Asphalt Pavement Performance Model of Airport Using Microwave Remote Sensing Satellite

Weerakaset Suanpaga[1]

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Abstract:
The purpose of this study is to build the binary logit model of an airport pavement that could monitor the pavement condition in near real time using microwave remote sensing satellite, then the relationship between the international roughness index (IRI) of an airport and backscattering values from PALSAR images of the ALOS satellite was determined. Total 390 data were used in analysis. This model could be applied to evaluate the efficiency of the quality of running service on the airport pavement. The analysis showed that the backscattering values in the HH and HV polarization have correlated with IRI, and HH polarization was the highest correlation with IRI value (r = 0.90). If the backscattering value in HH polarization was increased, the roughness will be increased. After the validation process on other 100 data, the result presented high correlation at 94.00%. Therefore, these can be concluded that this model could be applied to the airport pavement maintenance.

Keywords: Multi-objective optimization, traffic assignment, Pareto optimal solution, user equilibrium, system optimization.

Corresponding author E-mail: weerakaset@KU.ac.th
1. Department of Civil Engineering, Faculty of Engineering, Kasetsart University, Bangkok, Thailand

1. Introduction

Functional failure is the main damage type of the airport pavement. The inspection methods, which can be used to identify the type of damage, can be separated into four condition categories: structural condition, distress or surface condition, safety or skid resistance condition and roughness condition [Weerakaset and Kamiya, 2010]. The current pavement condition standard describes how the pavement condition changes with time or how the pavement performs [Hans et al., 2003]. The pavement condition can be defined as the ability of the pavement to serve traffic demand within acceptable levels. The IRIs could be used to summarize the roughness qualities that impact vehicle response. These were most appropriate to measure the overall vehicle operating cost, overall ride quality and overall surface condition [Sayers and Karamihas, 1998]. Figure 1 shows IRI scale and road surface condition around the world, for airport pavement the IRI should be less or equal than 2.0 (Sayers et al., 1996). The IRI also relates to the Present serviceability rating (PSR), which is based on individual observation. PSR is defined as "the judgment of an observer as to the current ability of a pavement to serve the traffic it is meant to serve" [Highway Research Board, 1962].The relationship between PSR and IRI was developed by Paterson in year 1986 by

$$PSR=5e^{-0.18(IRI)} \quad (1)$$

Where PSI = Present serviceability rating

IRI = international roughness index

Another relationship was reported in a 1992 by Al-Omari and Darter (1992):

$$PSR=5e^{-0.26(IRI)} \quad (2)$$

Where PSI = Present serviceability rating

IRI = international roughness index

The timing of M&R actions can greatly influence their effectiveness and cost, as well as the overall pavement life from both. Figure 2 shows that the first 75% of pavement life, the pavement condition drops by about 40%. However, it only takes another 17% of pavement life for the pavement condition to drop another 40% [Stevens, 1985; Weerakaset and Kamiya, 2010]. Additionally, it will cost four to five times as much if the pavement is allowed to deteriorate for even two-to-three years beyond the optimum rehabilitation point. Many techniques using GIS have been developed to determine pavement quality [Terzi, 2007; Grote et al., 2005; Baus and Hong, 1999; Dashevsky et al., 2005; Simonsen and Isacsson, 1999], but all techniques could not be applied in near-real time. If we have some technique to evaluate pavement condition in near-real time, it was possible to reduce the cost and monitor the airport pavement more frequently, there would be several benefits. Nowadays using microwave remote sensing technology could be applied such as [Weerakaset and

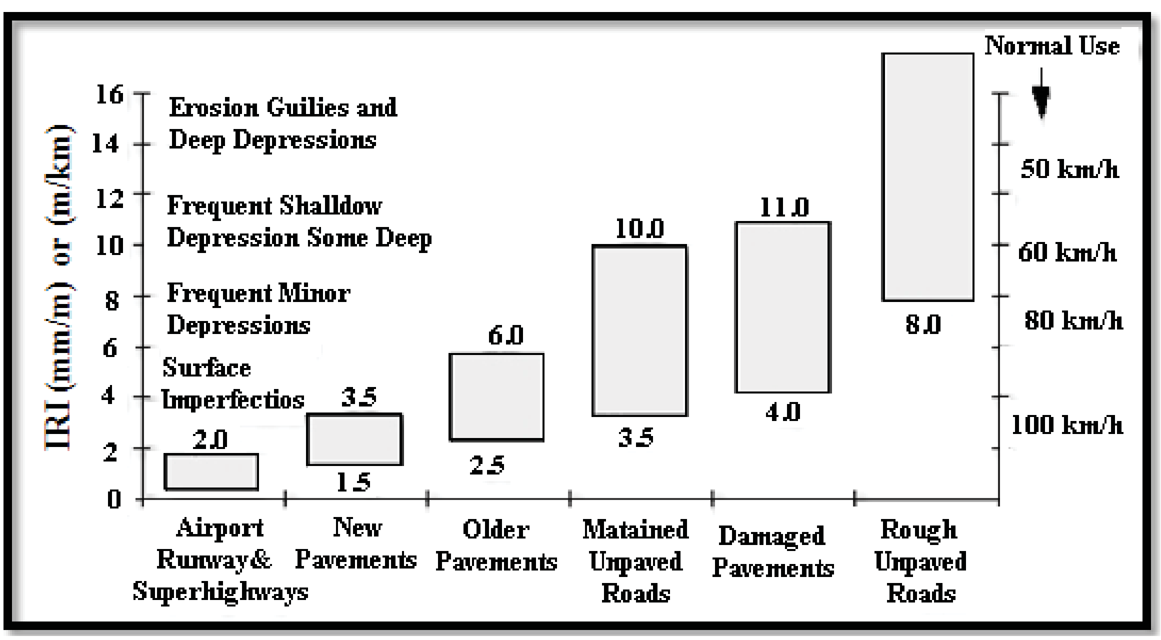


Figure 1. IRI scale and Road Surface condition around the world (Sayers et al., 1996)

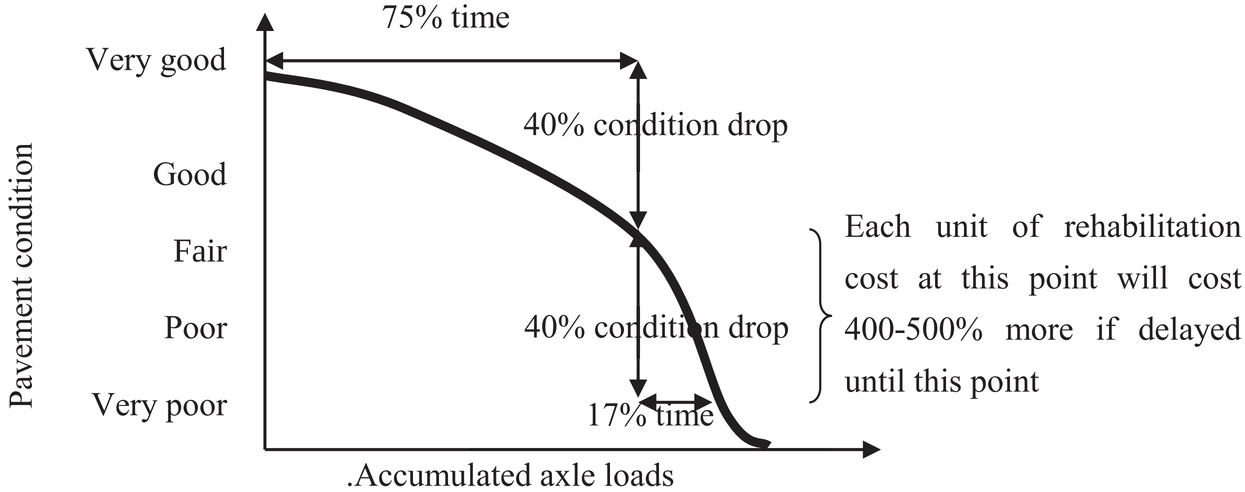


Figure 2. Rehabilitation time versus cost (adapted from Stevens, 1985).

Kamiya, 2010], proposed new approach to monitoring the pavement in Thailand.

1.1 ALOS and PALSAR Characteristics

The Advanced Land Observing Satellite (ALOS) revolves around the earth every 100 minutes, or 14 times each day and repeats its path (repeat cycle) every 46 days. The ALOS has three payloads, two optical instruments – the panchromatic remote sensing instrument for stereo mapping (PRISM) and the advanced visible and near infrared radiometer type 2 (AVNIR-2), and the phased array type L-band synthetic aperture radar (PALSAR) for day-and-night and all-weather land observation [JAXA,2008]. The PALSAR is shown in Table 1 which is an active microwave radar using the L-band frequency. It has three modes, namely high resolution, ScanSAR and polarimetric mode. The high resolution mode is used under regular operation and it has a ground resolution of 7m. The ScanSAR mode enables the off-nadir angle to be switched from three to five times (scanning a swath of 70 km) to cover a wide area from 210 km^2 (70x3) to 350 km^2 (70x5), but the resolution is inferior to that of the high resolution mode. PALSAR can simultaneously receive both horizontal (H) and vertical (V) polarization per each H and V polarized transmission, called multi polarimetry or full polarimetry (HH, HV, VH and VV polarization). The incidence angle ranges from 8 to 30°. This polarimetric mode was used in the current study [Weerakaset and Kamiya, 2010].

As refer above then the objective of the study was to determine the relationship between the backscattering data of PALSAR with the international roughness index (IRI) data and to develop a binary logit model for the evaluation of level of airport pavement riding service.

2. Study Area

Suvarnabhumi international airport is shown in Figure 3, is located in Bangkok Metropolitan of central Thailand (Figure 3), which is the responsibility of the Airports of Thailand Public Company Limited (AOT).The study site was at latitude 14° 26′ 56″ N and longitude 100° 39′ 36″ E, which equates to WGS84 format as UTM Zone 47 at 674,836.20N and 1,598,002.01E. Total Area of the airport is 32 million m2 or 20,000 RAI cover 2 main runways and 2 taxiways.

3. Method and Data

Asphalt pavement performance (APP) model or call the level of riding service was determined using a binary logit (BL) model. Estimation of the parameters of this model can be carried out easily using the maximum likelihood (ML) method. The dependent variable was the ground-truth IRI data measured by the bump integrator along runway and taxiway. The method involved with developing model as the following steps:

1. Calculation of the descriptive statistical values of

Table 1. Details of the PALSAR system (JAXA, 2008).

Mode	Fine		ScanSAR	Polarimetric (Experimental mode)
Center Frequency	1270 MHz (L band)			
Chirp Bandwidth	28MHz	14MHz	14MHz 28MHz	14MHz
Polarization	HH or VV	HH+HV Or VV+VH	HH or VV	HH+HV+VH+VV
Incident angle	8 to 60°	18 to 43°	18 to 43°	8 to 30°
Range Resolution	7 to 44m	14 to 88m	100m (multi-look)	24 to 89m
Observation Swath	40 to 70km	40 to 70km	250 to 350km	20 to 65km
Bit Length	5 bits	5 bits	5 bits	3 or 5 bits
Data rate	240Mbps	240Mbps	120Mbps, 240Mbps	240Mbps
NE sigma zero	< -23dB (swath width 70km) < -25dB (swath width 60km)		< -25dB	< -29dB
S/A	< -16dB (Swath width 70km) < -21dB (Swath width 60km)		> 21dB	> 19dB
Radiometric accuracy	Scene: 1 dB / orbit: 1.5 dB			

IRI and backscattering data: the maximum, minimum, mean and standard deviation values of the IRI data and backscattering data sampled were calculated.
2. Building of the utility function of the riding quality choice model (BL model) from the IRI and backscattering data.
3. Parameter estimation: estimates were obtained using the maximum likelihood method.
4. Goodness of fit test for selection: the backscattering polarization that had the highest McFadden log likelihood ratio index (ρ^2) and the greatest significance by the t-test and sign test was selected to be the most appropriate polarization.
5. Validation of the level of riding service model.
6. Application of the level of the riding service model to Runway number 19R.

3.1 Input Data

The two PALSAR images which have a resolution of 6.25 m at 15 October 2009 and resolution of 12.5 m at 7 July 2010 were collected. Because of the limited of PALSAR image data then the HH and HV polarization were used in this research. The single path IRI data along the taxiway (Number TXL-T6 and TXL-T11) and Runway (Number 19L and 19R) were collected from the bump integrator on a moving vehicle as ground-truth data.

3.2. Backscattering Data

The two dates of ALOS/PALSAR scenes (ALPSRP198470260-P1.5GUA and ALPSRP239383340-P1.5GUA) were used for analysis with an image resolution of 10.0 m, Figure 4 shows the back scattering image with HH and HV polarization. Both images already have radiometric calibration those were done by JAXA, as normalizing all pixels using the cosine of the incidence angle.

Table 3 shows basic statistics for the backscattering values in HH and HV polarization .For this study area, the average backscattering value and the range in value in the co-polarization plane (HH) was higher than in the cross-polarization plane (HV). Table 3 also shows an advantage of the higher range in values is that there should be a high correlation between co-polarization and the IRI value in the development of a riding quality model.

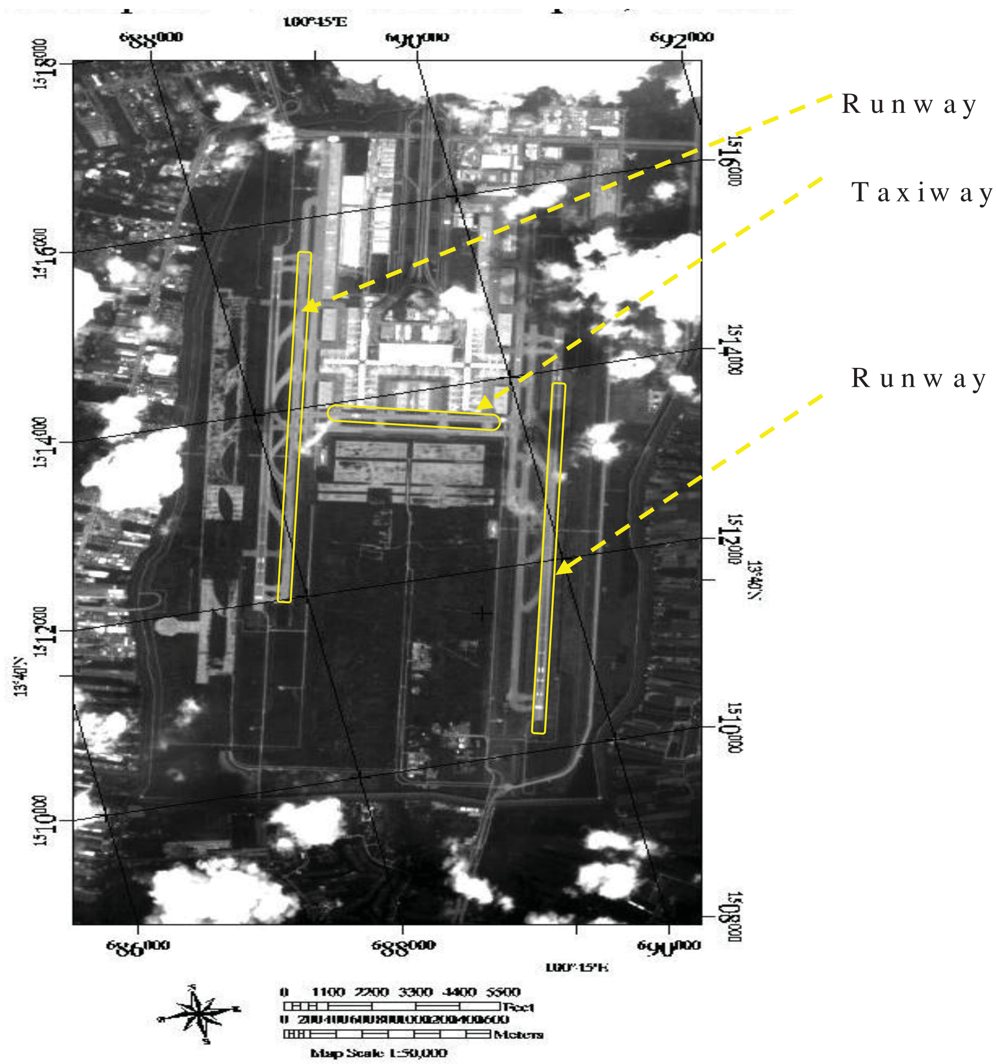
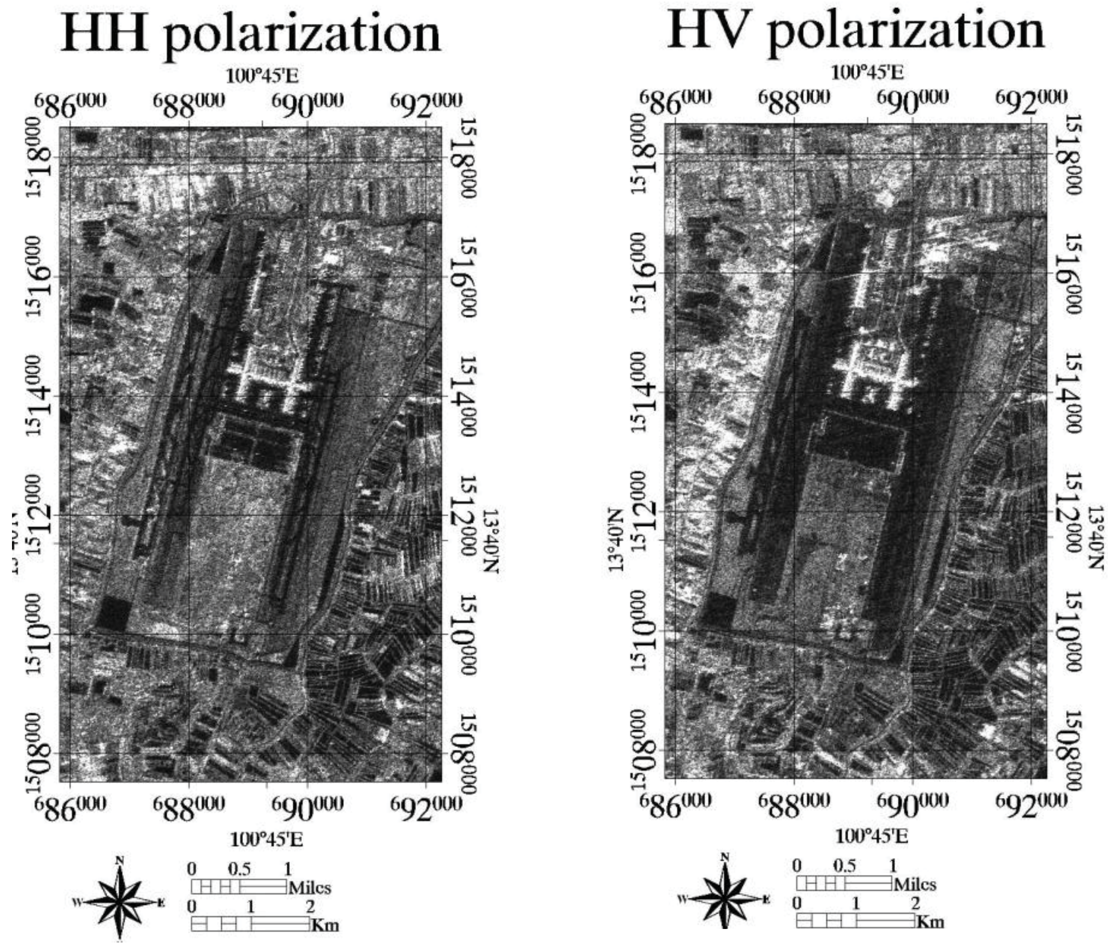


Figure 3. Image of Suvarnabhumi international airport, Thailand, overlaid with region of interest of ACC's airport (yellow boxes).

Table 3. Basic statistical values along the asphalt airport pavement sampled in HH and HV polarization those related with IRI value.

Statistical Parameter	Backscattering Value (unit: DN)		IRI (mm/m)
	HH	HV	
Average	๑.๕๖๒.๓๔	๖๕๙.๒๕	1.31
Standard Deviation	๔๖๘.๐๙	๑๕๖.๑๖	0.66
Maximum	๓.๓๖๔.๐๐	๑.๐๐๕.๐๐	4.60
Minimum	๑.๐๒๕.๐๐	๓๘๕.๐๐	0.50
Number of Pixels	195	195	390



(a) (b)

Figure 4. ALOS/PALSAR of Suvarnabhumi international airport image (scene id: ALPSRP198470260-P1.5GUA), with back scattering in the (a) HH and (b) HV.

Table 4. IRI values and associated airport pavement surface condition.

IRI (m/km or mm/m)	Level of Riding Service
≤ 2.0	Good
>2.0	Poor

3.3 IRI Data

Total 390 IRI samples (Table 3) were classified in to the level of riding service those adopt from Paterson (1987). The level of airport riding service was separated into two classes (Table 4) following Sayers (1996) scales. A low IRI value indicates a very smooth pavement surface, while a high IRI value means the airport pavement surface is very rough.

4. Results

Level of the riding service on the airport is the result of Binary logit (BL) model, developing BL model was necessary to evaluate which backscattering polarization data had the highest correlation with the IRI, so the relationship between the IRI and backscattering value for each set of polarization data was determined. Figure 5 shows the relationship between the IRI and backscattering value for HH and HV polarization. It was found that the Pearson correlation in HH polarization (r = 0.90) higher than in HV polarization (r = 0.84) that was significant at the 0.01 level (two-tailed test). Consequently, this polarization was used as the input parameter in the model.

BL model as the same as ORL with one cut-off level that was developed by reclassifying the level of riding service into two groups, namely good, if the IRI value was less than or equal to 2.0 mm/m, otherwise the quality was classified as poor. The new quality of riding service estimation model was constructed as Eq.(3). This model was significant at the 0.01 level (two-tailed test), the variable β_0 and variable DNHH were significant at the 0.01 level with student's t-test (two-tail).

$$ARQ_{good|poor} = 28.6372 - 0.0149DNHH \quad (3)$$

(t = 3.96) (t = -3.87)

(ρ^2=0.82, χ^2 =51.74, df =1, p = 0.00)

where: DNHH is the digital number of the HH polarization;

$ARQ_{good|poor}$ is the airport riding quality of service of the good condition with the reference category being the poor condition.

Using this riding quality model, the probability to select the level of riding service could be determined as shown in Eq.(4) (the reference category is the poor condition).

The decision criteria to select the level of airport riding service model were provided using Eq.(5).

$$P_{good}(DNHH) = \frac{1}{1+\exp[-28.6372+0.0149\, DNHH]} \quad (4)$$

$$LRD = \begin{cases} \text{good}, P_{good}(DNHH) \geq 0.50 \\ \text{poor}, P_{good}(DNHH) < 0.50 \end{cases} \quad (5)$$

where: DNHH is the digital number of the HH polarization;

LRD is the Level of Riding Quality of service of the airport pavement.

Table 6 shows validation of the binary logit function, after substitution of the digital number (DN) value into the BL model indicated that the model had an accuracy assessment of prediction of the airport level of service equal to 96.41% .

Figure 6 shows the relationship between backscattering and the probability of selection of prediction the service level being good. If the digital value is greater than or equal to 1,922 (28.6372/ 0.0149), then the riding service will be poor.

The application of a BL model of Runway number 19R, involved substitution of the backscattering value (100 samples) into the model for the probability of selecting the good condition, which resulted in the accuracy assessment for the prediction of the highway level of service being 97.00% (Table 7).

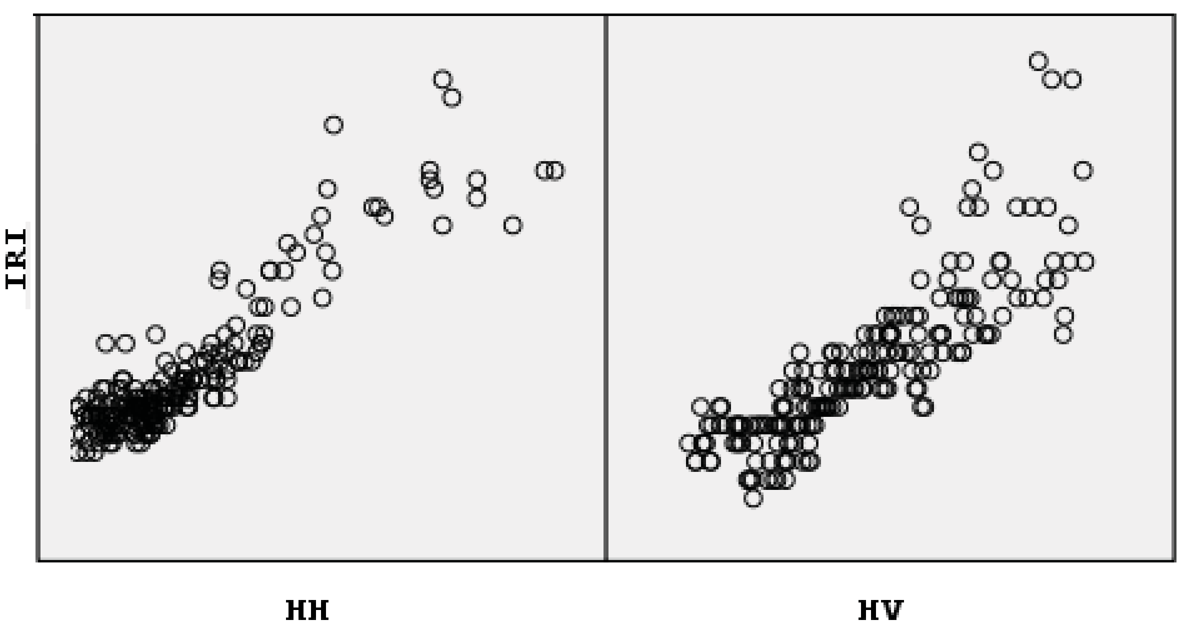


Figure 5. Relationship between IRI and backscattering values for each set of polarization data: HH (left) and HV (right). Note ** = correlation significant at the 0.01 level (two-tailed test).

Table 6. Classification results of level of riding quality model (binary logit model).

Observed	Predicted		Percentage of
	Poor	Good	Successive Prediction
Poor	28	4	87.50
Good	3	160	98.16
Overall percentage	15.89	84.10	96.41

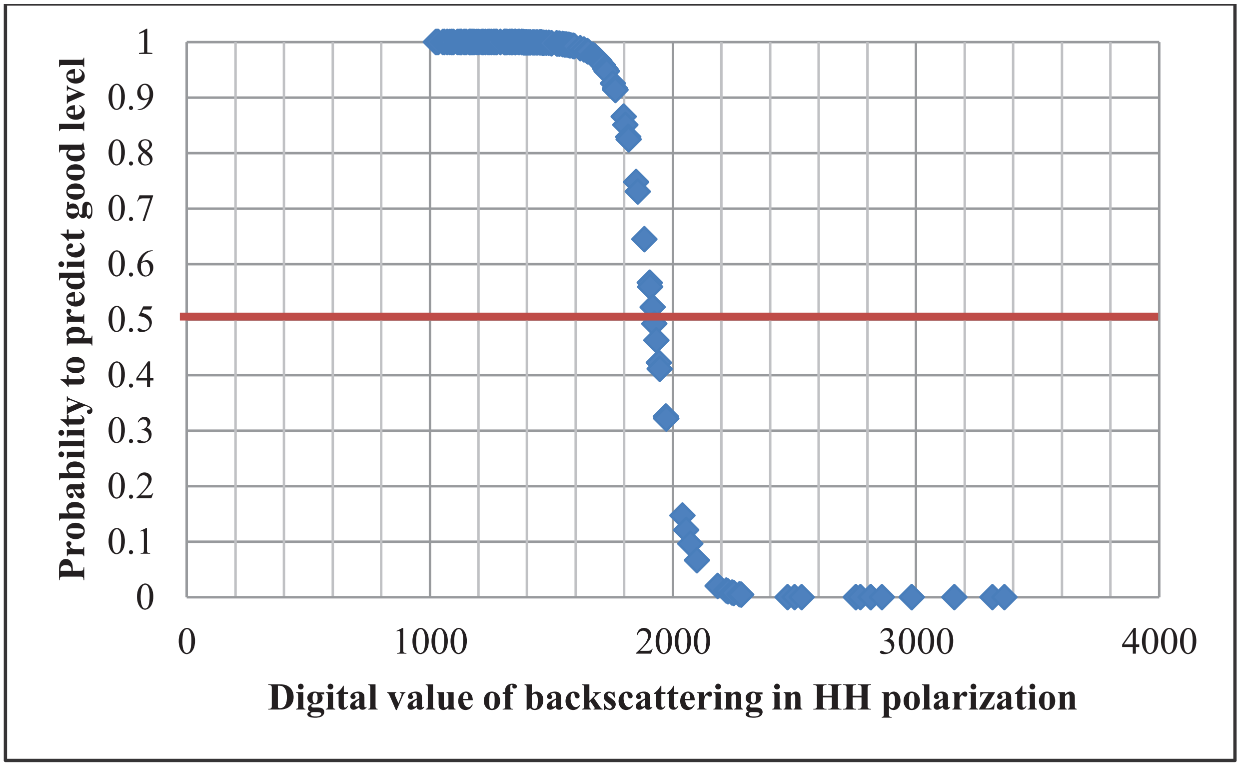


Figure 6. Relationship between backscattering and probability of selection of riding service level = good.

Table 7. Classification results using the level of riding quality model of Runway NO.19R (100 samples).

Observed	Predicted		Percentage of
	Poor	Good	Successive Prediction
Poor	22	4	84.62
Good	2	72	97.30
Overall percentage	24.00	76.00	94.00

5. Discussion and Conclusion

This paper presents the new method to know the performance of airport asphalt pavement via the BL model by using backscattering value of HH polarization of PALSAR image. The accuracy of the model was 96.41%. The analysis showed that an increase on the backscattering value both in HH and HV polarization indicated a poor condition of the pavement surface. The HH polarization was appropriate variable for developing performance or BL model.From the probability function of the BL model, if the DNHH value were greater than or equal to 1,922 (28.6372/ 0.0149), then the riding quality would be poor. The models developed were applied to analyze Runway number 19R (100 samples), it was found that the accuracy assessment for the prediction of airport pavement performance's level equalled 94.00%.

The current study developed the relationship between IRI and satellite data in terms of a mathematical model. Further study should be carried out to develop a physical properties model to explain this relationship.

For more intensive investigation must be carried out using PALSAR images with IRI data in various seasons, incident angle and especially various frequencies (X, S or C band). For more precise proposed models, should to verify the proposed model by using airborne Synthetic Aperture Radar image (AirSAR).

6. Acknowledgements

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