

# Effect of Sample Unit Size on Visually Examining Pavement Condition for Asphalt-Surfaced Roads

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**Abstract:** Road surface condition evaluation involves the collection of data over pavement surface for different types of distresses. The exercise consumes a lot of resources if the whole road section length is surveyed and may be prone to errors as a result of surveyors' fatigue. It is therefore important to develop a representative sample to be used when evaluating road condition manually. This study aimed at determining an adequate sample size for section level as well as a way forward for network level condition evaluation of highways in Nepal. Again the study was conducted to quantify the effects of altering the sample unit size for performing a distress survey according to the PCI (pavement condition index) and SDI (surface distress index) method separately for asphalt surfaced roads. The effect of reducing/increasing sample unit size was investigated adopting visual examination through field survey by eight teams in July, 2015, along the section of Banepa-Bardibas highway. The PCI was then calculated for each sample unit using standard deduct curves and PCI calculation methodology as per SHRP (Strategic Highway Research Program) recommendations and the computation of SDI was done as per DoR (Department of Roads) guidelines. The results show that 13% sample unit are needed for SDI and 21% for PCI computation, however, the results are out of the significant level. This is higher than DoR and SHRP guidelines. Again no strong relationship is observed between SDI and PCI values.

**Key words:** Pavement condition evaluation, PCI, SDI, sample size, policy implications.

## 1. Introduction

### 1.1 Background

Pavement condition evaluation is one of the important components of pavement design, rehabilitation and management which include evaluation of distress, roughness, friction and structure. Most of the cost effective M&R (maintenance and rehabilitation) strategies developed using PMS (pavement management system) is due to accurate pavement evaluation [1]. Pavement condition information is used to evaluate the current condition, determine rate of deterioration, project future condition, determine M&R needs, and determine the costs to repair pavement segments. It is also used to establish M&R strategies and is often used to help prioritize M&R fund expenditures [2]. Since so many decisions supported by the PMS are based on the condition

assessment, it is important to ensure that the data collected and used is accurate enough to provide the desired level of support. However, since the collection of condition data is the most expensive portion of maintaining the PMS, the cost must be matched to the resources and needs of the adopting agency [2]. Several new nondestructive technologies have been developed and applied in collecting raw condition data and processing them to produce useful condition input to infrastructure IM&R (inspection, maintenance, and rehabilitation) decision making aimed at minimizing expected total life-cycle cost [3]. Such advances initially motivated the quantification of condition measurement uncertainty and the incorporation of this uncertainty in decision making. Following this development, the spatial variation of condition has been quantified and has led to the recent extension of decision-making methods to take into account sampling uncertainty and determine the optimal sample size, along with the other IM&R activities [3].

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The evaluation of the contributions of the condition sampling-related advances to improved decision making is presented by Mishalani and Gong [4]. The results of the application of this evaluation methodology indicate that the magnitudes of the value of the condition-sampling advances of interest are found to be appreciable in both expected total life-cycle cost and IM&R agency cost.

The PCI (pavement condition index) and SDI (surface distress index) are the numerical indicator that rates the surface condition of the pavement through visual examination. These indicators provide a measure of the present condition of the pavement based on the distress observed on the surface of the pavement which also indicates the structural integrity and surface operational condition (localized roughness and safety). However, these indicators cannot measure the structural capacity; neither they provide direct measurement of skid resistance or roughness. They provide an objective and rational basis for determining maintenance and repair needs and priorities [5, 6]. Continuous monitoring of the PCI is used to establish the rate of pavement deterioration, which permits early identifying of major rehabilitation needs. The PCI provides feedback on pavement performance for validation or improvement of current pavement design and maintenance procedures [5]. Surface distress surveys of the strategic network have been undertaken annually by planning branch since fiscal year 1992-1993 [7]. The survey was interrupted for some year and it is continued form fiscal year 2012-2013.

### *1.2 Objectives and Scope*

The main objective of this study is to assess the effect of sample unit size on pavement condition index for asphalt-surfaced roads. Specifically following objectives are set out:

- To evaluate the pavement section for SDI and PCI values;
- To recommend the suitable sample size for the evaluation of pavement;

- To develop the relationship between SDI and PCI indices;
- To compare the maintenance strategy as recommended by SDI and PCI.

## **2. Literature Review**

For the time being, prioritizing in the selection of the roads (or resealing) will be limited to the consideration of the four parameters namely road age, visual survey ratings, traffic and strategic importance [8].

It is recommended that a section sample of 20 m long from the beginning of a 100 m section be used in evaluating the pavement surface condition of such roads. This will result in a reasonably accurate representation of the condition of the whole section with huge savings in resources [9]. Comparisons were made between PCI values calculated using standard PCI procedures (19 distress types) and PCI values calculated using modified distress identification procedures developed by the Metropolitan Transportation Commission (seven distress types) [10]

The study area in Ref. [11] consists of 10 urban road sections constituting 29.92 km of Noida city. The methodology includes identification of urban road sections, pavement distress data collection, development of individual distress index and finally developing a combined OPCI (Overall Pavement Condition Index) for the network. The four performance indices, namely, pavement condition distress index (PCI distress), pavement condition roughness index (PCI roughness), pavement condition structural capacity index (PCI structure) and pavement condition skid resistance index (PCI skid) are developed individually. Then all these indices are combined together to form an OPCI giving importance of each indicator. The proposed index is expected to be a good indicative of pavement condition and performance. The developed OPCI was used to select the maintenance strategy for the pavement section [11].

Pavement condition has been known as a key factor related to ride quality, but it is less clear how pavement

conditions are related to traffic crashes. The results in Ref. [12] suggested that poor pavement condition scores and ratings were associated with proportionally more severe crashes, but very poor pavement conditions were actually associated with less severe crashes. Very good pavement conditions might induce speeding behaviors and therefore could have caused more severe crashes, especially on non-freeway arterials and during favorable driving conditions. These results provide insights on how pavement conditions may have contributed to crashes, which may be valuable for safety improvement during pavement design and maintenance. Although the study found statistically significant effects of pavement variables on crash severity, the effects were rather minor in reality as suggested by frequency analyses [12].

Infrastructure management is the process through which IM&R decisions are made to minimize the total life-cycle cost. Measurement, forecasting, and spatial sampling are three main sources of errors introducing uncertainty into the process. The first two uncertainties are captured in the infrastructure management literature. However, the third one has not been recognized and quantified. Ref. [4] presents a methodology where the spatial sampling uncertainty in question is captured and the sample size is incorporated as a decision variable in an optimization. The results

indicate that by not addressing the sampling uncertainty and decisions, the optimum IM&R decisions would not be achieved, and consequently, marked unnecessary overspending could take place [4].

The effect of sample size on PCI accuracy was investigated for asphalt roadways [10] by employing the 35-mm film automated distress data collection technique. Twenty four asphalt pavement sections were surveyed. Fig. 1 shows a plot between relative sample unit size for regular size and expected amount of error in the PCI. Fig. 2 shows a comparison between PCI calculated using 10% regular sample size and PCI calculated using a full road section. As long as the size is within 40% from the regular size, from Figs. 1 and 2 the error is limited to about 2%.

The evaluation of the contributions of the condition sampling-related advances to improved decision making is presented by Mishalani and Gong [4]. In this paper, the methodology is based on comparing decision-making frameworks that reflect the advances of interest with those that do not. The basic idea behind comparing any two frameworks is to use each to produce optimal IM&R policies that are based on the specific assumptions they reflect and then to simulate these optimal policies within the framework reflecting the truth with regard to capturing the most realistic assumptions. The results of the application of this

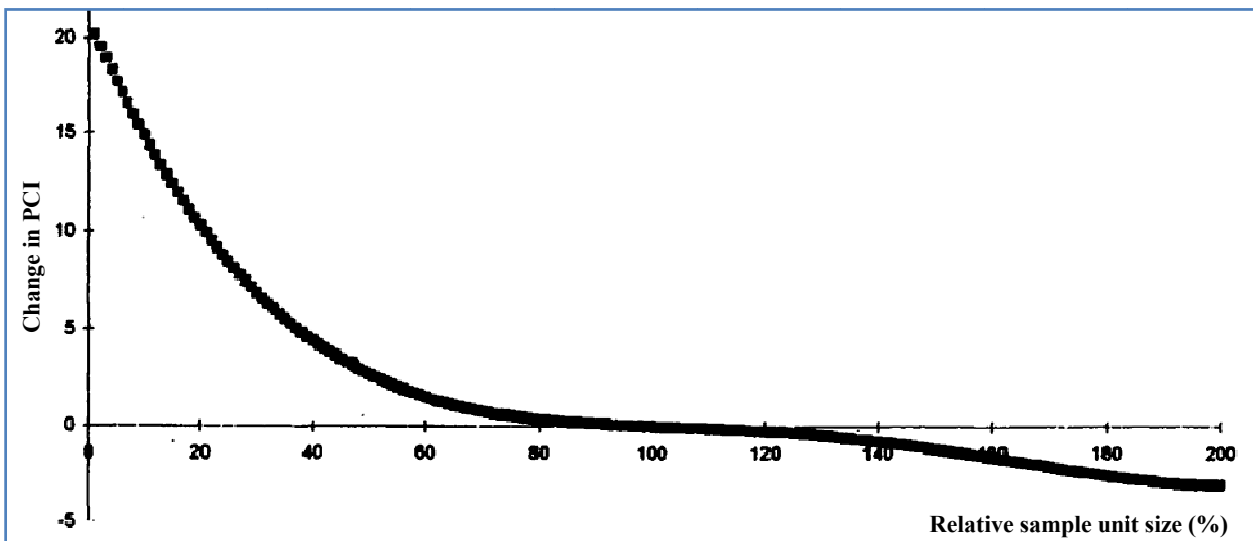


Fig. 1 Relative sample unit size and expected amount of error in PCI calculation [10].

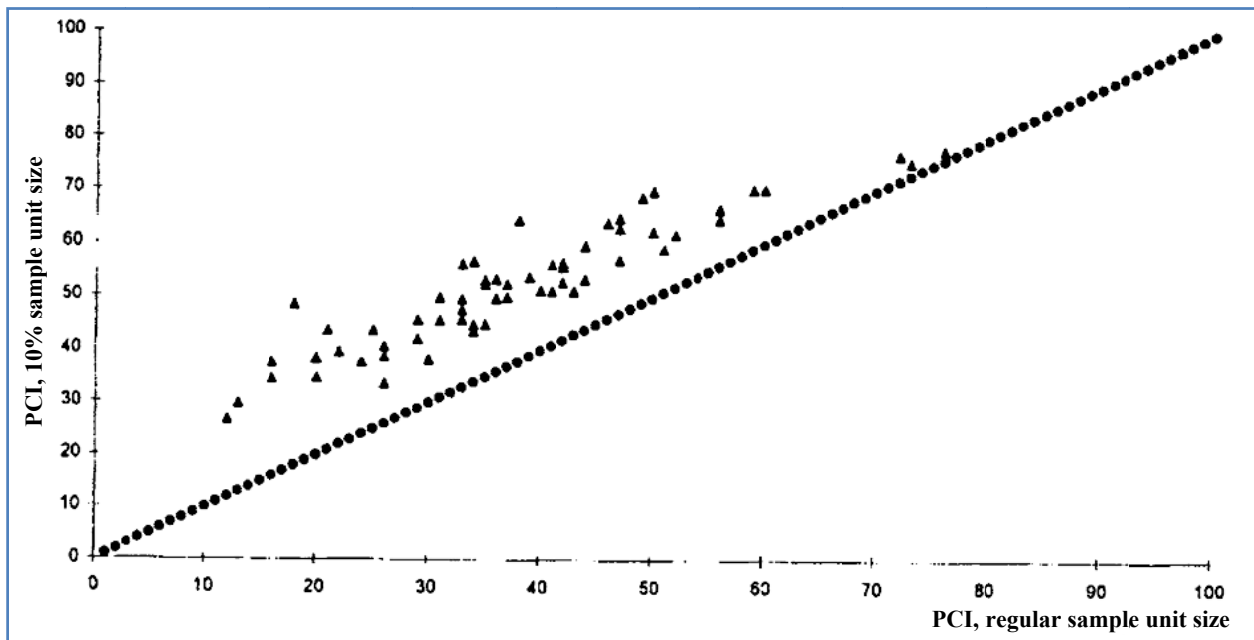


Fig. 2 Comparison of the effect of sample unit size on PCI accuracy [10].

evaluation methodology indicate that the magnitudes of the value of the condition-sampling advances of interest are found to be appreciable in both expected total life-cycle cost and IM&R agency cost [4].

### 3. Data Collection and Computation for SDI and PCI

#### 3.1 Criteria for Site Selection

The project sites were chosen meeting the following criteria: “Roads with low to medium traffic volume in order to avoid accidents and conveniently collect data and the roads with as many types of distresses as possible [13]. Banepa Bardibas (BP) highway was selected for the study. The total length of the highway is about 206 km and the carriageway width is 5.5 m, with unpaved shoulders. Traffic is a hazard as inspectors may walk on the pavement to perform the condition survey. Accurate, consistent, and repeatable distress evaluation surveys can be performed by using the Distress Identification Manual for the Long-Term Pavement Performance Project [13]. Eight groups with two trained engineer in each have conducted condition surveys for the determination following categorical distresses:

- Distress type—identifying each type of distress;
- Distress severity—the level of severity of each distress present showing the degree of deterioration of the pavement;
- Distress extent—relative area affected by each combination of distress type and severity.

#### 3.2 SDI (Surface Distress Index) Survey

There are various methods of collecting surface distress data and these increase in complexity and sophistication according to the quality of information required. The method adopted in this research is the method adopted by DoR (Department of Roads) and is a simplified procedure recommended by the World Bank which has been modified to suit the particular conditions in Nepal and the needs of DoR. The SDI is a six-level rating index from 0 to 5. The rating 0 indicates a pavement surface without any defects, whereas a rating of 5 indicates for the maximum possible deterioration. A shoulder condition survey is recommended to carry out at the same time using rating in the range 0 to 4. However, the shoulder condition is out of the scope of this research. The three most predominant types of defect present in each sample section are recorded.

### 3.2.1 Field Work Plan and Sampling

Pavement distresses surveys are carried out manually by the trained engineers using drive and walk survey. Surface distress comprises cracking, disintegration (potholes), deformation, textural efficiency, pavement edge defects and maintenance works (patching). These faults are visually assessed using a 10% sampling procedure and recorded using a cumulative index called an SDI. The distress elements are divided into two groups: major and minor defects. Among the different defect types, cracking, raveling and potholes are generally characterized by extent and severity, while rut depth being continuous in nature, only the severity of the deformation is noted. The defect types and therefore resulting score are different for bitumen and gravel roads, which are separately presented in Ref. [6].

The 10% sampling procedure comprises a walk-over survey generally covering the last 100 meter section in each kilometer of the road on which the SDI is to be determined [6, 7]. The full width of pavement is to be evaluated for each sample of length 100 m.

### 3.2.2 SDI Data Use

The SDI is averaged over each road link or section under consideration. The results can be used to provide the objective assessment of the pavement condition and to indicate the need for periodic maintenance, rehabilitation or reconstruction. For assessing pavement condition, the terms “Good”, “Fair” and “Poor” are used based on averaged values of SDI as

presented in Table 1.

These values are based on conditions in Nepal. Planned maintenance can be carried out on roads in good/fair condition and rehabilitation or reconstruction is generally needed for roads in poor condition to bring them to a maintainable state. Similarly, an indicator for different types of pavement remedial action is given by the percentage of the number of sample section with the given SDI values of a particular link as shown in Table 2.

### 3.3 PCI (Pavement Condition Index) Survey

The information was processed to obtain PCI values for each road section sample and for whole section. The pavement is divided into branches that are divided into sections. Each section is divided into sample units. The type and severity of pavement distress is assessed by visual inspection of the pavement sample units [5]. Information about date, location, branch, section, sample unit size, slab number and size, distress types, severity levels, quantities, and names of surveyors, were recorded on data sheets [14]. Again the instruments used are measuring tape (30.0 m and 3.0 m length with 2 mm and 1 mm least count) straightedge, scale (300 mm).

#### 3.3.1 Field Work Plan and Sampling

First, divide the pavement sections into sample units. Individual sample units to be inspected should be marked or identified in a manner to allow inspectors and quality control personnel to easily locate them on

**Table 1 SDI chart for pavement condition in Nepal [6].**

SDI values	Condition
0~1.7	Good
1.8~3.0	Fair
3.1~5.0	Poor

**Table 2 Pavement remedial action based on SDI values in Nepal [6].**

Percentage SDI values	Action
20%, <i>SDI</i> = 5	Reconstruction
10%~30%, <i>SDI</i> = 4	Rehabilitation
20%~30%, <i>SDI</i> = 3	Resealing with local patching
20%~30%, <i>SDI</i> = 2	Resealing only

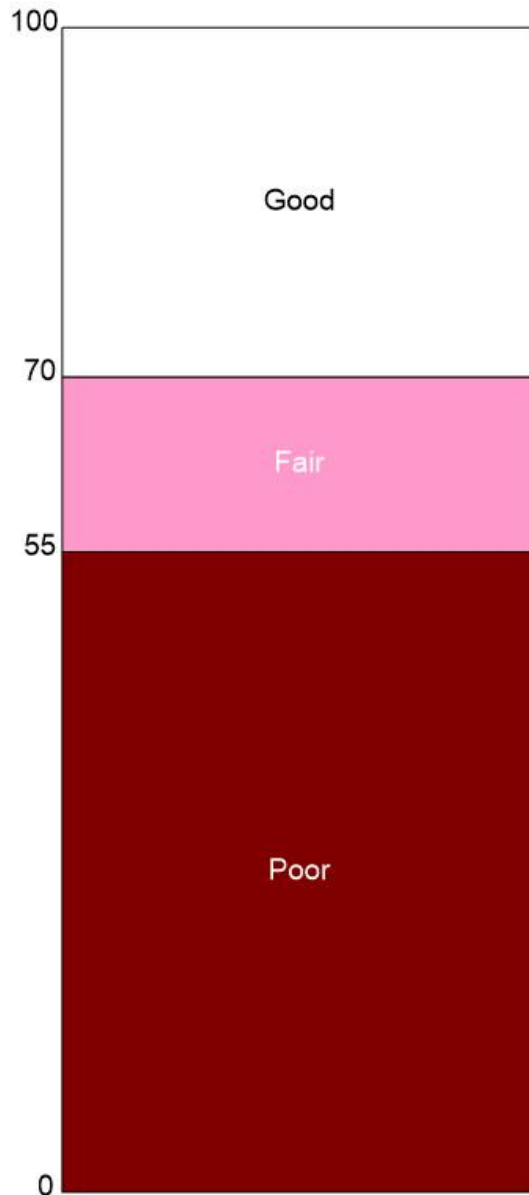


Fig. 3 PCI rating system [15].

the pavement surface. The minimum number of sample units ( $n$ ) that must be surveyed within a given section to obtain a statistically adequate estimate (95% confidence) of the PCI of the section is calculated using Eq. (1), the following formula and rounding  $n$  to the next highest whole number [5]:

$$n = Ns^2 / [(e^2/4)(N - 1) + s^2] \quad (1)$$

where:

$e$  = acceptable error in estimating the section PCI; commonly,  $e = 65$  PCI points;

$s$  = standard deviation of the PCI from one sample

unit to another within the section;

$N$  = total number of sample units in the section.

If obtaining the 95 % confidence level is critical, the adequacy of the number of sample units surveyed must be confirmed. The number of sample units was estimated based on an assumed standard deviation. The actual standard deviation ( $s$ ) can be calculated as follows (Eq. (2)):

$$S = \sum_{i=1}^n (PCI_i - PCI_s)^2 / (n - 1)^{1/2} \quad (2)$$

where:

$PCI_i$  = PCI of surveyed sample units  $i$ ;

$PCI_s$  = PCI of section (mean PCI of surveyed sample units);

$n$  = total number of sample units surveyed.

The revised minimum number of sample units should be calculated (Eq. (1)) which is to be surveyed using the calculated standard deviation (Eq. (2)). If the revised number of sample units to be surveyed is greater than the number of sample units already surveyed, select and survey additional random sample units. These sample units should be spaced evenly across the section. Repeat the process of checking the revised number of sample units and surveying additional random sample units until the total number of sample units surveyed equals or exceeds the minimum required sample units ( $n$ ) in Eq. (1), using the actual total sample standard deviation. Once the number of sample units to be inspected has been determined, compute the spacing interval of the units using systematic random sampling. Samples are spaced equally throughout the section with the first sample selected at random. The spacing interval ( $i$ ) of the units to be sampled is calculated by the following formula (Eq. (3)) rounded to the next lowest whole number:

$$i = N/n \tag{3}$$

where:

$N$  = total number of sample units in the section; and

$n$  = number of sample units to be inspected.

The first sample unit to be inspected is selected from sample units 1. The sample units within a section that are successive increments of the interval  $i$  after the first selected unit also are inspected.

Additional sample units only are to be inspected when non-representative distresses are observed. These sample units are selected by the user.

### 3.3.2 Computation of PCI

The total quantities of each distress type are added for at each severity level, and recorded in the “Total Severities”. The units for the quantities may be either in square feet (square meters), linear feet (meters), or

number of occurrences, depending on the distress type. Divide the total quantity of each distress type at each severity level by the total area of the sample unit and multiply by 100 to obtain the percent density of each distress type and severity. Determine the DV (deduct value) for each distress type and severity level combination from the distress deduct value curves. Determine the maximum  $CDV$  (corrected deduct value). The following procedure must be used to determine the maximum  $CDV$  [5]:

- If none or only one individual deduct value is greater than two, the total value is used in place of the maximum  $CDV$  in determining the PCI; otherwise, maximum  $CDV$  must be determined;
- List the individual deduct values in descending order. Determine the allowable number of deducts,  $m$ , using the formula (Eq. (4)):

$$m = 1 + (9/98)(100 - HDV) \leq 10 \tag{4}$$

where:

$m$  = allowable number of deducts including fractions ( $\leq 10$ ); and

$HDV$  = highest individual deduct value;

- The number of individual deduct values is reduced to the  $m$  largest deduct values, including the fractional part. For:

(1) Determine maximum  $CDV$  iteratively;

(2) Determine total deduct value by summing individual deduct values. The total deduct value is obtained by adding the individual deduct values;

(3) Determine  $q$  as the number of deducts with a value greater than 2.0;

(4) Determine the  $CDV$  from total deduct value and  $q$  by looking up the appropriate correction curve for AC pavements;

(5) Reduce the smallest individual deduct value greater than 2.0 and repeat above steps until  $q = 1$ ;

(6) Maximum  $CDV$  is the largest of the  $CDV$ s.

- PCI calculation by subtracting the maximum  $CDV$  from 100 (Eq. (5)):

$$PCI = 100 - \max CDV \tag{5}$$

$$PCI_s = \overline{PCI}_r = \frac{\sum_{i=1}^n (PCI_{ri} * A_{ri})}{\sum_{i=1}^n A_{ri}} \quad (6)$$

where:

$\overline{PCI}_r$  = area weighted PCI of randomly surveyed

sample units;

$PCI_{ri}$  = PCI of random sample unit  $i$ ;

$A_{ri}$  = area of random sample unit  $i$ ;

$n$  = number of random sample units surveyed.

If there is no additional sample, then PCI of the section is given by Eq 6 but if additional sample units are surveyed, the area weighted PCI of the surveyed additional units ( $PCI_a$ ) is calculated using Eq. (7). The PCI of the pavement section is calculated using Eq. (8).

$$\overline{PCI}_a = \frac{\sum_{i=1}^n (PCI_{ai} * A_{ai})}{\sum_{i=1}^n A_{ai}} \quad (7)$$

where:

$PCI_a$  = area weighted PCI of additional sample units;

$PCI_{ai}$  = PCI of additional sample unit  $i$ ;

$A_{ai}$  = area of additional sample unit  $i$ .

$$PCI_s = \frac{\overline{PCI}_r (A - \sum_{i=1}^m A_{ri}) + \overline{PCI}_a (\sum_{i=1}^n (*A_{ai}))}{A} \quad (8)$$

where;

$A$  = area of section;

$m$  = number of additional sample units surveyed; and

$PCI_s$  = area weighted PCI of the pavement section.

The overall condition rating of the section should be determined by using the section PCI and the condition rating [5].

#### 4. Results and Discussions

Following are the summary of the data that are collected from the field.

Table 3 shows for SDI values whether Table 4 shows for PCI values. As per DoR guidelines, the SDI value of the section based on Table 3 is 2.3. Similarly, the PCI value from Table 4 based on SHRP (Strategic Highway Research Program) guideline is computed as 63.4. Based on Table 1, and the SDI value 2.3, the pavement condition is “Fair”. Again based on PCI value of 63.4 and from Fig. 3, the pavement condition is “Fair”. Hence, it is concluded that the findings of both the system (SDI and PCI) are same, i.e., pavement is in “Fair Condition”.

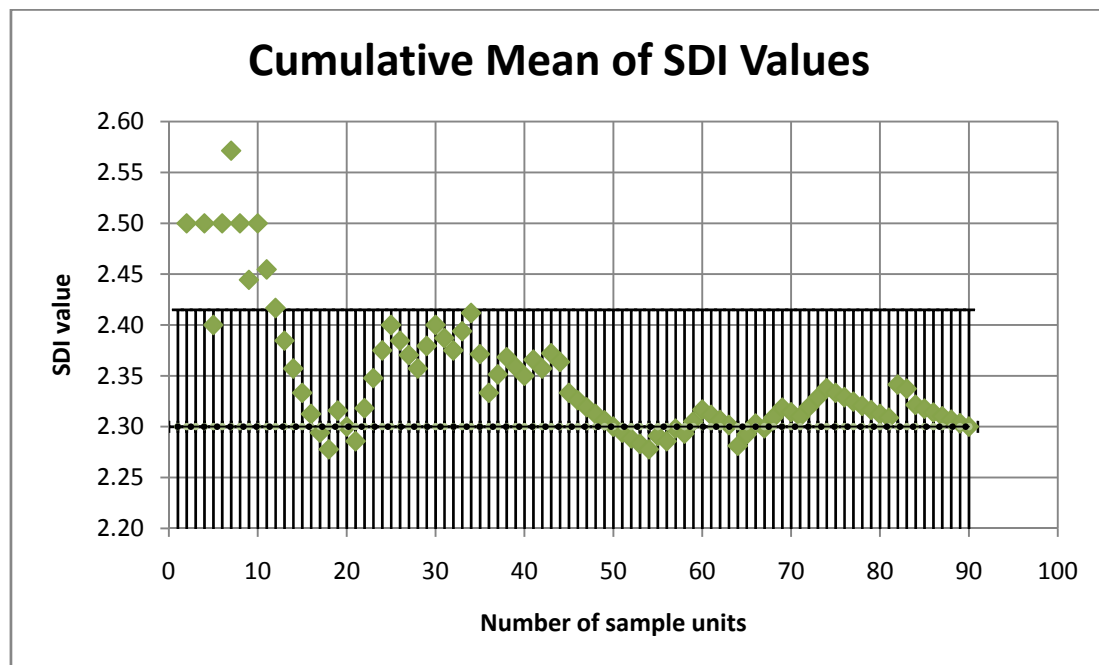
**Table 3 SDI of each of the sample.**

Sample No.	Chainage (m)		Chainage (km)									SDI for sample unit
	from	To	9+	10+	11+	12+	13+	14+	15+	16+	17+	
	Area ==>		550	550	550	550	550	550	550	550	550	
1	0	100	2	3	3	2	2	3	3	2	2	2.444
2	100	200	3	2	2	2	2	2	2	2	2	2.111
3	200	300	3	2	2	3	3	3	3	2	2	2.556
4	300	400	2	3	3	2	2	3	3	1	1	2.222
5	400	500	3	3	2	2	3	2	3	2	1	2.333
6	500	600	2	2	2	2	2	2	2	2	2	2.000
7	600	700	3	2	3	2	3	3	2	2	2	2.444
8	700	800	1	3	3	2	3	3	2	2	3	2.444
9	800	900	3	3	2	2	2	2	2	2	2	2.222
10	900	1,000	5	2	1	2	2	2	2	2	2	2.222
Average SDI of the section												2.300



**Table 4** PCI of each sample unit.

Sample No.	Chainage (m)		Chainage (km)									PCI for sample unit
	from	To	9+	10+	11+	12+	13+	14+	15+	16+	17+	
	Area ==>		550	550	550	550	550	550	550	550	550	
1	0	100	76	50	81	58	87	37	2	58	65	57.111
2	100	200	64	60	56	39	70	78	69	33	42	56.778
3	200	300	71	71	86	74	86	35	53	56	58	65.556
4	300	400	78	56.1	78	92	92	45.9	57.5	45.9	69.5	68.322
5	400	500	60	60	44	40	91	65	16	74	100	61.111
6	500	600	27	88	89	26	94	30	25	62	32	52.556
7	600	700	56	79	59	70	88	35	78	92	69	69.556
8	700	800	85	62	79	67	71	60	51	85	63	69.222
9	800	900	60	60	91	68	96	58	80	74	45	70.222
10	900	1,000	22	62	90	77	73	84	59	60	62	65.444
Average PCI of the section												63.381



**Fig. 4** Cumulative mean value of SDI over number of sample units.

*4.1 Effect of Sample Size on Error and Precision*

According to SHRP recommendations, the PCI values should lie within  $\pm 5\%$ , however, based on DoR recommendations, there is no criteria for the validation of the data observed from field for SDI based on DoR recommendations. So based on  $\pm 5\%$  permissible error and from Figs. 4 and 5, the recommended sample size for SDI is 13% and that for PCI is 21%.

The effect of sample size over the accuracy on the

pavement condition data was found best fit on logarithmic equation  $R^2$  value = 72% (Fig. 6 and 7). For linear equation  $R^2$  value = 55%, for polynomial  $R^2$  value = 67%, power and exponential are not feasible for these trendline. In other words, the error decreases exponentially at lower sample size and the rate of error reduction will decline for higher sample size. So, it can be said that the taking 100% sample for the pavement condition evaluation is the loss of time and money. So selection of accurate sample size is very much important

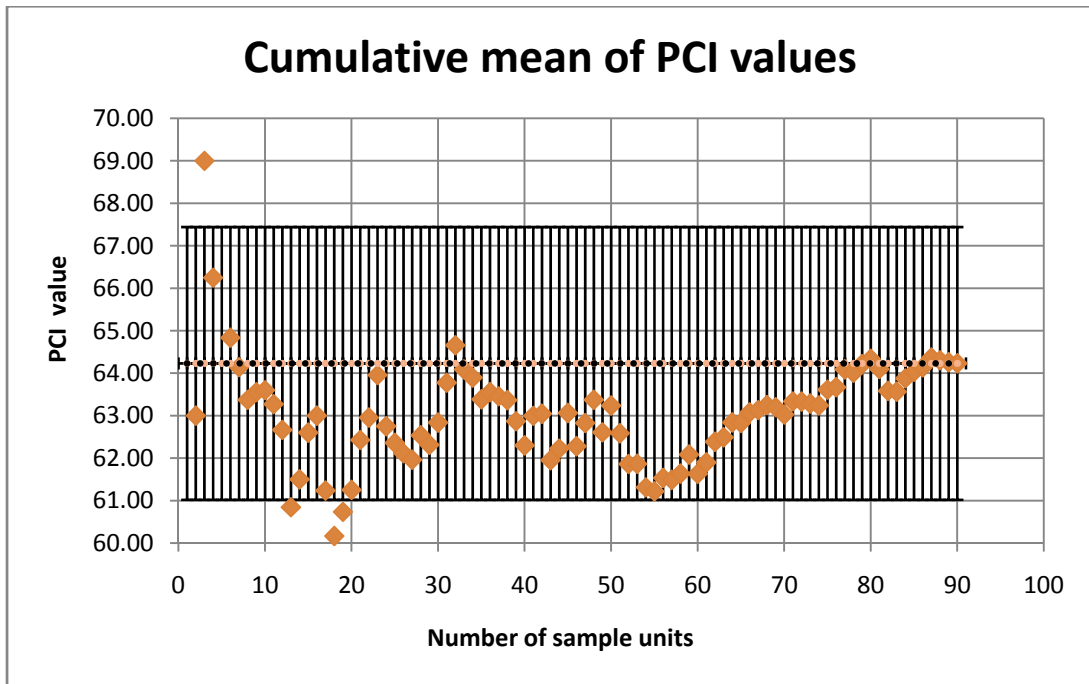


Fig. 5 Cumulative mean value of SDI over number of sample units.

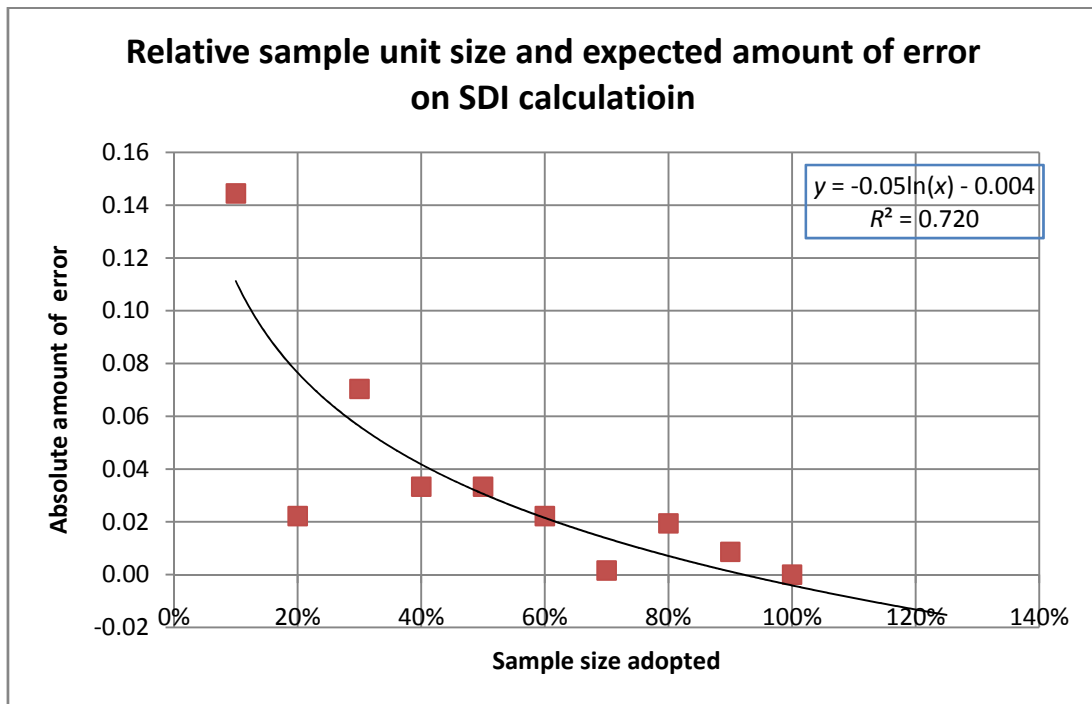


Fig. 6 Relative sample unit size and expected amount of error in SDI calculation.

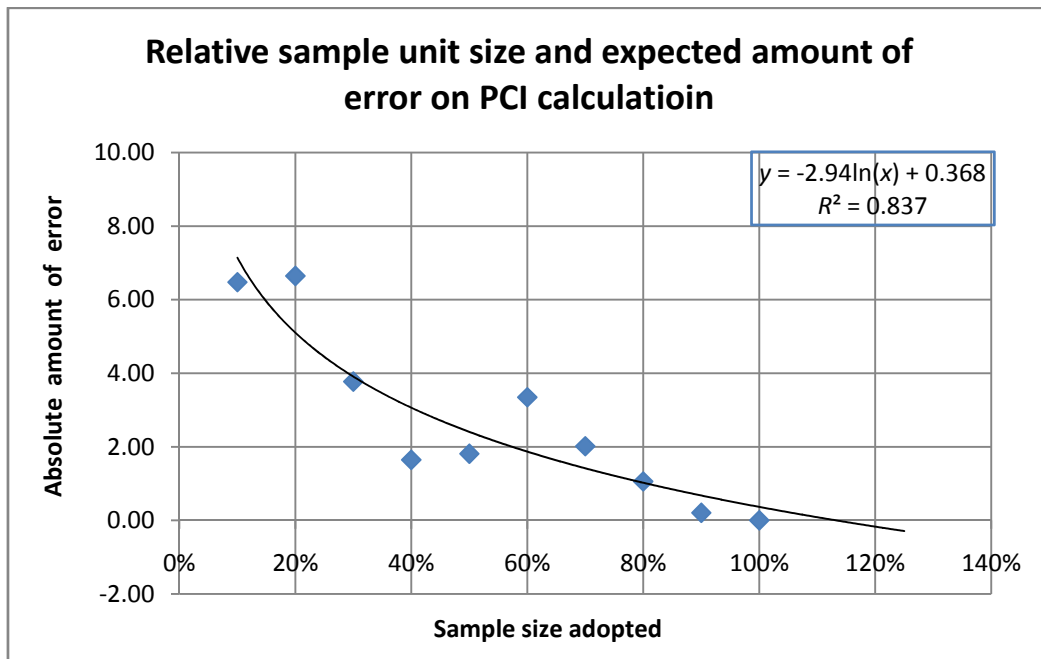


Fig. 7 Relative sample unit size and expected amount of error in PCI calculation.

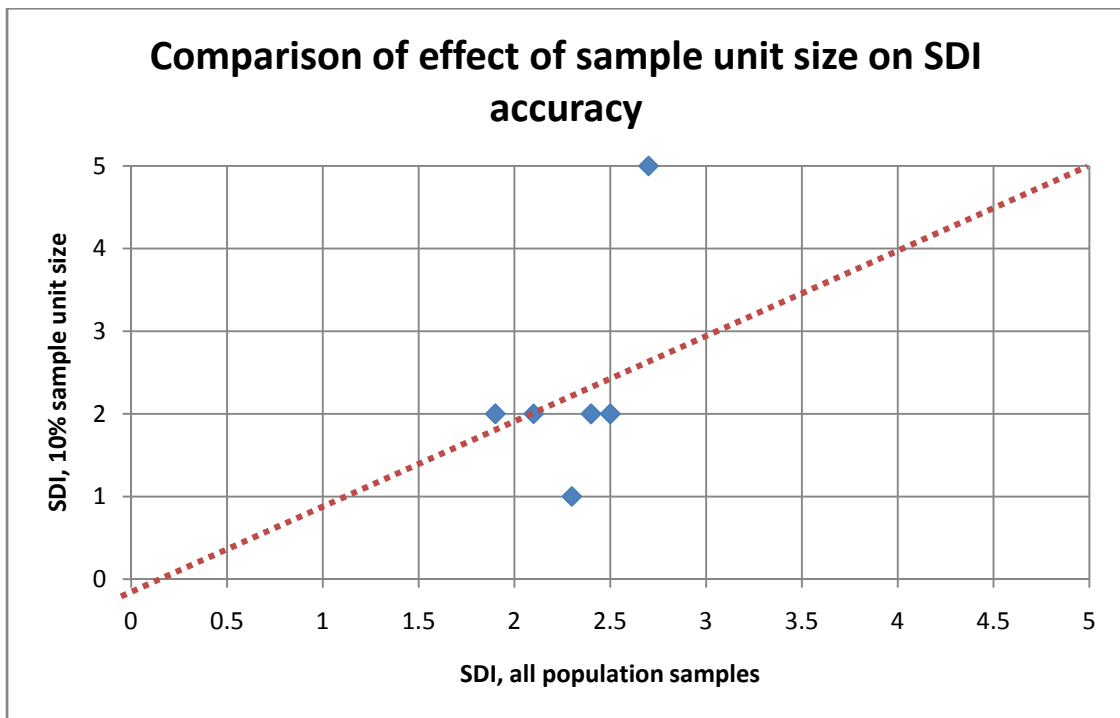


Fig. 8 Comparison of effect of sample unit size on SDI accuracy.

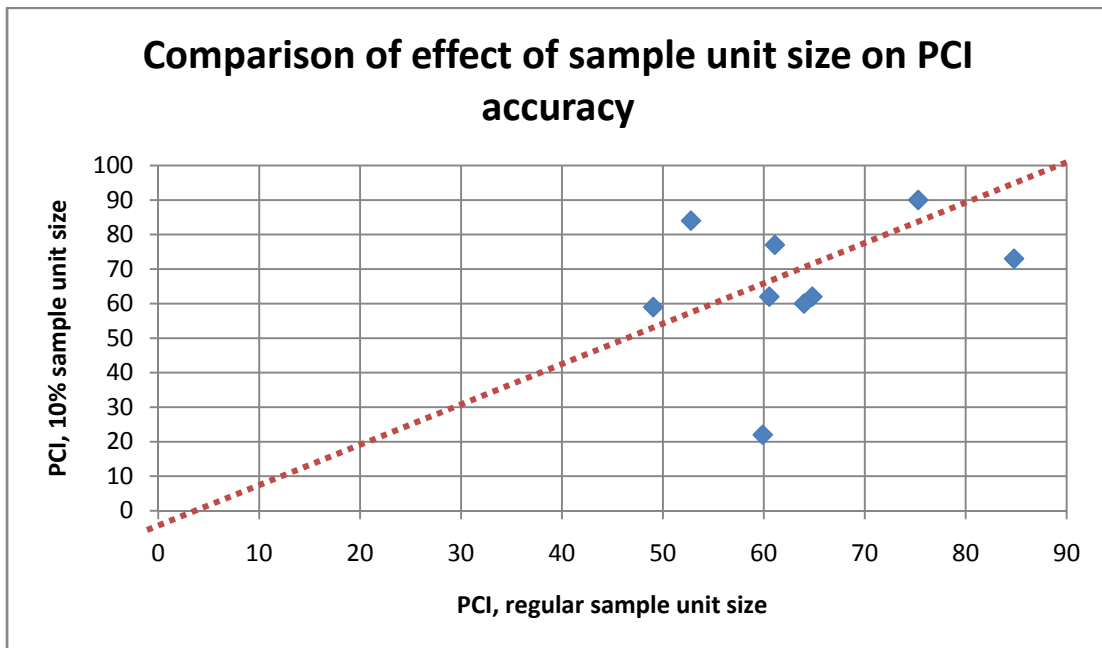


Fig. 9 Comparison of effect of sample unit size on PCI accuracy.

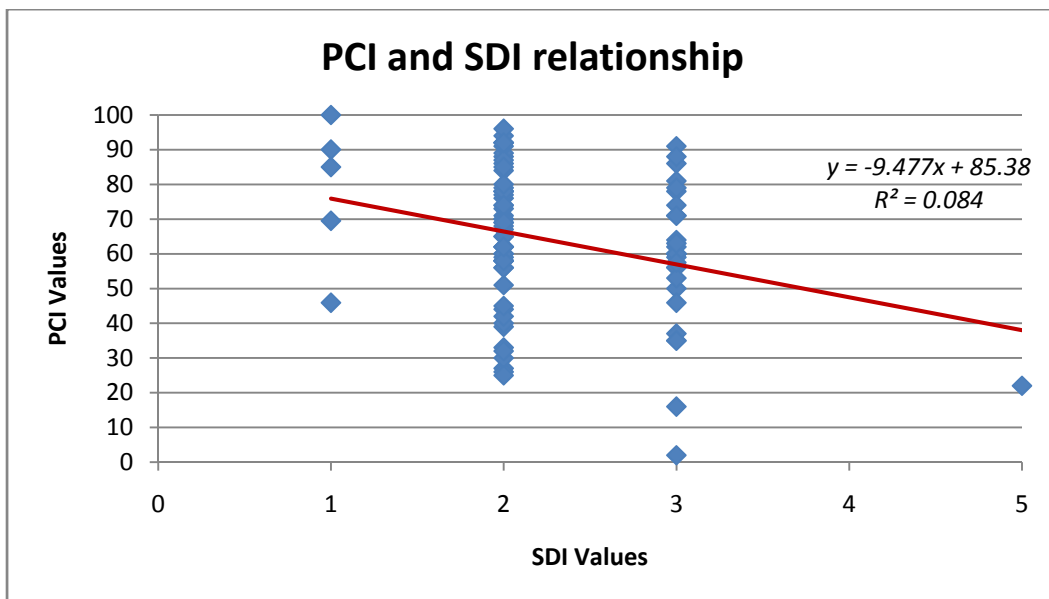


Fig. 10 SDI & PCI relationship in linear pattern.

that it should be representative of the road section. These results are also supported by Fig. 1 [10].

Figs. 8 and 9 show the comparison between 10% sample data and the whole population. The results show that the 10% sample will not be the representative of the population. Similar results are also supported by Fig. 2 [10].

#### 4.2 Relationship between SDI and PCI

It is tried to develop the relationship between SDI and PCI based on the same data. The single and multiple regressions is analyzed for the development of best fit model. The power, exponential and logarithmic models are also being tested along with linear and curvilinear pattern of the database system. Fig. 10

shows the linear relation between SDI and PCI value with  $R^2$  value of 8%, which means that the model is only 8% reliable. The polynomial equation of second degree is found same level of goodness. So it is concluded that the not strong relationship is found between SDI and PCI.

## 5. Conclusion and Recommendations

The value of SDI and PCI is computed for the section of Banepa-Bardibas highway and the SDI value as per DoR guidelines is computed as 2.3 and that for PCI based on SHRP guideline is computed as 63.4. Based on both SDI and PCI, the recommended condition of the pavement condition is the same which is in "Fair Condition". For  $SDI = 2.3$ , resealing with local patching is recommended as the M&R technique, however, as per PCI, the recommended techniques are based on distress types and the probable causes of distresses. The comparison between sample data and the population data shows that the 10% sample will not be the representative of the population. Again, the effect of sample size over the accuracy on the pavement condition data was found best fit on logarithmic equation with  $R^2$  value = 72% for SDI and that for PCI is 84%. Hence, it is concluded that the pavement condition evaluation survey for the whole population is the loss of time, labour and money, and selection of accurate sample size is very much important such that the sample will be the representative of the population within the permissible precision. Based on  $\pm 5\%$  permissible error, the recommended sample size for SDI is 13% and that for PCI is 21%. It is concluded that the 10% sample size as recommended by Ref. [6] seems insufficient, so a rigorous analysis with higher sample size is recommended in order to revise the national guidelines for the pavement condition evaluation for SDI survey. Finally, the no strong relation is found between SDI and PCI. As the samples are limited with similar type of failures, a rigorous analysis with higher sample size is recommended for further studies.

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