

EVALUATION OF THE AIRPORT PAVEMENT CONDITION INDEX IN THE AIRCRAFT LATERAL WANDER AREA

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ABSTRACT: The Airport Pavement Condition Index (PCI) is important in developing a runway maintenance strategy, which is carried out on the entire surface using the ASTM D5340 method. However, a significant amount of time, money, and comprehensive observation is needed for the management of hundreds of airports, especially the middle of runway, which measures 18m with numerous aircraft wheels. Therefore, this research examined PCI in the lateral wander area and modeled the relationship with standard PCI values. The ASTM D5340 guidelines with two scenarios were used to analyze the overall runway pavement survey. In scenario 1 PCI was calculated on the entire runway surface, while in scenario 2 PCI it was evaluated only on the lateral wander area. The analysis results showed that the PCI value in Scenario 2 is 23.8% (PKY) to 49.7% (TJQ) lower than in Scenario 1 because the analyzed area comprised of aircraft wheels and the environment (heat, rain). This research succeeded in developing a model of the relationship between $PCI_{overall}$ as a function of $PCI_{lateral\ wander}$, which requires development by increasing the number of runway samples. However, using PCI calculations for the lateral wander area has the potential to improve flight safety and decrease the monitoring costs for airport pavement.

Keywords: Pavement Condition Index, ASTM D5340, Lateral Wander, Flight Safety

1. INTRODUCTION

Pavement Condition Index (PCI) is a measure that ranges from 0 (worst) to 100 (best) [1], signifying the general condition of a pavement section. The assessment of pavement condition must be considered when planning maintenance strategies. However, delaying maintenance period by a year has the potential to increase runway pavement life cycle costs by approximately 16% [2].

Surveys on runway pavement conditions are generally carried out visually and on foot. However, another method requiring the use of vehicles, produces similar R^2 values of 0.89 [3]. In both methods, the damage detection process relies on the perception of the surveyor. Although, in recent years, various damage detection research were carried out using artificial neural network methods.

Damage detection using an automatic superpixel extraction algorithm had been proven to outperform conventional binary methods [4]. The Convolutional Neural Network (CNN), which is a more advanced method, was successfully used to predict accuracies of 75.8%, 84.1%, 76.3%, 79.4%, and 83.1% in damages characterized by holes, patches, marks, longitudinal, and block cracks, respectively [5]. The use of CNN based on data obtained from surveys conducted with Unmanned Air Vehicles (UAV) produced positive results although the method requires improvements in terms of equipment and damage detection algorithms [6]. This led to the development of a similar method, namely Deep Convolutoinal Neural

Network (DCNN) with a precision accuracy of approximately 0.89 [7].

Damages to runway pavement was commonly observed on the entire surface. Moreover, it was found that 20% of the total sample units on flexible pavement met the maximum error requirement of five points [8]. Runway with a width of 45 m generally accommodate aircraft wheels in the middle. However, aircraft movements during landing, takeoff, or taxiing lead to lateral shifting from runway or taxiway centerline, known as lateral wander [9]. This phenomenon is defined as the shifting from the runway centerline to the right or left due to the influence of a crosswind. The degree of lateral wander is influenced by aircraft type. For example, the Airbus A319 can laterally shift to approximately 182 cm [10]. The areas frequently passed by aircraft wheels tend to deteriorate more rapidly. Additionally, the configuration and weight of the main gear contribute to damages on the runway pavement [11]. This can also be caused by other factors such as subgrade conditions, excessive loads, and fuel droplets [12]. Previous research provided important information regarding the observation area and number of sample units that need to be considered during the application of the Airport Pavement Management System (APMS).

The implementation of APMS had been carried out in several countries all over the globe. A runway with a PCI of less than 55 requires reconstruction with a lot of processing, while one with a value between 55 and 70 needs slight volume treatment. Maintenance needs to be carried out to keep runway

in good condition if the value is between 70 and 90 [13]. PCI value decreases as the pavement ages, therefore, estimating the current PCI includes applying a reduction rate based on the initial index [14]. An alternative method is to directly estimate PCI reduction at a lowered rate of 3 to 4% annually [15].

Several literature reviews stated that PCI is an important variable representing runway pavement readiness. However, carrying out a general survey of runway pavement requires a lot of effort in terms of cost and time, which is a major problem in countries with numerous airports. Meanwhile, carrying out random sampling occasionally led to estimates of PCI values that does not correspond with field results. This research proposed a process for selecting controlled sample units, known as lateral wander. Additionally, the present research aimed to obtain a correlation between standard and modified calculations for the lateral wander area. The subsequent sections sequentially focused on the research significance, methodology, data analysis, and conclusion.

2. RESEARCH SIGNIFICANCE

Examining PCI in the lateral wander area provided a clearer understanding of the airport pavements condition. The precision was achievable because the adopted method focused on the influence of aircraft loads and environmental factors on pavement deterioration in that particular area. This also led to several benefits including reducing the measured pavement area compared to the standard method, which assesses the entire surface. Additionally, since the surveyed area corresponded with the aircraft wheel track, the developing PCI value was typically lower. This led to the basis for airport operators to commence maintenance earlier, eventually improving total flight safety.

Fig. 1 shows the data collection methods, and sample units with data collected by visual inspection of runway on foot. Meanwhile, the sample unit area observed was the selected part of the runway where the aircraft wheels usually passed. Pavement monitoring in these areas tends to significantly reduce costs by relatively 40%. However, in countries with a large number of airports such as Indonesia (>200 airports), this method has a significant impact on reducing cost requirements, while ensuring sustainable runway maintenance.

This research developed a model focusing on the relationship between pavement condition values in the lateral wander area (PCI_{LW}) and the entire runway ($PCI_{overall}$). The model can be used as a rapid and more economical alternative for measuring similar conditions with tolerable accuracy.

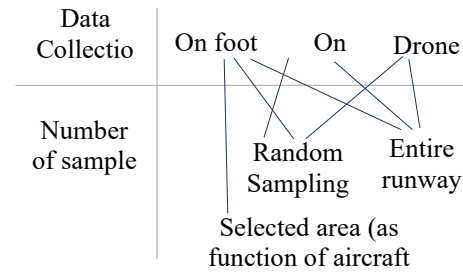


Fig. 1 Methods of data collection and sample units

3. METHODOLOGY

Fig. 2 shows the adopted methods, with the initial stage focused on determining the location of the airport used as the research object. Another criteria focused on the fact that the pavement had been in use for a long time. Therefore, it is expected that varying types of damage can be found on the runway pavement. Aside from that, efforts were also made to select airports with less busy aircraft traffic.

In the next stage, damage on the runway pavement was observed. This included recording all types, levels, and areas or location of damage. The following stage focused on performing PCI calculations under two conditions. First, the PCI was calculated over the entire runway surface ($PCI_{overall}$). Second, it was only calculated in areas traversed by aircraft wheels (PCI_{LW}). The results of the analysis were further reviewed to obtain a comparison of PCI in these two conditions. This led to the basis for determining the PCI calculation model if carried out in a limited area traversed by aircraft wheels.

The concluding part of this research focused on the dominant types of damages on the runway, comparison of PCI values, and a model of the relationship between $PCI_{overall}$ and PCI_{LW} . In addition, the findings served as a reference for future investigations needed to determine airport runway PCI values.

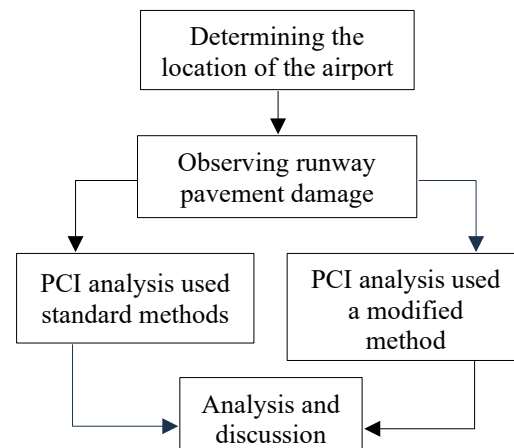


Fig. 2 Methods of data collection and sample units

3.1 PCI Analysis Using Standard Method

PCI was calculated by subtracting the maximum pavement condition (C) from the deduct value, which depended on damage type (Ti), severity (Si), and damage density (Di). Equation (1) was used to calculate the PCI, while variables i, j, and p represented the amount, level, and the number of damage types considered, respectively. F (t, d) is an adjustment factor connected to the total deduct value (t) and the number of deducts (d).

$$PCI = C - \sum_{i=1}^p \sum_{j=1}^{m_i} a(T_i, S_j, D_{ij}) F(t, d) \quad (1)$$

The minimum number of samples (N) that met the requirements for an error value (e) and flexible pavement (s) standard deviation of $\pm 5\%$ and 10 were calculated using Equation (2).

$$n = \frac{Ns^2}{\left(\frac{e^2}{4}\right)(N-1) + s^2} \quad (2)$$

A minimum of 20% of the total number of sample units was needed to meet the maximum error requirement of 5% in PCI calculations. Since runway at both TJQ and PKY were constructed with flexible pavement, a single sample unit covering an area of 450 m² was established. These airports had similar runway dimensions, with lengths and widths of 2500 m and 45 m, respectively, leading to a total of 250 sample units (N). The distribution of the sample units followed the runway length at 10-meter intervals, as shown in Fig. 3.

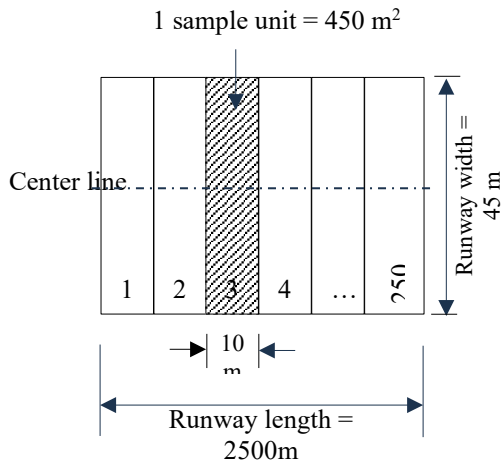


Fig. 3 Scenario 1 PCI measurement over the entire runway surface (N=250)

The assessment of pavement condition is similar to the scenario in Fig. 3, where the sample units were divided. Furthermore, Fig. 4 shows the rutting-type damage measurements on the TJQ runway. The identification of damage types and

severity levels followed the guidance of ASTM D5340.



Fig. 4 Rutting measurements on TJQ runway

In this investigation, checking runway during the PCI survey included manual observation, which turned out to be a time-consuming task. Another research used the vehicle method to achieve an index value R² of 0.89 comparable to the manual method.

The runway pavement condition measurements, in line with the sample distribution in Fig. 3, were processed using ASTM D5340 method to generate 250 PCI values, later divided into two sections. The results of this analysis were referred to as Scenario 1. The average PCI value in each section was calculated using Equations (3) and (4).

$$\overline{PCI}_a = \frac{\sum_{i=1}^m (PCI_{ai} \cdot A_{ai})}{\sum_{i=1}^m A_{ai}} \quad (3)$$

$$PCI_s = \frac{\overline{PCI}_r(A - \sum_{i=1}^m A_{ai}) + \overline{PCI}_a(\sum_{i=1}^m A_{ai})}{A} \quad (4)$$

where

$\overline{PCI}_a$ = area-weighted PCI in additional sample units

PCI_{ai} = PCI value in additional sample unit

A_{ai} = area

m = number of additional sample units surveyed

PCI_s = area-weighted PCI of the pavement section

3.2 PCI Analysis Using Modified Method

In this investigation, the lateral wander area was estimated to be 18 m wide, with each side of runway measuring 9 m. This specific zone experienced the heaviest load from aircraft wheels, as showed in the Cumulative Damage Factor (CDF) curves for the largest aircraft at the two airports. Meanwhile, the CDF values for large aircraft such as B737-800, B737-900ER, and A320-200, are shown in Fig. 5. The impact of aircraft wheel on the pavement reached ± 7.5 m on both sides of the runway centerline. Based on the assumption of the lateral wander of 1.5 m, the load coverage expanded to

± 9.0 m on both sides of runway.

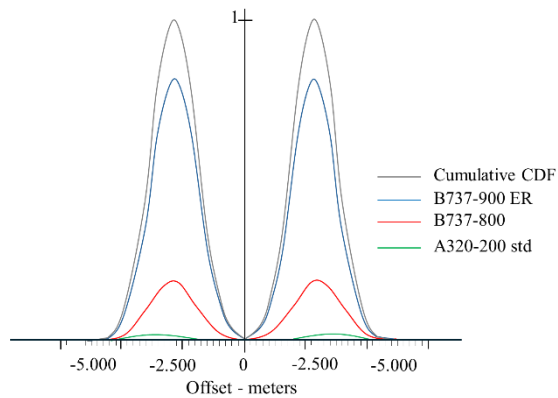


Fig. 5 CDF curve of various aircraft in the research area

The CDF value was used to estimate how much life was left in the pavement by comparing it to the accumulated fatigue strength [16]. In accordance with these assumptions, a sample size of 100 units was needed to fulfill the area requirements for each sample unit of 450 m². The sample units on the runway were specifically divided into dimensions of 18 m (in the lateral direction) by 25 m (in the longitudinal direction), as shown in Fig. 6.

Following the sample unit distribution scheme, another survey was conducted on the runway pavement condition. Furthermore, Fig. 7 shows measurements of crack-type damage on the PKY runway. These measurements included photographing cracks in the field by placing a ruler as calibration. The crack width was determined in the office using an image processing method.

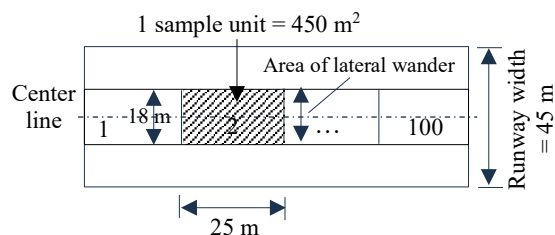


Fig. 6 Scenario 2 PCI measurement over the lateral wander of aircraft (N=100)



Fig. 7 Crack measurement on PKY runway

The results of the runway pavement condition measurements, based on the sample distribution scenario in Fig. 6, were further analyzed to obtain 100 PCI values at TJQ and PKY, respectively. The PCI value calculated in this scheme was represented as Scenario 2.

4. DATA ANALYSIS

4.1 Airport Pavement Damage

The investigation focused on Tjilik Riwt (PKY) and Hanandjoeddin Airports (TJQ). During the survey in 2021, these airports were both undergoing maintenance. PKY and TJQ Airports were selected as the research location, due to the original runway pavement conditions and the absence of resurfacing. These circumstances enabled the analysis of the different damage types, severity, and locations.

Runway at both airports were made with flexible pavement structures. In this context, the division of the sections was based on the thickness of the pavement structure. TJQ had two sections, measuring 650 m and 1850 m. Similarly, PKY was split into two sections, each with lengths of 1420 m and 1080 m. The general information on runway segmentation based on pavement thickness at TJQ and PKY airports, are shown in Tables 1 and 2 respectively.

Table 1. Runway segmentation of TJQ

Section	Section 1	Section 2
Runway dimension (m x m)	2500 x 45	
Length (m)	650	1850
Pavement type	Flexible	Flexible
Pavement thickness (mm)	800	900

Table 2. Runway segmentation of PKY

Section	Section 1	Section 2
Runway dimension (m x m)	2500 x 45	
Length (m)	1420	1080
Pavement type	Flexible	Flexible
Pavement thickness (mm)	1130	660

TJQ and PKY managed 3998 and 7011 movements annually. The Airbus A320-200 was the most commonly used aircraft at TJQ Airport, engaging in approximately 29.2% of operations as shown in Table 3. Meanwhile, ATR 72-600 took the lead at PKY, constituting a 35.1% share as shown in Table 4. Each of these aircrafts produced a unique CDF curve.

Table 3. TJQ aircraft movement statistics in 2020

No	Type of aircraft	Annual departure (mov)	Percentage (%)
1	B 737-800	934	23.4%
2	A 320-200	1166	29.2%
3	ATR 72-600	482	12.1%
4	B 737-500	1084	27.1%
5	ATR 72-500	332	8.3%
		3998	100.0%

Table 4. PKY aircraft movement statistics in 2020

No	Type of aircraft	Annual departure (mov)	Percentage (%)
1	B 737-800	1753	25.0%
2	A 320-200	692	9.9%
3	ATR 72-600	2463	35.1%
4	ATR 72-500	486	6.9%
5	B 737-900ER	1617	23.1%
		7011	100.0%

In Scenario 1, 1063 and 1023 cases of pavement damage were identified at TJQ, and PKY Airports, respectively. At TJQ, the most common pavement damage type was weathering or raveling, accounting for 425 cases (40.0%). This is in line with the research by [17], which stated raveling caused a decrease in bonding power between aggregate and asphalt due to aging. Another significant damage was rutting, comprising 363 cases (34.1%). The rarest types of pavement damage found at TJQ airport were depression and longitudinal/ transverse cracking. Similar conditions were observed at PKY Airport, where the most prevalent damage types were rutting (31.2%) and weathering or raveling (24.4%). Block cracking started to occur but at a low percentage. A review of the damaged cases identified at TJQ and PKY, are shown in Tables 5 and 6, respectively.

Table 5. Damage distribution at TJQ (Scenario 1)

No	Damage	Cases	(%)
1	Weathering/ Raveling	425	40.0%
2	Rutting	363	34.1%
3	Patching	176	16.6%
4	Alligator cracking	75	7.1%
5	Bleeding	12	1.1%
6	Depression	6	0.6%
7	Longitudinal/ transverse cracking	6	0.6%
		1063	100.0%

Table 6. Damage distribution at PKY (Scenario 1)

No	Damage	Cases	(%)
1	Rutting	319	31.2%
2	Weathering/ Raveling	250	24.4%
3	Alligator cracking	214	20.9%
4	Longitudinal/ Transverse cracking	90	8.8%
5	Patching	81	7.9%
6	Bleeding	47	4.6%
7	Depression	12	1.2%
8	Slippage Cracking	7	0.7%
9	Block cracking	3	0.3%
		1023	100.0%

In Scenario 2, 597 and 511 cases of pavement damage, were observed at TJQ and PKY Airports, as shown in Tables 7 and 8, respectively. The main types of pavement damage in these situations were rutting, weathering or raveling, patching, and alligator cracking. The increased cases of rutting were due to the combination of aircraft load factors and environmental conditions such as temperature. Under these circumstances, fatigue affected the pavement, preventing the elastic properties of the asphalt mixture from returning to the initial condition. Weathering/raveling is often found in scenario 2, indicating the aging factor has occurred on the pavement at both airports.

Table 7. Damage distribution at TJQ (Scenario 2)

No	Damage	Cases	(%)
1	Rutting	206	34.5%
2	Weathering/ Raveling	203	34.0%
3	Patching	112	18.8%
4	Alligator cracking	57	9.5%
5	Bleeding	9	1.5%
6	Depression	5	0.8%
7	Longitudinal/ transverse cracking	5	0.8%
		597	100.0%

Table 8. Damage distribution at PKY (Scenario 2)

No	Damage	Cases	(%)
1	Rutting	170	33.3%
2	Alligator cracking	136	26.6%
3	Weathering/ Raveling	63	12.3%
4	Patching	50	9.8%
5	Longitudinal/ transverse cracking	43	8.4%
6	Bleeding	34	6.7%
7	Depression	10	2.0%
8	Slippage Cracking	3	0.6%
9	Block cracking	2	0.4%
		511	100.0%

Maintenance of damaged runway, especially in Indonesia, was generally carried out using simple methods. For example, longitudinal or transverse cracks required sealing the gaps. Other damage types, such as alligator cracking, were repaired by patching, which entailed replacing the damaged material with new one. Another preventive method required modifying asphalt pavement with carbon nanotubes additive (CNT). Meanwhile, the addition of 1.5% CNT to asphalt with a grade of 40/50 succeeded in increasing rutting resistance and stability by approximately 61.0% and 35.0% [18].

Based on the damage in TJQ and PKY airport pavements, asphalt pavement damage is more dominant compared to the subgrade damage (i.e. depression). Pavement failure on the fatigue cracking criteria is more prevalent than the subgrade deformation criteria [19]. The pavement damage resulting from subgrade failure in this case is depression. Although the damage is not extensive, it must still be addressed to prevent further deterioration. Many methods are available for handling subgrade issues in pavement construction, including geconfinement systems, polymers, and geocomposites [20].

4.2 Analysis of PCI

Table 9 shows that PCI values for TJQ, had different outcomes in the two scenarios. In Scenario 1, the average condition index covering the entire runway area, was 56.4 and 50.6 in sections 1 and 2, respectively. However, in Scenario 2, which focused only on the lateral wander area, the average condition index was reduced to 29.2 and 25.1 in sections 1 and 2. Considering the variation in pavement thickness in the two sections, the overall PCI values were 52.1 and 26.2 for Scenarios 1 and 2, respectively. Additionally, the condition index value of the lateral wander at TJQ airport was 49.7% lower than the entire pavement surface.

Table 9. TJQ PCI analysis resume

Statistical parameters	Scenario	
	Scenario 1	Scenario 2
Section 1		
Minimum	31.9	16.9
Maximum	87.0	51.6
Mean	56.4	29.2
Standard deviation	10.1	10.0
Section 2		
Minimum	24.2	4.2
Maximum	98.0	47.7
Mean	50.6	25.1
Standard deviation	12.1	8.7
Overall PCI value	52.1	26.2

For PKY, in Scenario 1, the average PCI values were 58.5 and 34.2 in sections 1 and 2, respectively.

In Scenario 2, the average condition index values were 46.8 and 23.1 in sections 1 and 2, respectively. Considering variations in pavement thickness, the overall condition index values at PKY were 48.0 and 36.6 for Scenarios 1 and 2. In addition, PCI value on the lateral wander was 23.8% lower than the entire pavement surface as shown in Table 10.

Table 10. PKY PCI analysis resume

Statistical parameters	Scenario	
	Scenario 1	Scenario 2
Section 1		
Minimum	11.0	8.1
Maximum	97.0	90.0
Mean	58.5	46.8
Standard deviation	20.5	21.4
Section 2		
Minimum	4.2	3.9
Maximum	92.8	42.7
Mean	34.2	23.1
Standard deviation	18.3	7.8
Overall PCI value	48.0	36.6

The high standard deviation of PCI at PKY suggested that damages at the airport had significant variation in severity and the average value in Scenario 2 was lower in Scenario 1. Furthermore, in Scenario 2, pavement deterioration was associated with traffic loads and weather factors such as temperature and rain. Scenario 1 had a better value because the area outside the lateral wander was reduced due to weather factors.

PCI calculation significantly relied on the deduct value, determined by a nomogram based on damage type and level. The nomogram curve used did not show how well maintenance was performed, leading to deviations from the actual conditions. Similar observations were reported in the research by [21], where the curve was modified and recommended for Korean airports. The nomogram curve used to evaluate pavement conditions needs to be modified according to the pavement maintenance scenario in Indonesia using the pavement expert rating method. Additionally, the visual detection of pavement damage was subjective. The standard deviation of the PCI in the case studies at TJQ and PKY was relatively high. This condition was influenced by the widespread damage across the entire runway surface. Another factor that could lead to the high standard deviation was the unit area of 450 m². If the sample unit area were smaller, it could potentially reduce the standard deviation, resulting in a better overall PCI.

In TJQ, PCI variation was relatively uniform in both sections 1 and 2, as shown in Fig. 8 and 9. However, at PKY the value of section 1 was greater than section 2 as shown in Fig 10 and 11. This

scenario was due to significant differences in pavement structure thickness.

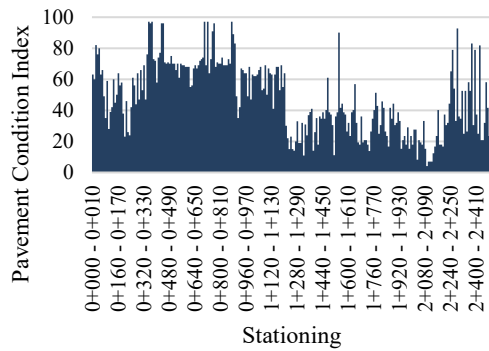


Fig. 8 TJQ PCI Distribution (Scenario 1)

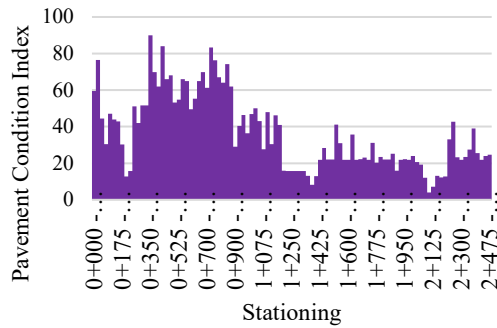


Fig. 9 TJQ PCI Distribution (Scenario 2)

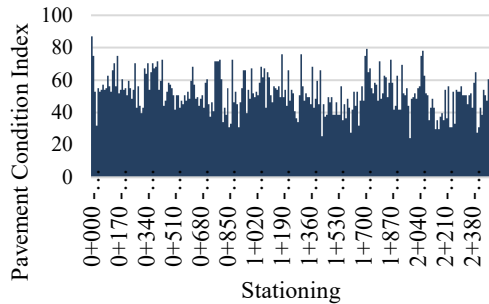


Fig. 10 PKY PCI Distribution (Scenario 1)

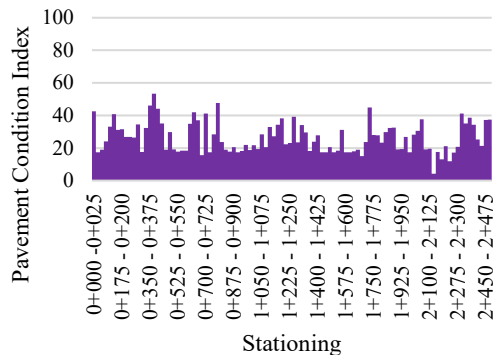


Fig. 11 PKY PCI Distribution (Scenario 2)

A linear regression equation was carried out to determine the relationship between PCI in the lateral wander area and throughout runway. Furthermore, this equation was used to convert the PCI value in the lateral wander area to become equivalent to the entire runway.

The adopted method aimed to determine the PCI value at the same stationing between the two scenarios. In this case, the division of the sections in the longitudinal direction of scenarios 1 and 2 was 10 m and 25 m respectively. Therefore, in order to be able to compare the values equally, a specific value was determined every 50 m. Fig. 12 shows a plot of the analysis combination of TJQ and PKY.

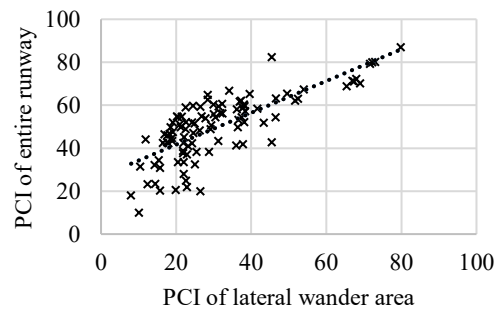


Fig. 12 Relationship between PCI of entire runway (scenario 1) versus lateral wander area (scenario 2)

Based on linear regression equation, the following relationship was obtained

$$PCI_{overall} = 0.74.(PCI_{LW}) + 26.841, R^2=0.59 \quad (5)$$

Where $PCI_{overall}$ is the PCI value obtained based on analysis of the entire runway surface. PCI_{LW} is the PCI value obtained from analysis of the lateral wander area. The R^2 value of 0.5932 is relatively low, therefore the equation was used with a significant level of confidence. This was due to the limited number of samples. Generally, this research successfully showed that with limited budget, runway pavement conditions can be monitored by observing the lateral wander area. This saves quite a lot of money and time compared to covering the entire runway surface.

5. CONCLUSIONS

In conclusion, the same area of 450 m², where the sample was placed on runway significantly affected the calculation of PCI value. The unit sample had a lower condition index because it was closer to the aircraft wheel path. Consistent maintenance of airport runways was crucial for ensuring smooth and safe operations. The condition index was an important factor that showed the state of the runway pavement. It was frequently assessed using a sampling method to save time and costs

efficiently. Furthermore, accessing the runway area was challenging, particularly at busy airports.

- Based on data obtained from the two airports regarded as the object of this research, the types of damage that occurred most frequently on runway pavement were raveling or weathering, alligator cracking, and patching.
- PCI value in the lateral wander area at TJQ was 49.7% lower than the overall runway. Similarly, at PKY, the value in the lateral wander area was 23.8% lower than the overall PCI. The significant variation between the two scenarios at TJQ was attributed to a more dispersed pattern of damage on the runway surface compared to the PKY.
- Runway pavement conditions were estimated by conducting a survey of the lateral wander area. At network-scale, the overall PCI was equalized by making adjustments using the Equation (5).
- The application of survey methods to these lateral wander areas was limited to network-scale pavement management. As for the project-scale, a comprehensive survey of the runway pavement must be conducted.
- The accuracy of the PCI value was increased by defining a deduct value curve to precisely represent field conditions.
- Further research was necessary to determine the sample area that produced a more accurate PCI value and also more efficient in conducting the survey.

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