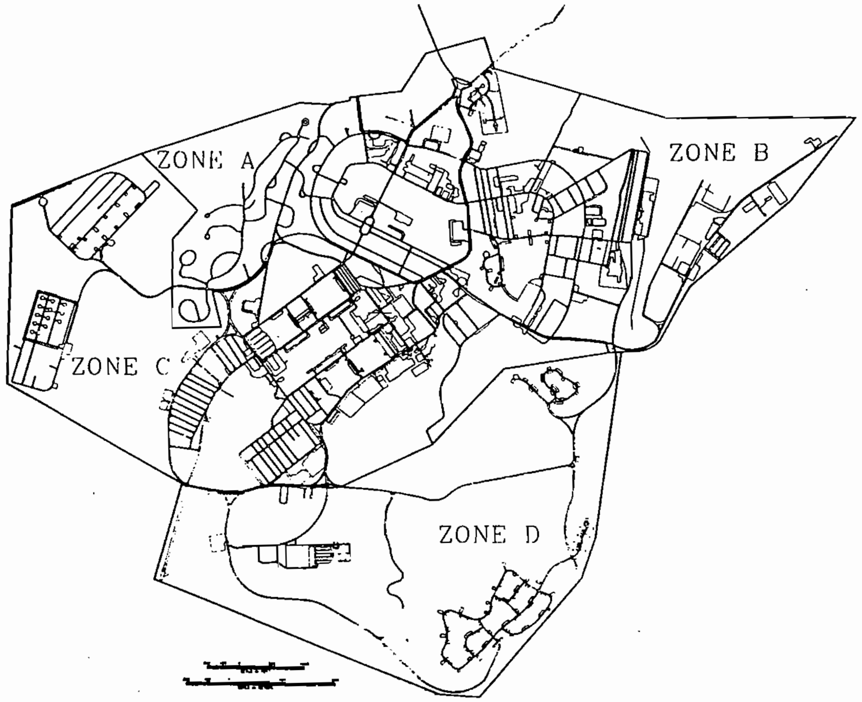


Figure 2-6. Example network divided into zones. (From Shahin and Walther, 1990.)

fications factors: "Zone" and "Section Category." Typically zones are used to group geographic portions of a network based on a characteristic common to the subset. Zones can be used in any way that would prove useful to the agency implementing the PMS. Zones have been used effectively to designate remote areas, funding sources for M & R work, snow removal priority zones, and snow routes. Fig. 2-6 shows an example map broken down into zones. Zones and other factors for section grouping can be very useful as an option in report generation and data selection.

References

Engineering and Research International (ERI). Consulting Reports (1984); Savoy, IL.

Shahin, M. Y. and Walther, J. A. (1990) Pavement Maintenance Management for Roads and Streets Using the PAVER System; USACERL Technical Report MO-90/05, July.

Shahin 1994.

3

Pavement Condition Survey and Rating Procedure

3.1 Overview

An important feature of a pavement management system (PMS) is the ability both to determine the current condition of a pavement network and to predict its future condition. To predict condition reliably, an objective, repeatable rating system for identifying the pavement's condition must be used. The pavement distress condition rating procedure presented here is the Pavement Condition Index (PCI) developed by the U.S. Army Corps of Engineers (Eaton Gerard, and Gate 1987; Kohn and Shahin 1984; Shahin and Walther 1990; Shahin et al. 1976–1984). The use of PCI for airfield pavement, roads, and parking lots has received wide acceptance and has been formally adopted as standard procedure by many agencies worldwide. These agencies include the Federal Aviation Administration (FAA 1982), The U.S. Department of Defense (U.S. Air Force 1981, U.S. Army 1982), the American Public Works Association (APWA 1984), and many others. The PCI for airfields has also been published as an ASTM test method. (ASTM 1993)

The PCI is a numerical index, ranging from 0 for a failed pavement to 100 for a pavement in perfect condition. Calculation of the PCI is based on the results of a visual condition survey in which distress type, severity, and quantity are identified. The PCI was developed to provide an index of the pavement's structural integrity and surface operational condition. The distress information obtained as part of the PCI condition survey provides an insight into the causes of distress, and whether it is related to load or climate.

The degree of pavement deterioration is a function of distress type, distress severity, and amount or density of distress. Because of the large number of conditions possible, producing one index that would take into account all three factors was a considerable problem. To overcome this problem, "deduct values" were introduced as a type of weighing factor to indicate the degree of effect that each combination of distress type, severity level, and distress density has on pavement condition. Based on in-depth knowledge of pavement behavior, input from many experienced pavement engineers, field testing and evaluation of the procedure, and accurate descriptions of distress types, severity levels and their corresponding deduct values were derived so that a composite distress index—the PCI—could be determined.

To determine the PCI of a pavement section, the section is first divided into inspection units, called sample units, as described in Section 3.2. Section 3.3 presents methods for determining the number of sample units to inspect, and identifying which ones to inspect. Section 3.4 presents the survey procedures for asphalt and concrete pavement as well as unsurfaced roads. Section 3.5 covers calculation of the PCI for each sample unit, and determination of the average PCI for a pavement section.

3.2 Dividing Pavement into Sample Units

A sample unit is a conveniently defined portion of a pavement section designated only for the purpose of pavement inspection. For unsurfaced and asphalt surfaced roads (including asphalt over concrete), a sample unit is defined as an area 2500 ± 1000 sq ft. For asphalt surfaced airfields each sample unit area is defined as 5000 ± 2000 sq ft. It should be noted that sample unit sizes close to the recommended mean are preferred for accuracy.

For concrete roads and airfields with joints spaced ≤25 ft, the recommended sample unit size is 20 ± 8 slabs. For slabs with joints spaced >25 ft, imaginary joints ≤25 ft apart, and in perfect condition, should be assumed. For example, if slabs have joints spaced 60 ft apart, imaginary joints are assumed at 20 ft. Thus, each slab would be counted as three slabs for the purpose of pavement inspection.

An important consideration in dividing a pavement section into sample units is convenience. For example, an asphalt pavement section 22 ft wide by 4720 ft long (Fig. 3-1) can be divided into sample units 22 ft wide by 100 ft long, for a sample unit size of 2200 sq ft. Because of the length of the section some sample units may have to be a different length than the others. Not all sample

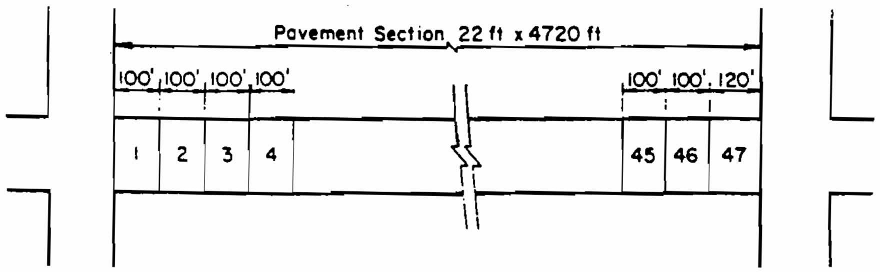


Figure 3-1. Example of an asphalt section divided into sample units.

units are required to be the same size, but they do have to fit within the guidelines for recommended sample unit size to ensure an accurate PCI. The section discussed in the example given previously can be divided into 46 units that are each 100 ft long, plus one unit that is 120 ft long. Therefore, this last sample unit has an area of 22 ft by 120 ft, or 2640 sq ft. Fig. 3-2 shows an example

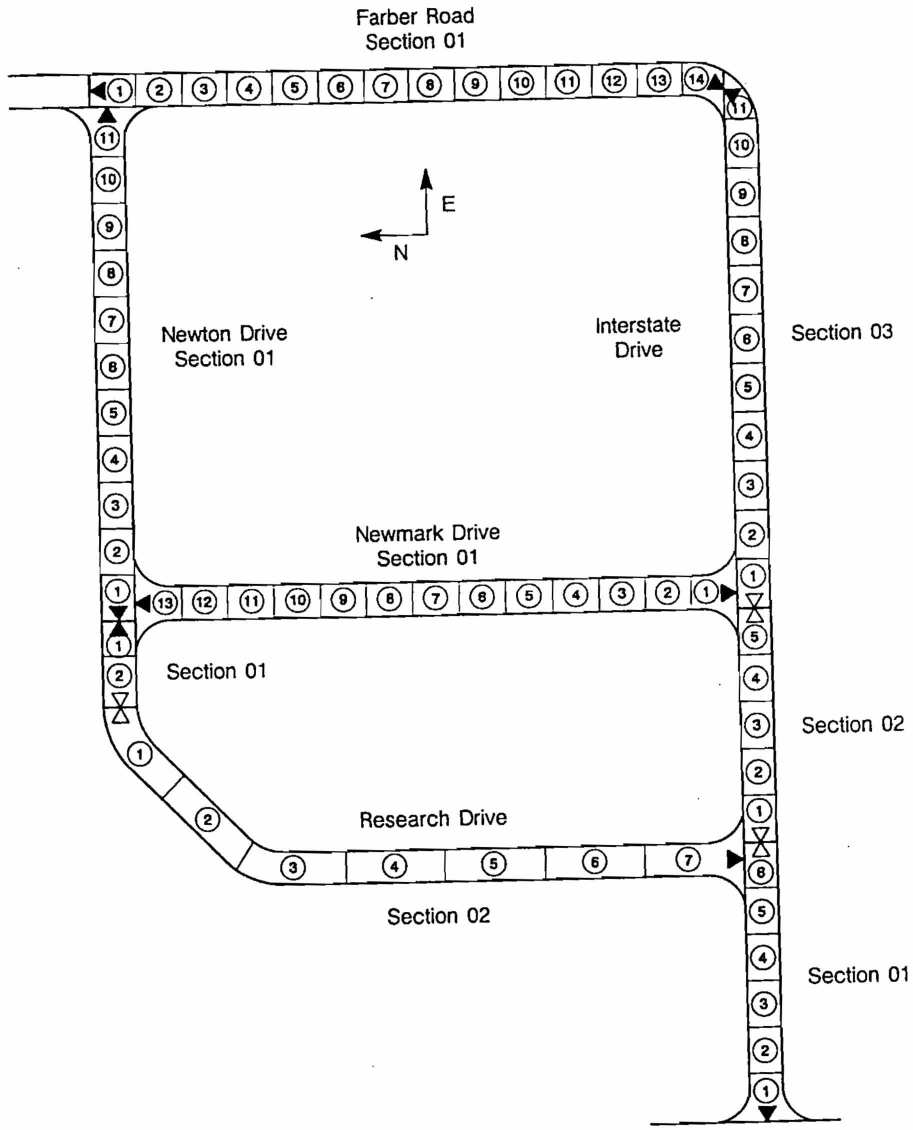


Figure 3-2. Example road network divided into sample units.

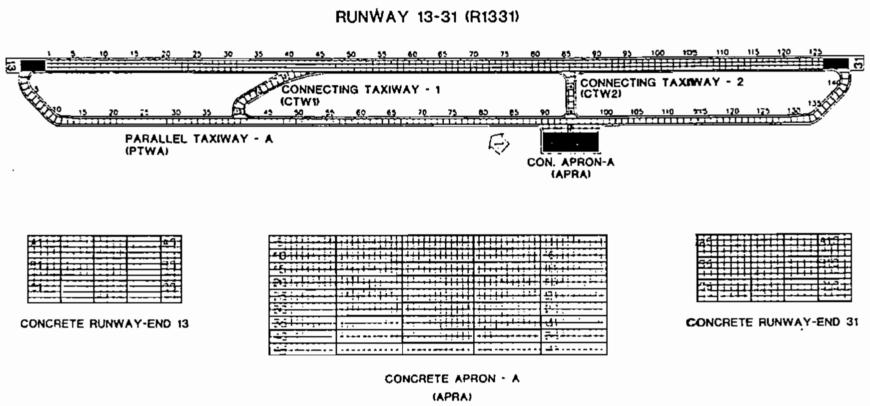


Figure 3-3. Example airfield pavement network divided into sample units. (From ERI Consulting Reports 1984)

road network, divided into sample units. Fig. 3-3 shows an example airfield pavement network divided into sample units.

For each pavement section being inspected, it is strongly recommended that sketches be kept showing the size and location of sample units. These sketches can be used to relocate sample units for future inspections. Guidance on the minimum number of sample units from a pavement section to be inspected is provided in Section 3.3.

3.3 Determining Sample Units to Be Surveyed

The inspection of every sample unit in a pavement section may require considerable effort, especially if the section is large. To limit the amount of resources required for an inspection, a sampling plan was developed so a reasonably accurate PCI could be estimated by inspecting only a limited number of the sample units in the pavement section. The required degree of sampling depends on the use of the pavement and whether the survey is conducted at the network or project level.

If the objective is to make network-level decisions such as budget planning, then a survey of a limited number of sample units per section is sufficient. If the objective is to evaluate specific pavement sections at the project level, then a higher degree of sampling for a section may be required.

3.3.1 Project-Level Inspection

3.3.1.1 Determining the Number of Sample Units to be Inspected.

Management at the project level requires accurate data for the preparation of work plans and contracts. Therefore, more sample units are inspected than are usually sampled for network level management. The first step in sampling is to

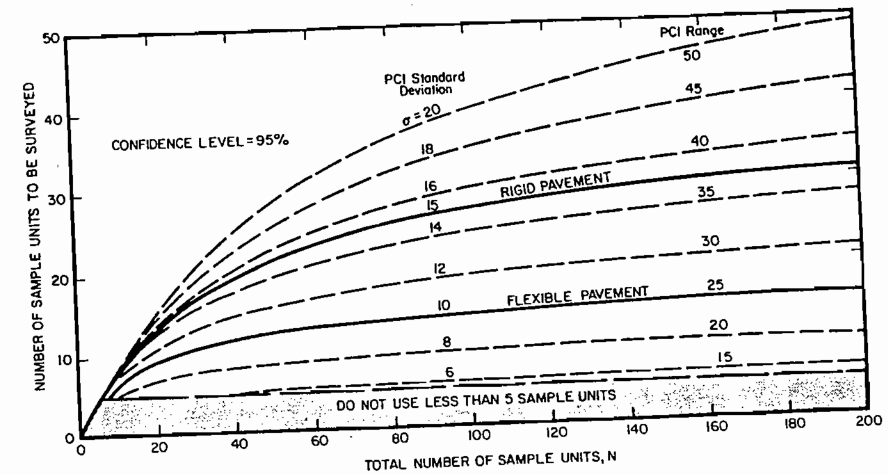


Figure 3-4. Selection of the minimum number of sample units. (From Shahin et al. 1976–1984).

determine the minimum number of sample units (n) that must be surveyed to obtain an adequate estimate of the section's PCI. This number is determined for a project-level evaluation by using the curves shown in Fig. 3-4. Using this number, a reasonable estimate of the true mean PCI of the section will be obtained. The estimate is within ±5 points of the true mean PCI 95% of the time. The curves in Figure 3-4 were constructed using Eq. 3.1:

$$n = [N \cdot s^2]/[(e^2/4)(N-1) + s^2] \tag{3-1}$$

where

N = total number of sample units in the pavement section

e = allowable error in the estimate of the section PCI (e was set equal to 5 when constructing the curves of Figure 3-4)

s = standard deviation of the PCI between sample units in the section.

The curves in Figure 3-4 can be used based on the PCI standard deviation among sample units, or PCI range (i.e., lowest sample unit PCI subtracted from the highest sample unit PCI). When performing the initial inspection, the PCI standard deviation for a pavement section is assumed to be 10 for asphalt concrete (AC) surfaced pavements (or PCI range of 25) and 15 for Portland cement concrete (PCC) surfaced pavements (or PCI range of 35). These values are based on field data obtained from many surveys; however, if local experience is different, the average standard deviations reflecting local conditions should be used for the initial inspection. For subsequent inspections, the actual PCI standard deviation or range (determined from the previous inspection) should be used to determine the minimum number of sample units to be surveyed. As

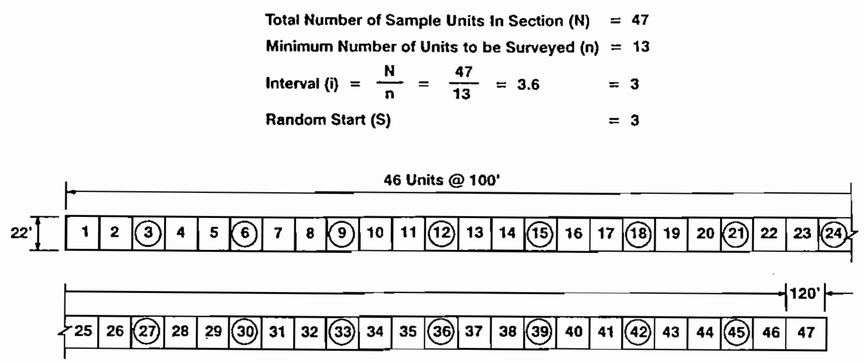


Figure 3-5. Example of systematic random sampling.

Figure 3-4 shows, when the total number of samples within a section is less than five, it is recommended that all of the sample units be surveyed.

3.3.1.2 Selecting Sample Units to Inspect

It is recommended that the sample units to be inspected be spaced equally throughout the section, and that the first one be chosen at random. This technique, known as "systematic random," is illustrated in Fig. 3-5 and described by the following three steps:

1. The sampling interval (i) is determined by $i = N/n$, where N equals the total number of available sample units and n equals the minimum number of sample units to be surveyed. The sampling interval (i) is rounded off to the smaller whole number (e.g., 3.6 is rounded to 3.0).
2. Random start(s) is/are selected at random between sample unit 1 and the sampling interval (i). For example, if $i = 3$, the random starts would be a number from 1 to 3.
3. The sample units to be surveyed are identified as s, $s + i$, $s + 2i$, etc. If the selected start is 3, and the sampling interval is 3, then the sample units to be surveyed are 6, 9, 12, etc.

3.3.2 Network-Level Inspection

3.3.2.1 Determining the Number of Sample Units to Be Inspected

A network-level survey can be conducted by surveying only a few sample units per section. Table 3-1 provides an example of criteria used by agencies for determining the number of sample units to survey at the network level. The number of units to be inspected (n) is increased by 1 for every increase of five units in the section (N) until N equals 15. When N equals 16 to 40, the value of n is set at 4. When the value of N is >40, n is set at 10% of N and rounded up to the next whole sample unit. For example, if $N = 52$, the $n = 6$ (rounded up from 5.2).

Table 3-1 Example of Network Level Sampling Criteria Used by Some Agencies

No. of Sample Units in Section (N)	No. of Units to Be Inspected (n)
1–5	1
6–10	2
11–15	3
16–50	4
over 40	10% (round up to next whole sample unit)

Table 3-2 differs slightly from Table 3-1. It was based on Eq. 3-1 assuming a standard deviation, s, equal to the allowable error, e, of 5. There is no scientific basis for this assumption, but it provides a consistent basis for selecting the number of units to inspect for different size sections. The criteria in Table 3-2 result in a higher n when N is <5, whereas those in Table 3-1 result in a higher n when N is >40.

The values in Tables 3-1 and 3-2 are provided as examples. The degree of sampling presented in either table is sufficient for developing network-level maintenance work plans, assessing the condition of the pavement, and identifying candidate sections that may warrant detailed project-level inspections.

3.3.2.2 Selecting Sample Units to Inspect

The sample units selected should be representative of the overall condition of the section. The main objective for budget estimating and network condition assessment is to obtain a meaningful rating with the least cost.

As can be seen in tables 3-1 and 3-2, when performing inspection at the network level, one can survey as little as one sample unit. The selected sample unit should be representative of the section. This requires the inspector to pre-

Table 3-2 Network Level Sampling Based on Eq. 3.1 ($e = 5$, $s = 5$)

No. of Sample Units in Section (N)	No. of Units to Be Inspected (n)
1	1
2–4	2
5–20	3
over 20	4

walk or at least drive slowly over the entire section to be able to select a representative unit. An alternate way to pre-walking is to survey several equally spaced smaller areas so that the total area surveyed add up to the area of the desired number of sample units to inspect. For example, it was decided to survey one sample unit from an asphalt pavement section that is 25 ft wide by 400 ft long. Instead of selecting one representative sample unit that is 25 ft wide by 100 ft long, one can survey five equally spaced smaller areas each 25 ft wide by 20 ft long. The areas will be spaced at 400/5 or 80 ft. The first area will be selected within the first 80 ft of the section. This will eliminate the need to pre-walk the section and may be more representative of the section. This method of sample unit selection may be more applicable for urban roads. In rural roads, where sections are long, it may be more convenient to drive and stop to survey a full sample unit.

3.3.3 Special Considerations

3.3.3.1 Airfield Pavement Inspection

Airfield pavements are normally held to higher maintenance standards than roads and parking lots because loose objects from spalled pavements or unfilled cracks can cause serious damage to aircraft engines and propellers.

On the central 50 ft of runways (the keel section), where 95% of the traffic takes place, it is not unreasonable to survey 50% of the sample units, or even every sample unit. On the outside of a runway, and on taxiways and aprons, a 20% to 25% sampling may be sufficient. This level of inspection may be appropriate both at the network and project levels.

3.3.3.2 Roads and Parking Lot Pavement Inspection

For roads and parking lots, it is difficult to justify a high degree of sampling unless a project level evaluation is being performed. A 10% to 25% degree of sampling, as presented in Tables 3-1 and 3-2, is normally sufficient at the network level. The project-level inspection is sampled as discussed in Section 3.3.1. However, every sample unit may be surveyed if accurate distress quantities are to be determined for contractual purposes.

3.3.3.3 Selecting Additional Sample Units

One of the major drawbacks to both systematic random sampling at the project level and representative sampling at the network level is that sample units in exceptionally bad condition may not necessarily be included in the survey. At the same time, sample units that have a one-time-occurrence type of distress (e.g., railroad crossings) may inappropriately be included as a random sample.

To overcome these drawbacks, the inspection should identify any unusual sample units and inspect them as "additional" units rather than as random or representative units. When additional sample units are included in the survey, the calculation of the Section PCI is slightly altered to prevent extrapolation of the unusual conditions across the entire section. This procedure is discussed in more detail in Section 3.5

3.4 Performing the Condition Survey

The procedures used to perform a PCI condition survey will vary depending on the surface type of the pavement being inspected. For all surface types, the pavement section must first be divided into sample units and selected as described in the previous section. The inspection procedures for asphalt and concrete surfaced pavements and unsurfaced roads are described in the sections that follow. Blank field condition survey sheets are provided in Appendix A. The distress definitions must be followed so an accurate PCI can be determined. These definitions are provided in Appendices B through F.

3.4.1 Asphalt Surfaced Pavements

The condition survey of all asphalt, tar-surfaced, and asphalt-over-concrete pavements involves the following:

Equipment

Inspectors need a hand odometer to measure distress lengths and areas, a straightedge, a ruler to measure the depth of ruts or depressions, and the PCI distress manual.

Procedure

A sample unit is inspected by measuring the distress type and severity according to the PCI distress manual, and recording the data on the flexible pavement survey sheet (Fig. 3-6). The distress definitions and procedures for measuring them for asphalt surfaced roads and airfield pavements are provided in Appendices B and D, respectively. These definitions should be followed closely when performing the PCI survey. One data sheet is used for each sample unit. The distress codes provided on the data sheets correspond to the distress identification codes used in the Micro PAVER system. Each row on the data sheet is used to represent a distress type at a given severity level. In Figure 3-6, for example, number 48 (longitudinal and transverse cracking, low severity) is measured in linear feet, so 10 indicates 10 ft of low-severity cracking and so on. All distress data are used to compute the PCI of the sample unit, as discussed later in this chapter.

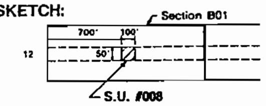
3.4.2 Concrete Surfaced Pavements

The following equipment and procedure are used to inspect both plain and jointed reinforced concrete pavements:

AIRFIELD ASPHALT PAVEMENT CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH R1230 SECTION B01 SAMPLE UNIT 008
SURVEYED BY MYS DATE MAR/15/92 SAMPLE AREA 5000 sf

SKETCH:



41. Alligator Cracking	45. Depression	49. Oil Spillage	53. Rutting
42. Bleeding	46. Jet Blast	50. Patching	54. Shoving from PCC
43. Block Cracking	47. Jt. Reflection (PCC)	51. Polished Aggregate	55. Slippage Cracking
44. Corrugation	48. Long. & Trans. Cracking	52. Raveling/Weathering	56. Swell

DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE
48 L	10	20	17							47	0.94	4.8
48 M	7	9								16	0.32	6.7
41 L	53									53	1.06	21.0
45 L	10	5								15	0.3	1.6
53 L	20	45	10							75	1.5	17.1
53 M	25									25	0.5	20.1

Figure 3-6. Example airfield AC sample unit condition survey sheet.

Equipment

Inspectors need a hand odometer for measuring slab size, a straightedge and ruler for measuring faulting and lane/shoulder drop-off, and the PCI distress manual.

Procedure

The inspection is performed by recording the distress found in each slab on the concrete pavement field inspection data sheet, an example of which is shown in Fig. 3-7. The distress definitions and procedures for measuring them for concrete surfaced roads and airfield pavements are provided in Appendices C and E, respectively. These definitions should be followed very closely when conducting the PCI survey. One data sheet is used for each sample unit. The sample unit is sketched using the dots as joint intersections. The appropriate number code for each distress found in the slab is entered in the square representing the slab. These number codes correspond to the distress identification codes used in the Micro PAVER system. The letter L (low), M (medium), or H (high) is included with the distress number code to indicate the severity level of the distress. For example, 62L indicates that a slab has low-severity linear cracking.

Space is provided on the concrete pavement inspection data sheet for summarizing the distresses for the sample unit. Remember to record the overall severity level of the joint sealant (i.e., L, M, or H). Calculation of the PCI is discussed in Section 3.5.

AIRFIELD CONCRETE PAVEMENTS
CONDITION SURVEY DATA SHEET FOR SAMPLE UNIT

BRANCH R1230 SECTION B03 SAMPLE UNIT 005
SURVEYED BY MYS DATE MAR/15/90 NUMBER OF SLABS 20

Distress Types

61. Blow up	69. Pumping
62. Corner Break	70. Scaling/Map Crack/ Crazing
63. Long/Trans/ Diagonal Crack	71. Settlement/Fault
64. Durability Crack	72. Shattered Slab
65. Joint Seal Damage	73. Shrinkage Crack
66. Patching, 5 sf	74. Spalling–Joints
67. Patching/Utility Cut	75. Spalling–Corner
68. Popouts	

DIST TYPE	SEV	NO. SLABS	DENSITY %	DEDUCT VALUE
65	H			12
62	L	2	10	7.8
62	M	1	5	8.6
63	L	3	15	11.5
63	M	3	20	24.0
72	L	1	5	11.0
74	L	2	10	3.5
75	L	3	15	5.5
75	M	1	5	3.6

SKETCH:

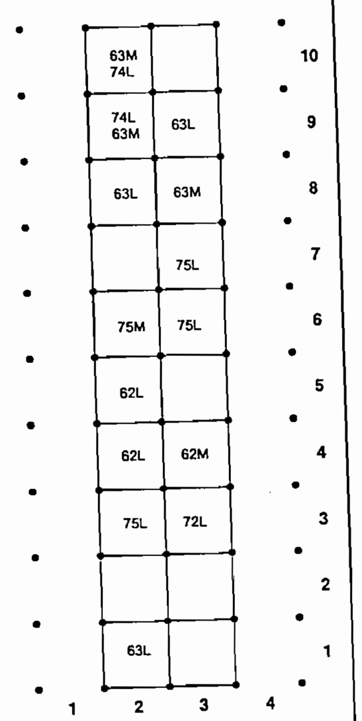


Figure 3-7. Example airfield PCC sample unit condition survey sheet.

3.4.3 *Unsurfaced Roads*

The unsurfaced road PCI procedure was developed by the U.S. Army Cold Regions Research and Engineering Laboratory through funding from the Federal Highway Administration (Eaton, Gerard, and Gate 1988). An unsurfaced road, as used in this procedure, is defined as a road that does not have asphalt concrete (AC), portland cement concrete (PCC), or surface treatment.

Equipment

A hand odometer, straightedge, ruler, and the unsurfaced road distress manual are needed.

Procedure

Two kinds of inspections are performed on unsurfaced roads: a "windshield inspection" and an inspection based on detailed distress measurement within the sample units.

The windshield inspection is conducted by driving the full length of the road at 25 mph. The speed may be higher or lower, depending on road conditions or local practice. Surface and drainage problems are noted during the inspection. Windshield inspections are performed once each season, or four times a year. The results can be used for estimating maintenance needs and priorities.

The detailed distress inspection may be conducted less frequently but should be done at least once every 3 years. The inspection should be performed at the time of year when the roads are in their best and most consistent condition (Eaton, Gerard, and Gate 1988). Seven distresses have been defined for unsurfaced roads: improper cross section, inadequate roadside drainage, corrugations, dust, potholes, ruts, and loose aggregate. An example of a completed field condition survey sheet is shown in Fig. 3-8. The distress definitions and procedures for measuring them are provided in Appendix F.

3.4.4 Performing Inspection Using Electronic Clipboards

The PCI inspection can be expedited, especially for asphalt surfaced pavements, using hand held electronic clipboards. The electronic clipboards are lightweight (about 1 LB), pen-based computers that operate by receiving data through a pen-shaped instrument or a keyboard. An example electronic clipboard is the PoqetPad (Fujitsu 1994) shown in Fig. 3-9. The field inspection is performed as described in the previous sections except date are entered onto the PoqetPad screen instead of the paper inspection forms. Fig. 3-10 is an example distress data entry screen available through the Micro PAVER system. To enter data in empty boxes, the inspector touches the box with the pen and options for selection will be displayed. The inspector then touches the desired option to enter in the box. To enter data in non-boxed fields, simply write on the blank line.

There are several advantages to using electronic clipboards. The inspector has the option to download pavement section information, including previous inspection data, to the electronic clipboard. This information then becomes available for viewing as needed in the field. This information will also save on information to enter in the field. After the inspection is complete, a file is created in the electronic clipboard for automatic loading into the pavement management system (PMS). This eliminates the tedious and error prone process of manual data reduction and entry into the PMS.

UNSURFACED ROADS
CONDITION SURVEY DATA SHEET
FOR SAMPLE UNIT

SKETCH: 100' × 16.5' (N ↑)

BRANCH CENGRO2 SECTION AGO3 SAMPLE UNIT 2
SURVEYED BY KTL DATE Jul 13 '92 SAMPLE AREA 1650 ft²

1. Improper Cross Section (Linear feet)
2. Inadequate Roadside Drainage (Linear feet)
3. Corrugations (Square feet)
4. Dust
5. Potholes (Number)
6. Ruts (Square feet)
7. Loose Aggregate (Linear feet)

DISTRESS SEVERITY	QUANTITY									TOTAL	DENSITY %	DEDUCT VALUE
1M	12	18								30	1.8	6
3L	16	20								36	2.2	2
3M	18									18	1.1	2
5L	9	12	7							28	1.6	23
5M	2	6								8	0.48	16
6L	180									180	14.5	18

Figure 3-8. Example unsurfaced road sample unit condition survey sheet.

3.5 Calculating the PCI

When the condition survey has been completed for every selected sample unit, the results are used to calculate the PCI. The PCI can be calculated manually, with a PCI computer program, or by entering the distress information into the Micro PAVER database. The PCI calculation is based on the deduct values—weighing factors from 0 to 100 that indicate the impact each distress has on pavement condition. A deduct value of 0 indicates that a distress has no effect on pavement performance, whereas a value of 100 indicates an extremely serious distress.

3.5.1 Calculation of a Sample Unit PCI for Asphalt Surfaced Pavements and Unsurfaced Roads

The calculation steps are similar for roads and airfields. They are summarized in Fig. 3-11. Following is a description of each step.

Step 1: Determine deduct values.

1a. Add the totals for each distress type at each severity level, and record them under "Total" on the survey form. For example, Figure 3-6 shows two

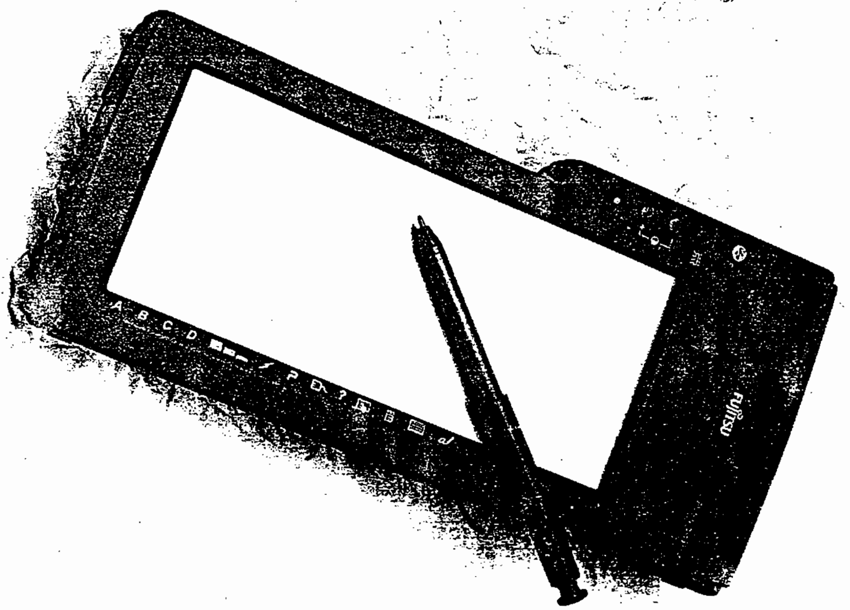


Figure 3-9. PoqetPad electronic clipboard (from Fujitsu 1994).

entries for distress type 48M. The distress is added and entered under "Total" as 16 feet. Quantities of distress may be measured in square feet (square meters), linear feet (meters), or number of occurrences, depending on the distress type.

1b. Divide the quantity of each distress type at each severity level by the total area of the sample unit, then multiply by 100 to obtain the percentage of density per sample unit for each distress type and severity.

1c. Determine the deduct value for each distress type and severity level combination from the distress deduct value curves. Fig. 3-12 shows an example of

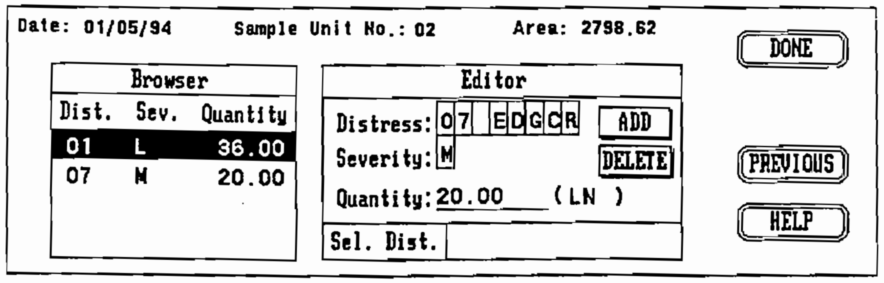


Figure 3-10. Example electronic clipboard data entry screen.

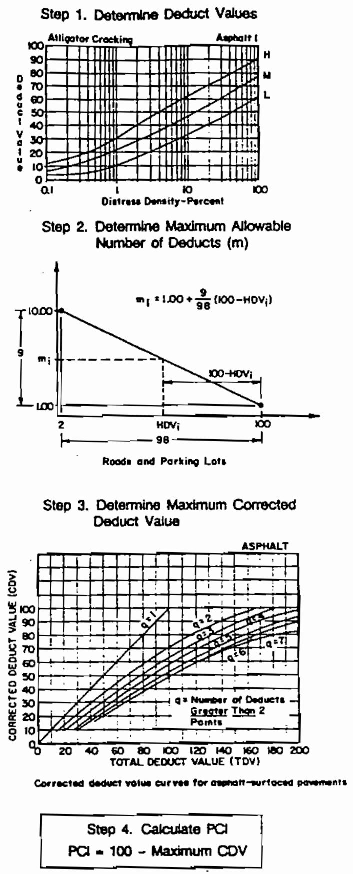


Figure 3-11. PCI calculation steps for a sample unit.

a deduct curve for distress type 41, "Alligator Cracking," for airfield pavements. Deduct curves for all distresses are provided in Appendix B (for asphalt roads), Appendix D (for asphalt airfields), and Appendix F (for unsurfaced roads).

Step 2: Determine the maximum allowable number of deducts (m).

2a. If only one individual deduct value (or none) is >5 for airfield and unsurfaced roads, or 2 for surfaced and unsurfaced roads, the total deduct value is used in place of the maximum CDV in Step 4; otherwise, Steps 2b and 2c should be followed.

2b. List the individual deduct values in descending order. For example, the values in Figure 3-6 would be sorted as follows: 21, 20.1, 17.1, 6.7, 4.8, and 1.6.

PCC m = 8.20 < 9

* 0.7 = (0.2) x 9 th Deduct Value
= 0.2 x 3.5

#	Deduct Values										Total	q	CDV
1	24	12	11.5	11.0	8.6	7.8	5.5	3.6	0.7*		84.7	7	54
2	24	12	11.5	11.0	8.6	7.8	5.0	3.6	0.7		84.2	6	56
3	24	12	11.5	11.0	8.6	5.0	5.0	3.6	0.7		81.4	5	56.5
4	24	12	11.5	11.0	5.0	5.0	5.0	3.6	0.7		77.8	4	54.5
5	24	12	11.5	5.0	5.0	5.0	5.0	3.6	0.7		71.8	3	54
6	24	12	5.0	5.0	5.0	5.0	5.0	3.6	0.7		65.3	2	54.5
7	24	5.0	5.0	5.0	5.0	5.0	5.0	3.6	0.7		58.3	1	58.3
8													
9													
10													

PCI = 100 - 58 = 42

Figure 3-16. PCI calculation sheet for example sample unit shown in Figure 3-7.

Step 4: Calculate the PCI by subtracting maximum CDV from 100.

Fig. 3-16 summarizes the PCI calculation for the example of PCC pavement data given in Figure 3-7.

3.5.3 Calculation of the PCI for a Section

If all sample units in a section are surveyed, the PCI of the section is computed by averaging the PCIs of all sample units. Inspection by sampling, however, requires a different approach. If all surveyed sample units are selected either by using the systematic random technique or on the basis of being representative of the section, the PCI of the section is determined by averaging the PCIs of the sample units inspected. If any additional sample units are inspected as discussed in Section 3.3.3.3, a weighted average must be used.

The weighted average is computed by using the following equation:

$$PCI_s = \frac{(N - A)\,PCI_r + A\,PCI_a}{N} \tag{3-4}$$

where

PCI_s = PCI of pavement section
PCI_r = average PCI of random (or representative) samples
PCI_a = average PCI of additional samples
N = total number of samples in the section
A = number of additional samples inspected.

For example, if in a section of 13 sample units, five random sample units out of 13 were inspected and determined to have PCIs of 56, 72, 65, 69, and 61, and two additional sample units with PCIs of 42 and 39 were included, the PCI of the section would be:

$$PCI_r = (56 + 72 + 65 + 69 + 61)/5 = 64.6$$
$$PCI_a = (42 + 39)/2 = 40.5$$
$$PCI_s = [(13 - 2)(64.6) + (2)(40.5)]/13 = 61$$

3.5.4 Determining Distress Quantities for a Pavement Section

When a pavement has been inspected by sampling, it is necessary to extrapolate the quantities and densities of distress over the entire pavement section to determine total quantities for the section. If all sample units surveyed were selected at random, the extrapolated quantity of a given distress at a given severity level would be determined as shown in the following example for medium-severity alligator cracking:

Surface Type: Asphalt concrete
Area: 24,500 sq ft
Total Number of sample units in section: 10

Five sample units were surveyed at random, and the amount of medium-severity alligator cracking was determined as follows:

Sample unit ID number	Sample unit area (sq ft)	Medium-severity alligator cracking (sq ft)
02	2500	100
04	2500	200
06	2500	150
08	2500	50
10	2000	100
Total random	12,000	600

The average density for medium-severity alligator cracking, then, is 600 divided by 12,000, or 0.05. The extrapolated quantity is determined by multiplying density by section area (i.e., 0.05 × 24,500 = 1225 sq ft).

If additional sample units were included in the survey, the extrapolation process would be slightly different. In the example given above, assume that sample unit number 01 was surveyed as an additional unit, and that the amount of medium-severity alligator cracking was measured as follows:

Additional sample unit ID	Sample unit area (sq ft)	Medium severity alligator cracking (sq ft)
01	2500	1000
Total additional	2500	1000

Since 2500 sq ft were surveyed as additional in this example, the section's randomly represented area is 24,500 − 2500 sq ft, or 22,000 sq ft. The extrapolated distress quantity is obtained by multiplying the distress density by the section's randomly represented area, then adding the amount of additional distress. In this example the extrapolated distress quantity equals (0.05 × 22,000) + 1000, or 2100 sq ft.

3.5.5 Automated PCI Calculation

Computing the PCI manually is not a tedious operation for a single sample unit, but the volume of data generated from a survey is generally quite large, and calculations involving these data are time consuming. Once distress information has been entered into PAVER, the program automatically calculates the PCI of each sample unit surveyed and determines an overall PCI for a section, as well as extrapolated distress quantities. The program can also determine the percentage of deduct values based on distress mechanism (i.e., load, climate, and other) for a section. The percentage of deduct values attributed to each distress mechanism is the basis for determining the primary cause or causes of pavement deterioration. The procedure for calculating these percentages is presented in Chapter 10. Fig. 3-17 shows an example of an automated PCI calculation from the PAVER system.

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Inspection Date: JUL/01/1992
Riding Quality :                  Safety:              Drainage Cond.:
Shoulder Cond. :           Overall Cond.:                   F.O.D.:
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------------------------------------------------------------------------

SAMPLE UNIT=8  (RANDOM)        SAMPLE SIZE= 5000.00 SF
```

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
41 ALLIGATOR CR	LOW	53.00 (SF)	1.06	21.0
45 DEPRESSION	LOW	15.00 (SF)	.30	1.6
48 L & T CR	LOW	47.00 (LF)	.94	4.8
48 L & T CR	MEDIUM	16.00 (LF)	.32	6.7
53 RUTTING	LOW	75.00 (SF)	1.50	17.1
53 RUTTING	MEDIUM	25.00 (SF)	.50	20.1

```
SAMPLE PCI =  57

PCI OF SECTION =  57                                   RATING = GOOD

TOTAL NUMBER OF SAMPLE UNITS =       10
NUMBER OF RANDOM SAMPLE UNITS SURVEYED      =     1
NUMBER OF ADDITIONAL SAMPLE UNITS SURVEYED =      0
RECOMMENDED MINIMUM OF       5 RANDOM SAMPLE UNITS TO BE SURVEYED.
STANDARD DEVIATION OF PCI BETWEEN RANDOM UNITS SURVEYED =      .0%

*** EXTRAPOLATED DISTRESS QUANTITIES FOR SECTION ***
```

DISTRESS-TYPE	SEVERITY	QUANTITY	DENSITY %	DEDUCT VALUE
41 ALLIGATOR CR	LOW	530.00 (SF)	1.06	21.0
45 DEPRESSION	LOW	150.00 (SF)	.30	1.6
48 L & T CR	LOW	470.00 (LF)	.94	4.8
48 L & T CR	MEDIUM	160.00 (LF)	.32	6.7
53 RUTTING	LOW	750.00 (SF)	1.50	17.1
53 RUTTING	MEDIUM	250.00 (SF)	.50	20.1

```
*** PERCENT OF DEDUCT VALUES BASED ON DISTRESS MECHANISM ***

LOAD               RELATED DISTRESSES =  81.59 PERCENT DEDUCT VALUES.
CLIMATE/DURABILITY RELATED DISTRESSES =  16.13 PERCENT DEDUCT VALUES.
OTHER              RELATED DISTRESSES =   2.28 PERCENT DEDUCT VALUES.
```

Figure 3-17. Example automated PCI calculation from the PAVER system.

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4

Nondestructive Deflection Testing

4.1 Introduction

One of the most reliable methods available for determining the structural condition of an in-service pavement is through the use of nondestructive deflection testing (NDT). NDT has two major advantages over destructive testing. First, destructive testing by definition disturbs the underlying paving layers or necessitates removal of the pavement materials to a laboratory for testing, whereas NDT is truly an in situ test that evaluates the pavement without any material disturbance or modification. The second advantage of NDT is that the tests are relatively quick and inexpensive, allowing more of them to be completed while causing less disruption to traffic than destructive testing. It is recommended practice that some coring be performed in association with NDT to verify layer thicknesses for accurate back-calculation of the layer module. In general, however, the amount of destructive testing needed to evaluate a pavement in conjunction with NDT is minimal.

NDT equipment operates by applying a load to the pavement and measuring the resulting maximum surface reflection or the surface deflection basin. NDT results are used to determine the following:

a. Asphalt Pavements
   1. Elastic modulus of each of the structural layers
   2. Pavement structural adequacy
   3. Overlay thickness design
   4. Load limits
   5. Remaining structural life
b. Concrete pavements
   1. Concrete elastic modulus and subgrade modulus of reaction
   2. Load transfer across joints
   3. Void detection