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EFFECT OF OVERLOADED VEHICLES ON VEHICLE DAMAGE FACTOR AND PAVEMENT REHABILITATION

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Abstract

Overloading has become a common problem, especially in developing countries including Indonesia. Overloaded vehicle has negative impacts on the pavement, one of which is premature deterioration which leads to increased rehabilitation costs. This research was conducted to calculate the impact of overloaded vehicles on the pavement in terms of vehicle damage factor (VDF), ESAL, and rehabilitation costs based on the traffic data on Jakarta-Cikampek Toll Road. The calculation is done using three scenarios to compare different conditions. Scenario 1 is the actual condition of the traffic. Scenario 2 is the ideal condition where the axle configuration of the overloaded vehicles was changed to accommodate the load. Scenario 3 is the ideal condition where the excess overload is carried by adding more vehicles. It was found that by changing the vehicles' axle configuration, the rehabilitation cost was reduced as much as 70.12%, while adding more vehicles reduced the cost by 55.14%.

Keywords: Overloading, Vehicle Damage Factor, Pavement, Rehabilitation Cost, ESAL

Abstrak

Overloading sudah menjadi masalah umum, terutama di negara berkembang termasuk Indonesia. Kendaraan yang kelebihan muatan memberikan dampak negatif terhadap perkerasan, salah satunya adalah kerusakan dini yang berujung pada peningkatan biaya rehabilitasi. Penelitian ini dilakukan untuk menghitung dampak kelebihan beban kendaraan pada perkerasan ditinjau dari daya rusak jalan atau *vehicle damage factor* (VDF), ESAL, dan biaya rehabilitasi berdasarkan data lalu lintas di Jalan Tol Jakarta-Cikampek. Perhitungan dilakukan dengan menggunakan tiga skenario untuk membandingkan kondisi yang berbeda. Skenario 1 adalah kondisi lalu lintas yang sebenarnya. Skenario 2 adalah kondisi ideal dimana konfigurasi sumbu dari kendaraan yang kelebihan beban diubah agar dapat mengangkut beban tanpa *overloading*. Skenario 3 adalah kondisi ideal dimana beban berlebih diangkut dengan menambah jumlah kendaraan. Ditemukan bahwa dengan mengubah jumlah gandar kendaraan, biaya rehabilitasi berkurang sebanyak 70,12%, sementara menambah jumlah kendaraan mengurangi biaya rehabilitasi sebesar 55,14%.

Kata Kunci: Beban Berlebih, *Vehicle Damage Factor*, Perkerasan, Biaya Rehabilitasi, ESAL

INTRODUCTION

Toll roads become one of the infrastructures that connect one region with another region. One of the toll roads that has an important role in the Indonesian economy is the Jakarta-Cikampek Toll Road. This toll road connects the city of Jakarta, the center of the economy, with cities to its east in the Province of West Java, which mostly are industrial areas. Due to this reason, in serving its daily traffic, the Jakarta-Cikampek Toll Road is often passed by logistics vehicles with heavy loads such as small trucks, large trucks, and trailers.

As one of the toll roads traversed by many heavy-loaded trucks, cases of overloading are often found on the Jakarta-Cikampek Toll Road. According to data from PT Jasa Marga, in 2019 there were more than 53,000 trucks that passed the Jakarta-Cikampek toll road every day in one way. Moreover, based on a survey conducted by Setiawan (2019), out of 492 samples of heavy vehicles, 218 of them were overloaded or equivalent to 44.3% of the total sample.

The amount of traffic and load of vehicles that pass through this road every day causes damage to the pavement; therefore, increasing the cost of road maintenance. Due to the overloading of vehicles that pass on it, road damage occurs before its design life is reached, as a result, it requires more pavement rehabilitation. Based on this condition, this research is conducted to analyze the impact of overloaded vehicles on vehicle damage factor and maintenance costs of Jakarta-Cikampek Toll Road.

LITERATURE REVIEW

Overloading

Overload is the condition where the vehicle axle load exceeds the maximum axle load as stated in the applicable regulations. Each axle configuration has its own maximum axle load because different configurations have different effects on the pavement. Total Permitted Weight (JBI) is the maximum weight of motorized vehicles based on the class of road traversed. The JBI was determined by the government with consideration of the carrying capacity of the road class, the strength of the tires, and the strength of the axle design as an effort to increase the service life of roads and vehicles, as well as to maintain road safety.

Axle Load

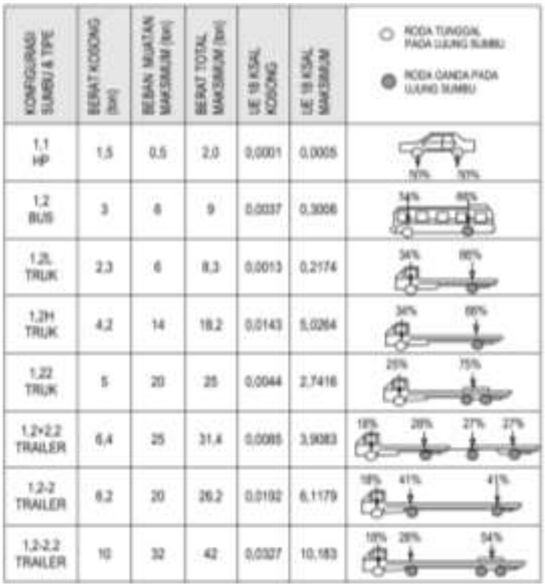
Heaviest axle load is the largest axle load of several vehicle axle loads that must be borne by the road.

Table 1. Axle Load and Total Load for Various Type of Vehicles

No.	Type of Vehicle	Axle Load (Ton)						Total Load (Ton)
		Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	
1.	Passenger Cars (1.1)	1	1					2
2.	Small Bus (1.1)	3	6					9
3.	Bus (1.2)	6	10					16
4.	Truck 2-axle (1.1)	6	6					12
5.	Truck 2-axle (1.2)	6	10					16
6.	Truck 3-axle (11.2)	5	6	10				21
7.	Truck 3-axle (1.22)	6	9	9				24
8.	Truck 4-axle (1.1.22)	6	6	9	9			30
9.	Truck 4-axle (1.222)	6	7	7	7			27
10.	Truck 4-axle (1.2-22)	6	10	9	9			34
11.	Truck 4-axle (1.2+2.2)	6	9	9	9			33

No.	Type of Vehicle	Axle Load (Ton)						Total Load (Ton)
		Axle 1	Axle 2	Axle 3	Axle 4	Axle 5	Axle 6	
12.	Truck 5-axle (1.1.222)	6	6	7	7	7		33
13.	Truck 5-axle (1.22-22)	6	9	9	9	9		42
14.	Truck 6-axle (1.22-222)	6	9	9	7	7	7	45

Table 2. Axle Load Distribution



KONFIGURASI SUMBU & TIPE	BERAT KOSONG (ton)	BEBAN MUATAN MAKSIMUM (ton)	BERAT TOTAL MAKSIMUM (ton)	UE 18 KSAL KOSONG	UE 18 KSAL MAKSIMUM	○ RODA TUNGGAL PADA UJUNG SUMBU ● RODA GANDA PADA UJUNG SUMBU
1,1 HP	1,5	0,5	2,0	0,0001	0,0005	50% 50%
1,2 BUS	3	6	9	0,0037	0,3006	34% 66%
1,2L TRUK	2,3	6	8,3	0,0013	0,2174	34% 66%
1,2H TRUK	4,2	14	18,2	0,0143	5,0264	34% 66%
1,22 TRUK	5	20	25	0,0044	2,7416	25% 75%
1,2+2,2 TRAILER	6,4	25	31,4	0,0085	3,9083	18% 28% 27% 27%
1,2-2 TRAILER	6,2	20	26,2	0,0192	6,1179	18% 41% 41%
1,2-2,2 TRAILER	10	32	42	0,0327	10,183	18% 28% 54%

Traffic Growth

The number of vehicles passing on the road is increasing from year to year. Traffic growth is expressed in a percentage. Traffic growth can be determined using the following formula:

$$i = \left[\sqrt[n]{\frac{AADT_1}{AADT_n}}\right] - 1 \tag{1}$$

Where I = Traffic growth rate (%), n = nth Year, $AADT_1$ = AADT of the first year, $AADT_n$= AADT of Nth year.

Vehicle Damage Factor (VDF)

The vehicle damage factor (VDF) or also called the equivalent number (E) of a vehicle axle load is a number that expresses the ratio of the level of damage caused by a single axle load path of the vehicle to the level of damage caused by a single axle load path weighing 8.16 tons or 18000 lb. The vehicle damage factor for each axle load is determined according to the Bina Marga formula below:

$$VDF = k\left(\frac{P}{8160}\right)^4 \tag{2}$$

Where VDF = Vehicle damage factor, P = Axle load (kg), k = 1 for single axle, 0.086 for double axle, and 0.021 for triple axle.

Equivalent Single Axle Load (ESAL)

In the 2013 Road Pavement Design Manual, the Equivalent Single Axle Load (ESAL) or also called the cumulative vehicle damage factor, is the cumulative amount of traffic axle load on the design lane during the design life, which is determined according to the following equation. The lane distribution factor (DL) is based on the Road Pavement Design Manual of 2013 by Bina Marga. The DL for a road with three lanes in each direction is 0.6. Whereas the directional distribution factor (DD) is 0.5 according to AASHTO (1993).

$$ESAL = (\Sigma AADT\ vehicle\ type \times VDF \times DL \times DD \times 365) \quad (3)$$

Where ESAL = Equivalent Single Axle Load, AADT = Annual Average Daily Traffic, VDF = Vehicle Damage Factor, DL = Lane Distribution Factor, DD = Direction Distribution Factor.

METHODOLOGY

This research takes the study area on the Jakarta-Cikampek Toll Road, in accordance with the background of this research where there are many cases of overloading on this toll road. The segment that was used as the study area is KM 54 – 67 eastbound routes. It is a 13 km long flexible pavement, consisting of two routes with three lanes on each route. The strategy for this research is started with collecting data for the analysis. The overloading data is obtained from the thesis of a previous researcher, Setiawan (2019), and the road technical data, traffic data, and maintenance cost data are obtained from PT Jasa Marga (Persero) Tbk.

The data processing and analysis are conducted with three scenarios;

a. Scenario 1: Using the AADT and vehicle load from the actual condition. The AADT data is obtained from PT Jasa Marga (Persero) Tbk. and the vehicle load is from Setiawan's thesis data.
b. Scenario 2: The axle number of the overloaded vehicles is changed in order to accommodate the load and fulfill the ideal condition.
c. Scenario 3: The excess load from the overloaded vehicles will be carried by additional vehicles in order to fulfill the ideal condition.

The vehicle data that was available was only the number of axles. The axle configurations were unknown; therefore, the axle configuration of each vehicle class was assumed to be the most commonly found configuration in Indonesia. For Class 1, the axle configuration is assumed to be 1.1, Class 2 is 1.2, Class 3 is 1.22, Class 4 is 1.222, and Class 5 is 1.22-22.

Other than that, the axle load distribution from Bina Marga was based on the condition of the vehicle that is not over-dimensional. With this matter in hand, the vehicles that were the subject of this research were assumed to have ideal dimensions in accordance with the standard.

RESULT AND DISCUSSION

Traffic Composition

1. Scenario 1

The first scenario is based on the actual condition of the traffic. Therefore, the AADT and the traffic composition are according to the data obtained from PT Jasa Marga. The AADT data of the toll section is only available for the years 2017-2021. In order to determine the AADT for the years before 2017 and after 2021, the traffic growth factor needs to be calculated. For the years before 2017, the traffic growth factor is determined based on the Road Pavement Design Manual 2017 by Bina Marga, in which the traffic growth factor for toll roads in Java is 4.8%. In 2020, the traffic is affected by the COVID-19 pandemic; therefore, to determine the traffic after the year 2021, the traffic growth factor is calculated from traffic data in 2020 and 2021. The growth factor is 8.99%.

2. Scenario 2

The second scenario is when the overloaded vehicles are changed to a vehicle with a different axle configuration in order to accommodate the load. The determination of the new axle configuration is based on the total permitted weight (JBI) in Circular Letter of Directorate General of Land Transportation No: SE.02/AJ.108/DRJD/200.

Table 3. Maximum JBI

Class	Axle Configuration	Max. JBI (kg)
1	1.1	2,000
2	1.2	16,000
3	1.22	24,000
4	1.222	27,000
5	1.22-22	42,000

Table 4. Vehicle Class Changes

Class	1	2	3	4	5
1	60%	-	-	-	-
2	40%	74%	-	-	10%
3	-	23%	50%	-	20%
4	-	2%	28%	38%	-
5	-	1%	22%	62%	70%

3. Scenario 3

The third scenario is when the excess load from the overloaded vehicles is carried with a number of additional vehicles. The number of additional vehicles was determined based on the total overload in each class, then the number of additional vehicles to carry those loads are calculated. Same as Scenario 2, the axle configuration and total permitted weight (JBI) for the additional vehicles is based on Circular Letter of Directorate General of Land Transportation No: SE.02/AJ.108/DRJD/200. The JBI for each vehicle class can be seen in Table 3.

Table 5. Additional Vehicles for Scenario 3

Class	No. of Sample	Total OL (kg)	Additional Vehicles	Percentage of Additional Vehicles
1	5	1,125	1	20.0%
2	242	478,715	30	12.4%
3	169	387,250	17	10.1%
4	26	95,280	4	15.4%
5	50	83,120	2	4.0%

4. Traffic Composition Comparison of All Scenarios

After the adjustments were made for Scenarios 2 and 3, the composition became different. The AADT of Scenario 2 did not change because the only thing that changed is the configuration. The number of vehicles remains the same; however, the composition of each vehicle class is different because of the changes. The AADT of Scenario increased because there are additional vehicles.

Table 6. Traffic Composition Percentage Comparison

Class	Scenario 1	Scenario 2	Scenario 3
1	62.10%	37.26%	63.82%
2	20.70%	40.54%	19.92%
3	9.46%	10.02%	8.92%
4	4.68%	4.83%	4.62%
5	3.06%	7.35%	2.72%

Table 7. AADT Comparison

No.	Year	AADT Scenario 1	AADT Scenario 2	AADT Scenario 3	No.	Year	AADT Scenario 1	AADT Scenario 2	AADT Scenario 3
1	2005	36,029	36,029	42,075	12	2016	60,343	60,343	70,469
2	2006	37,758	37,758	44,094	13	2017	63,239	63,239	73,851
3	2007	39,571	39,571	46,211	14	2018	61,201	61,201	71,471
4	2008	41,470	41,470	48,429	15	2019	53,593	53,593	62,586
5	2009	43,461	43,461	50,754	16	2020	38,474	38,474	44,930
6	2010	45,547	45,547	53,190	17	2021	41,931	41,931	48,967
7	2011	47,733	47,733	55,743	18	2022	45,701	45,701	53,370
8	2012	50,024	50,024	58,418	19	2023	49,809	49,809	58,167
9	2013	52,425	52,425	61,223	20	2024	54,287	54,287	63,397
10	2014	54,942	54,942	64,161	21	2025	59,167	59,167	69,096
11	2015	57,579	57,579	67,241					

Vehicle Damage Factor (VDF)

In calculating the vehicle damage factor, the first thing to do is to calculate the load distribution on each axle. The axle load distribution is calculated according to the Bina

Marga shown in Table 2. After calculating the axle load distribution, the VDF of each axle can be determined using formula 2. The VDF of one vehicle is calculated by summing the VDF of each axle. After the VDF of every vehicle is calculated, the average value of VDF is determined for each vehicle class. The VDF for the three scenarios can be seen in the following table.

Table 8. VDF of Scenario 1, 2, and 3

Class	Scenario 1	Scenario 2	Scenario 3
1	0.00085	0.00006	0.00039
2	2.61065	0.20309	0.86988
3	2.25817	0.58465	0.91245
4	0.13842	0.40062	0.70692
5	0.10790	0.92705	0.22113
Average	1.02320	0.42310	0.54215

The reason Scenario 2 acquired lower VDF is because the overloaded vehicles are changed to a different vehicle with more axles. The result shows that configuration and number of axles have a significant impact on the Vehicle Damage Factor. When given the same load, the vehicles with more axles had a less damaging effect on the road pavement compared to the vehicles with a smaller number of axles. The reason being a larger number of axles allows a more uniform distribution of load on the pavement, hence, generating a lower damaging effect.

ESAL

The ESAL is calculated using formula 3. It is calculated per year using the AADT and VDF of the respective year. The ESAL value of all scenarios throughout the years was compared. The table of comparison can be seen below.

Table 9. ESAL of Scenario 1, 2, and 3

No.	Year	Scenario 1	Scenario 2	Scenario 3
1	2005	3,015,298	901,020	1,352,650
2	2006	3,160,032	944,269	1,417,577
3	2007	3,311,714	989,594	1,485,620
4	2008	3,470,676	1,037,094	1,556,930
5	2009	3,637,269	1,086,875	1,631,663
6	2010	3,811,858	1,139,045	1,709,983
7	2011	3,994,827	1,193,719	1,792,062
8	2012	4,186,578	1,251,017	1,878,081
9	2013	4,387,534	1,311,066	1,968,229
10	2014	4,598,136	1,373,997	2,062,704
11	2015	4,818,846	1,439,949	2,161,713
12	2016	5,050,151	1,509,067	2,265,476
13	2017	5,292,558	1,581,502	2,374,219
14	2018	5,121,995	1,530,535	2,297,705
15	2019	4,485,271	1,340,272	2,012,073
16	2020	3,219,942	962,171	1,444,452
17	2021	3,509,263	1,048,625	1,574,240

No.	Year	Scenario 1	Scenario 2	Scenario 3
18	2022	3,824,745	1,142,896	1,715,764
19	2023	4,168,590	1,245,642	1,870,011
20	2024	4,543,346	1,357,625	2,038,125
21	2025	4,951,793	1,479,676	2,221,353

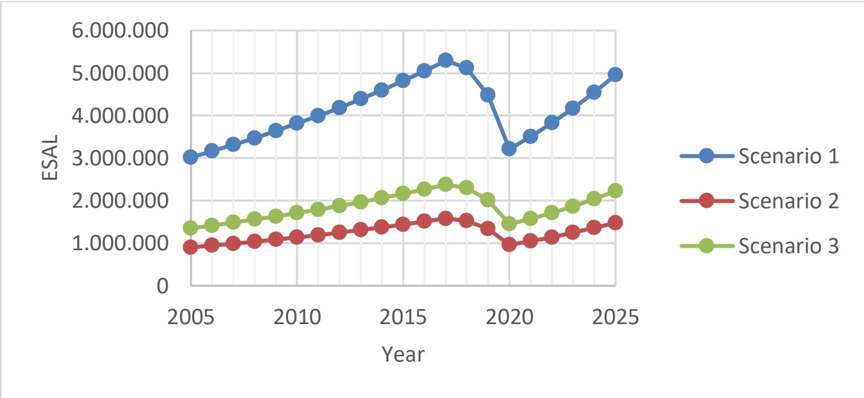


Figure 1. Graph of ESAL for Scenario 1, 2, and 3

The graph above shows that a gradual decrease in traffic occurred from 2017-2020. Moreover, the most drastic drop happened in 2020 due to the COVID-19 pandemic. However, in 2021 the traffic has begun to rise again and is expected to keep increasing in the upcoming years.

Among three scenarios, Scenario 2 had the lowest ESAL. Scenario 2 was able to generate the lowest VDF due to the changes in configuration and the number of axles. The vehicles with more axles tend to distribute the load more uniformly on the pavement; therefore, the damaging effect that is produced is less than the vehicles with a smaller number of axles. The single axle–single tire stresses the road pavement in two different areas, while the single axle–dual tire stresses the pavement in four different areas thereby, reducing the intensity of stress experienced by the pavement. Although Scenario 3 also had lower ESAL compared to Scenario 1, the values are not as low as Scenario 2. This result is due to the increase in AADT. Unlike Scenario 2, the AADT in Scenario 3 is increased because of the additional vehicles needed to carry the excess load.

Rehabilitation Cost

In order to estimate the rehabilitation cost for Scenarios 2 and 3, the cost is divided by the length of the road section and ESAL of the respective year to find the cost per km per ESAL (Rp/km/ESAL).

Table 10. Calculation of Rehabilitation Cost (Rp/km/ESAL)

Year	Total Cost	Cost Rp/km	ESAL	Cost Rp/km/ESAL
2018	Rp2,183,390,921	Rp167,953,147	5,121,995	Rp32.79
2019	Rp3,855,838,907	Rp296,602,992	4,485,271	Rp66.13
2021	Rp4,783,651,829	Rp367,973,217	3,509,263	Rp104.86
			Average	Rp67.93

The rehabilitation cost in 2020 is Rp3.07/km/ESAL. This value has a significant difference compared to the cost in other years. The low cost in 2020 was caused by the COVID-19 pandemic, which resulted in minimum road rehabilitation. Due to these unusual circumstances, in calculating the average cost, the cost in 2020 was not included in order to determine the average cost in normal conditions. From the calculation, the rehabilitation cost is Rp67.93/km/ESAL. After determining the average cost, the rehabilitation cost for Scenarios 2 and 3 is estimated by multiplying the cost with its respective ESAL.

Table 11. Rehabilitation Cost of Scenario 1, 2, and 3

Year	Rehabilitation Cost (Rp/km)		
	Scenario 1	Scenario 2	Scenario 3
2005	Rp204,815,621	Rp61,202,225	Rp91,879,394
2006	Rp214,646,771	Rp64,139,932	Rp96,289,605
2007	Rp224,949,816	Rp67,218,648	Rp100,911,506
2008	Rp235,747,407	Rp70,445,143	Rp105,755,258
2009	Rp247,063,282	Rp73,826,510	Rp110,831,510
2010	Rp258,922,320	Rp77,370,183	Rp116,151,423
2011	Rp271,350,591	Rp81,083,952	Rp121,726,691
2012	Rp284,375,420	Rp84,975,981	Rp127,569,572
2013	Rp298,025,440	Rp89,054,828	Rp133,692,912
2014	Rp312,330,661	Rp93,329,460	Rp140,110,172
2015	Rp327,322,533	Rp97,809,274	Rp146,835,460
2016	Rp343,034,014	Rp102,504,119	Rp153,883,562
2017	Rp359,499,647	Rp107,424,317	Rp161,269,973
2018	Rp347,914,070	Rp103,962,359	Rp156,072,734
2019	Rp304,664,283	Rp91,038,622	Rp136,671,068
2020	Rp218,716,131	Rp65,355,922	Rp98,115,102
2021	Rp238,368,407	Rp71,228,341	Rp106,931,027
2022	Rp259,797,727	Rp77,631,769	Rp116,544,127
2023	Rp283,153,542	Rp84,610,865	Rp127,021,444
2024	Rp308,609,046	Rp92,217,381	Rp138,440,671
2025	Rp336,352,999	Rp100,507,724	Rp150,886,488

The ESAL and rehabilitation costs are assumed to be linearly proportional to each other; therefore, as the ESAL gets higher, the rehabilitation cost will also get higher. It can be seen that the highest cost was found in 2017 when the ESAL was at its peak and decreased gradually until it reached its lowest in 2020. The savings for each scenario is calculated by finding the difference between rehabilitation cost in Scenario 1 with Scenario 2 and 3.

Table 12. Total Cost Savings of Scenario 2 and 3

Year	Cost Savings (Rp/km)		Year	Cost Savings (Rp/km)	
	Scenario 2	Scenario 3		Scenario 2	Scenario 3
2005	Rp143,613,396	Rp112,936,227	2016	Rp240,529,895	Rp189,150,452
2006	Rp150,506,839	Rp118,357,166	2017	Rp252,075,330	Rp198,229,674
2007	Rp157,731,167	Rp124,038,310	2018	Rp243,951,711	Rp191,841,336
2008	Rp165,302,263	Rp129,992,149	2019	Rp213,625,661	Rp167,993,215
2009	Rp173,236,772	Rp136,231,772	2020	Rp153,360,209	Rp120,601,029
2010	Rp181,552,137	Rp142,770,897	2021	Rp167,140,066	Rp131,437,380
2011	Rp190,266,640	Rp149,623,900	2022	Rp182,165,958	Rp143,253,600
2012	Rp199,399,438	Rp156,805,847	2023	Rp198,542,678	Rp156,132,099
2013	Rp208,970,611	Rp164,332,528	2024	Rp216,391,665	Rp170,168,375
2014	Rp219,001,201	Rp172,220,489	2025	Rp235,845,275	Rp185,466,511
2015	Rp229,513,258	Rp180,487,073			

By calculating the difference between each scenario, the percentage of savings can be calculated to determine the scenario that has the highest savings. From the calculation, it was found that Scenario 2 was able to save as much as 70.12% of the rehabilitation cost, while Scenario 3 was able to save 55.14%. By looking at this result, it was proven that adding more axles to the overloaded vehicles is more effective in saving rehabilitation costs compared to adding more vehicles to accommodate the excess load.

CONCLUSION

From the data processing and analysis done by writer, it can be concluded that:

1. The lowest average VDF was found in Scenario 2, followed by Scenario 3, and lastly, Scenario 1. Scenario 1 having the highest VDF shows that overloads are impacting the VDF, the greater the load, the higher the damaging effects.
2. Although both Scenario 2 and 3 are in ideal condition, Scenario 2 still has lower VDF compared to Scenario 3. This proves that other than the vehicle load, configuration and number of axles also have a significant impact on the VDF. By adding more axles, the load will be distributed to the pavement more uniformly with lower stress, thus, reducing the damaging effects.
3. ESAL is directly proportional to VDF and AADT, then it is natural that Scenario 2 had the lowest ESAL among all scenarios. Although Scenario 3 had higher AADT compared to Scenario 1, Scenario 3 had lower ESAL. This shows that in this case, the VDF had more impact in ESAL than the AADT.
4. Scenario 2 managed to save rehabilitation costs as much as 70.12%, while Scenario 3 saved 55.14%. This revealed that adding more axles on the overloaded vehicles was more effective in reducing the rehabilitation cost compared to adding more vehicles.

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