\mathrm{LG}} = \left(\frac{P_{\mathrm{LG}}}{P_{\mathrm{TG}}}\right) \times W_{\mathrm{TG}} \tag{2}$$

where

W_{LG} = weight for an LG cell (in the same column as the TG cell),
P_{LG} = priority value associated with the LG cell (in the same column as the TG cell),

TABLE 3 PRIORITY VALUES FOR OVERLAID PAVEMENT (1990)

Distress Type	Severity				
	None	Small	Medium	Large	Total
Centerline cracking	0.00	1.05	2.89	3.22	4.11
Other types of lane cracking	0.00	1.00	2.89	3.11	4.11
Surface defects	0.00	1.57	3.27	4.11	–
Rutting	0.11	–	–	3.22	4.00
Transverse cracking	0.00	1.11	2.99	3.01	4.00
Edge cracking	0.00	1.11	3.00	3.11	4.00
Shoulder defects	0.00	1.00	2.08	2.95	–
Lane/shoulder displacement	0.00	2.00	3.11	4.11	–

TABLE 4 PRIORITY VALUES FOR CONCRETE PAVEMENT (1990)

Distress Type	Severity				
	None	Small	Medium	Large	Total
Loss of transverse joint seal	0.00	–	–	3.29	–
Transverse joint spalling	0.00	1.33	3.00	3.38	4.00
Transverse joint faulting	0.00	–	–	3.00	–
Longitudinal joint spalling	0.00	1.33	2.38	3.67	3.89
Slab surface defects	0.00	0.88	1.22	2.88	3.50
Slab cracking	0.00	1.00	1.14	2.11	3.88
Shoulder defects	0.00	1.00	2.08	2.95	–
Lane/shoulder displacement	0.00	2.00	3.11	4.11	–

TABLE 5 SIGNIFICANCE SCORES

Distress Type	Significance Score
OVERLAID PAVEMENT	
Centerline cracking	70.5
Other types of lane cracking	75.1
Surface defects	62.5
Rutting	88.3
Transverse cracking	75.7
Edge cracking	40.2
Shoulder defects	39.7
Lane/shoulder displacement	51.8
CONCRETE PAVEMENT	
Loss of transverse joint seal	71.6
Transverse joint spalling	79.3
Transverse joint faulting	73.2
Longitudinal joint spalling	78.6
Slab surface defects	76.6
Slab cracking	68.2
Shoulder defects	38.1
Lane/shoulder displacement	58.4

P_{TG} = priority value associated with the TG cell, and
W_{TG} = weight for a TG cell.

5. Use the LG weight from the column that holds the anchor cell to calculate the weight for the remaining LG cells (i.e., those scales that have a maximum rating of LG). Use the ratio of significance scores, as in Step 3.
6. Calculate weights for all the remaining "general" cells in the columns that have LG cell as the maximum rating. Use the ratio of priority values as in Step 4.
7. Calculate weights for all the "local" cells in the table as a weighted average of the "general" cells immediately above and below the "local" cell. For example, in a given column the weighted average is expresses as follows:

$$W_{ML} = 0.75\,(W_{MG}) + 0.25\,(W_{SG}) \quad (3)$$

where

W_{ML} = weight associated with the ML cell of a given column,
W_{MG} = weight associated with the MG cell of a given column, and
W_{SG} = weight associated with the SG cell of a given column.

In summary, weights are generated by assigning the value of 10 to the highest severity-extent combination of the distress that had the highest significance score and then using the priority values and significance scores to proportionately scale weights for the remainder of the cells in the table that correspond to a general extent. Weights for the local cells were derived by taking a weighted average (3:1) of the weights representing the next worst state and the next best state, respectively. The procedure was applied separately for overlaid and concrete pavements and the resulting values for the weights are presented in Tables 6 and 7, respectively.

It should be noted that the weighting factor for Level N of the distress Rutting in Table 6 is greater than zero. This is the (deliberate) case for rutting only and reflects the possibility that maintenance action may still be required even when Rutting is rated N. Rating of N is assigned to sections that exhibit up to 0.5 in. of rutting due to limitations of the current visual distress survey procedure (*1*).

TABLE 6 PDI WEIGHTS FOR OVERLAID PAVEMENT (1990)

	Distress Type							
Rating	A	B	C	D	E	F	G	H
N	0.00	0.00	0.00	0.28	0.00	0.00	0.00	0.00
SL	1.53	1.55	1.63	–	1.78	0.95	0.92	1.72
SG	2.04	2.07	2.18	–	2.38	1.26	1.23	2.30
ML	4.72	5.00	3.95	–	5.40	2.87	2.22	3.25
MG	5.61	5.98	4.54	–	6.41	3.41	2.55	3.57
LL	6.09	6.33	5.41	6.11	6.44	3.51	3.35	4.43
LG	6.25	6.44	5.70	8.05	6.45	3.54	3.62	4.72
TL	7.55	7.99	–	9.51	8.04	4.30	–	–
TG	7.98	8.51	–	10.0	8.57	4.55	–	–

A = Centerline cracking
B = Longitudinal cracking
C = Surface defects
D = Rutting
E = Transverse cracking
F = Edge cracking
G = Shoulder cracking
H = Lane/shoulder displacement

TABLE 7 PDI WEIGHTS FOR CONCRETE PAVEMENT (1990)

	Distress Type							
Rating	G	H	I	J	K	L	M	N
N	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
SL	1.04	2.27	–	2.50	–	2.54	1.82	1.66
SG	1.38	3.03	–	3.33	–	3.39	2.43	2.22
ML	2.49	4.29	–	6.46	–	5.39	3.14	2.45
MG	2.86	4.71	–	7.50	–	6.06	3.37	2.53
LL	3.76	5.84	5.80	8.21	5.85	8.53	6.81	4.14
LG	4.06	6.22	7.63	8.45	7.80	9.35	7.95	4.68
TL	–	–	–	9.61	–	9.77	9.23	7.62
TG	–	–	–	10.0	–	9.91	9.66	8.60

G = Shoulder defects
H = Lane/shoulder displacement
I = Loss of transverse joint seal
J = Transverse joint spalling
K = Transverse joint faulting
L = Longitudinal joint spalling
M = Slab surface defects
N = Slab cracking

INDEX CALCULATION

Distress indexes are determined by developing a repair priority score for a given segment and converting the result to a value between 0 and 100. Index values are reported on a 100-point scale, with 100 being the maximum possible score for a given index. Consequently, high index values represent pavement surfaces that exhibit relatively minor distress, and, inversely, low index values correspond to pavement surfaces that are highly distressed.

Related distresses are similarly combined to produce subindexes that are representative of the surface condition of various roadway components. For overlaid and concrete pavements, the two main roadway components considered are the (driving) lane and the shoulder. For concrete pavements, the lane is further divided into slabs and joints. Indexes determined include the index (PDI), lane distress index (LDI), shoulder distress index (SDI), and (for concrete pavement only) joint distress subindex (JDS) and slab distress subindex (SDS). All indexes are calculated similarly and are reported on a 100-point scale. Thus, for example, the expression for determining the pavement distress index for overlaid pavement is as follows:

$$\mathrm{PDI} = \frac{100\left(\sum_{d=A}^{H} W_{\bar{r}d} - \sum_{d=A}^{H} W_{rd}\right)}{\sum_{d=A}^{H} W_{\bar{r}d}} \quad (4)$$

where

$W_{\bar{r}d}$ = weight for the distress state specified by the highest possible rating $\bar{r}$, for Distress Type d;

W_{rd} = weight for the distress state specified by Rating r for Distress Type d for overlaid pavement;

r = linguistic distress rating, with $r \in$ {N, SL, SG, ML, MG, LL, LG, TL, TG}; and

d = distress type for overlaid pavement, with $d \in$ {A, B, C, D, E, F, G, H} (as identified in Table 6).

ILLUSTRATIVE EXAMPLE

Table 8 lists an example of distress ratings for an overlaid pavement segment and the values of the weights and maximum weights that correspond to each distress rating. The calculations for determining each index of interest are as follows:

Overlaid pavement distress index:

$$\sum_{d=A}^{H} W_{\bar{r}d} = (7.98 + 8.51 + 5.70 + 10.00 + 8.57 + 4.55 + 3.62 + 4.72) = 53.65$$

$$\sum_{d=A}^{H} W_{rd} = (5.61 + 0.00 + 2.18 + 0.28 + 5.40 + 3.41 + 1.23 + 2.30) = 20.41$$

$$\text{PDI} = \frac{100}{53.65}(53.65 - 20.41) = 61.96$$

Overlaid lane distress index:

$$\sum_{d=A}^{F} W_{\bar{r}d} = (7.98 + 8.51 + 5.70 + 10.00 + 8.57 + 4.55) = 45.31$$

$$\sum_{d=A}^{F} W_{rd} = (5.61 + 0.00 + 2.18 + 0.28 + 5.40 + 3.41) = 16.88$$

$$\text{LDI} = \frac{100}{45.31}(45.31 - 16.88) = 62.76$$

Overlaid shoulder distress index:

$$\sum_{d=G}^{H} W_{\bar{r}d} = (3.62 + 4.72) = 8.34$$

$$\sum_{d=G}^{H} W_{rd} = (1.23 + 2.30) = 3.53$$

$$\text{SDI} = \frac{100}{8.34}(8.34 - 3.53) = 57.67$$

The results of the index calculations for the illustrative example are given in Table 9.

TABLE 8 DISTRESS CONDITION FOR ILLUSTRATIVE EXAMPLE

Distress	Rating	Weight	Maximum Weight
A. Centerline cracking	MG	5.61	7.98
B. Other types of lane cracking	N	0.00	8.51
C. Surface defects	SG	2.18	5.70
D. Rutting	N	0.28	10.00
E. Transverse cracking	ML	5.40	8.57
F. Edge cracking	MG	3.41	4.55
G. Shoulder defects	SG	1.23	3.62
H. Lane/shoulder displacement	SG	2.30	4.72

DISCUSSION OF RESULTS

Use of Expert Opinion

The Delphi technique used to acquire expert opinion enabled the development of a consensus on repair priorities. Using questionnaires proved to be a convenient device for interacting with a large number of participants at different locations, and anonymity prevented undesirable individual domination. As expected, agreement between experts increased with increasing iterations.

Shortcomings of the applied method were due to the excessive demands placed on the participants' time and to the relatively large number of distress states involved. In an effort to offset these shortcomings, questions were presented in multiple-choice format rather than in the unstructured form associated with the Delphi technique.

Although participants were encouraged to write explanatory notes when necessary, doing so was rare. The multiple-choice format may have suppressed some valuable information that might have otherwise surfaced in a less-directed (e.g., verbal) exchange. Nevertheless, the used questionnaires did serve the goal of keeping the activity focused on repair priority.

TABLE 9 SUMMARY OF RESULTS FOR ILLUSTRATIVE EXAMPLE

Index	Unscaled Values $\Sigma W_{rd}/\Sigma W_{\bar{r}d}$	Percentage $100(\Sigma W_{rd}/\Sigma W_{\bar{r}d})$	Reported Value (100-percentage)
LDI	16.88/45.31	37.25%	62.75
SDI	3.53/8.34	42.33%	57.67
PDI	20.41/53.65	38.04%	61.96

Data Reduction

Responses identified some distress types (particularly those relating to shoulders) to be much less significant than others. This was determined to be consistent with the use of distresses for pavement maintenance purposes.

Significance scores were introduced as a means to adjust the weights so that they better reflect the relative importance of each distress type. Priority values were used to determine weights associated with the remaining ratings for each distress type in proportion to the maximum value. The fact that priority values generally increased monotonically with the severity of a distress was considered supportive evidence that the derived relationships were appropriate.

The process for deriving weights for the "local" cells involved a simple weighted average (75/25) of the "general" weights immediately above and below the "local" cell, respectively. This weighting was considered by the experts to be reasonable and consistent with the use of the distress scales (i.e., the requirement that the contribution of a "local" distress state be less than the "general" state of the same severity level and greater than the "general" state that is one severity level lower).

Index Calculation

The calculation method produces the total significance of the distress present in a pavement section by using weighting factors as deduct points. For every distress state that exists, the corresponding weighting factor is deducted from the maximum (worst) possible combination of weights for the roadway component of interest. After all deductions have been considered, the remaining value is scaled proportionately to the maximum and reported on 100-point scale.

The scaled value denotes the calculated cumulative distress condition relative to the maximum value a given distress index may receive.

The PDI is useful for comparing projects on the basis of exhibited surface distresses. The established indexes permit comparison from the perspective of (a) lane condition, (b) shoulder condition, and (c) overall pavement condition. For concrete pavements, comparisons of joint and slab condition can also be made.

Comparisons between projects of different pavement types is often necessary. As PDI may be interpreted to represent the percentage of maximum repair priority, it is reasonable to directly compare the PDI values of projects of different pavement type. Projects with similar PDI have similar repair priorities for their respective combinations of surface distresses, regardless of pavement type.

Finally, it should be noted that nondistress aspects of pavement condition (e.g., ride quality and drainage) and performance (e.g., deterioration rate, remaining life) may be quite different for projects with similar PDI values, even if such projects belong to the same pavement type. Based solely on distresses, PDI is a useful tool for pavement surface condition analyses and project comparisons; but it must be supplemented with other engineering parameters for comprehensive project evaluations.

SUMMARY AND CONCLUSIONS

This study presented the methodology followed in determining PDI needed for pavement management purposes. The methodology involved a Delphi-like process for the acquisition of expert opinion and the derivation of weighted average condition measures for various pavement components. Emphasis was placed on making the methodology useful for making a wide range of maintenance decisions.

On the basis of the findings of the study, the following conclusions may be drawn:

- The developed pavement distress index is a viable single measure of pavement surface condition. It is used mainly for network-level analysis.
- The applied Delphi technique enabled the establishment of the relative importance of the various distresses and helped achieve adequate consensus among experts.

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