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THE OVERLOAD IMPACT ON DESIGN LIFE OF FLEXIBLE PAVEMENT

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ABSTRACT: Overloaded vehicles is one of the main problems that cause premature failure in road infrastructure. This paper presents an analysis of overloaded vehicles' effect on flexible pavement based on historical weigh-in-motion data. This article highlights the potential use of weigh-in-motion (WIM) data in pavement design by addressing the overload, the percentage of overloading, and axle load distribution. The percentage of overloaded vehicles can reach more than 80% of the total number of trucks and maybe one of the substantial factors that reduce pavement's service life. The actual traffic load is presented in the form of distribution for each type of axle load (axle load spectra) and the Vehicle Damage Factor (VDF) for each truck type. The effect of overload on the flexible pavement's design life is estimated by using the Cumulative ESAL comparison and Pavement Damage Ratio. Both analyses show that overload vehicles significantly decrease the pavement design life up to nearly half of the pavement life.

Keywords: Overload, Weigh-in-motion, Axle load distribution, Vehicle damage factor, Pavement damage ratio

1. INTRODUCTION

Road infrastructure tends to have a shortage of reliability due to several factors, such as inappropriate design standards, low construction quality, overloading, and ineffective maintenance [1]. From these factors, overloading is the most significant factor that causes premature failure to road pavement, both flexible and rigid pavement. The percentage of overloading conditions as a cause can reach 38% to 47%. [2].

Previous studies about overloading and its effect on pavement indicate that they can substantially decrease the pavement service life [3, 4]. Other adverse effects of overloading are increasing the maintenance cost due to premature deterioration of pavement [5,6] and increasing accident risk and severity because of truck instability or longer stopping distance during emergency braking [7,8].

The percentage of overload vehicles can describe the magnitude of overloading in the total number of trucks. In developing countries, where the traffic control level is low, the percentage of overload can reach incredibly high, from 60% to 80% [9, 10]. One of the main factors behind the overloaded trucks is an economic reason. Without intervention or law enforcement, people tend to disrespect the legal axle load limit to gain more income and minimize transport costs. Traffic control is needed to ensure the vehicles, especially trucks, respect the maximum permitted axle limit and prohibit the negative effect of overloading. Weigh-in-motion (WIM) is one of the technologies that can be used for detection and enforcement.

WIM is a survey tool used for pavement and bridge engineering, traffic data collection, traffic controls; and provides vehicle load characteristics, has higher accuracy data and has no interruption to traffic flows. WIM data resources can be potentially used for assigning freight transport more efficiently and decreasing the pavement maintenance cost [11]. WIM survey can also provide the distribution of axle load (axle load spectra) as an input in the mechanistic-empirical pavement design guide (MEPDG). The axle load spectra are used directly by the mechanistic model to calculate the critical responses under the applied load [12].

WIM survey is very costly; because of that, it is usually conducted only annually by the Directorate General of Highway (DGH), Ministry of Public Works and Housing at some strategic roads. The period time of each survey for each location varying between several days into weeks. Although the WIM survey is quite often conducted, the data has not been appropriately studied in Indonesia. This present study highlights the potential use of WIM data in pavement design by addressing the overload, the percentage of overloading, and the distribution of axle load, which has never been analyzed in detail in Indonesia yet. Some previous studies in Indonesia related to overloaded focus only on truck factor determination and residual service life analysis [13,14]. In comparison, other studies analyze the cost of pavement maintenance due to overloaded trucks [15,16]. Further research is needed to improve and update the information for pavement design.

Therefore, this study's main objective is to develop the distribution of actual load to evaluate the overload condition and its effect on pavement design life.

2. METHODOLOGY

The weigh-in-motion data is used to develop the actual traffic load and estimate the percentage of the overloaded vehicle. The actual traffic load is presented in the form of distribution for each type of axle load and the Vehicle Damage Factor (VDF) for each type of truck. Vehicle Damage Factor or standard ESA/vehicle is used to convert the number of trucks into a number of equivalent single axle loads (ESAL). The comparison of Cumulative ESAL and Pavement Damage Ratio between the standard and overload condition is presented to estimate the effect of overload vehicles on pavement design life.

3. WEIGH-IN-MOTION DATA

WIM data is collected from the WIM survey conducted by the Directorate General of Highway (DGH) on two strategic road segments in the south part of Sumatera Island. Both locations are the main segment heading to the main port that connects to Java Island, the main island in Indonesia. The data were collected from 2007 to 2013, but each survey's periods can differ for each location (between several days into weeks). Table 1 showed the total records of trucks and the year of the WIM survey for each section. The entire record of trucks is more than 80,000 trucks.

Table 1 WIM location and the total number of trucks

Location	Year of survey	Total number of trucks
Sec. 1 Palembang	2007, 2012, 2013	41,687
Sec. 2 Lampung	2007, 2010, 2013	38,537

In Indonesia, the trucks are classified into several types or classes based on the configuration and number of axles. The type and the number of trucks analyzed in this study are presented in Table 2. The information on the maximum legal load limit is also presented for each truck as a reference to identify the overloaded vehicle. In this present study, the overloaded vehicle is a vehicle or truck with at least one axle load that exceeds the maximum legal load.

Every axle load of each truck is checked to identify the number of overload vehicles. The percentage of overload trucks was calculated for each type of truck, each location, and each year of the survey. The axle load that exceeds the maximum legal limit is mostly in the middle or rear axle where the freight is located. To simplifies the results, the annual average percentage of overload vehicles is used and described in Figure 1.

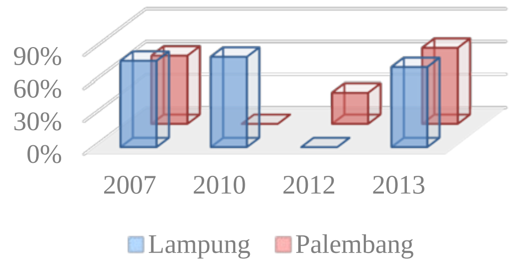

Fig 1 Percentage of overload trucks

Based on Figure 1, the average percentage of overload trucks is ranged between 29% - 82%. The overload trucks' percentage is extremely high and shows that the traffic control or law enforcement is poor. Without regular traffic control and a high law enforcement level, this statistic number cannot be reduced.

4. LOAD SPECTRA

Load Spectra or Axle Load Spectra (ALS) is a new method used to represent the vehicle loads in the Mechanistic-Empirical Pavement Design Guide (MEPDG) [17]. ALS represents the actual load in the total axle load percentage for each type of axle load (single, tandem, tridem, and quad axles). Figure 2 illustrates the configuration of each type of axle load. The MEPDG method uses the axle load spectra for the traffic input and analyzes the effects of a diverse range of loads on pavement and resulting in an optimal pavement structure design.

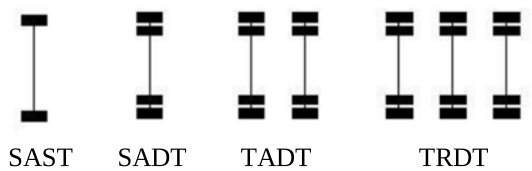

Fig. 2 Axle load group types

The concept of ALS is not developed in the design of flexible pavement in Indonesia yet. The concept of the empirical approach of equivalent single axle loads (ESAL) from AASHTO 1993 [18] is still used to represent the vehicle loads in pavement design. One of the problems to utilize the

Table 2 Vehicle classes, number records in WIM survey and maximum legal load

Vehicle class		Total number of records in the WIM survey		maximum legal load per axle (kg)					
				1st axle	2nd axle	3rd axle	4th axle	5th axle	6th axle
6B		35171	28949	60	100				
7A		5946	8846	60	180				
7C1		323	117	60	100	180			
7C2		44	139	60	100		210		
7C3		203	486	60	180			210	

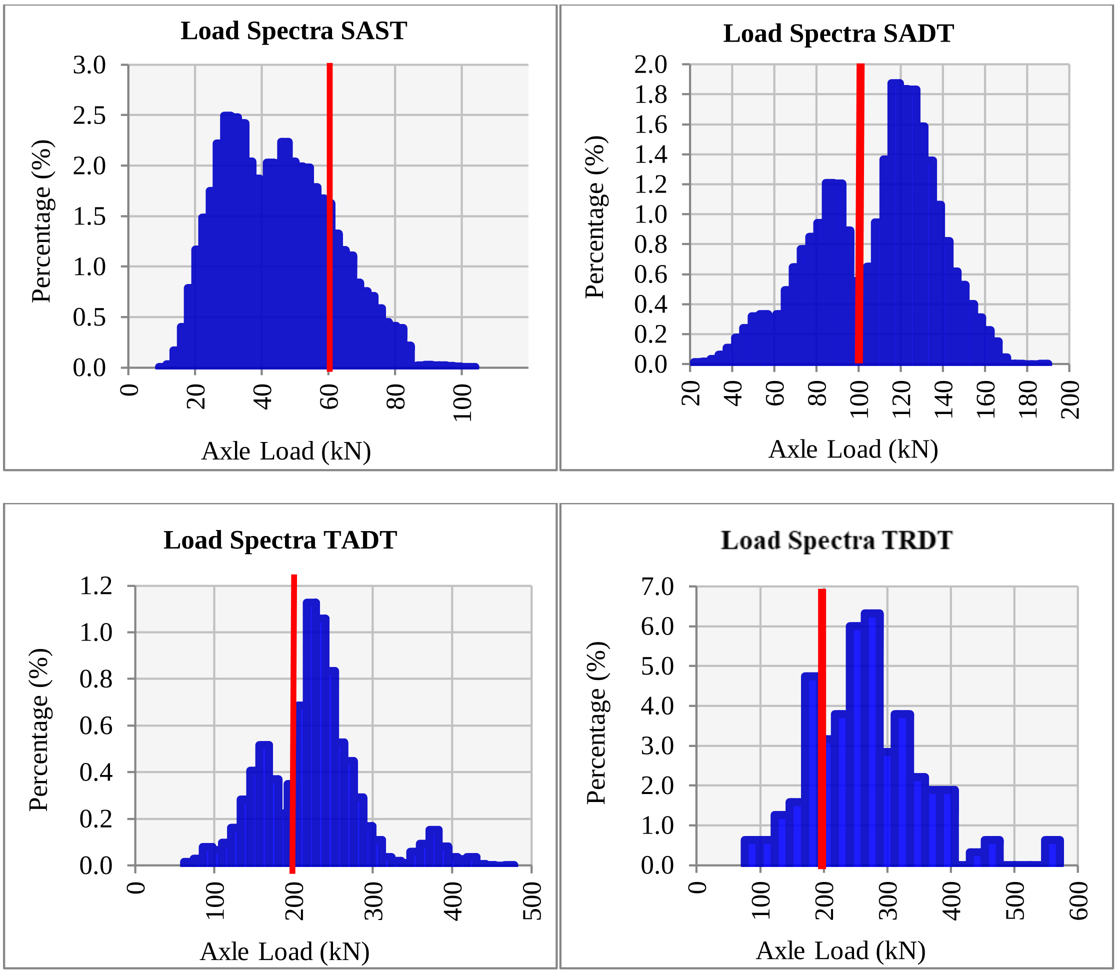

Fig. 3 Load Spectra for each type of axle load (Palembang 2013)

ALS concept in Indonesia is to provide more detailed traffic input, especially the load spectrum. Load spectra can be derived from the WIM survey, and it is very costly. The annual WIM survey conducted regularly by DGH has been stopped due to institutional change in the new government. The WIM survey application, for now, is a Regional Road Administration Agency's responsibility and rarely conducted the WIM survey.

Figure 3 presents the axle load distribution for Palembang section road at the 2013 year of measurement. The Redline in each of the distribution shows the maximum legal axle limit that refers to table 2. Most of each type of axle load exceeds the maximum axle load limit. The Single Axle Single Tire (SAST) has the lowest percentage of overload axle since this type of axle is the front axle that carrying less freight than other axles.

The Single Axle Double Tire (SADT), Tandem Axle Double Tire (TADT), and Tridem Axle Double Tire (TRDT) type of axle load that carrying the most freight and have a bigger chance to exceed the maximum legal axle load limit

The distributions that develop in this present study can be used in future research especially related to mechanistic-empirical pavement design methods. The distribution of each axle load can be optimized in pavement design to characterize the actual load more precisely than using the VDF factor to converts the traffic.

5. VEHICLE DAMAGE FACTOR

Vehicle Damage Factor (VDF) is a Load Equivalent Factor for each class/type of truck. It states the comparison of the level of damage caused by the passage of the actual load relative to damage caused by a standard axial load in equivalent single axle load units (80 kN) [19]. The Manual of Pavement Design in Indonesia adopted the empirical ESAL formula from AASHTO 1993 (Eq. 1) based on fatigue criteria – fourth power equation.

$$ESAL = \left(\frac{P_{actual}}{P_{Standard}}\right)^{\alpha} \qquad (1)$$

where;
P_{actual} = the actual or applied axle load; $P_{standard}$ = The standard load (80 kN) and α = a coefficient function of the type of pavement, distress, failure, and contact stress

The value of α, mainly $\alpha = 4$, is used, based on the fourth power formula. For considering the type of axle load, i.e., single, tandem, or tridem axle, the k coefficient factor is proposed [20]. The suggested value of k based on the Indonesia pavement design guide is presented in Eq. 2, as follows:

$$ESAL = \mathrm{k}\left(\frac{P_{actual}}{P_{Standard}}\right)^{\alpha} \qquad (2)$$

where;
k : 1 for single; 0.086 for tandem and 0.053 for tridem axle load

In general, the VDF value is determined by the road regulator (DGH) as the representative value of a vehicle /truck by considering the combination of the load and the vehicle's axis and based on the maximum legal axle load limit. The VDF value for each type/class of truck is presented in Table 3.

The deterministic value of standard VDF in the Indonesia pavement design guide is used to represent the damaging effect of a given truck on the pavement. This method simplifies ESAL estimations, but there is a risk that the VDF standard does not accurately represent the actual traffic loading, mainly when the overloading problem arises.

Table 3 The Standard VDF value

Vehicle class		VDF
6B		3.898
7A		3.679
7C1		5.934
7C2		6.222
7C3		6.003

One of this present study's focal points is determining the VDF value from the actual traffic load based on WIM data. Every truck on the WIM records is calculated based on their axle weight to calculate the VDF value of each truck. The VDF distribution on the Palembang section in 2013 is shown in Figure 4. The VDF value varies between the types of trucks, location, and time of the survey. To compare the VDF standard from Pavement Design Guide in Indonesia and the VDF value from the actual traffic, Figures four are presented in Table 4. Based on Table 4, the VDF value from the actual traffic load is greater than the standard ones. The ratio between the mean value of actual and standard varies between 130% to 800%. It does mean that the VDF standards cannot represent the actual traffic load and lead to improper pavement design.

Table 4 The VDF value comparison between standard and actual traffic

Type	VDF Standard	VDF value (Palembang)		VDF value (Lampung)	
		Mean	Max	Mean	Max
6B	3.898	5.33	23.42	5.30	71.21
7A	3.679	8.29	110	12.22	64.29
7C1	5.934	14.02	31.55	14.22	14.22
7C2	6.222	19.37	73.52	28.50	160
7C3	6.003	16.87	162	47.26	122

To simplifies the result, the average of VDF and the average of the percentage of overload was calculated for each location and each of the measurement periods. The linear correlation of the VDF value and the percentage of overload is determined and presented in Figure 5. The regression model found the relationship between the VDF and the percentage of overload relatively poor (R2=0.679).

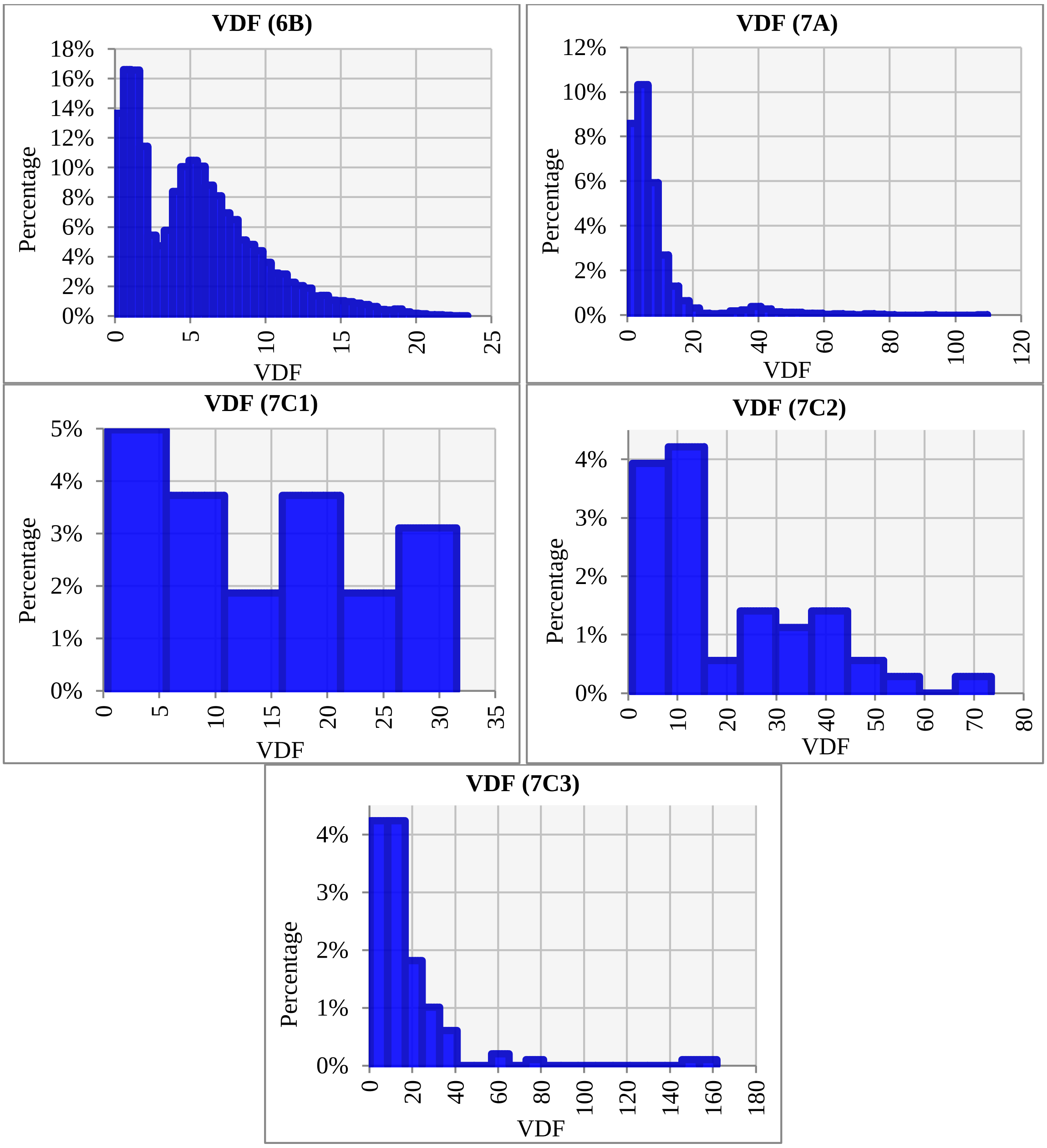

Fig. 4 VDF for each type of truck (Palembang 2013)

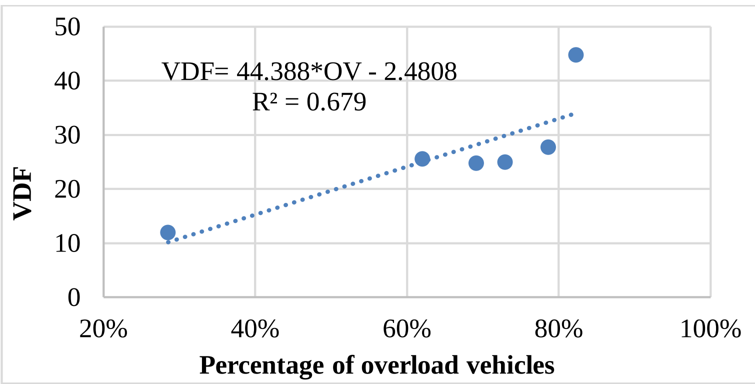

Fig. 5 Relationship between Average of VDF value and the average percentage of overload truck (year

These results confirm the finding result from Rys, et al. in 2016 and 2018 [4,6] that the VDF value is affected not only by the percentage of overload but also the character of the axle load distribution and some local conditions of the traffic.

Another important finding, this figure showed that an increase in the percentage of overload trucks would cause an increase in VDF value. From the regression model in figure 5, an increase in the percentage of overload from 40% - 80% will increase the VDF value from 15 – 33. The increase in VDF value is more than 200%, caused by a 40% increase in the percentage of overload. It is another essential fact that traffic control and law enforcement related to the overload problem are needed to ensure the pavement's service life.

6. OVERLOAD IMPACT ON PAVEMENT

The pavement design for flexible pavement in Indonesia is based on ESAL concepts that convert the number of vehicles into the number of ESAL repetitions. The VDF factor in pavement design plays a vital role in determining the traffic input for pavement analysis. The Cumulative of Equivalent Single Axle Load (CESAL) is calculated as a traffic design during the pavement's design life. The formula of ESAL in pavement design in Indonesia [19], as follows:

$$ESALT_{TH-1} = \sum_{j=1}^{n} N_j \times VDF_j \times D_D \times D_L \times 365 \qquad (3)$$

where;
$ESAL_{TH-1}$ = ESAL in the first year of pavement life; Nj = denotes the number of vehicles; DD and DL = distribution factor for direction and lanes; CESAL= Cumulative of Equivalent Single Axle Load in the design life of the pavement and R = Growth factor

6.1 CESAL Comparison

To analyze the impact of the overloaded truck on design life; The VDF value and the percentage of overloading from the WIM survey analysis was used to estimate the CESAL and the number of design traffic. The daily traffic data collected from traffic counting surveys in location. The CESAL result (Overloaded CESAL) will be compared with CESAL estimation using standard load (Standard CESAL) to calculate the impact of overloading. Then the reduction value of the service life of pavement structures can be measured.

Figure 6 represents the CESAL value comparison taking the Palembang location in 2013 as a case study. As shown in that figure, the CESAL value from WIM data analysis is greater than the Standard CESAL value. At the end of design life (10 years), the total number of standard CESAL is 24.83 million ESAL. While the total number of Overloaded CESAL approximately 48.47 million ESAL. The Overloaded CESAL value is nearly 1.95 times more than Standard CESAL

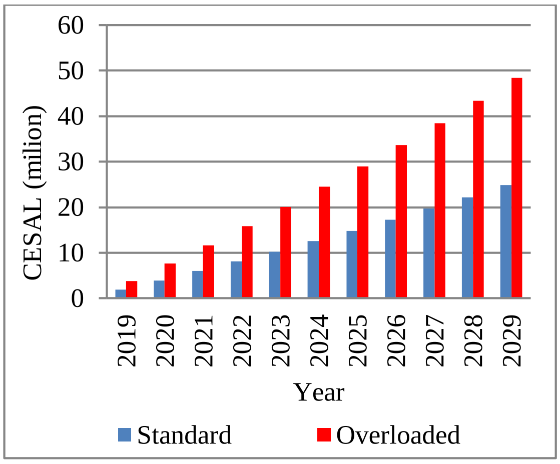

Fig. 6 CESAL comparison between standard and overload condition

The impact of overloaded vehicles on the pavement structure is calculated by estimating the pavement's remaining service life. 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 with only routine preservation [3]. The RSL was calculated using the formula:

$$RSL = \frac{CESAL\ Standard}{CESAL\ Overloaded}\ x\ DL \qquad (4)$$

Where:
RSL is remaining service of pavement (years) and
DL is design life (10 years)

By using this equation, the RSL of pavement in this study is 5.12 years. From this result, we can conclude that there is a reduction in service life. The deduction is approximately 4.88 years from the pavement design life or nearly half of the pavement design life.

6.2 Pavement Damage Ratio

This present study only considers the load analysis to estimate the pavement damage by comparing the actual traffic load and the design traffic in design life. The Pavement Damage Ratio concept (PDR) by Almeida et al. in 2019 [21] is used in this present study to assess the impact of overload condition on pavement design life. The PDR formula is presented in Equation 5, as follows:

$$PDR = \frac{N_{\mathrm{ESAL}_{\mathrm{actual}}}}{N_{\mathrm{ESAL}_{standard}}} = \frac{N_{vehicles} \times TF}{\mathrm{N}_{vehicles} \times TF_{Standard}} = \frac{TF}{TF_{Standard}} \quad (5)$$

Where the TF formula is shown in equation 6

$$TF_{mixed\ traffic\ stream} = \sum_{i=1}^{Nr.Vehicles} P_i \times \sum_{j=1}^{load} \left(TF_i^j \times P_i^j\right) \quad (6)$$

Where;
P_i = The percentage of class i in the traffic; TF_{ij} = The TF of the vehicle of class i in the load case j (VDF) and P_{ij} = the percentage of vehicles of class i in the load case j

As a comparison, the same set of data is used. From the calculation from Equation 6, the TF for the actual load is 7.81, and the $TF_{standard}$ is 4.12. In this case, the Pavement Damage Ratio is about 1.90, which practically the same result as the Cesal Comparison results.

The PDR results show that overload vehicles can reduce almost half of the flexible pavement life span (4-5 years in this study). Previous studies in Ecuador [21] have nearly the same results with the present study, where there is a significant reduction in the life span of pavement up to 40%. Another study in Indonesia also shows a substantial reduction (60%-80%) in the level of serviceability of pavement due to overload vehicles [22].

7. CONCLUSION

Several points of conclusion from this present study are:

- This study used a historical weigh-in-motion database from two strategic road segments in Indonesia to analyze the effect of overload on pavement service life. The percentage of overload vehicles varies between 29% - 82% and shows that traffic control and law enforcement are poor.
- The actual traffic load is presented in the form of distribution for each type of axle load (ALS) and the Vehicle Damage Factor (VDF) for each type of truck. Even though the ALS approach has never been used in the flexible pavement design guide in Indonesia, ALS development can give a new perspective in pavement design especially related to the mechanistic-empirical approach.
- The VDF distribution of each type of truck is presented, and the ratio between the mean value of actual and standard VDF varies between 130% to 800%. It does mean that the VDF standards cannot represent the actual traffic load and lead to improper pavement design.
- The linear correlation of the VDF value and the percentage of overload is found in the study. The increase in VDF value is more than two times, caused by a 40% increase in the percentage of overload.
- The TF for the actual load on Palembang Section in 2013 is 7.81, and the $TF_{standard}$ is 4.12. The value of the overloading condition is nearly double the standard value.
- The effect of overload on the flexible pavement's design life is estimated by using the CESAL comparison and Pavement Damage Ratio. Both results are approximately equal and show that the overload has a significant effect in decreasing the pavement design life (the analysis has been demonstrated that the decrease is nearly half of pavement design life).

8. ACKNOWLEDGMENTS

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