Comparison analysis between plan and actual remaining service life of road pavement using Weight in Motion (WIM) data

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Abstract. Transportation mobility is increasing every year and road infrastructure experiences increased loads. If the traffic load exceeds the planned load, premature damage can occur immediately and need more resources to maintain the damage. Therefore, Weigh in Motion (WIM) is needed to analyze the actual vehicle load on road infrastructure. The purpose of this study is to identify the Remaining Service Life and direct its maintenance patterns. By using WIM, the value of Remaining Service Life can be estimated. This paper presents the analysis result of the Weight in Motion data at Serang Barat Toll Gate in Indonesia and the impact on the Remaining Service Life. The axle loads were converted to represent single-axle loads based on 4th power formula by MDP 2017. The analysis showed that the CESA value obtained by using WIM data increased by 60.91% compared to the planned load and would cause a decrease in Remaining Service Life from the 20-year plan period to 16.82 years.

Keywords. Weight in Motion, Remaining Service Life, Cumulative Equivalent Standard Axle, Manual Desain Perkerasan 2017, Toll Road.

1. Introduction
Roads are used to guide various modes of transportation from the starting point to the destination. Methods of transportation such as passenger cars, buses, and trucks are vehicles for transporting people and goods. In this regard roads are planned to channel the flow of vehicles from various types of vehicles according to their function [1].

Road infrastructure is the main facility that drives economic growth. Roads are planned to channel the flow of various types of vehicles according to their functions. It plays a role in the mobility of goods, passengers, and services and nearly 90% of cargo distribution uses land transportation [2]. Damages to road infrastructure could occur earlier than the end of design life because there are some factors will affect road performance or the road performance factor itself, such as traffic loading and weather [3].

Transportation mobility increases every year, which leads to increasing traffic volume and traffic loading imposed onto the pavement. The road, however, must be able to carry this increasing load and this could escalate the degree of damage to road infrastructure, which means that the extra load will significantly contribute to the shorter road age and need more resources to maintain the service life. If the traffic load exceeds the planned standard load, premature damages can immediately occur.

In Indonesia, Weigh in Motion survey is limited and high cost, and it conducted by badan Pengurus Jalan Tol (BPJT), Kementerian PUPR at several strategic national roads [4] [5] [6] [7]. Although the Weigh in Motion often conducted, the data has not been studied properly. The axle load and vehicle damage factor data has not been used well to pavement design and planning in Indonesia.
Therefore, Weigh in Motion (WIM) is needed to analyze the actual vehicle load on road infrastructure. Weigh in Motion survey is a survey that can be used for infrastructure (pavement and bridge), traffic data management, traffic control, etc. [8]. Different from any other weigh static or weigh survey methods, Weigh in Motion data has a higher accuracy in data and have no interruption to traffic flow [9].

2. Research Methodology

The WIM data contains traffic data for maintenance and management and is available in descriptive manner. Accurate data loading makes maintenance and repair based on actual damage even more effective. In this study, the data was taken from the entrance section after passing the Serang Barat Toll Gate, which has a composite pavement type along the road. The road at the Serang Barat Toll Gate has a change of many lanes before and after passing the Toll Gate, from four lanes to six lanes (six Toll Gates) and two lanes after passing through the Toll Gate as shown in Figure 1.

![Figure 1. Survey Location](image)

The measurement of load data, including the vehicle axis of each type of passing vehicles, was carried out directly on the road. The technique of assessing the weight and configuration of the vehicle wheel axle was carried out by using a weighing motion, where measurements were made without stopping the traffic [10]. The measurements carried out by WIM include data on vehicle type, speed, vehicle length, vehicle weight configuration, and vehicle wheelbase. At the same time, the traffic volume data can also be collected by using a camera. The data have already been verified and filtered to remove invalid data records. Which nearly more than 100,000 total number of vehicles.

The collected data was then used to calculate the value of the Vehicle Damage Factor (VDF) by merging all the axes from each vehicle into single axle [11]. Vehicle Damage Factor used as representation of vehicle that cross on the pavement that defined as Equivalent Standard Axle (ESA) [12]. The value or amount of road damage was determined according to the axle load (P). From the results of level measurements at the time of axle load measurement, the average Equivalent Standard Axle (ESA) values can be calculated.
3. Result and Discussion

3.1. Cumulative Equivalent Standard Axle (CESA)
Cumulative Equivalent Standard Axle (CESA) is the sum of the cumulative load axle traffic on the lane during the life of the road service. The CESA value is calculated based on the *Manual Desain Perkerasan (MDP) 2017* [11] [13].

To calculate the Vehicle Damage Factor (VDF) value based on the *MDP 2017*, the load equivalent factor was calculated by using WIM data. The values of the Planned VDF were calculated by classifying the vehicles as shown in Table 2. The actual VDF values were calculated by averaging all the equivalent axle values from the WIM data, as shown in Table 3.

The percentage of overloaded vehicle is estimated by identifying axle load that greater than the maximum legal limit (10 tons) [14]. Each of type vehicle has a different percentage number of overloaded. In Table 1, the percentage of the overloaded vehicles varies for each type of vehicle. The value is varying between 40% - 400%.

**Table 1. Average Load Plan and WIM**

| No | Axle Configuration | Vehicle Classification | Axle Group | Average Load Plan (Ton) | Average Load WIM (Ton) |
|----|--------------------|------------------------|------------|-------------------------|------------------------|
| 1  | 1.1                | Passenger Car          | 2          | 2                       | 2.15                   |
|    | 1.1                | Medium Truck/Small Bus |            |                         |                        |
| 2  | 1.2                | 2 Axles Truck          | 2          | 8.3                     | 13.69                  |
| 3  | 1.2                | Bus                    | 2          | 9                       | 15.71                  |
| 4  | 1.22               | 3 Axles Truck          | 3          | 18.2                    | 33.99                  |
| 5  | 1.22               | 4 Axles Truck          | 4          | 25                      | 36.33                  |
| 6  | 1.2-22             | 2 Axles Truck + 2 Axles Trailer | 4 | 42 | 53.58 |
| 7  | 1.22-22            | 3 Axles Truck + 2 Axles Trailer | 5 | 31.4 | 45.61 |
| 8  | 1.22-222           | 3 Axles Truck + 6 Axles Trailer | 6 | 50 | 58.58 |

**Table 2. Planned VDF According to MDP 2017**

| No | Axle Configuration | Vehicle Classification | Axle Group | Plan VDF4 | VDF5 |
|----|--------------------|------------------------|------------|-----------|------|
| 1  | 1.1                | Passenger Car          | 2          | -         | -    |
|    | 1.1                | Medium Truck/Small Bus |            |           |      |
| 2  | 1.2                | 2 Axles Truck          | 2          | 5.30      | 9.20 |
| 3  | 1.2                | Bus                    | 2          | 1.00      | 1.00 |
| 4  | 1.22               | 3 Axles Truck          | 3          | 10.20     | 19.00|
| 5  | 1.22               | 4 Axles Truck          | 4          | -         | -    |
| 6  | 1.2-22             | 2 Axles Truck + 2 Axles Trailer | 4 | 11.00 | 19.80 |
| 7  | 1.22-22            | 3 Axles Truck + 2 Axles Trailer | 5 | 17.70 | 33.00 |
| 8  | 1.22-222           | 3 Axles Truck + 6 Axles Trailer | 6 | 18.10 | 34.40 |

**Table 3. Actual VDF Value Using WIM Data**

| Method | Actual VDF4 | VDF5 |
|--------|-------------|------|
| *Manual Desain Perkerasan 2017* | 8.66 | 15.59 |
The calculation of the annual CESA plan using the *MDP 2017* method for a period of 20 years can be seen in Table 4 and the results of the annual CESA recapitulation plan are presented in Table 5.

**Table 4. Recapitulation of Cumulative Equivalent Standard Axle (CESA) Plan**

| Period | ESA4  | CESA4 | ESA5  | CESA5  |
|--------|-------|-------|-------|--------|
| 1      | 3638758.00 | 3638758.00 | 6647708.50 | 6647708.50 |
| 2      | 7452176.38 | 11090934.38 | 13614507.01 | 20262215.51 |
| 3      | 11448638.85 | 22539573.23 | 20915711.84 | 41179727.35 |
| 4      | 15636931.52 | 38176504.75 | 28567374.51 | 69745301.87 |
| 5      | 20026262.23 | 58202766.98 | 36586316.99 | 106331618.85 |
| 6      | 24626280.81 | 82829047.79 | 44990168.71 | 151321787.56 |
| 7      | 29447100.29 | 112276148.09 | 53797405.30 | 205119192.86 |
| 8      | 34499319.11 | 146775467.19 | 63027389.26 | 268146582.12 |
| 9      | 39794044.43 | 186569511.62 | 72700412.44 | 340846994.56 |
| 10     | 45342916.56 | 231912428.18 | 82837470.74 | 423684735.30 |
| 11     | 51158134.55 | 283070562.73 | 93461660.79 | 517146396.10 |
| 12     | 57252483.01 | 340323045.74 | 104595529.01 | 621741925.11 |
| 13     | 63639360.20 | 403962405.94 | 116263822.91 | 738005748.01 |
| 14     | 70332807.48 | 474295213.42 | 128492194.90 | 866497942.92 |
| 15     | 77347540.24 | 551642753.67 | 141307528.76 | 1007805471.68 |
| 16     | 84698980.18 | 636341733.84 | 154737998.64 | 1162543470.32 |
| 17     | 92403289.22 | 728745023.07 | 168813131.08 | 1331356601.39 |
| 18     | 100477405.11 | 829222428.17 | 183563869.87 | 1514920471.26 |
| 19     | 108939078.55 | 938161506.73 | 199022644.12 | 1713943115.38 |
| 20     | 117806912.32 | 1055968419.05 | 215223439.54 | 1929166554.92 |
Table 5. Recapitulation of Cumulative Equivalent Standard Axle (CESA) Actual

| Period | ESA4       | CESA4       | ESA5       | CESA5       |
|--------|------------|-------------|------------|-------------|
| 1      | 4815702.54 | 4815702.54  | 10697333.99| 10697333.99 |
| 2      | 9862558.81 | 14678261.36 | 21908140.18| 32605474.01 |
| 3      | 15151664.18| 29829925.54 | 33657064.73| 66262538.74 |
| 4      | 20694646.60| 50524572.14 | 45969937.83| 112232476.57|
| 5      | 26503692.19| 77028264.33 | 58873828.84| 171106305.42|
| 6      | 32591571.96| 109619836.28| 72397106.62| 243503412.03|
| 7      | 38971669.95| 148591506.24| 86569501.73| 330072913.76 |
| 8      | 45658012.66| 194249518.89| 101422171.80| 431495085.57 |
| 9      | 52665299.81| 246914818.70| 116987770.04| 548482855.61 |
| 10     | 60008936.74| 306923755.44| 133300517.00| 681783372.61 |
| 11     | 67705068.25| 374628823.70| 150396275.81| 832179648.42 |
| 12     | 75770614.07| 450399437.77| 168312631.04| 1000492279.47|
| 13     | 84223306.09| 534622743.86| 187088971.32| 1187581250.79|
| 14     | 93081727.33| 627704471.20| 206766575.94| 1394347826.73|
| 15     | 102365352.79| 730069823.98| 227388705.58| 1621736532.31|
| 16     | 112094592.27| 842164416.25| 249000697.44| 1870737229.75|
| 17     | 122290835.24| 96455251.49| 271650649.11| 2142387294.66|
| 18     | 132976497.88| 1097431749.36| 295386602.01| 2437773896.68|
| 19     | 144175072.32| 1241606821.68| 320262492.90| 2758036389.59|
| 20     | 155911178.33| 1397518000.01| 346332426.56| 3104368816.15|

Table 4 shows that at the Serang Barat Toll Gate, the values of the planned CESA, which were calculated by using the load of the planned vehicle, the pavement was designed to withstand a load equal to the value of CESA at the end of the design life of 215,223,439.54 ESAL.

Table 5 shows that at the Serang Barat Toll Gate, the actual CESA values which were calculated by using the actual vehicle loads as obtained from WIM data, the pavement will withstand a load equal to the CESA value at the end of the design life of 346,332,426,562 ESAL.

Based on the calculation results for each planned and actual loads, it can be concluded that the ratio between the planned and the actual CESA values was 60.91%. Figure 2 shown the comparison between actual load and planned load which is found that the actual load increase from the beginning.

![Figure 2. Equivalent Standard Axle on Actual Load and Planned Load](image-url)
3.2. Remaining Service Life (RSL)

The RSL is the estimation of the number of years measured based on the last (up to estimate) road condition survey to predict when the next road improvement activities are required. To estimate the damage caused by vehicle loads on pavement structures, the calculation of RSL values was based on equations based on the AASHTO method [11]. Remaining service life (RSL) has been defined as the estimation of total years that a pavement will be functionally and structurally in a normal condition by with only routine preservation [15].

| Period | CESA5      | CESA5 Plan | RSL (%) |
|--------|------------|------------|---------|
| 1      | 6647708.50 | 1929166554.92 | 99.66   |
| 2      | 20262215.51| 1929166554.92 | 98.95   |
| 3      | 41177927.35| 1929166554.92 | 97.87   |
| 4      | 69745301.87| 1929166554.92 | 96.38   |
| 5      | 106331618.85| 1929166554.92 | 94.49   |
| 6      | 151321787.56| 1929166554.92 | 92.16   |
| 7      | 205119192.86| 1929166554.92 | 89.37   |
| 8      | 268146582.12| 1929166554.92 | 86.10   |
| 9      | 340846994.56| 1929166554.92 | 82.33   |
| 10     | 423684735.30| 1929166554.92 | 78.04   |
| 11     | 517146396.10| 1929166554.92 | 73.19   |
| 12     | 621741925.11| 1929166554.92 | 67.77   |
| 13     | 738005748.01| 1929166554.92 | 61.74   |
| 14     | 866497942.92| 1929166554.92 | 55.08   |
| 15     | 1007805471.68| 1929166554.92 | 47.76   |
| 16     | 1162543470.32| 1929166554.92 | 39.74   |
| 17     | 1331356601.39| 1929166554.92 | 30.99   |
| 18     | 1514920471.26| 1929166554.92 | 21.47   |
| 19     | 1713943115.38| 1929166554.92 | 11.16   |
| 20     | 1929166554.92| 1929166554.92 | 0.00    |

Table 6 shows that the planned remaining life of the pavement will end in the 20 years but based on the RSL calculation, the pavement life will end between the period of 16 and 17 years or more precisely in the period of 16.22 years (see Figure 3).
Figure 3. Comparison Between Remaining Service Life on Actual Load and Plan Load

4. Conclusions And Suggestions
Based on the observations results and data analysis, it can be concluded that the difference between the actual load and the planned load of vehicles passing through the Serang Barat Toll Gate had a variation of 40% - 400% increasing load. The increase in CESA for the plan life period of 20 years between Actual Load and Plan Load has a significant increase from 215,223,439.54 ESAL to 346,332,426.56 ESAL or an increase of 60.91% from the planned CESA. Meanwhile, by using the value of the CESA to obtain the value of RSL of 20 years period as the design life of the road section of the Serang Barat Toll Gate, it shows that the road section will not be able to withstand traffic loads after 16.22 years.

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