Evaluation of Road Performance Based on International Roughness Index and Falling Weight Deflectometer

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Abstract. Assessment to the performance of road pavement is deemed necessary to improve the management quality of road maintenance and rehabilitation. This research to evaluate the road base on functional and structural and recommendations handling done. Assessing the pavement performance is conducted with functional and structural evaluation. Functional evaluation of pavement is based on the value of IRI (International Roughness Index) which among others is derived from reading NAASRA for analysis and recommended road handling. Meanwhile, structural evaluation of pavement is done by analyzing deflection value based on FWD (Falling Weight Deflectometer) data resulting in SN (Structural Number) value. The analysis will result in SNₘ (Structural Number Effective) and SNₖ (Structural Number Future) value obtained from comparing SNₘ to SNₖ value that leads to SCI (Structural Condition Index) value. SCI value implies the possible recommendation for handling pavement. The study done to Simpang Tuan-Batas Kota Jambi road segment was based on functional analysis. The study indicated that the road segment split into 12 segments in which segment 1, 3, 5, 7, 9, and 11 were of regular maintenance, segment 2, 4, 8, 10, 12 belonged to periodic maintenance, and segment 6 was of rehabilitation. The structural analysis resulted in 8 segments consisting of segment 1 and 2 recommended for regular maintenance, segment 3, 4, 5, and 7 for functional overlay, and 6 and 8 were of structural overlay.

1. Introduction
Evaluation of pavement performance is crucial for improved quality of road handling to materialize more efficient, reliable, and effective and accurately-targeted handling so as to facilitate sustainable monitoring and evaluation of road performance.

This study was aimed at investigating the functional and structural conditions of Simpang Tuan-Batas Kota Jambi road segment based on the International Roughness Index Method with NAASRA (SNI 03-3426-1994) and Non-destructive Method (NDT) with Falling Weight Deflectometer (FWD) and seeking for possible handling recommendations.

Functional evaluation comprises information concerning the characteristics of pavement that directly affect the safety and comfort of road users and road services. The Survey targeted skid resistance, surface texture, and road roughness and serviceability [4]. Simulated prediction of IRI value determines the plan for the functional road rehabilitation and maintenance [3].

International Roughness Index (IRI) serves as one of the parameters to determine the serviceability level of road segments that may affect the riding quality. Good roads should be strong, flat, watertight, durable and economical throughout the planned lifetime. Therefore, roads should be
regularly/periodically monitored and evaluated for correct method of rehabilitation. Determining road roughness index can be done with NAASRA [7], a method that Bina Marga and AASHTO widely recommend.

Evaluation comprises information about the performance of pavement structure on traffic load and environmental condition. To this extent, surveys on road characteristics help obtain information on the pavement structure performance, pavement damage and road mechanical/structural properties [4]. Road structural capacity indicates the capability of road pavement to support the traffic load. It is commonly resulted from evaluating the mechanical properties of each pavement structure layer such as elastic modulus, fatigue properties, and deflection condition, measured by laboratory studies or on-site non-destructive (NDT) tests. One of the NDT methods is Falling Weight Deflectometer (FWD) [4]. The dynamic analysis done with Falling Weight deflectometer (FWD) test aims to predict the strength characteristics of flexible pavement and the contributing factors [4], one of which is overloaded vehicle axles that affect the service life of pavement [5].

2. Experimental

2.1. Functional Evaluation Analysis

Functional evaluation was done along with collecting NAASRA-based data of International Roughness Index (IRI) in a 100-meter range of halda setting. Segmentation was subsequently made based on uniformity of IRI value along 28,892 meters of road segment to facilitate grouping and deciding the recommended handling.

2.2. Traffic Volume Analysis

Traffic volume analysis was based on factual surveys. To support design, traffic volume was obtained from actual traffic surveys corresponding to the Traffic Enrollment Survey Manual by exercising Pd T-19-2004-B Manual or using equipment with the same approach to the results of previous traffic survey results, which incorporated traffic growth (R) factor based on historical growth data or correlation formulations with other valid growth factors, lane distribution factors and lane capacity referring to Ministry of Public Works Decree No.19/PRT/M/2011 and MKJI, Vehicle Damage Factor (VDF). The data were gained from static weighbridges and regional WIM data that the Directorate of Engineering issued, current Cumulative ESAL (Np), Cumulative ESAL at end of design life (Nf), calculated the remaining life that indicated gradual, repeated fatigue damage due to vehicle load by the percentage of traffic load in the pavement damage.

2.3. Structural Evaluation Analysis

Analysis of structural evaluation suggests that collecting data of deflection value derived from Falling Weight Deflectometer (FWD) shall consider parameters such as Resilient Modulus (Mr) of each pavement material both asphalt mix and subgrade with the stiffness value or resilient modulus. The study employed Subgrade Resilient Modulus (Mr), Effective Elastic Modulus (Ep) calculated on the basis of the deflection under the center plate load adjusted to the standard temperature of 68°F which was trial and error. The value of Structural Number Effective (SNeff) was obtained based on the analysis of road segment deflection value obtained from FWD. Further, analysis of deflection value of segmented road was carried out adhering to the uniformity of deflection value. The analysis resulted in SNeff value which refers to the value of pavement structural capacity currently suffering from structural deterioration. Structural Number Future (SNf) refers to the value of pavement structural capacity for serving future/estimated traffic load (cumulative traffic load for the next 5 or 10 years).
2.4. Structural Condition Index (SCI) Calculation

The value of Structural Condition Index (SCI) serves as a parameter for determining road handling. SCI was obtained by comparing SN_eff to SN_f ratio resulting in classification value of segmented road handling. SCI value indicates the category of road handling in which SCI > 1 was categorized into maintenance type, SCI = 0.7-1 was categorized into functional overlay, SCI = 0.5-0.7 belonged to structural overlay, and SCI <0.5 was categorized into reconstruction.

3. Results and Discussion

3.1. Road Functional Evaluation Analysis

Evaluation of road pavement condition to Simpang Tuan-Batas Kota Jambi road segment split into 12 segments adhering to the uniformity of IRI value and handling recommendation which refers to the Minister of Public Works Regulation as shown in Figure 1 and Table 1 below.

| Segment No. | Segment of STA | Length (m) | IRI          | Condition | Recommendation       |
|-------------|----------------|------------|--------------|-----------|----------------------|
| 1           | Km 0 + 000 up to 02 + 674 | 2,674      | IRI ≥ 3.5    | Good      | Routine Maintenance  |
| 2           | Km 02 + 674 up to 03 + 174 | 500        | 3.5 < IRI ≤ 5.8 | Fair      | Periodic Maintenance |
| 3           | Km 03 + 174 up to 04 + 274 | 1,100      | IRI ≥ 3.5    | Good      | Routine Maintenance  |
| 4           | Km 04 + 274 up to 04 + 674 | 400        | 3.5 < IRI ≤ 5.8 | Fair      | Periodic Maintenance |
| 5           | Km 04 + 674 up to 07 + 120 | 2,446      | IRI ≥ 3.5    | Good      | Routine Maintenance  |
| 6           | Km 07 + 120 up to 07 + 520 | 400        | 5.8 < IRI ≤ 9.0 | Damaged  | Reconstruction       |
| 7           | Km 07 + 520 up to 10 + 077 | 2,557      | IRI ≥ 3.5    | Good      | Routine Maintenance  |
| 8           | Km 10 + 077 up to 11 + 677 | 1,600      | 3.5 < IRI ≤ 5.8 | Fair      | Periodic Maintenance |
| 9           | Km 11 + 677 up to 16 + 543 | 4,866      | IRI ≥ 3.5    | Good      | Routine Maintenance  |
| 10          | Km 16 + 543 up to 19 + 311 | 2,768      | 3.5 < IRI ≤ 5.8 | Fair      | Periodic Maintenance |
| 11          | Km 19 + 311 up to 27 + 630 | 8,319      | IRI ≥ 3.5    | Good      | Routine Maintenance  |
| 12          | Km 27 + 630 up to 28 + 892 | 1,262      | 3.5 < IRI ≤ 5.8 | Fair      | Periodic Maintenance |

3.2. Traffic Volume Analysis

The analysis was based on secondary data of Routine Traffic Counting conducted by the National Road Planning and Implementation Agency of IV Jambi Region in May 2016. The analysis indicated that the growth value of traffic (R) at Simpang Tuan-Batas Kota Jambi road segment corresponded to five and ten years of design life, traffic growth factor (i) for Primary Arterial Road so that the
percentage of traffic factor (i)=5%, Lane Distribution Factor by 80% for 2-way lane distribution.

Vehicle Damage Factor (VDF) were used in reference to the Road Pavement Design Manual.

Current cumulative ESAL (Np or W18), cumulative ESAL at design life (Nf) and service life were derived from daily traffic volume (LHR). Np, Nf and service life can be seen in Table 2 and 3.

Table 2. Current cumulative ESAL (Np) or (W18)

| Classification | Type of Vehicle | UNIT | LHR in 2016 | VDF | DD | DL | R | DAYS IN A YEAR | W 18 |
|----------------|-----------------|------|-------------|-----|----|----|---|----------------|------|
| 2              | PASSENGER CAR   | VEHICLE | 923 | 0.0005 | 0.5 | 0.8 | 1 | 365 | 67 |
| 3              | COMBI VAN, MINIBUS (UTILITY 1) | VEHICLE | 1,116 | 0.035 | 0.5 | 0.8 | 1 | 365 | 5,703 |
| 4              | PICK UP, SHUTTLE CAR (UTILITY 2) | VEHICLE | 758 | 0.035 | 0.5 | 0.8 | 1 | 365 | 3,873 |
| 5a             | SMALL BUS       | VEHICLE | 132 | 0.3 | 0.5 | 0.8 | 1 | 365 | 5,782 |
| 5b             | BIG BUS         | VEHICLE | 233 | 1 | 0.5 | 0.8 | 1 | 365 | 34,018 |
| 6a             | 2-AXLE LIGHT TRUCK | VEHICLE | 590 | 0.8 | 0.5 | 0.8 | 1 | 365 | 68,912 |
| 6b             | 2-AXLE HEAVY TRUCK | VEHICLE | 216 | 7.3 | 0.5 | 0.8 | 1 | 365 | 230,213 |
| 7a             | 3-AXLE HEAVY TRUCK | VEHICLE | 221 | 28.9 | 0.5 | 0.8 | 1 | 365 | 932,487 |
| 7b             | 4-AXLE TOW TRUCK | VEHICLE | 47 | 36.9 | 0.5 | 0.8 | 1 | 365 | 253,208 |
| 7c             | SEMI TRAILER TRUCK | VEHICLE | 258 | 13.6 | 0.5 | 0.8 | 1 | 365 | 512,285 |

VEHICLE 4,494 TOTAL (Nf) or W18 2,046,548

Table 3. Cumulative ESAL at Design Life (Nf)

| NO | YEAR | W18 | R | ESAL ke-n | Umur layan |
|----|------|-----|---|-----------|------------|
| 1  | 2015 | 2,046,548 | 1.0000 | 2,046,548 | 98,18454 |
| 2  | 2016 | 2,046,548 | 2.0005 | 4,094,119 | 94,55272 |
| 3  | 2017 | 2,046,548 | 3.0015 | 6,142,714 | 89,10363 |
| 4  | 2018 | 2,046,548 | 4.0030 | 8,192,333 | 81,83636 |
| 5  | 2019 | 2,046,548 | 5.0050 | 10,242,977 | 72,75000 |
| 6  | 2020 | 2,046,548 | 6.0075 | 12,294,647 | 61,84364 |
| 7  | 2021 | 2,046,548 | 7.0105 | 14,347,342 | 49,11637 |
| 8  | 2022 | 2,046,548 | 8.0140 | 16,401,064 | 34,56728 |
| 9  | 2023 | 2,046,548 | 9.0180 | 18,455,812 | 18,19546 |
| 10 | 2024 | 2,046,548 | 10.0225 | 20,511,588 | - |

Nf 20,511,588

3.3. Structural Evaluation
The analysis consists of traffic analysis, structural condition analysis, setting structural condition index (SCI), and recommendation for segmented road handling. Data comprising deflection curve and pavement temperature were obtained from the Falling Weight Deflectometer, the tool that has a 300 mm diameter load plate, a 200 kg weight load and a 315 mm falling height. The distance between the deflectometers was set between 0, 200, 300, 450, 600, 00, 1200 and 1500 mm from the load center to fit the total pavement thickness which was 300-700 mm (normal). Data of deflection curve (FWD) were projected for structural analysis with AASHTO 1993 along with the data of traffic analysis and pavement thickness. Therefore, segmentation should be grouped based on the uniformity level of deflection value as seen in Table 4.

Table 4. Segmentation of Road Based on Uniformity of Deflection (D1)

| Segment No. | Segment of STA | Length (m) | Standard Deviation (S) | Mean of Deflection Value (D1) | Uniformity Factor (Fk) % | Uniformity |
|-------------|----------------|------------|------------------------|-------------------------------|------------------------|------------|
| 1           | Km 0 + 000 up to 03 + 602 | 3,602 | 32.11 | 157.11 | 20.4368 | Fairly Good |
| 2           | Km 03 + 602 up to 06 + 411 | 2,839 | 40.05 | 171.26 | 23.3886 | Fairly Good |
| 3           | Km 06 + 411 up to 08 + 004 | 1,593 | 46.61 | 178.20 | 26.1549 | Fairly Good |
| 4           | Km 08 + 004 up to 11 + 440 | 3,436 | 56.10 | 200.83 | 27.9326 | Fairly Good |
| 5           | Km 11 + 440 up to 15 + 408 | 3,968 | 41.69 | 179.64 | 23.2096 | Fairly Good |
| 6           | Km 15 + 408 up to 19 + 641 | 4,233 | 93.61 | 341.01 | 27.4502 | Fairly Good |
| 7           | Km 19 + 641 up to 23 + 750 | 4,109 | 66.04 | 226.52 | 29.1527 | Fairly Good |
| 8           | Km 23 + 750 up to 27 + 777 | 4,027 | 52.20 | 192.90 | 27.0623 | Fairly Good |
| Total Road Length | 27,807 | | | | | |
Subgrade Resilient Modulus ($M_R$) was calculated on the basis of per segment representative. $M_R$ value shall meet the required distance of the farthest geophone sensor at $R=9=1500$ mm away from the load center with greater or equal to 0.7 of stress basin radius on subgrade ($R \geq 0.7$ ae). $M_R$ for each segment can be seen in Table 5.

### Table 5. Resilient Modulus ($M_R$) of Subgrade

| SEGMENT No. | DISTANCE (m) | P (Lbs) | Psi | C (mm) | r9 (inch) | d9 (x 0.001 mm) | d9 (inch) | $M_R = C (0.24^*P/dr)$ (psi) |
|-------------|--------------|---------|-----|--------|----------|-----------------|-----------|-----------------------------|
| 1           | 3,602        | 9565.89 | 87.22 | 0.33  | 1,500    | 59.06           | 45.08     | 0.00177                     | 7,229     |
| 2           | 2,839        | 9568.35 | 87.24 | 0.33  | 1,500    | 59.06           | 38.52     | 0.00152                     | 8,462     |
| 3           | 1,593        | 9534.77 | 86.94 | 0.33  | 1,500    | 59.06           | 46.81     | 0.00184                     | 6,938     |
| 4           | 3,436        | 9472.49 | 86.37 | 0.33  | 1,500    | 59.06           | 51.65     | 0.00203                     | 6,248     |
| 5           | 3,968        | 9296.92 | 84.77 | 0.33  | 1,500    | 59.06           | 44.43     | 0.00175                     | 7,129     |
| 6           | 4,233        | 9370.20 | 85.44 | 0.33  | 1,500    | 59.06           | 54.89     | 0.00216                     | 5,815     |
| 7           | 4,109        | 9352.01 | 85.27 | 0.33  | 1,500    | 59.06           | 40.35     | 0.00159                     | 7,894     |
| 8           | 4,027        | 9322.09 | 85.00 | 0.33  | 1,500    | 59.06           | 37.54     | 0.00148                     | 8,459     |

Pavement Layer Modulus ($E_p$) was calculated as trial and error by iterating each segment as seen in Table 10. The data of pavement layer thickness at Simpang Tuan-Batas Kota Jambi road segment, which were obtained from P2JN Work Unit of Jambi, can be seen in Table 7 below. To note, overlay was done to the road segment in 2015.

### Table 6. Radius of stress basin on subgrade (Ae)

| Segment No. | Distance (km) | A (inch) | D (inch) | Mr (psi) | Ep (psi) | R (inch) | Ae (inch) | 0.7Ae | r ≥ 0.7Ae |
|-------------|---------------|----------|----------|----------|----------|----------|-----------|-------|-----------|
| 1           | 3.602         | 5.91     | 28.54    | 7228.91  | 85,328   | 59.06    | 65.26     | 45.68 | OK        |
| 2           | 2.839         | 5.91     | 28.54    | 8461.58  | 76,050   | 59.06    | 59.63     | 41.75 | OK        |
| 3           | 1.593         | 5.91     | 28.54    | 6938.28  | 75,732   | 59.06    | 63.59     | 44.51 | OK        |
| 4           | 3.436         | 5.91     | 28.54    | 6247.88  | 65,240   | 59.06    | 62.66     | 43.87 | OK        |
| 5           | 3.968         | 5.91     | 28.54    | 7128.72  | 68,946   | 59.06    | 61,099    | 42.77 | OK        |
| 6           | 4.233         | 5.91     | 28.54    | 5814.65  | 34,185   | 59.06    | 51,855    | 36.30 | OK        |
| 7           | 4.109         | 5.91     | 28.54    | 7894.37  | 48,548   | 59.06    | 52,626    | 36.84 | OK        |
| 8           | 4.027         | 5.91     | 28.54    | 8458,782 | 57,068   | 59.06    | 54,246    | 37.98 | OK        |

### Table 7. Existing Pavement Layers Thickness(D)

| Pavement Type | Thickness (mm) | Thickness (inch) |
|---------------|----------------|------------------|
| AC-WC         | 40             | 1.57             |
| AC-BC         | 60             | 2.36             |
| AC-BASE       | 75             | 2.95             |
| LPA           | 300            | 11.81            |
| Pavement Thickness | 475  | 28.54 |

### Table 8. Effective Elastic Modulus ($E_p$) of Pavement Layers

| Seg No. | P (Lbs) | P (psi) | T (°C) | T (°F) | TAF | d1 (x 0.001 mm) | d1 (inch) | d1 x TAF (inch) | $E_p$ (psi) |
|---------|---------|---------|--------|--------|-----|-----------------|-----------|-----------------|-------------|
| 1       | 9565.89 | 87.22   | 34.92  | 93.86  | 0.83| 221.33         | 44.00     | 0.00077         | 85,328      |
| 2       | 9568.35 | 87.24   | 35.20  | 95.36  | 0.82| 251.37         | 40.00     | 0.00099         | 76,050      |
| 3       | 9534.77 | 86.94   | 37.40  | 99.32  | 0.76| 271.42         | 42.00     | 0.00107         | 75,732      |
| 4       | 9472.49 | 86.37   | 37.41  | 99.33  | 0.76| 313.03         | 49.00     | 0.00123         | 65,240      |
| 5       | 9296.2  | 84.77   | 33.40  | 92.12  | 0.84| 263.02         | 41.00     | 0.00134         | 68,946      |
| 6       | 9370.20 | 85.44   | 32.23  | 90.01  | 0.85| 528.23         | 42.00     | 0.00176         | 34,185      |
| 7       | 9352.01 | 85.27   | 29.85  | 85.73  | 0.88| 358.59         | 45.00     | 0.00141         | 48,548      |
| 8       | 9322.09 | 85.00   | 28.10  | 82.57  | 0.90| 297.31         | 49.00     | 0.00117         | 57,068      |

Structural Capacity Analysis was done by calculating $S_{Nef}$ based on $E_p$ value and asphalt-layered thickness with AASHTO 1993 for the analysis, based on reliability on Simpang Tuan-Batas Kota Jambi road segment referring to Manual for Planning Bending Pavement Thickness (Pt- 01-2002-B) that was classification of inter-city arterial roads with the value of 75% -95%, 95% of the value was selected so that value of standard deviation (ZR) was -1.645. Overall standard deviation (S0) represented local condition. Among the range of $S_{N}$ value, the highest value was 0.50. Surface index
(IP) used comprises final surface index (IPt), Initial Pavement Index (IP0), Design serviceability loss ($\Delta$PSI=IP0-IPt) and Subgrade Resilient Modulus (Mr).

3.4. Calculation of Structural Condition Index Value (SCI)
Structural Condition Index (SCI) implies compared Effective Structural Number ($SN_{eff}$) to Future Structural Number ($SN_f$). The comparison resulted in the classification value of segmented road handling as seen in Table 9.

| STA | Distance (km) | SNf 2020 | SNeff  | SCI     | Recommendation     |
|-----|--------------|----------|--------|---------|-------------------|
| Km 00 + 000 up to 03 + 602 | 3,602 | 5.590 | 5.654544 | 1.012 | Regular Maintenance |
| Km 03 + 602 up to 06 + 411 | 2,839 | 5.316 | 5.441688 | 1.024 | Regular Maintenance |
| Km 06 + 411 up to 08 + 004 | 1,593 | 5.662 | 5.434092 | 0.960 | Functional Overlay |
| Km 08 + 004 up to 11 + 440 | 3,436 | 5.850 | 5.170574 | 0.884 | Functional Overlay |
| Km 11 + 440 up to 15 + 408 | 3,968 | 5.614 | 5.266681 | 0.938 | Functional Overlay |
| Km 15 + 408 up to 19 + 641 | 4,233 | 5.982 | 4.168504 | 0.697 | Structural Overlay |
| Km 19 + 641 up to 23 + 750 | 4,109 | 5.436 | 4.685525 | 0.862 | Functional Overlay |
| Km 23 + 750 up to 27 + 777 | 4,027 | 5.316 | 4.944987 | 0.930 | Structural Overlay |

4. Conclusion
The functional analysis to the segmented road indicated that the road segment split into 12 segments in which segment 1, 3, 5, 7, 9, and 11 were of regular maintenance, segment 2, 4, 8, 10, 12 belonged to periodic maintenance, and segment 6 was of rehabilitation.

Meanwhile, the structural analysis resulted in 8 segments consisting of segment 1 and 2 recommended for regular maintenance, segment 3, 4, 5, and 7 for functional overlay, and 6 and 8 were of structural overlay.

It could be concluded that the results of Functional Evaluation and Structural evaluation do not suggest the similar recommendation for pavements treatment, the combination of both functional and structural evaluation will result in the best recommendation for pavement rehabilitation, maintenance or reconstruction.

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