Indian Journal of Engineering & Materials Sciences
Vol. 32, October 2025, pp. 562-580
DOI: 10.56042/ijems.V32i05.17077

Comparative assessment of airport pavement condition using PCI and ACN-PCN methods

Hamid Noori*, & Raju Sarkar

Department of Civil Engineering, Delhi Technological University, Bawana Road, New Delhi 110 042, Delhi, India
Delhi Technological University, Bawana Road New Delhi 110 042, India

Received: 11 February 2025; accepted: 08 August 2025

A scientific approach is essential for evaluating pavement surface conditions at the network level. The prime objective of airport pavement in terms of functional condition analysis is to focus on the current and future pavement conditions. The Pavement Condition Index (PCI) is a well-known method widely used to assess the surface conditions of airport pavements. The aircraft movement from the Runway while take-off and landing or taxiing at the taxiway and parking at aprons induces a high magnitude of repetitive loads that create excessive stresses due to which pavement layers are affected and distress appears on the surface of the pavement. This study has been computed the analysis of the distress and traffic measurement to evaluate pavement condition index (PCI), Structural condition index (SCI), and FOD index. In addition, the aircraft classification number and pavement classification number (ACN-PCN) methods have been applied to all sections of airport branches to estimate the structural bearing capacity of the airport pavement network. By adopting the traditional method of the PCI, the relationship between the pavement condition index and pavement classification number has been studied. Finally, based on the combined rating index, a treatment methodology has been proposed for the improvement of the existing critical pavement section by using a decision tree (DT).

Keywords: Aircraft classification number, Pavement classification number, Pavement condition index, Structural condition index, Traffic

1 Introduction

The airport pavements can generally deteriorate rapidly due to repetitive aircraft operation and climatic conditions effects[1]. The initial phase of the pavement evaluation process involves identifying the various distresses present on the pavement surface. Following this, it is essential to quantify each distress type by assessing its density and severity level to facilitate accurate condition assessment and subsequent decision-making. Recognizing pavement distress types is a critical step in the evaluation process, as the absence of explicit severity-based guidelines can lead to inconsistencies in distress classification. Consequently, the PCI procedure offers a straight-forward and practical approach for assessing pavement conditions based on surface distresses, enabling consistent evaluation and supporting the selection of appropriate maintenance and rehabilitation treatments. The PCI approach is mostly used in the United States of America (USA) to assess the surface qualities of airport pavement. The PCI procedure is an easy and practical way to assess pavement conditions in terms of surface distress and offer maintenance and restoration options[2-3]. Although the PCI technique does not provide information on structural bearing capacity, surface evenness, or roughness, it remains a valuable tool for assessing surface-level pavement conditions[4]. The number of years a pavement stays in good condition before reaching the point of rapid deterioration depends on several factors, including construction type and quality, pavement use, climate, and Maintenance[5]. Traditionally, pavement maintenance strategies have been developed using two key indicators: the Pavement Condition Index (PCI) and the Structural Condition Index (SCI)[6]. There are two types of pavement failure, which include functional and structural. The functional failures of the pavement are related to distresses that appear on the surface of the pavement structures, mainly occurring due to operations and climate effects. Structural failures are related to distress that occurs due to poor construction practices or heavy traffic loading. It causes the

---

*Corresponding author
(Email: hamidnoori_2k21phdce511@dtu.ac.in)

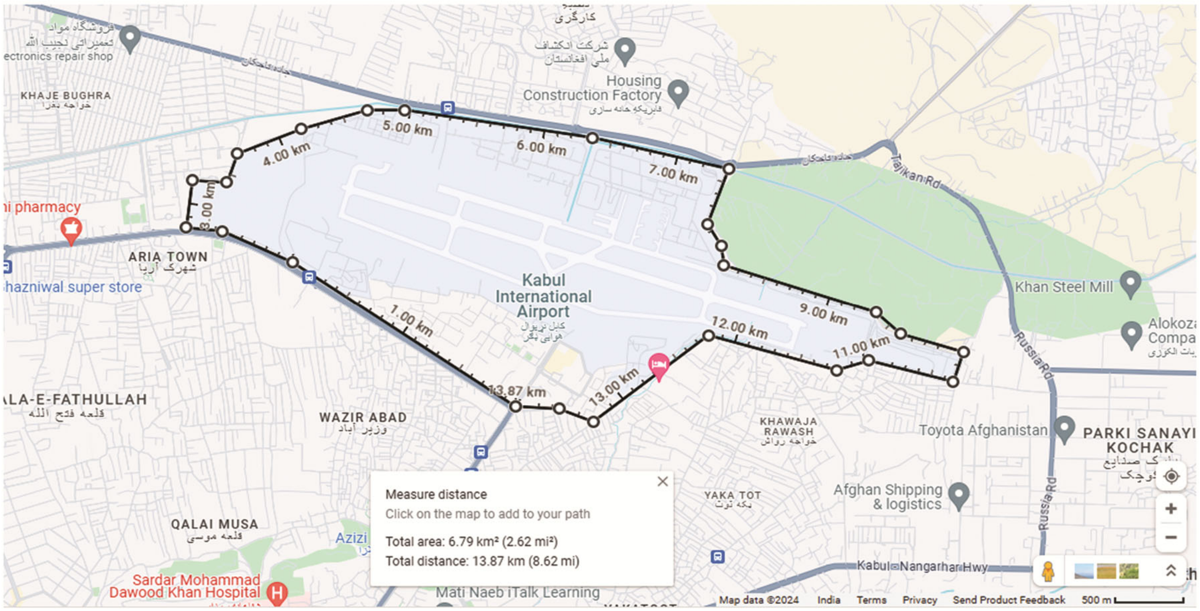
pavement structure to break down with such magnitude that the pavement section cannot sustain the loads imposed upon its surface[7]. Therefore, a standard procedure for a better pavement management system must be followed to determine the pavement condition based on estimated distress and implement an appropriate method of the pavement evaluation program. The pavement management system can support the organization's decision at various levels, such as strategic, network, and project levels[8]. Poor planning in the initial stage will affect the infrastructure's future conditions, which will cause it to fail and require massive rehabilitation and maintenance costs. A range of methods for determining the Pavement Condition Index (PCI) has been documented in both the literature and operational practice, most of which rely primarily on systematic inventories of surface deterioration. Among these, the ASTM methodology is the most widely adopted international standard. Authors from India developed the overall pavement condition index for the urban road network by considering the pavement distresses, roughness, structure characteristics, and skid parameters. The author used the PCI procedure to identify pavement distresses and to evaluate pavement conditions index in urban road networks[9,10]. Chen *et al.*[11]proposed a PCI calculation method based on mathematical modeling, incorporating weighting factors to account for specific types of pavement deterioration. Sharaf *et al.*[12] applied the analysis of variance "ANOVA" statistical technique to predict remaining service life using the PCI procedure. Optimization techniques based on Artificial Neural Networks (ANN) and genetic programming were implemented to develop an alternative method of determining the PCI by Shahnazari *et al.*[13]. Majidifard et al.[14]developed the deep learning algorithms and proposed a new asphalt PCI model to quantify the pavement condition of road networks based on imaging. Sue et al.[15] established mathematical prediction models for the deterioration of rigid airfield pavement in South Korea. A similar approach was proposed by Camarena *et al.*[16] to predict airport pavement conditions in Peru. Liu *et al.*[17] developed a new set of indices and thresholds for preventive maintenance decision-making for airport runways with composite pavement structures. Shah *et al.*[18] suggested a priority ranking of pavement sections for maintenance. Performance models for the Oklahoma airfield pavement were studied by Yuan *et al.*[20], and the PCI family modeling method was performed by Greene & Shahin (2004)[21] to forecast the deterioration rate of airfield pavement. Guo *et al.*[22] studied the relationship of PCI, SCI, and FOD index as a comparative analysis of airfield pavement for lifecycle determination. Arhin *et al.*[23] considered the prediction of pavement condition index using the international roughness index (IRI) method in a dense urban area. An APCI evaluation method was proposed by Wesolowski & Iwanowski (2020)[24]for cement concrete of Airport pavements to scope air operation safety and air transport participants' lives. The literature review reveals and highlights the existence of a small number of studies that can be practically used to study the in-service airport pavement, taking into account all branches with different pavement characteristics and pavement surface structures with usage by considering the behaviors of different types of pavements. In addition, the study demonstrates the assessment of functional and structural conditions of an in-service airport pavement.

1.1 Study area

Afghanistan is a land-locked and mountainous country; thus, air transportation is considered an essential mode of transport for people and goods. There are 28 Airfields in the country, including Kabul International Airport, which has a 3,500-meter runway and records the most significant traffic. The Airport is the central base of air transportation for domestic and international air routes. The Airport is located 1790 meters above sea level in a narrow valley of the Hindu-Kush Mountain range and surrounded by mountains with peaks above 3200m within 24km of the Airport, including Koh-e-Paghman mountain to the east; Koh-e-Qrough mountain to the south-west and Koh-e-Shir Darwaza mountains to the north-east. The Airport's total area is 6.79 km^2, and the boundary perimeter is about 14 km, as shown in Fig. 1.

1.1.1 Airports history

The Airport started operating in 1952, and the runway length was 1,700 meters, oriented 15/33 towards a saddle between hills on the northern side of the Airport. In 1963, the Runway had extended to 2,800 m, and the runway direction became 11/29. In 1988, the Runway was extended 700meters towards the eastern side, and the total runway length became 3500 meters, as shown in Fig. 2. In 2005, the runway



Measure distance
Click on the map to add to your path
Total area: 6.79 km² (2.62 mi²)
Total distance: 13.87 km (8.62 mi)

Fig. 1 — Study Area (Source: Google Maps).

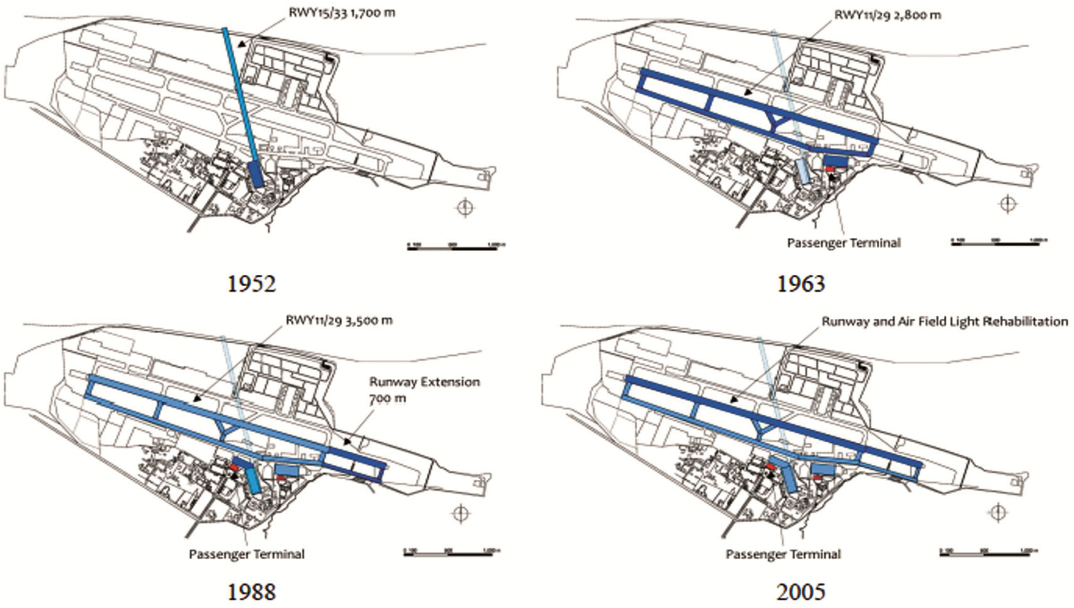


Fig. 2 — Airport development history.

was rehabilitated and an international passenger terminal was constructed by funding of Japan government.

1.2 Research objective

The primary objective of this research study is to analyze and determine the functional condition of airport pavement by applying mechanistic-empirical performance models and compare the results with probabilistic performance models developed using traditional machine learning methods.

The detailed objectives of the study include:

a) Determine and analyze the distress appearing on the surface area of an airside pavement structure.
b) To study the functional condition of airport pavements, such as pavement condition index (PCI), and examine the consequence of pavement bearing capacity using the ACN-PCN method.
c) To study the relationship between the PCI, SCI, FOD Index, and ACN/PCN by considering

the Airport branches with different pavement structures.

d) To develop a PCI family model for different categories of pavement structure and estimate the remaining life of the structure.

e) To introduce a combined index rating for pavement treatment method based on the decision tree model.

2 Material and Methods

The overall methodology shown in Fig. 3 presents the phase vise steps to implement and analyze the functional and structural condition of the airport pavement. The first step of the study includes:1) data collection and distress analysis, which comprise distress identification and measurement. 2) The traffic analysis will describe the traffic area, including aircraft assignment, and traffic loading based on traffic operation, with estimation of equivalent passes. 3) For a case study, it is also required to study the temperature and provide the geometric characteristics of the airfield. The second step of the study describes the development of a simulation model based on PVAER and PCASE applications. Each software can be integrated to analyze the airfield data simultaneously. PAVER software estimates the pavement condition index and provides functional evaluation results based on identified distresses observed on the airside. Pavement-transportation computer-assisted structural engineering (PCASE) is an application used to assess airfield pavement, including design and pavement evaluation. This application can evaluate pavement types both rigid and flexible by analyzing the different pavement behaviors and construction materials using the empirical method considering the input parameters such as pavement type, pavement thickness, layer details, California Bearing Ration (CBR) or K-value for each layer of the structure, type of soil for sub grade, sub-base and base course. The third step of the study presents a probabilistic performance model development by using a supervised machine learning algorithms (traditional machine learning models) to investigate and examine the model's accuracy and their relationship.

2.1 Pavement condition index

The Pavement Condition Index (PCI) is a standardized rating measure that evaluates pavement condition through a systematic visual inspection of surface distresses. The survey procedures and PCI computation follow the guidelines outlined in the ASTM standard[25]. The PCI value is determined based

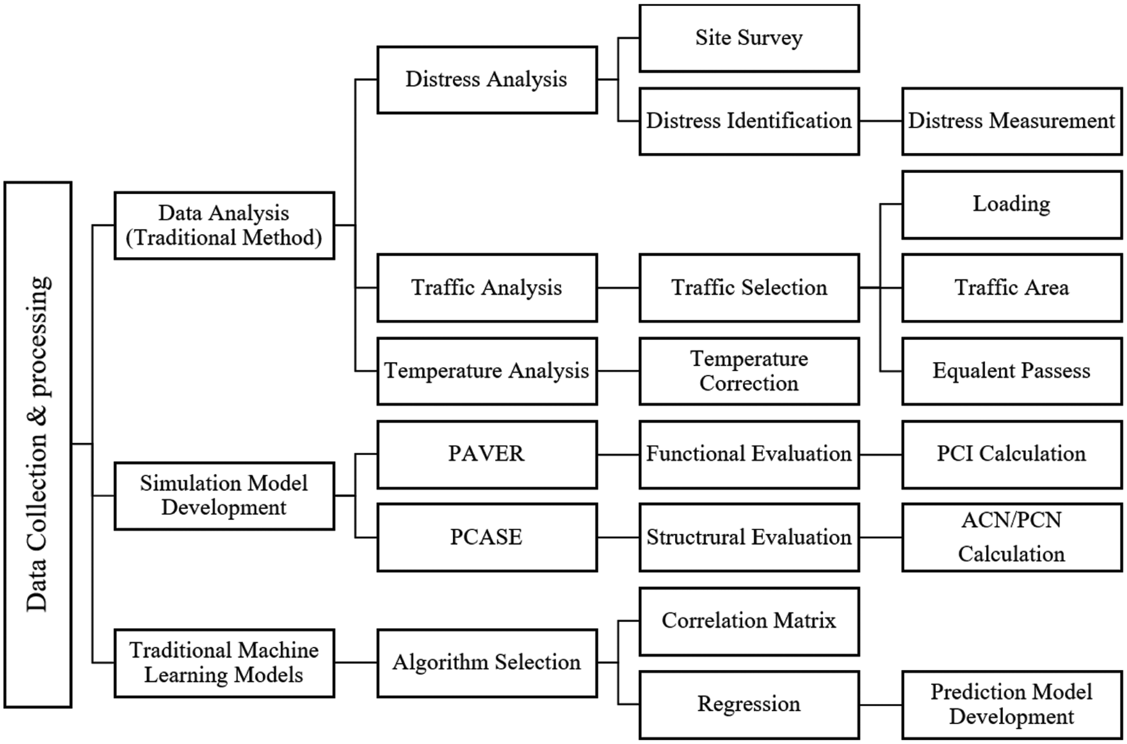


Fig. 3 — Methodology flowchart.

on the type, severity, and density of observed distresses, as expressed in *Eq. (1).*

$$\mathrm{PCI} = 100 - \max g\left(\mathrm{q}, \sum_{\mathrm{i}=1}^{\mathrm{m_s}} \sum_{\mathrm{j}=1}^{\mathrm{n_j}} \mathrm{f}\ (\mathrm{T_i}, \mathrm{S_j}, \mathrm{D_{ij}})\right) \quad \ldots (1)$$

Where *ms* represents the total number of distress types, n_j denotes the severity levels of the ith distress, and $f(T_i, S_j, D_{ij})$ is the deduct-value function determined by distress type, severity, and density. The parameter q is the number of deduct values exceeding 5, while $g(q, T_i, S_j, D_{ij})$ represents the corrected deduct-value function. After identifying each distress type T_i and severity level S_j through visual inspection, and calculating density D_{ij} as distress quantity per sample-unit area, the deduct values are obtained from ASTM curves using $f(T_i, S_j, D_{ij})$. Deduct values greater than 5 are then normalized to 5, and the corresponding corrected deduct values (CDV) are computed using additional ASTM curves defined by $g(q, T_i, S_j, D_{ij})$. After that, the PCI can be computed by 100, deducted from the maximum value among those CDVs. Specifically, PCI is a number from zero to 100. The lowest value indicates a failed condition, and the highest value denotes the perfect state of the pavement[20-22].

2.2 Structural condition index

Pavement distresses are generally classified as structural distresses—such as transverse, longitudinal, and corner cracking; corner breaks; pumping; shrinkage cracks; joint and corner spalling; and shattered slabs—or functional distresses, including corrugation, faulting, heaving/swell, and bleeding. This classification is based on whether the distress affects the pavement's load-bearing capacity. Structural distresses typically warrant greater attention in pavement design. The Structural Condition Index (SCI) is calculated using a procedure analogous to that of the PCI, as shown in Eq. (2).

$$\mathrm{SCI} = 100 - \max g\ (\mathrm{q}, \sum_{\mathrm{i}=1}^{\mathrm{m_s}} \sum_{\mathrm{j}=1}^{\mathrm{n_j}} \mathrm{f}\ (\mathrm{T_i^F}, \mathrm{S_j^F}, \mathrm{D_{ij}^F}) \ldots (2)$$

Where $f(T_i^F, S_j^F, D_{ij}^F)$= function of deducting the value determined by SCI-related distress type, T_i^F at severity level S_j^F and density D_{ij}^F. The threshold of SCI defining the structural failure of the pavement is used as 80 for concrete pavement as defined by the FAA-Advisory Circular[26-27]. However, the threshold of the SCI has yet to be regulated for flexible pavement in the airfield. For consistently comparing the service life of airfield pavements, the SCI threshold of 70 was considered for flexible pavement in this study.

2.3 Foreign object damage

Foreign Object Damage (FOD) encompasses a wide range of hazards arising from debris, materials, or particles within airfield environments, including bird strikes, vehicle-related fragments, and hail; however, many of these sources are difficult to quantify. For pavement condition evaluation, the FOD Index focuses specifically on pavement distresses that may generate loose debris. The index is calculated by considering the relevant aircraft category (F-16, KC-135, or C-17) and pavement surface type (concrete or asphalt). The KC-135 category is typically used for commercial airports due to its representation of aircraft such as the A-320, B-737, and B-757. This study evaluates only pavement-related FOD, although additional sources may include personnel, environmental factors, and ground equipment. The FOD Index is computed using a method analogous to the PCI, but limited to selected distress types. In this study, the index ranges from 100 to 0, decreasing as pavement conditions deteriorate, following a trend similar to the PCI and SCI.

$$\mathrm{FOD} = 100 - \max g\left(\mathrm{q}, \sum_{\mathrm{i}=1}^{\mathrm{m_s}} \sum_{\mathrm{j}=1}^{\mathrm{n_j}} \mathrm{f}\ (\mathrm{T_i^F}, \mathrm{S_j^F}, \mathrm{D_{ij}^F}, \mathrm{w_i^F})\right) \ldots (3)$$

The function $f(T_i^F, S_j^F, D_{ij}^F, w_i^F)$ represents the deduct value associated with each FOD-related distress type T_i^F, its severity level S_j^F, distress density D_{ij}^F, and the corresponding modification factor w_i^F. After converting the FOD index to a scale consistent with PCI and SCI, a threshold value of 40 is established to indicate unacceptable pavement-related FOD risk within airfield environments. This threshold corresponds to a high likelihood of generating foreign object debris and has been applied in previous studies alongside a PCI threshold of 55 for asphalt pavements, as mentioned in Table 1, adopted by Greene & Shahin[21].

Table 1 — Criteria for engineering assessment rating[21]

Rating/Assessment Category	Pavement Condition Index (PCI)	(ACN/PCN) index	FOD index
Adequate	71-100	<1.10	<40
Degraded	56-70	1.10-1.40	40-60
Unsatisfactory	0-55	>1.40	>60

2.4 Aircraft classification number and pavement classification number

In 1980, the aircraft classification number (ACN) and pavement classification number (PCN) methods were introduced by the International Civil Aviation

Organization (ICAO)and followed by state members to implement them in all airports for the safety of aircraft and passengers[28].The ACN is determined according to the procedure defined by the ICAO, assuming that the standard quantities in the calculation process are:

- pressure in a single-wheel tire of 1.25 MPa,
- allowable bending stress in a concrete slab (for rigid pavements) of 2.75 MPa,
- the allowable number of loads in the case of flexible pavements,
- The load capacity of the ground subsoil is described with the subsoil reaction coefficient (k) for rigid pavements and the (CBR) for flexible pavements.

The ACN is determined using the formula written in Eqs. (4) –(5).

$$ACN = 2 \times P_r \qquad \dots (4)$$

Where, Pr – equivalent load in thousands of kilograms of such value that the pavement thickness required for its transferring is equal to the thickness determined as for the actual load:

$$P_r = \pi \times q \times a^2 \qquad \dots (5)$$

q – uniform load of intensity of 1.25 MPa distributed on a circular area of radius a.

The Pavement Classification Number (PCN) shows the pavement's ability to carry loads without any restrictions on operations or expresses the load capacity of an airport pavement for a limited number of aircraft with the ACN = PCN. It corresponds to a 1/500 of the allowable load (expressed in kilograms of weight) applied to the pavement through a single wheel with a standard pressure of 1.25 MPa. Its calculation considers factors such as the sub grade strength, types of pavements, pavement thickness, aircraft fleet mix, and operations. Following this method, airport pavements are fit for use by aircraft if the ACN of the plane in question is equal to or smaller than the load-carrying capacity of the relevant pavements, expressed as PCN[29, 30-31].

As a general guideline, when granting authorization for aircraft operations and maneuvers within an airport zone, it is crucial to compare the actual ACN with the PCN of the relevant pavement. If the ACN is less than the PCN, the aircraft can maneuver or operate without restriction. If the ACN exceeds the PCN, the aircraft may operate with certain limitations. These limitations can include considerations such as the aircraft's maximum weight or the frequency of operations. Overall, the ACN-PCN method aims to maintain the quality of the airport pavement and extend the pavement's service life[29,30, 31, 32-33]. This is why operations under specific limitations are approved, as they do not compromise the safety of aircraft and individuals involved. The ACN-PCN code is a five-part code depicting the pavement type, sub grade strength category, tire pressure, and evaluation method shown in Table 2.

2.4.1 Pavement strength analysis

Structural analysis for pavement assessment calculates the maximum tensile stress of concrete pavement and maximum tensile strain of asphalt concrete to estimate the pavement's remaining life and allowable load. It is conducted using a modulus of elasticity calculated from the deflection data, the modulus of soil reaction (K) of the sub base, and the Aggregate value for rigid pavement and California bearing ratio (CBR) of the sub base and sub grade for flexible pavement structure. The study defines the performance models used to calculate the design criteria for traditional flexible and rigid pavement and criteria for expeditionary environments. The Pavement design criteria include:

Table 2 — Explanation of the ACN/PCN Code[34]

PCN	Pavement Type		Sub grade Strength		Tire Pressure		Calculation Method	
Numerical Value 42/R/B/W/T	R	Rigid	A	High	W	High	T	Technical Evaluation
			B	Medium	X	Medium		
	F	Flexible	C	Low	Y	Low	U	Using Aircraft
			D	Ultra-Low	Z	Ultra-Low		

Subgrade Strength Code	Flexible Pavement (CBR)		Rigid Pavement (K)		Tire Pressure		
					Code	Level	MPa
A	High	15%	High	150 MN m^{-3}	W	High	No limit
B	Medium	10%	Medium	80 MN m^{-3}	X	Medium	Up to 1.50
C	Low	6%	Low	40 MN m^{-3}	Y	Low	Up to 1.00
D	Ultra Low	3%	Ultra Low	20 NM m^{-3}	Z	Ultra Low	Up to 0.50

- Pavement Design for Airfield [35]

Performance models are a transfer function between pavement response models and actual pavement performance. Table 3 provides a model category description and its application for implementation in the pavement evaluation program.

2.4.2 Traffic analysis

Traffic analysis consists of determining the aircraft type, number of aircraft movements across an imaginary transverse line, and Traffic area selection according to the operation of the particular aircraft shown in Table 4. The main components of traffic analysis are the number of passes and coverages of particular aircraft movements and the vehicle pass-to-coverage ratio. The definitions of several passes and coverages over the different branches of airside vary as follows:

a) Runway: Number aircraft movements across the imaginary transverse line within (152 meter) of runway end."Touch and go" aircraft operations do not count.
b) Taxiway and Aprons: Number of aircraft movements across the imaginary line on the primary taxiway connecting the Runway and apron
c) Single-Runway Airfield: $\text{Passes}_{\text{Runway}} = \text{Passes}_{\text{Taxi}} = \text{Passes}_{\text{Apron}}$

2.4.3 Pass-to-coverage Ratio

Load repetitions are also quantified as Coverages. Coverage is a function of gear geometry and tire width. Coverage varies based on the wander width of the aircraft for a given pavement use type, i.e., Runways, Taxiways, or aprons.

1. Flexible pavements: Coverage occurs when every point on the pavement surface within the traffic lane is subjected to one application of maximum stress by operating aircraft.
2. Rigid Pavements: Coverage occurs when each point in the pavement within the limits of the traffic lane has been subjected to maximum stress by operating aircraft. Maximum stress is the stress induced in the pavement by the aircraft wheels when operating at its maximum gross weight.

Table 3 — Model Categories[35]

Model name	Mechanistic-empirical performance models	Probabilistic performance models
Description	The response model is associated with empirically derived pavement failure indicators (for example, vertical stress (response) versus Coverage of failure (performance)).	It is associated with risk analysis or confidence levels. • Regressions • Multi-variable regressions
Application	Compute a mechanistic response using layered elastic analysis as related to distress. Adjust material properties according to climate data Traffic Consideration through Cumulative Damage Use of Transfer Function relating stress/strain to performance.	Attempts to capture the variability of parameters that drive pavement performance and serviceability. One could estimate the probability of failure and service life through reliability measures.

Table 4 —Traffic Area[35]

Traffic Area A	▪ Runway ends and primary taxiways are assigned ▪ 75% of the traffic is within ± 90 cm of the center line ▪ Wander width = 180 cm ▪ Full Aircraft Weight
Traffic Area B	▪ Most aprons are assigned ▪ 75% of the traffic is within ±180 cm of the center line ▪ Wander width = 355.6 cm. ▪ Full Aircraft Weight
Traffic Area C	▪ Runway Interiors, Secondary Taxiway, and aprons that do not see full load are assigned ▪ 75% of the traffic is within ± 180 cm of the center line ▪ Wander Width = 355.6 cm ▪ 75% Aircraft Weight
Traffic Area D	▪ Overruns are assigned ▪ 75% of the traffic is within ±190 cm of the center line ▪ Wander Width = 355.6 cm ▪ 75% Aircraft Weight ▪ 1% of Design Passes

2.4.4 Temperature adjustment

Asphalt concrete pavement is sensitive to temperature; correction work is essential when calculating a modulus of elasticity. In other words, the time that aircraft use airport pavement varies by season (spring, summer, fall, winter) and time of day. Therefore, temperature correction and adjustment are required to reflect the different impacts of temperature variation on the pavement by the season or inspection time. For this temperature correction, the deflection value should first be converted into the deflection value for a temperature of 20ºC, considering the temperature change on the inspection day.

2.4.5 Analysis of load transfer efficiency of concrete pavement

The load transfer efficiency for concrete pavement is essential to determine the deflection ratio of one side of a joint to that of the other. If the difference between the deflections of both sides of the joint increases, the concrete stress might be concentrated on one side of a slab. This phenomenon may cause pumping or faulting and damage the concrete, eventually shorting the pavement's lifetime. The load transfer efficiency between concrete slabs can be computed as a ratio of the deflection of both sides of the slabs. In other words, it is determined by calculating the ratio of D0, which is the deflection of a slab with an HWD load applied near the joint, to D12, which is the deflection of the adjacent slab with no load applied. This ratio determines the percentage of the main gear load of an aircraft loaded on one slab that is transferred to another adjacent slab with no load applied; in a case where the value of the load transfer efficiency increases, the flexural stress of another slab with no load decreases, and the life of the Pavement increases. The load transfer efficiency is affected by many factors, including the space between the aircraft gear, tire contact area, pavement temperature, whether a dowl bar is installed, and whether a stabilized sub grade exists. The Eq. (6) is used to calculate the load transfer efficiency.

$$LTE = \frac{\Delta ul}{\Delta l} \times 100(\%) \qquad \ldots (6)$$

Where: LTE is Load transfer efficiency, Δul: Deflection of the loaded side of the slab connection part, Δl: Deflection of the unloaded side of the slab connection part. Table 5 provides LTE criteria introduced by Federal Administration Aviation[27].

3 Results and Discussion

The Airport airside areas consisted of three primary pavement sections, as shown in Fig. 4. Most of the aprons are Portland cement concrete (PCC). The Runway and southern taxiways are Asphalt concrete (APC) over Portland cement concrete. The northern taxiways are made of Asphalt Concrete (AC). All types of pavement categories are considered in the distress analysis. Distress information for each airport section was collected manually, analyzed and interpreted in the simulation application for further assessment.

Figure 5 highlights the counts for different branches with construction material on the pavement's surface. It demonstrates that most of the Aprons are constructed with Portland cement concrete, and the Runway and Taxiways sections consist of Asphalt

Table 5 — Determination of load transfer efficiency criteria adopted by FAA[27]

Load transfer efficiency	Condition
71-100 (%)	Good
51-71 (%)	Fair
50(%) or less	Poor

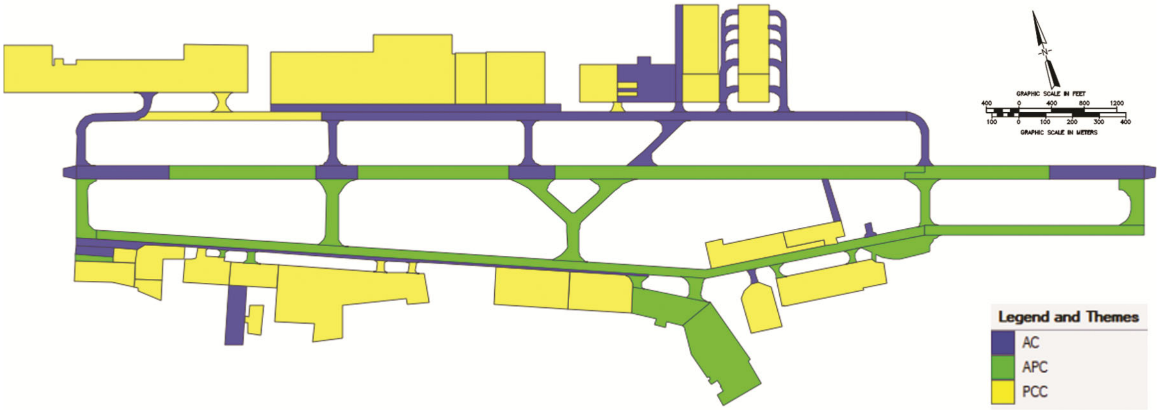


Fig. 4 — Airport pavement types.

concrete and Asphalt overlay material over Portland cement concrete. The pavement area for airport branches, including the surface type percentages and their categories are listed in Table 6.

3.1 Distresses data calculation

The distress data for all sections of the Airport pavement is summarized in Fig. 6. It establishes the distress types and their frequency. It was concluded that asphalt concrete pavement is more susceptible to the weather18%, Jet Reflection cracking 15.4%, Longitudinal and transverse cracking 9.4%, Alligator cracking 6.8%, and Oil spillage 5.1% with the total 60%. Portland cement concrete structures, which are showing 57% of the total pavement construction statistics built in aprons of the Airport, show scaling 9.4%, Joint spalling 7.7%, Joint seal damage 6.8%, and 5% for corner break, corner spall, and 2.6%for small patches only with the total of 30% overall records that affect concrete pavement structure and causes failures. The remaining distress, such as raveling, rutting, shrinkage cracking, etc., represents 10%, that are less than 1% statistics. Table 7 demonstrates the details for distress calculation including PCI, SCI, and FOD index measurement for one section of airside.

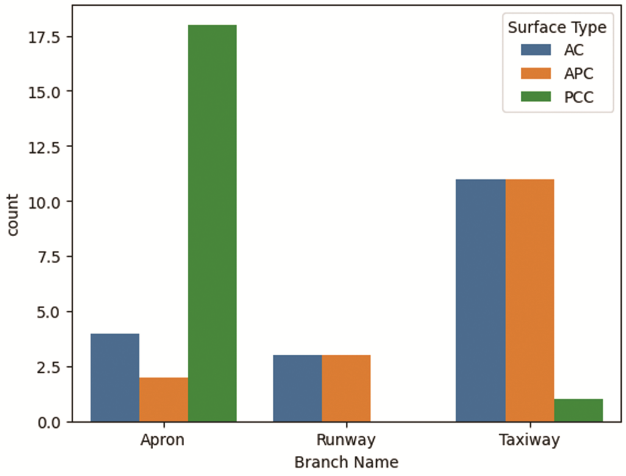


Fig. 5 — Airport branches surface category.

3.2 Airport branches physical properties data

The physical properties of the airport network and its geometric characteristics, including network identification number, branch name, section, layers/materials type, and the layers K/CBR values for (rigid and flexible) pavements, are collected for this study, as shown in Table 8. A total of 51study sections were considered for the pavement condition index calculation.

A dynamic cone penetration test (DCP) was conducted to collect field data to estimate the CBR and K-value of the sub grade soil. The soil type and its classification, including the construction date for all the layers of the pavement structures, were collected for this study and analyzed by PCASE.

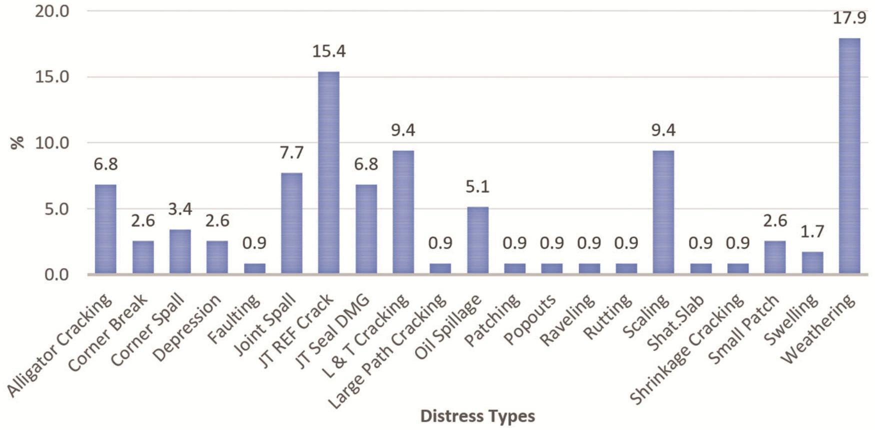


Fig. 6 — Distress percentage (%).

Table 6 — Airport branch details

No	Surface Type	Pavement Area (m^2)	%	Branch	Pavement Area (m^2)	%
1	Asphalt Concrete	202,432.54	16.4	Taxiway	796210.87	64.5
2	APC	328,783.08	26.6	Runway	133915	10.8
3	PCC	703,890.65	57.0	Apron	304980.4	24.7
	Total	1,235,106.27	100	Total	1,235,106.27	100.0

3.3 Airport PCI measurement using PAVER

The airside pavement database was created in PAVER for PCI measurement. The airside inventory hierarchy comprises four elements: (1) Network, (2) Branch, (3) Section, and (4) Unit. The inventory contains the pavement work history and the last inspection data of the pavement. Maps like Arc Map were formed outside the PAVER application and exported to PAVER as a shape file for displaying pavement conditions. Distress data collected from the field was given in the PAVER application as an input parameter, including location, type, density and severity level of distress that appears on the surface of airport pavements. These were documented and introduced as inventory data to the application. Figure 7 shows the graphical layout of the Airport with the PCI scale.

Table 7 — Distress data analysis & PCI, SCI, and FOD index calculation sample

Sample ID	Distress code	Description	Severity	Density	Deduct	Quantity	Units
001	47.	Joint Reflection Cracking	Low	27.00	14.1	27.00	Meter
001	48.	Longitudinal/Transverse Cracking	Low	35.00	24.1	35.00	Meter
Section ID	T06C	Pavement Condition Index	SCI	FOD Index	FOD Potential (C-17)	FOD Potential (F-16)	FOD Potential (KC-135)
Condition		70.9	100	29	20	42	31
Category		Adequate	Good	Good	Good	Fair	Good

Table 8 — Airport physical properties data

Network ID	KBL_AIR_01	Section:	AP-01: A01B
Traffic Area:	Area A	Branch:	Apron
Pavement Condition Index:	68.1	Joint Deflection. Ratio:	0.76
Sub grade CBR/K value:	200	Rigid Failure Criteria:	First crack

Layer Information

Layer Type	Material	Thickness (mm)	K (MPa/m)	Computed Eff. K (MPa/m)	Flex Strength (MPa)	Modulus (MPa)	Poisson's Ratio	Controlling Layer
Asphalt Overlay	Asphalt Cement	114	NA	0	NA	1379	0.45	NA
PCC Base Slab	Portland Cement	292	176	NA	4.48	27579	0.15	NA
Base	Unbound Aggregate	330	108	87	NA	414	0.35	X
Natural Sub grade	Cohesive Cut	0	54	54	NA	103	0.40	NA

Evaluation Results

Vehicle	Load	Passes	ACN	PCN String	AGL (kg)	Allowable Passes	ACN/PCN Ratio
C-17A GLOBEMASTER III	265351.54	100000	47	67/R/B/W/T	373201	8508965	0.7

KBL_Kabul; AIR_Airport; AP_Apron; AGL_Aircraft gross loading

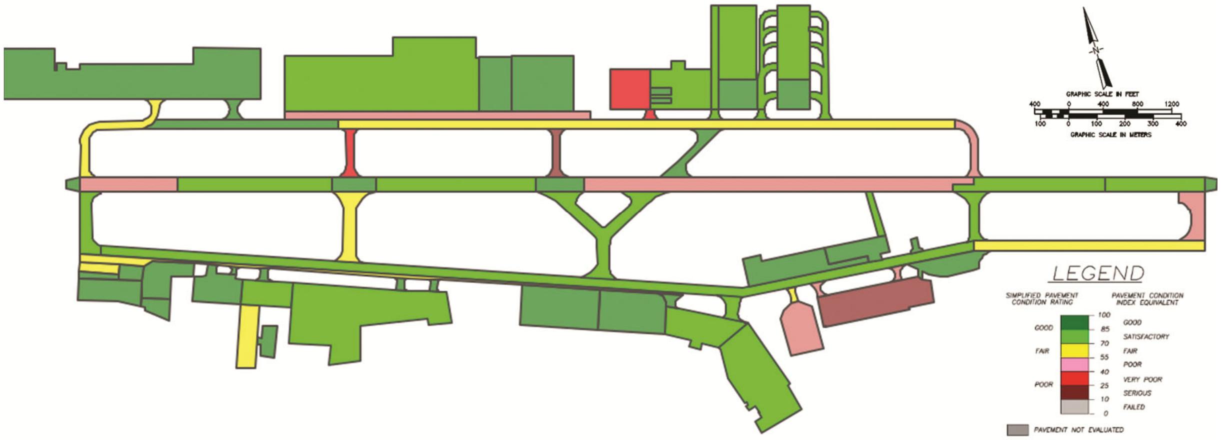


Fig. 7 — Airport PCI map.

3.3.1 Development of PCI family modeling by using PAVER application

The PCI family modeling has been implemented by using the PAVER application. The input parameters include network, branch use, section units, area, pavement category and construction type, construction history, etc. The PCI family model developed to represent the pavement deterioration curve shown in Fig. 8 for Asphalt concrete pavement. The model deterioration rate indicates a PCI value of 0.87 points per year with a boundary outlier of 1.96 (95% confidence interval), and localized preventive maintenance is included in the model. The slope is limited, and the number of coefficients is automatically determined. The critical condition was defined as 55 PCI, with a model fit of 0.678 and a correlation coefficient of 0.824.

A separate deterioration model has been developed for each APC-paved section, indicating an annual PCI reduction rate of 0.03 points. The model incorporates localized preventive maintenance, including surface treatments such as asphalt overlays, and identifies 55 PCI as the critical condition threshold. The analysis yielded a boundary outlier value of 1.96 (95% confidence), with a model fit of 0.813 and a correlation coefficient of 0.902. Fig. 9 presents the PCI family model for the APC pavement structure, showing how variations in the asphalt-overlaid pavement data reflect the effects of maintenance and rehabilitation (M&R), where surface treatments help increase PCI values over time.

Finally, the last model has been created for the Portland cement concrete pavement to examine the deterioration curve for all PCC sections. The model's deterioration rate indicates a PCI reduction value of 0.04 points per year. The boundary outlier of 1.96 (95%) is considered for this model. The critical condition was set to 70 PCI, and the slope was constrained, automatically calculating the number of coefficients. The coefficient of correlation for this model shows 0.795, with a model fit of 0.632, as shown in Fig. 10. Table 9 summarizes the PCI family model used to evaluate the three pavement section types constructed at the airport.

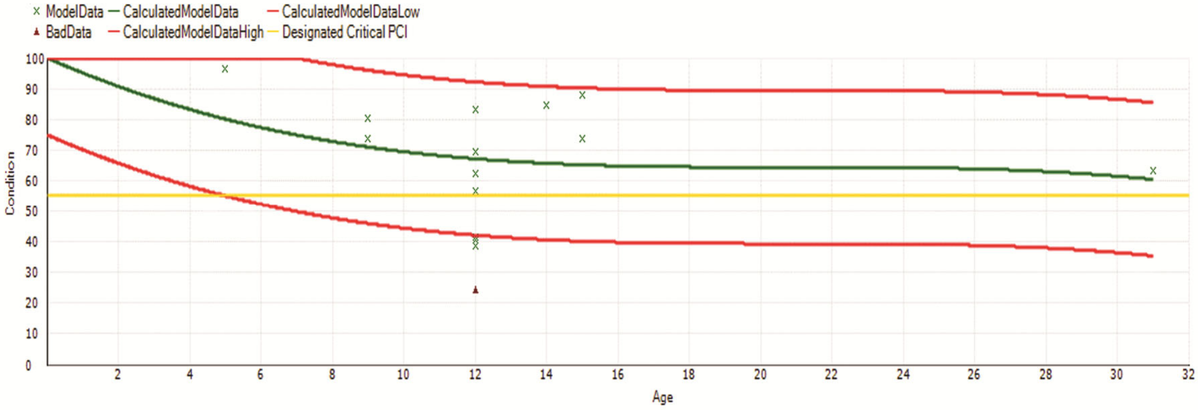


Fig. 8 — Asphalt concrete (AC) pavement PCI family model.

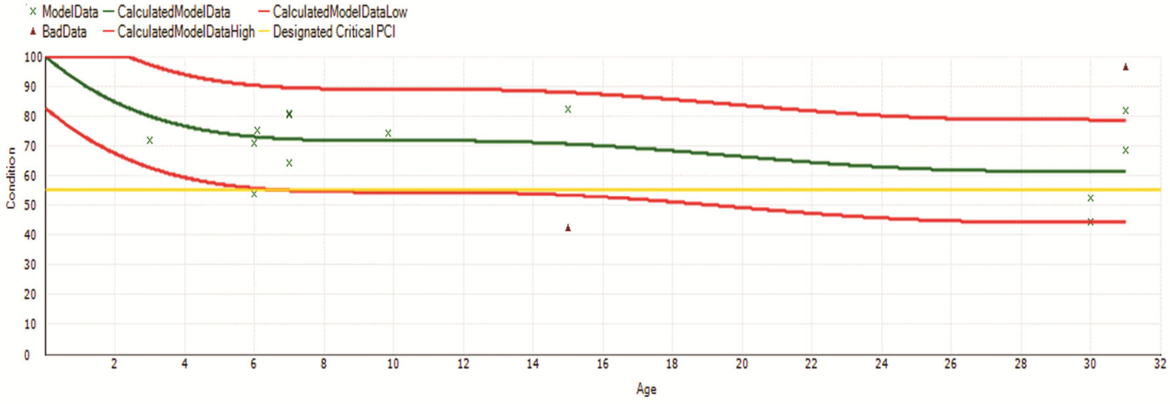


Fig. 9 — APC pavement PCI family model.

3.4 ACN and PCN evaluation using pavement computer-assisted structural engineering (PCASE) program

The pavement sections with different surface types, such as (rigid and flexible) were analyzed using the airfield pavement evaluation (APE). The airfield pavement evaluation (APE)can analyze pavement using the empirical method, producing resultant allowable loads, passes, pavement classification numbers, and provide with overlay requirements. For concrete pavement sections, the failure criteria for further assessment have been set based on the actual condition of the pavement structure. Rigid failure criteria consist of (1) First crack, (2) Shattered slab, and (3) Complete failure. The load transfer for rigid type structure is considered to be 25% of aircraft gross loading in (kg), which includes 25% load reduction, and the joint deflection ratio was set to 0.75 with a maximum edge stress of 75%. The traffic pattern has been created based on the actual traffic scenario and introduced as mixed-type pattern traffic for the PCN estimation. The sub grade categories were assigned as categories A, B, C, and D for different traffic areas to assess airfield pavement, shown in Table 3. The pavement classification number was evaluated based on a C-17 Globe master III-type controlling aircraft (using mission-critical aircraft for ACN calculation) with a maximum loading of 265 Tons and with an assumption of 100000 evaluation passes, listed in Table 10. The details of PCI, including PCN calculation for all sections of airport pavement, are presented in Table 11.

The assessment result indicates that the condition based on PCI calculation does not reflect the same

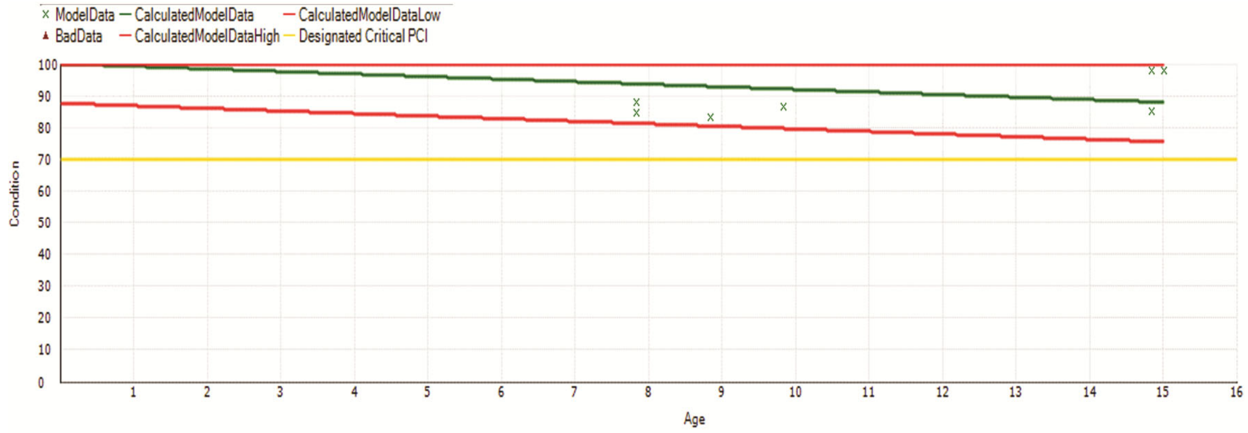


Fig. 10 — PCC pavement PCI family model.

Table 9 — PCI family modeling summary

Parameters	Asphalt Concrete	APC	Portland Cement Concrete
Coefficient of Correlation	0.824	0.902	0.795
Approximate R^2	0.678	0.813	0.632
The standard deviation of error	12.773 PCI Pts	8.789 PCI Pts	5.302 PCI Pts
Absolute Mean of error	6.78 PCI Pts	4.422 PCI Pts	2.656 PCI Pts
Arithmetic Mean of error	0.157 PCI Pts	-0.135 PCI Pts	-0.043 PCI Pts
Total Points	15 (14 Valid, 1 Invalid)	15 (13 Valid, 2 Invalid)	7 (7 Valid, 0 Invalid)
Extrapolation Slope	-0.87 PCI Points per Year	-0.03 PCI Points per Year	-0.04 PCI Points per Year

Table 10 — Traffic Analysis and Equivalent Passes Calculation

S. No	Aircraft Type	Load (Kg)		Passes		Equivalent Passes
		Area A, B	Area C, D	Areas A, B, C	Area D	
1	C-5A/B GALAXY	381,018	285,763	100,000	1,000	33,424
2	C-17A GLOBEMASTER III	265,352	199,014	100,000	1,000	100,000
3	C-130J HERCULES	79,379	59,534	100,000	1,000	5,649
4	CV-22	27,442	20,582	100,000	1,000	1
5	E-3 SENTRY AWAC	147,418	110,563	100,000	1,000	24,825
6	F-15C EAGLE	30,844	23,133	100,000	1,000	12,251
7	KC-135 REFUELER	146,510	109,883	100,000	1,000	8,440

Table 11 — Pavement condition based on criteria adopted by [21]

S. No	Section	PCI	SCI	FOD Index	Pavement Condition	PCN String	ACN/PCN Ratio	Pavement Condition
1	A01B	68.1	73.1	5.40	Degraded	67/R/B/W/T	0.7	Adequate
2	A07B1	74.0	79.62	26.0	Adequate	48/R/B/W/T	1	Adequate
3	A07B2	74.0	81	NA	Adequate	48/R/B/W/T	1	Adequate
4	A08B	10.1	27.8	84.0	Unsatisfactory	39/R/B/X/T	1.2	Degraded
5	A10B	86.5	93.42	13.5	Adequate	25/R/B/W/T	1.8	Unsatisfactory
6	A11B1	84.6	92.3	51.4	Adequate	44/R/B/W/T	1.1	Adequate
7	A11B2	83.9	91.89	52.1	Adequate	44/R/B/W/T	1.1	Adequate
8	A11A3	98.0	100	8.0	Adequate	64/R/B/W/T	0.7	Adequate
9	A11A4	98.0	100	NA	Adequate	64/R/B/W/T	0.7	Adequate
10	A12B	93.0	97.2	7.0	Adequate	39/R/B/W/T	1.2	Degraded
11	A12B2	89.5	95.2	10.5	Adequate	69/R/B/W/T	0.7	Adequate
12	A13B	78.0	84.5	22.0	Adequate	80/R/B/W/T	0.6	Adequate
13	A14B	85.1	91.9	14.9	Adequate	75/R/B/W/T	0.6	Adequate
14	A15B	93.0	97.1	7.0	Adequate	87/R/B/W/T	0.5	Adequate
15	A18B	66.5	72	42	Degraded	32/F/A/W/T	1.3	Degraded
16	A20B	86.5	93.4	13.5	Adequate	74/R/B/W/T	0.6	Adequate
17	A28B1	80.5	87.6	2.8	Adequate	36/F/C/X/T	1.5	Unsatisfactory
18	A28B2	73.9	79.3	26.1	Adequate	36/F/C/X/T	1.5	Unsatisfactory
19	A29B	87.8	94.1	12.2	Adequate	28/R/B/W/T	1.7	Unsatisfactory
20	A30B	83.1	91.4	52.9	Adequate	53/R/B/W/T	0.9	Adequate
21	A31B	88.1	94.36	17.1	Adequate	74/R/B/W/T	0.6	Adequate
22	A32B	84.4	92	18.6	Adequate	64/R/B/W/T	0.7	Adequate
23	A33B	28.1	14.6	71.9	Unsatisfactory	26/R/B/W/T	1.8	Unsatisfactory
24	R01A	35.1	51.7	40.1	Unsatisfactory	73/R/B/W/T	0.6	Adequate
25	R02C	88.0	94.1	12.0	Adequate	80/R/B/W/T	0.6	Adequate
26	R02A	82.1	90.9	17.9	Adequate	83/R/B/W/T	0.6	Adequate
27	R02C2	42.4	49.2	37.2	Unsatisfactory	80/R/B/W/T	0.6	Adequate
28	R02C3	72.0	80.7	14.6	Adequate	100/R/B/W/T	0.5	Adequate
29	R03A2	73.9	79	26.1	Adequate	110/R/B/W/T	0.4	Adequate
30	T01A	75.3	81	24.7	Adequate	49/R/B/W/T	1	Adequate
31	T02C	64.0	89	36.0	Degraded	67/R/B/W/T	0.7	Adequate
32	T03C	80.6	90.08	19.4	Adequate	63/R/B/W/T	0.7	Adequate
33	T06C	70.9	78	29.1	Degraded	63/R/B/W/T	0.7	Adequate
34	T10C	96.4	95	3.6	Adequate	33/R/B/W/T	1.4	Degraded
35	T11C	81.6	89	18.4	Adequate	37/R/B/W/T	1.3	Degraded
36	T12C	44.2	52.5	55.8	Unsatisfactory	20/R/B/W/T	2.3	Unsatisfactory
37	T13C	52.3	45.8	47.7	Unsatisfactory	28/R/B/W/T	1.7	Unsatisfactory
38	T14A	96.3	98	3.7	Adequate	56/F/A/W/T	0.7	Adequate
39	T15A	80.5	90	19.5	Adequate	60/R/B/W/T	0.8	Adequate
40	T16A	68.3	79	31.7	Degraded	50/R/B/W/T	0.9	Adequate
41	T17C	83.3	80	16.7	Adequate	30/F/A/W/T	1.4	Degraded
42	T18A1	41.4	44.3	36.3	Unsatisfactory	31/F/A/W/T	1.3	Degraded
43	T18A2	56.7	56.7	26.0	Degraded	31/F/A/W/T	1.3	Degraded
44	T18A3	40.4	56.7	48.2	Unsatisfactory	15/F/A/W/T	2.7	Unsatisfactory
45	T19C	24.6	34.6	51.3	Unsatisfactory	68/F/A/Y/T	0.6	Adequate
46	T20A	38.7	42.3	38.2	Unsatisfactory	40/F/A/W/T	1	Adequate
47	T21A	62.4	63.8	23.2	Degraded	65/F/A/W/T	0.6	Adequate
48	T22C	82.7	94	17.3	Adequate	50/F/A/W/T	0.8	Adequate
49	T24A	84.8	97	15.2	Adequate	6/F/C/Y/T	9.6	Unsatisfactory
50	T25A	63.1	68.1	0	Degraded	8/F/C/Y/T	7	Unsatisfactory
51	T26A	86.5	97.8	13.5	Adequate	102/R/B/W/T	0.5	Adequate

Branches (A_Apron, R_Runway, T_Taxiway); Pavement type (R_Rigid, F_Flexible);Subgrade strength (A_High, B_Medium, C_Low, D_Ultra low); Tire pressure (W_High, X_Medium,Y_Low, Z_Ultra low); PCN evaluation method (T_Technicalmethod,U_using aircraft) based on ACN-PCN; therefore, we can see if a section of the pavement in the PCI calculation reflects unsatisfactory, the same section shows a different condition, such as adequate or degraded using ACN-PCN method. The difference between the promoted sophistication of software applied for pavement design and the ACN-PCN pavement strength rating has caused anomalies [31]. A new method of pavement classification rating (PCR) and aircraft classification rating (ACR) was introduced and implemented by state members of ICAO. Overall, the ACN-PCN method aims to maintain the quality of the airport pavement and extend the pavement's service life. The aviation industry is undergoing a significant shift in the way airport pavement strength is assessed and communicated. The traditional ACN-PCN system is being replaced by a new ACR-PCR system. This transition is driven by the need for a more accurate and reliable method of evaluating pavement strength, especially in the context of increasingly heavy aircraft and complex operational scenarios. The key differences between the ACN-PCN system method and ACR-PCR are:

- ACN-PCN system is based on empirical data and is often criticized for its limitation in accuracy, reflecting the true bearing capacity of pavements.
- ACR-PCR is a newer system that is more scientifically rigorous, using advanced computational models to assess pavement performance. It considers factors such as pavement materials properties, thickness, and traffic loading to provide a more accurate rating.

3.5 Artificial Intelligence

3.5.1 Machine learning algorithms

Distress data is measured manually and assessed using traditional machine-learning algorithms. The most significant advantages of machine learning in pavement condition evaluation are their robust learning algorithms, which can extract rules and features (i.e., Distress of Pavements) from pavement datasets [36]. ML has shown better accuracy and computational time performance than conventional image processing techniques because they effectively learn many features and rules essential in detecting pavement distress due to their complicated patterns. Fig. 11 shows the classification and regression of supervised machine-learning algorithms.

3.5.2 Relationship of classic models

For this study, the supervised machine learning algorithm was used to predict the PCI and determine the relationship between the models (PCI, SCI, FOD index, and PCN). Both classification and regression analysis were studied. Models such as Artificial Neural Networks (ANN), K-Nearest Neighbors (KNN), Support Vector Machine (SVM), Random Forest Regressor (RF), Decision Tree (DT), XG-Boost, and Multiple Linear Regression were applied to find the performance output result for the different models' prediction accuracy and errors. A correlation matrix was examined, which shows the relationship between each classical model, such as PCI, SCI, FOD index, and PCN. Lastly, a prediction model based on the following data was developed to determine and predict a PCI value using Python code.

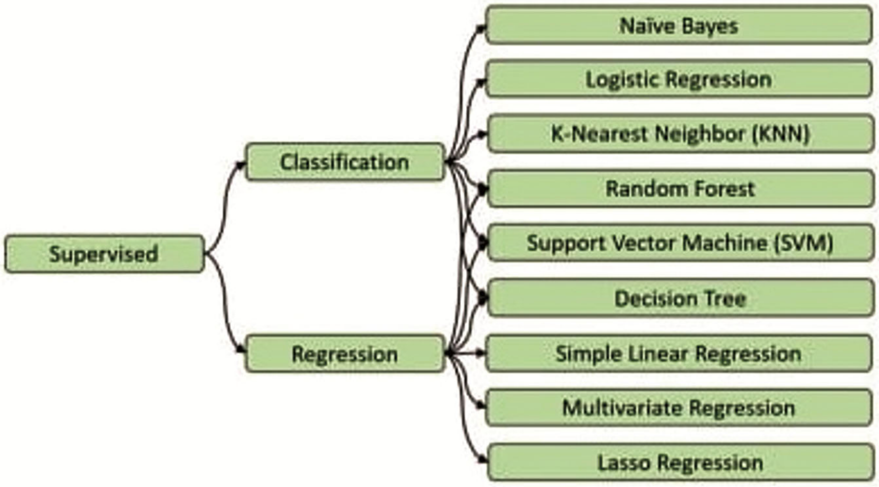


Fig. 11 — Supervised machine-learning algorithms.

Figure 12 shows the heat map for airport pavement condition indices. The heat map illustrates a linear and positive relationship between PCI and SCI (0.92), and A-negative linear relationship between PCI, SCI, and FOD index that (-0.75) and (-0.65) respectively. The scatter plot for the different models designates that PCI for all sections has a positive linear relationship with SCI and a negative linear relationship with the FOD index, as shown in Fig. 13 (a) –(c).

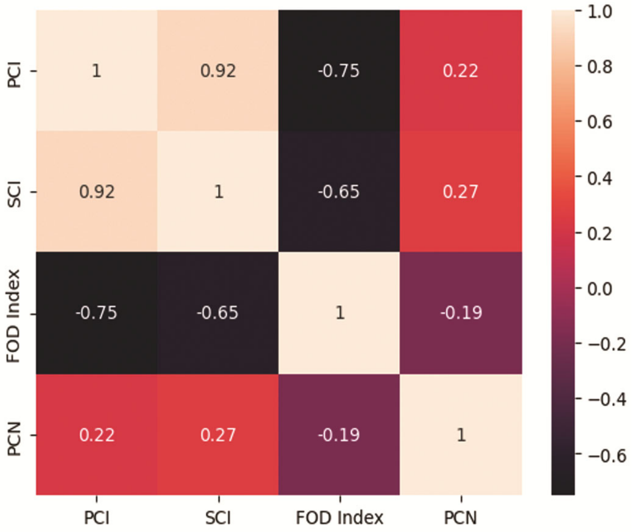


Fig. 12 — Airport Pavement Condition Indices (Heat map).

3.6 Development of MLR model for PCI prediction

The Multiple Linear Regression (MLR) model was developed to predict PCI by incorporating the pavement performance variables summarized in Table 12. MLR is applied when multiple independent variables collectively provide a more accurate prediction of a dependent variable than a simple linear regression model. The generalized form of the MLR model is presented in Eq. (7).

$$Yp = a + b1X1 + b2X2 + ..bnXn \quad \dots (7)$$

Where$Y_p$is the predicted value of the dependent variables of the trend, (a)is vertical axis intercept value xi= (for i=1,2,3…n) different independent variables; bi= (for i=1,2,3…n) the proportional contribution of the related independent variable the forecast of $Y_{p.}$

3.6.1 Multiple linear regression model result and summary

The above MLR model can be used to estimate PCI values based on statistical analysis [37]. The coefficient of the correlation value is 0.92, the MAE is 5.22, the mean square error of estimation of the PCI value is 60.51, and the RMSE is 7.19, representing a good PCI prediction.

Machine learning models such as Artificial Neural Network (ANN), Random Forest Regressor (RF), Decision Tree (DT), Support Vector Machine (SVM), XG-boosting, and K-Nearest Neighbors (KNN) implemented to predict PCI values for validation purposes. Table 12 provides the result of the PCI

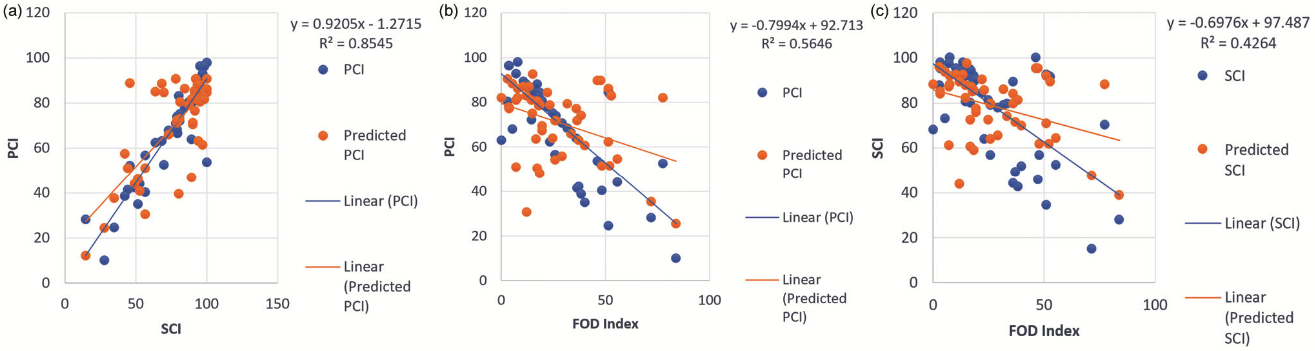


Fig. 13 — (a) PCI/SCI, (b) PCI/FOD index, & (c) SCI/FOD index relationship scatter plots.

Table 12 — Model performance prediction summary

Model	R^2	MAE	MSE	RMSE
Multiple Linear Regression (MLR)	0.836636	5.221660	60.511539	7.194964
K-Nearest Neighbors (KNN)	0.752884	5.849443	76.461160	8.224714
Decision Tree (DT)	0.716034	5.397061	84.852157	8.364914
Random Forest Regressor (RF)	0.834658	5.016565	59.088578	6.729294
Support Vector Machine (SVM)	0.830620	5.082913	61.139822	7.146986
XG-Boost	0.815020	5.895824	76.682411	8.371316
Artificial Neural Network ANN	0.818926	5.641920	60.968803	7.644834

prediction performance evaluation. The subsequent output demonstrates that linear regression has the highest accuracy with R^2 of 0.83 and lesser error compared to the other PCI prediction models.

3.7 Pavement treatment methods

3.7.1 Introduction to the ranking of maintenance and repair (M&R) projects

3.7.1.1 Definition of prioritization or ranking

After the determination of the pavement condition index, the best treatment alternative is calculated based on the effectiveness concept and with reference to cost calculations. To prepare a maintenance action plan, where the available budget is constrained and needs to be limited to a few projects, we want to prioritize and choose a logical order. This procedure of listing candidate pavement projects (section) for maintenance is widely termed ranking or prioritization.

3.7.1.2 Need for Prioritization

As the financial resources are limited, there should be a scientific, fair, and efficient method to rank and prioritize the candidate pavement projects for preservation. It eliminates unwanted political or local pressures and also undue doubts about the selection of a particular project for improvement. The procedure adopted for ranking the candidate projects should be able to explain why one project is chosen over another, such as competing projects. Prioritization also guides us on which projects to advance and which to postpone. Ultimately, scarce resources can be utilized for the right project at the right time to preserve and improve the condition of pavements in an airport pavement network.

3.7.1.3 Stages of Priority Ranking

Two primary stages of the priority ranking process are involved with decision support, particularly for economic decision-making by economic appraisal of investment alternative treatments and selecting a list of investment alternative candidate projects within a network under a constrained budget.

3.7.1.4 Methods of Priority Ranking

The following prioritization factors should be considered when deriving a formula or consistent procedure.

1. Ranking by individual factors: The parameters related to pavement condition, traffic, age, ride quality, structural condition index, and skid resistance are considered based on the importance of the project's needs.
2. Ranking by Combined Factors:

A priority score is a combined ranking technique based on relative weights assigned to the above factors. The Weighting factors should represent individual influences associated with each factor included for the calculation of a combined ranking index. As a general guideline, the factors contributing to the structural behavior of pavement are given more weightage than those representing the pavement surface's behavior [39-40].

3.7.2 Ranking of M&R projects based on CIR

Definition of prioritization or ranking: After the determination of the Pavement condition index, where the available budget is constrained and needs to be limited to a few projects, purge to prioritize and choose a logical order.

3.7.2.1 Need for Prioritization

Ranking by the combined factors studies method [38-39] has been considered in the present study. Eq.(8) has been used for ranking pavement sections by considering PCI, SCI, and FOD index values and calculated a combined index ranking(CIR) as presented below:

$$\mathrm{CIR} = (\mathrm{W1} \times \mathrm{PCIaverage}) + (\mathrm{W2} \times \mathrm{SCI\ average}) + (\mathrm{W3} \times \mathrm{FOD\ average}) \qquad \ldots (8)$$

$$\text{Where; } \mathrm{Wi} = \text{Weight factors, and } \mathrm{W1} = 1.0, \mathrm{W2} = -0.1 \text{ and } \mathrm{W3} = -$$

An example of the ranking of pavement sections based on CIR analysis is presented in Table 13. A proposed methodology for pavement treatment selection based on pavement evaluation studies using PCI values is presented in the following paragraphs.

Table 13 — Ranking of pavement sections based on CIR analyse

Network		Condition Index			CIR	Rank
Branch	Section	PCI	SCI	FOD index		
Apron	A08B	10.1	27.80	84.0	1.08	1
Taxiway	T19C	24.6	34.60	51.3	16.01	2
Apron	A33B	28.1	14.60	71.9	19.45	3
Runway	R01A	35.1	51.10	40.1	25.98	4
Taxiway	T20A	38.7	42.30	38.2	30.65	6
Taxiway	T18A3	40.4	56.70	48.2	29.91	5
Taxiway	T18A1	41.4	44.30	36.3	33.34	7
Runway	R02C2	42.4	49.20	37.2	33.76	9
Taxiway	T12C	44.2	52.50	55.8	33.37	8
Taxiway	T13C	52.3	45.80	47.7	42.95	10

3.7.3 Pavement treatment selection

The proposed methodology, illustrated in Fig. 14, integrates PCI, SCI, FOD index values, and ACN/PCN results. PCI is computed using distress evaluation models (DV curves) derived from field-measured distresses and the PAVER system, while PCN is estimated through the PCASE (APE) procedure based on mechanistic–empirical analysis for each pavement section. The calculated PCI values are compared with the ASTM-based customized PCI rating scale. If the PCI falls below the minimum acceptable limit, the pavement classification number technique is applied, followed by non-destructive tests such as DCP or FWD to assess structural capacity and estimate remaining service life. The ACN/PCN method is employed to evaluate the load-bearing capacity and layer characteristics of the pavement. If the PCI meets the minimum threshold, SCI and FOD index values are further examined. Sections with SCI < 70 (for AC pavements) or FOD index > 60 undergo FWD testing to determine remaining service life. Otherwise, appropriate maintenance treatments are selected using the decision tree in Fig. 15.

The proposed treatment selection process based on the decision tree is discussed below to select a consistent treatment option across the agency. However, these trees matrices may be updated in future needs based on new technology or innovative material.

3.7.3.1 Decision Tree (DT) based on PCI

It is a stepwise pictorial presentation of a predefined list of applicable and feasible treatment alternatives that are considered maintenance or rehabilitation strategies based on PCI values. The decision tree provides a framework for treatment selection relating to the applicable code of practice.

It is a challenging task to Develop a decision tree statement to cover all possible combinations of influencing factors of performance of each treatment of any pavement section [41].In order to choose the finest maintenance repair solution, it is essential to assess the efficacy of various treatments[42]. Based on experience and field observations, an appropriate set of rules with

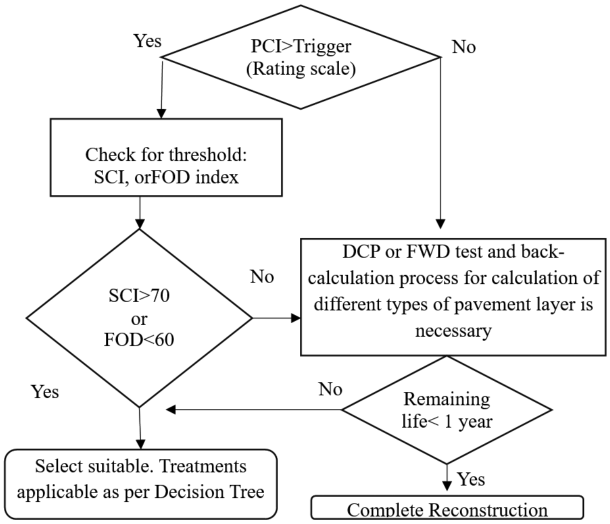


Fig. 14 — Proposed methodology for pavement treatment with applicable criteria.

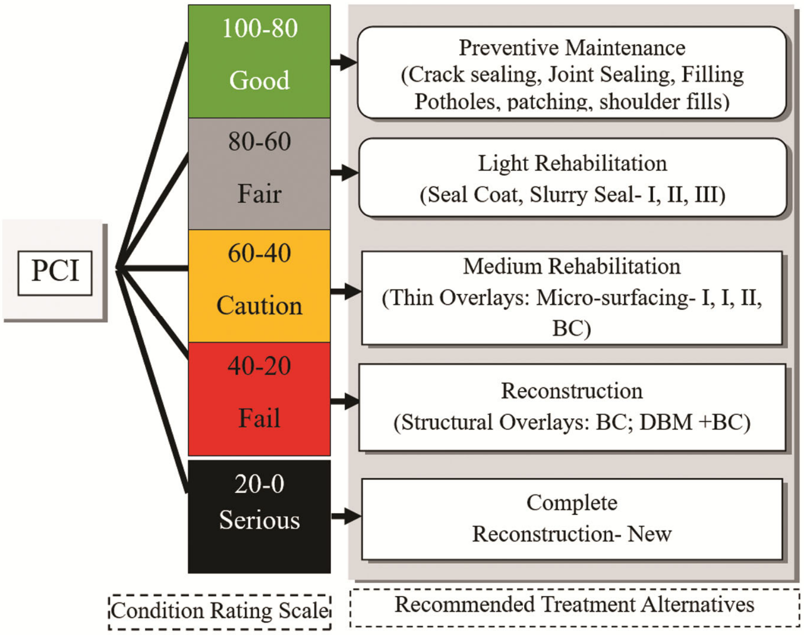


Fig. 15 — Decision tree for selecting feasible treatment options based on PCI rating.

treatments applicable to a rating on the PCI scale is recommended as a branch of DT. Similarly, a complete set of each branch of DT is prepared with feasible treatment alternatives versus a set of condition ratings. By considering the PCI family model conclusion, it was observed that Asphalt concrete is more damaged compared to Portland cement concrete and composite structures that have been overlaid before; therefore, the result of selecting the appropriate treatment method based on the decision tree describes the repair and maintenance of asphalt pavement categories with consideration of PCI rating scale. In addition, the decision tree is further categorized based on a broad category of PCI values. 1) Preventive Maintenance, 2) Corrective or light rehabilitation, 3) Moderate rehabilitation, 4) Reconstruction, and 5) Complete reconstruction.

The decision tree statements are used to estimate the cost of each applicable alternative treatment. So that the pavement manager can arrive at a decision on the best treatment, as defined in the decision tree, based on cost-effectiveness analysis. For all these alternative treatments, benefit analysis is carried out by calculating each cost of construction, effectiveness, and cost-effectiveness[43].

3.7.4 Techniques of validation

3.7.4.1 Accuracy

The single, most important criterion for making a final selection of a model or a parameter in a model is forecasting accuracy. Accuracy statistics can help make this selection decision. The most accurate model will generate the least forecasting error. See Eq. (9):

$$\text{Accuracy} = \frac{TN+TP}{TN+FN+TP+FP} \quad \ldots (9)$$

3.7.4.2 Mean Absolute Error

By adding all the different values among the realistic and enumerate values distant from the direction, we get the mean absolute error (MAE) value. See Eq. (10):

$$\text{MAE} = \frac{1}{N}\sum_{i=1}^{n}\left|V_{\text{predict}} - V_{\text{observe}}\right| \quad \ldots (10)$$

3.7.4.3 Root Mean Square Error

When the discrepancy between the enumerated and the real executed values is expressed in the form of a ratio, RMSE defines the square root of this ratio. See Eq.(11):

$$\text{RMSE} = \sqrt{\frac{1}{N}\sum(V_{\text{Predict}} - V_{\text{Observ}})^2} \quad \ldots (11)$$

3.7.4.4 Mean Square Error

Mean squared error assesses the quality of a predictor by measuring the average of the squares of the error that is, the average squared difference between the estimated values and the actual value. See Eq.(12):

$$\text{MSE} = \frac{1}{n}\sum_{i=1}^{n}(O_i - P_i)^2 \quad \ldots (12)$$

3.8 Observations and summary

The study concluded that the pavement condition index for the runway portions is 30% in poor condition, 33% in satisfactory condition, and 34% in good condition. Regarding the Aprons, the PCI scores are roughly 67% (Good), 25% Satisfactory, and only 10% in a severe or fail state. However, only 60% of the taxiways are in satisfactory shape; the remaining 40% are seriously damaged. Following the PCI data, only 10% of aprons were required to be reconstructed, and 30% of the Runway needed to be maintained and improved by implementing major maintenance and rehabilitation. For the taxies, 10% (localized maintenance), 25% (major maintenance and rehabilitation), and 5% needed to be reconstructed based on the repair types specified.

The overall condition of Kabul International Airport, as shown in Fig. 8, is satisfactory, with a mean PCI value of 68 for the Runway, 71 for Aprons, and 66 for taxis. Table 14 shows the summary of the pavement condition index for all the branches,

Table 14 — Airport PCI statistics summary

Descriptives	Airport Branch Name			Descriptives	Pavement Type		
	Apron	Runway	Taxiway		Asphalt Concrete	Portland Cement Concrete	APC
Mean	71	67.7	65.8	Mean	61	82.47	70.5
Median	84	73	68	Median	67	87	74
Variance	432	352	380	Variance	518.5	296.0	227
Std. Deviation	20.8	18.7	19.49	Std. Deviation	22.77	17.2	15.0
Minimum	10	42	25	Minimum	10	28	42
Maximum	98	88	96	Maximum	96	98	96
Range	88	46	71	Range	86	70	54
Skewness	-2.11	-0.59	-0.32	Skewness	-0.653	-2.45	-0.5
Kurtosis	4.73	-1.62	-0.69	Kurtosis	-0.070	6.430	-0.29

including the pavement categories of the Airport. The PCI results indicate that all the Aprons, which are 57% of the pavement structures, show a Mean of 82% PCI, while Runway and taxiways, which are both 43% of all the structures, indicate the lowest PCI (60-70) range.

4 Conclusion

This study investigated the relationship of PCI, SCI, and FOD index, including ACN-PCN. The analysis revealed a significant linear association between the Pavement Condition Index (PCI) and both the Structural Condition Index (SCI) and the Foreign Object Damage (FOD) index, although the confidence levels of the fitted models varied. The findings indicate that Portland Cement Concrete (PCC) pavements exhibit comparatively higher PCI values than Asphalt Concrete (AC) pavements. Moreover, AC pavements were found to be more vulnerable to climatic influences, demonstrating distress manifestations such as weather-related deterioration 18%, jet fuel and refueling-induced cracking 15.4%, longitudinal and transverse cracking 9.4%, alligator cracking 6.8%, and oil spillage damage 5.1%, collectively accounting for 60% of the observed distresses.

The findings of this study confirm that Portland Cement Concrete (PCC) pavement structures exhibit a longer service life than asphalt pavement structures, as indicated by the results of the PCI family model. Consequently, it is recommended that asphalt pavement sections be prioritized for maintenance interventions, as they require greater attention to enhance their service life and improve their Pavement Condition Index (PCI). The pavement treatment framework proposed using the Combined Index Rating (CIR) technique offers an effective and timely decision-making tool for repair and maintenance planning. Future research should focus on evaluating the limitations of traditional pavement condition assessment methodologies and exploring the transition toward advanced, computer-aided procedures, such as the ACR–PCR system.

References

1 Noori, H., Sarkar, R., *Iran J Sci Technol Trans Civ Eng,* 48 (2024) 1171–1190
2 Ragnoli, A., De Blasiis, M. R., & Di Benedetto, A., *Infrastructures*, 3(4) (2018) 58
3 Karim, F. M., Rubasi, K. A. H., & Saleh, A. A., *Int. Journal*, 8(1) (2016) 1446-1455
4 Shahin, M. Y., & Becker, J. M. *Trans Res. Record*, 25 (1984) pp. 985
5 Hajj, E. Y., Loria, L., Sebaaly, P. E., Borroel, C. M., & Leiva, P., *Trans research record*, *2235*(1) (2011) 66-81
6 Tarefder, R. A., & Rahman, M. M., *Journal of Transportation Engineering*, 142(8) (2016) 04016027
7 Smith, R. E., Darter, M.I., & Herrin, S.M., *Highway Pavement Distress Identification Manual*. Federal Highway Administration, United States (1979)
8 Miah, M., Oh, E., Chai, G., & Bell, P. *Int. Journal of Pavement Res. and Technol.*, 13(6) (2020) 581–590
9 Shah, Y. U., Jain, S. S., Tiwari, D., & Jain, M. K. *Procedia-Social and Behavioral Sci*, 104 (2013) 332-341
10 Mubaraki, M. *The Journal of Eng. Research*, 11(1) (2013) 44–54
11 Chen X, Michaels JE, Lee SJ, Michaels TE, *NDT E int*, 51 (2012) 142-149
12 Sharaf EA, Reichelt E, Shahin MY, Sinha KC *Transp Res Rec*, 1123 (1987) 30-39
13 Shahnazari H, Tutunchian MA, Mashayekhi M, Amini AA, *J Transp Eng,* 138(12) (2012) 149-1506
14 H. Majidifard, Y. Adu-Gyamfi, W.G. Buttlar, *Constr. Build. Mater.*, 247 (2020) 118513
15 Suh, Y. C., Park, D. Y., & Jeong, K. Y., *Transn res record*, 1788(1) (2002) 132-137
16 Camarena, K. A., Eng, B., & Flores, L., *Innovation in Education and Inclusion*: Proceedings of the 16th LACCEI International Multi-Conference for Engineering, Education and Technology, Lima, Peru, (2018)
17 Liu, S., Ling, J., Wu, Z., Li, P., & Zhang, J., *Journal of Trans Engineering, Part B: Pavements*, 148(1) (2022) 04022001
18 Shah, A., Tighe, S., & Stewart, *Canadian journal of civil Eng*, 31(4) (2004) 608–618
19 Li, X., Keegan, K., & Yazdani, *Transportation research record*, 2153(1) (2010) 81-87
20 Yuan J, Mooney MA, *Transp Res Rec,* 1853(1) (2003) 44-54
21 Greene, J., Shahin, M. Y., & Alexander, D. R., *Transportation research record*, 1889(1) (2004) 63-70
22 Guo, L., Wang, H., & Gagnon, J., *Journal of Transportation Engineering, Part B: Pavements*, 147(2) (2021) 04021002
23 Arhin, S. A., Williams, L. N., Ribbiso, A., & Anderson, M. F., *Journal of Civil Eng Research*, 5(1) (2015) 10–17
24 Wesołowski, M., & Iwanowski, P., *Int. J of Env. Res and Public Health*, 17(5) (2020) 1663
25 ASTM D64433-23, *Standard Practice for Roads and Parking lots PCI Survey*," United States (2023)
26 Federal Aviation Administration, *Guideline and procedures for Airport Pavement Design and Evaluations*, AC 150/5320-6F. Washington, DC: FAA, USDOT (2016)
27 Federal Aviation Administration, *Guideline and procedures for Airport Pavement Surface Evaluations*, AC 150/5320-17A. Washington, DC: FAA, USDOT (2016)