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REVEALING THE IMPACT OF LOSSES ON FLEXIBLE PAVEMENT DUE TO VEHICLE OVERLOADING

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Pavement overload has become a significant concern in Indonesia due to its damaging effects on the pavement system, where most roads use flexible pavements. Meanwhile, overloading is also typical in other developing countries, causing everything from damage to accidents to the detriment of road users and operators. The current problem is that there is no definite knowledge of handling these overloaded vehicles, which has adverse effects. Therefore, this study aims to reveal the impact of losses caused by overloaded vehicles on flexible pavement.

This research uses vehicle traffic load data to examine actual conditions in the field, which are converted to axle load values for each vehicle and used to determine pavement condition using the truck factor approach, mechanistic-empirical design, pavement smoothness level, and the impact of overloading due to fuel consumption by vehicles on flexible pavement.

The results show that overloaded vehicles harm the flexible pavement. The increase in truck factor values for all vehicles in overloaded vehicles beyond the maximum allowable load results in more damage to the flexible pavement with an increase in truck factor values up to 83 %. The effect of overloading can be mitigated by increasing the thickness of the asphalt layer and the modulus of asphalt, so it is essential to pay attention to the quality of asphalt in anticipation of this overloading. To anticipate the overload phenomenon, it was found that the thickness of the asphalt overlay in the range of 170–205 mm could mitigate this detrimental effect. In addition, overloading affects the flexible pavement roughness and vehicle fuel consumption. Increased roughness and fuel consumption will increase road maintenance costs and affect driving comfort and safety. In addition, excessive fuel consumption can pollute the surrounding environment

Keywords: flexible pavement, mechanistic-empirical pavement design, overloading, truck factor, excess fuel consumption

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1. Introduction

The type of road commonly used in Indonesia is flexible pavement with asphalt binder. Meanwhile, roads are necessary to serve vehicle loads to support activities in an area. Expanding the network of roads and highways increases the availability of resources and facilitates the movement of goods and services, leading to increased economic efficiency [1]. Road improvements have been shown to increase individual economic activity and boost regional economic growth by facilitating market access and trade [2]. [3] found that infrastructure development, especially road infrastructure, significantly encourages economic growth.

However, there are currently many problems related to on-road performance. The study [4] is based on the data mining method; the traffic load factor is the factor that most influences the predicted value of pavement performance. One of the causes of traffic load uncertainty is the existence of overloading conditions.

Overloading of vehicles is a common occurrence in developing countries. Road damage caused by overloaded vehicles is a significant cause of motor vehicle accidents in Indonesia [5]. According to [6], approximately 79 % of the overall damage was attributed to the degradation of roads due to overload. Moreover, [5] states that vehicle accidents can also be attributed to brake failure resulting from the overloading of vehicles.

Excessive load on pavements in Indonesia has become a major issue, causing significant harm to the country's flexible pavement system. Several studies have highlighted the adverse effects of overloading on pavement infrastructure. [7] have pointed out that the current Equivalent Axle Load (EAL) equation used in Indonesia needs to be more suitable for the country's situation. This is because many heavy vehicles in Indonesia carry excessive loads, resulting in the early deterioration of the flexible pavement system.

Meanwhile, [8] found that drivers consider trucks an affordable and efficient mode of transportation. Hence, the potential for overloaded vehicles increases because trucks are more efficient for transporting goods.

Therefore, research devoted to the condition of overloaded vehicles has scientific relevance due to meeting the need for the development and rehabilitation of transportation infrastructure, such as roads that continue to increase along with the increase in population and settlements supported by the mode of transportation. Thus, research related to overloading is needed to update and sustain to anticipate and give more attention to the adverse effects of this condition.

2. Literature review and problem statement

Vehicle overloading impacts the flexible pavement, resulting in losses to the road infrastructure. The works [9] revealed violations related to oversized vehicle dimensions in line with the overloading of vehicles by business actors. This significantly contributes to the road surface's deterioration and threatens road safety [10]. Besides that, [11] suggested limiting vehicle overloading, especially on low-speed road sections in high-temperature regions.

Currently, the Indonesian government still permits practitioners to choose their pavement design methods, especially in the thick layer of added pavement, which still allows using the AASTHO 1993 method with high traffic intensity [12]. However, the Mechanistic-Empirical Pavement Design Guide offers substantial advantages over the AASHTO 1993 Guide [13]. Furthermore, [14] found that overloaded vehicles can significantly increase the variation in distress predicted by MEPDG compared to AASHTO 1993 empirically. So, there is a need to update and implement the old methods adopted in Indonesia, especially in facing the challenge of vehicle overload.

Overloaded vehicles have a detrimental impact on flexible pavements. The same case is found when there is no traffic control, causing damage and shortening pavement life [15]. Although overloaded vehicles are less common than vehicles with the correct load, their ability to cause harm is much greater, making them a significant contributor to the deterioration of pavement structures [16]. However, precisely how the role of these overloaded vehicles adversely affects the flexible pavement structure has yet to be discovered.

The studies conducted by [17] demonstrate that pavement's serviceability level has reduced significantly by 60–80 % due to overloaded vehicles. This highlights the negative impact of overloading on pavement infrastructure. In addition, [18] stated that nearly 50 % of pavement failure in Indonesia is caused by overloading, underscoring its significant role in pavement deterioration. Therefore, [19] highlighted the problem of overloaded trucks in Indonesia, which causes early pavement deterioration, especially on national highways such as the Pantura National Road. These studies underscore the urgent need to address overloading in Indonesia to ensure the longevity and sustainability of the country's pavement network. However, it is not yet known which parts of the pavement structure are most affected by overloading, potentially making it challenging to address this condition accurately.

Besides the decrease in road service life, vehicle overloading is thought to affect fuel consumption. The amount of fuel a vehicle consumes is significantly impacted by the rolling resistance of its tires, which in turn is influenced by the road surface characteristics [20]. As a significant contributor to emissions in road transportation, reducing emissions is a crucial goal in the current planning and designing of road alignments, focusing on the vehicle use phase [21]. So, knowing how these overloaded vehicles contribute to the environment due to vehicle fuels is essential. In addition to the effects of overloading on the pavement, it will also affect road maintenance.

Conducting this research is essential because of the unresolved issue of overloading in emerging nations, necessitating the exploration of alternative remedies. Still, there is no obvious concern regarding the adverse effects that can be anticipated in the short term before the implementation of a definitive Zero Overloaded Trucks Policy in Indonesia. Examining how this truck factor affects the vehicle in terms of vehicle axes, excess load, and the environmental impact caused. The research aims to reveal the impact of losses incurred due to excessive vehicle loads as an additional insight related to new perspectives for stakeholders and practitioners in managing sustainable road conditions. The expected results can provide more insight to evaluate this phenomenon and provide alternative solutions.

3. The aim and objectives of the study

The aim of this study is to identify the disadvantages caused by the phenomenon of overloaded vehicles traveling on flexible pavements. This will provide new insights for road administrators regarding this phenomenon to create effectiveness and efficiency in road management.

To achieve this aim, the following objectives are accomplished:

– to investigate the weight of overloaded vehicles in the field to determine Truck Factor for every specific vehicle category;

– to analyze the impact of overloaded vehicles on flexible pavement structures;

– to analyze the added pavement thickness and cost increase due to the effect of overloading on vehicles;

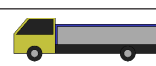
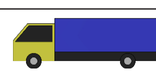
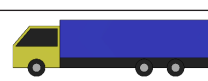
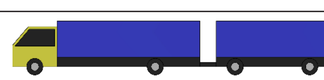
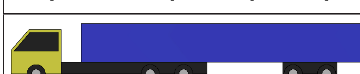
– to identify the effect of vehicle fuel consumption based on the surface roughness level of flexible pavement.

4. Materials and methods

This research primarily investigates the impact of overweight vehicles on flexible pavement. The study posits that the overloaded status of vehicles can have detrimental effects on the pavement, expenses, and the environment. The research methodology employs a mechanistic approach that leverages load data from heavy vehicles traversing the pavement and elucidates the elements contributing to flexible pavement degradation. The Equivalent Single Axle Load (ESAL) model is employed for vehicles, the MEPDG model for predicting damage, and the RSI model for predicting excess fuel consumption. The investigation was carried out on Indonesia's national highways, and Table 1 presents the prescribed upper limit for the load capacity of each truck category.

Table 1

Maximum allowable load

Vehicle class		Maximum legal load per axle (kN)				
		1^{st}	2^{nd}	3^{rd}	4^{th}	5^{th}
	6A	60		0	0	0
	6B	60	100	0	0	0
	7A	60	180		0	0
	7B	60	100	180		0
	7C	60	100	210		

Data from the WIM tool was used to determine the weight of each passing vehicle obtained from the relevant Department of Public Works and Highways displayed in Fig. 1, which is used to recognize the load distribution of each type of heavy vehicle, and the IRI value is used to describe the pavement condition.

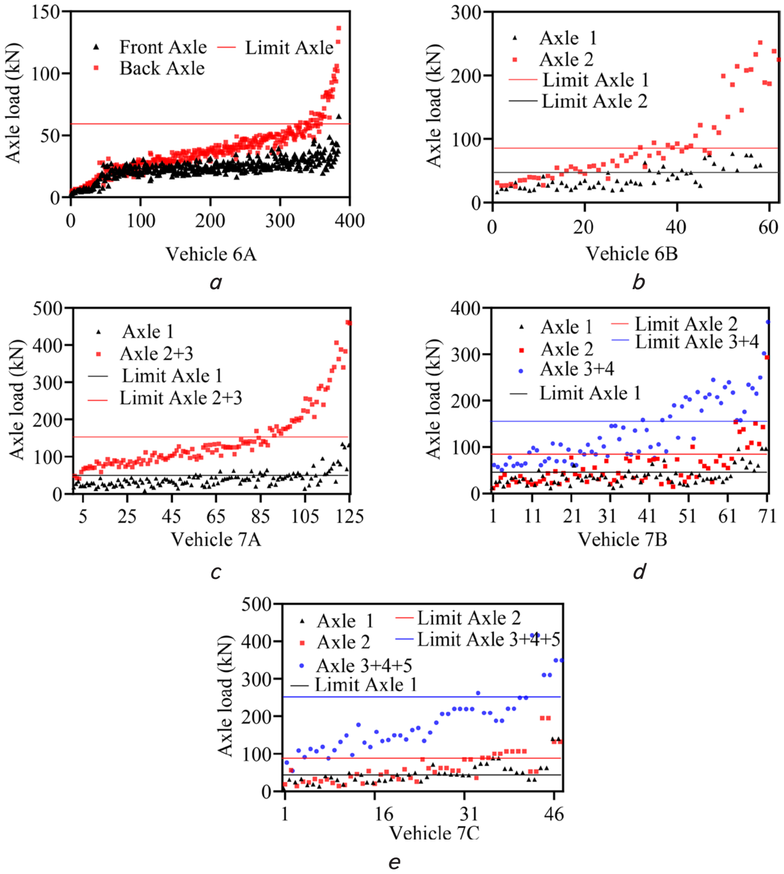


Fig. 1. Vehicle load distribution: *a* — vehicle class 6A; *b* — vehicle class 6B; *c* — vehicle class 7A; *d* — vehicle class 7B; *e* — vehicle class 7C

The data on a load of heavy vehicles was converted into the equivalent standard axle load (ESAL) using the model developed by [22, 23], which will be combined to obtain the Truck Factor for each vehicle and then calculate how this damage affects the flexible pavement using equation (1):

$$ESAL=(k)\times\left(\frac{P_x}{P_{ref}}\right)^a, \qquad (1)$$

where P_x is the applied axle load; P_{ref} is the standard axle load; a is the coefficient function of pavement type in this case reviewed based on fatigue (4). The value of k is determined by considering various factors, such as the composition of pavement, type of axle, and weight exerted by the wheel. This determination is based on a rigorous analysis of different pavement types, axle configurations, and wheel loads calculated using equation (2):

$$k=a_1\times\left(H_{asp}\right)^{a_2}\times\left(H_{gra}\right)^{a_3}\times$$
$$\times\left(E_{asp}\right)^{a_4}\times\left(E_{subg}\right)^{a_5}\times e^{(a_6\times AP)}, \qquad (2)$$

where H_{asp} – thickness of asphalt layer (m); H_{gra} – thickness of granular layer (m); E_{asp} – stiffness modulus of asphalt layer (MPa), E_{subg} – stiffness modulus of subgrade (MPa); AP – Axle Parameter shown in Table 2; for constants a_1–a_6 shown in Table 3.

This method is considered because Indonesia adopts pavement design based on ESAL. The losses from vehicle overload impacts will be calculated based on the pavement layer thickness requirement criteria based on the equation from [24] using equation (3):

$$H=\left(\frac{0.077}{E^{0.65}}\right)\times\left(\log N+8.5E^{0.12}\right)^{3.64}, \qquad (3)$$

where H is pavement thickness (mm); E is modulus of elasticity of asphalt mixture (MPa); N is traffic in million ESAL. The equation will be combined with the Mechanistic-Empirical Pavement Design (MEPDG) [25] using equation (4) to provide an alternative solution for flexible pavement:

$$RC=\frac{100}{1+e^{(a)(c)+(b^*t)(d)}}, \qquad (4)$$

where RC – percent of cracks reflected; t – year; a, b – regression fitting parameters determined through the calibration process using equations (5) and (6); c, d – user-defined cracking progression parameters, in this case, using the Arizona calibration:

$$a=3.5+0.75\left(H_{eff}\right), \qquad (5)$$

$$b=-0.688684-3.37302\left(H_{eff}\right)^{-0.915469}. \qquad (6)$$

Table 2

Axle Parameter (AP)

Single axle	Single axle	Tandem axle	Tandem axle	Tridem axle	Tridem axle
Single wheel	Dual wheel	Single wheel	Dual wheel	Single wheel	Dual wheel
1.0	2.0	2.7	4.1	3.8	5.2

Table 3

Constant *k*

a_1	a_2	a_3	a_4	a_5	a_6	a_7
1.275E+01	–9.370E–01	8.280E–02	8.280E–02	–2.939E–01	2.963E–01	–1.421E+00

The regression matching parameters in (5), (6) are a function of the adequate HMA layer thickness in (H_{eff}). *IRI* values were predicted using the equation from MEPDG [25] using equation (7):

$$IRI = IRI_0 + C_1(RD) + \\ + C_2(FC_{Total}) + C_3(TC) + C_4(SF), \quad (7)$$

where IRI_0 – initial value of *IRI*; *RD* – average rut depth (in); FC_{Total} – fatigue cracking area (%); *TC* – transverse crack length due to cold temperature, but Indonesia is tropical, so it is not considered; *SF* – Site Factor calculated using equation (4); C_1–C_3 – global calibration coefficients from MEPDG 2015:

$$SF = Age^{1.5} \times \left\{ \ln\left[(Precip+1)(F1+1)_{P02} \right] \right\} + \\ + \left\{ \ln\left[(Precip+1)(PI+1)_{P200} \right] \right\}, \quad (8)$$

where *Precip* – average precipitation (in); *F*1 – average frost index; *PI* – subgrade plasticity index; *P*02 – percentage passing 0.02 mm; *P*200 – percentage passing 0.075 mm.

This will determine excess fuel consumption based on the XRSI prediction model developed in [26] using equation (9):

$$\Delta\hat{E}(v, IRI) = \begin{pmatrix} -3.864\text{E}-01 * IRI + 8.4\text{E}- \\ -03 * IRI^2 + 1.6218\text{E}-04 * IRI * v^2 \end{pmatrix} * \\ *(1 + 3.42\text{E}-01 * V), \quad (9)$$

where $\Delta\hat{E}(v, IRI)$ – energy consumption per vehicle distance; *IRI* – pavement smoothness (in/mile); *v* – average speed (mph); *V* – local roughness variances. Furthermore, the percentage change in fuel consumption against the roughness level and average vehicle speed can be calculated using equation (10):

$$\Delta IFC(v, IRI) = \frac{\Delta\hat{E}(v, IRI = k) - \hat{E}(v, IRI)}{\hat{E}(v, IRI^0)} * 100\%, \quad (10)$$

where $\hat{E}(v, IRI^0)$ – primary instant fuel consumption of a vehicle under standard *IRI* conditions in Indonesia= =3 m/km (190.08 in/mile); $\hat{E}(v, IRI)$ – *IRI* value (in/mile); $\Delta\hat{E}(v, IRI = k)$ – prediction model of XRSI (in/mile). Fig. 2 shows this study, including a schematic flowchart illustrating the analysis.

The flowchart illustration of the analysis process is the steps taken by the author in conducting data analysis to reveal the impact of losses from overloaded vehicle loads, as shown in Fig. 2.

5. Results of flexible pavement losses due to overloaded vehicles

5. 1. Overloaded vehicle based on a Truck factor of the vehicle

Fig. 3 displays the values of the truck factor for each type of vehicle.

Truck Factor values for various vehicle types and loads are indicated. These conditions include a legal vehicle load condition, an average vehicle load condition determined from actual vehicle weight, a maximum allowable vehicle load condition, an excessive average vehicle load condition determined from actual vehicle weight, and an overloaded vehicle condition.

The Truck Factor was determined by considering all vehicles with a 25 cm asphalt layer and a modulus of elasticity of 1,225 MPa. The road is constructed with a sub-base layer with a thickness of 30 cm and a subgrade with a strength of 86 MPa. This information shows that vehicle 6B has the most significant truck factor. The pavement is overloaded in four specific spots due to the excessive weight of the overloaded single-axle dual wheels. Although the load intensity is reduced, the road load distribution is uneven. Elevated point pressures exerted on the road surface have the potential to cause destruction to the flexible pavement.

The occurrence of overloading contributes to an increase in the truck factor, exceeding 80 %, as depicted in Fig. 4 for vehicle 7B. In contrast, for vehicles 6B, 7A, and 7C, the truck factor ranges from 60 % to 70 %. The relatively low increase in truck factor caused by overloading only applies to vehicle 6A.

The truck factor is determined by comparing the load-limited truck factor of vehicles with the overall truck factor of all vehicles. However, these principles prioritize the evaluation and strategic consideration of the impact of overloading on pavement.

The impact of overload on vehicles based on four simulations of field conditions on truck factor values is shown in Fig. 5.

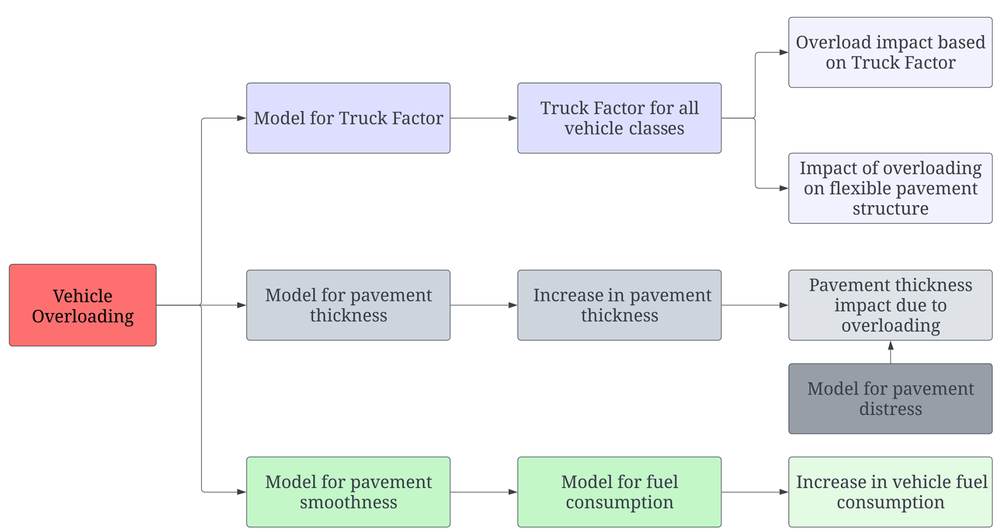


Fig. 2. Diagrammatic outline of the research investigation

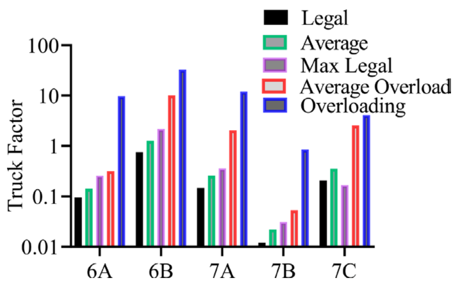


Fig. 3. Truck Factor for all vehicle types

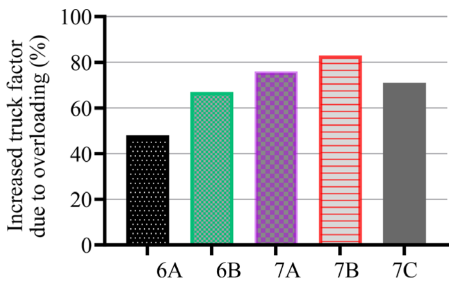


Fig. 4. Truck Factor increase due to vehicle load

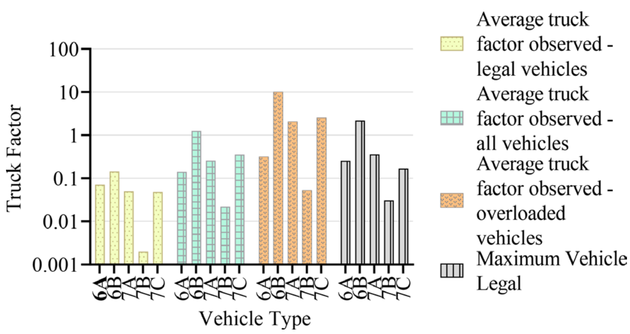


Fig. 5. Impact of overloaded vehicles on Truck Factor on roads

Fig. 5 demonstrates the correlation between overloaded vehicles and pavement performance by analyzing the Truck Factor of vehicles carrying the legal maximum load versus the average Truck Factor of overloaded vehicles, legal vehicles, and all vehicles combined. Notably, the results reveal that the Truck Factor for overloaded vehicles, such as vehicles 6A and 7B, is nearly identical to vehicles carrying the legal maximum load. However, the Truck Factor is considerably reduced for overloaded vehicles compared to the legal maximum load. Additionally, even legal load vehicles experience a significant reduction in their Truck Factor when the pavement sustains more damage than the permitted maximum load vehicle.

5. 2. Impact of overloaded vehicles on flexible pavement structure

According to the findings in Fig. 6 by using equation (2), increasing the thickness of the asphalt layer can lead to a reduction in the truck factor value, which can, in turn, minimize the impact of overloaded vehicle axle loads. Interestingly, the thickness of the granular layer seems not to affect the truck factor value, allowing for some variation. While the subgrade modulus can be disregarded due to its lower value than the truck factor, it's worth noting that the asphalt modulus may play a role in reducing the truck factor value.

This occurs because the load distribution pattern is centered on the asphalt and spreads to the subgrade, forming a triangle where the asphalt layer acts as a support and gradually flows to the subgrade. Thus, the stress decreases significantly when the load reaches the subgrade.

5. 3. Thickness of added pavement and increased cost due to the effect of overloaded vehicles

The pavement thickness displayed in Fig. 7 by using equation (3) indicates a correlation between pavement thickness, pavement age, and road traffic. Typically, a thickness of approximately 83 mm supports normal loads. However, an overloaded vehicle load at the start of the year necessitates a thickness of 89 mm, which increases to 102 mm by year 10, representing a 16 % increase. Notably, there is a difference of up to 7.4 % between the thickness requirements for standard versus overloaded vehicle loads.

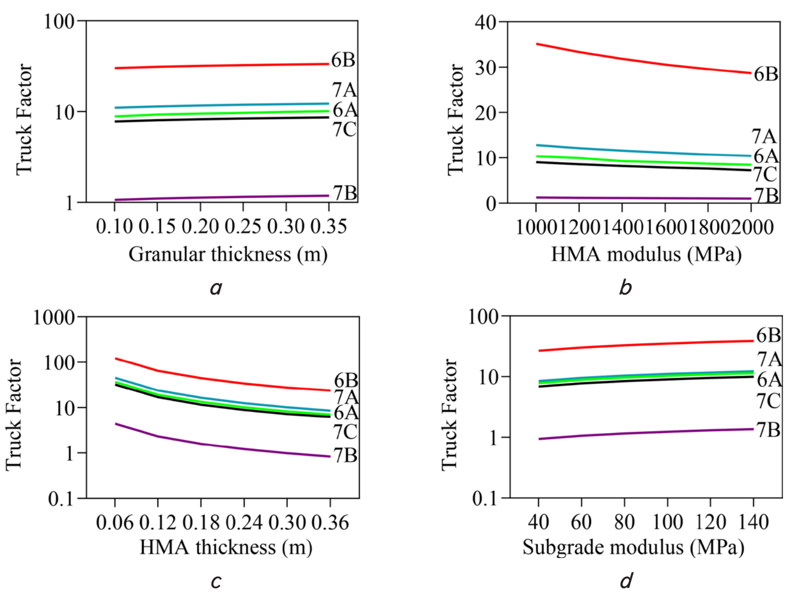


Fig. 6. Impact of truck factor on flexible pavement structure: *a* – overload on pavement thickness; *b* – overload on pavement modulus; *c* – overload on granular thickness; *d* – overload on subgrade modulus

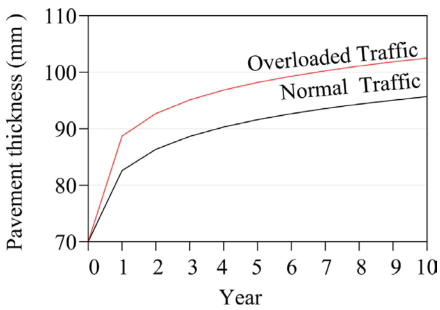


Fig. 7. Pavement thickness increase

The cost has a maximum increase of 24 % due to overloading of vehicles. This increase is calculated based on the percentage increase in pavement thickness requirement as shown in Fig. 7. In contrast, for standard vehicles, there is a 16 % increase in cost when calculated based on the cost of pavement thickness requirements shown in Fig. 8. At the beginning of the plan year, the cost increase due to overloaded vehicles is 7 % compared to standard vehicles, resulting in a cost increase of only 4 %. This significant difference requires the relevant agencies to carefully deal with the consequences of overloading, which causes considerable losses to road users and management.

After obtaining the value of the added layer thickness, the calculation is carried out again using the MEPDG method by using equation (4) as an alternative solution to the required added layer thickness based on overloading conditions. Fig. 9 presents thickness variations in the pavement design for ten years, depending on the previous calculation findings. This approach incorporates overloading as a solution for the national road segment.

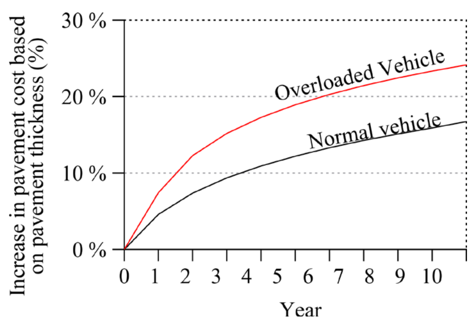


Fig. 8. Cost increase based on pavement thickness

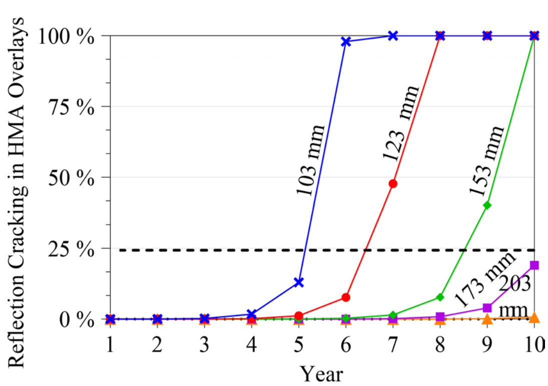


Fig. 9. Thickness of overlay based on reflection cracking

The dashed black line denotes the threshold for reflection cracking damage, with a 90 % reliability level. After evaluating four thickness variations for the 10-year design plan, only two thicknesses meet the criteria, 173 mm and 203 mm. Therefore, to ensure the thickness of the additional layer, it is advisable to use a layer thickness range of 170–205 mm on road sections with overload conditions.

5. 4. Effect of vehicle fuel consumption based on the roughness level of flexible pavement surface

The IRI values for each load data set are significantly different, as shown in Fig. 10 by using equation (7). The road condition and handling performance are affected by the different IRI values for each load data set.

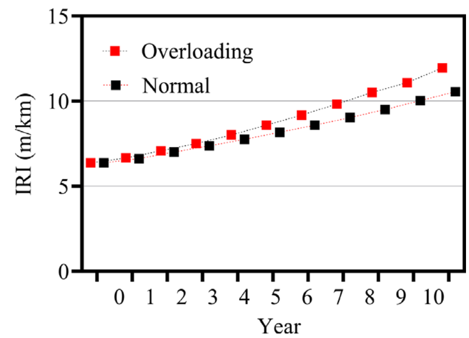


Fig. 10. Overload vs. normal *IRI* value

Two separate lines indicating decreasing *IRI* values can be seen on the increasing *IRI* value graph. Overload causes an increase in the red *IRI* value graph, while normal load causes an increase in the black *IRI* value graph. From an initial 6.37 m/km in the 10th year due to normal load, the difference in the increase in *IRI* values for all segments averaged overload increased to 11.95 m/km, while the rise due to normal load was 10.55 m/km.

The prediction of excessive fuel consumption due to a decrease in the smoothness value of the flexible pavement is shown in Fig. 11 by using equation (10).

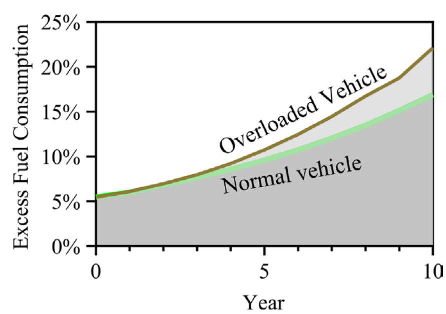


Fig. 11. Excessive fuel consumption under overload and normal load

Overloading has a detrimental effect on fuel consumption, negatively affecting vehicle performance. Vehicle overloading can lead to greater fuel consumption due to functionally failing road conditions. This excess fuel consumption reaches 22 % at year 10, with a 6 % difference from the standard vehicle load.

6. Discussion of the adverse effects of overloading on flexible pavement

According to the results obtained based on the observed vehicle load data, Fig. 3, vehicle 6B received the highest truck factor value with a dual-wheel single-axis configuration, followed by vehicle 6A with a single-wheel single-axis configuration when compared to dual-axis vehicles with dual wheels such as 7A, 7B and 7C. This single-wheel single-axis vehicle provides more damage effect on flexible pavement. This is because the load distribution on the dual axis of the dual wheel is better. After all, the load can be spread evenly. So, road administrators need to pay attention to these dual axes by minimizing their use and switching to wide-base tires because they can reduce the damage caused by conventional tires [27, 28].

As shown in Fig. 4, axle configuration and axle load are the most essential factors in determining the truck factor. The vehicle with the highest truck factor improvement due to overloading is 7B, which has a lower truck factor value than 6A. Increasing the number of vehicle axles and wheels evenly distributes the vehicle's weight over a larger area of the road surface, thereby reducing the stress at the point of contact between the tires and the pavement that results in road damage.

Fig. 5 shows that the effect of overloaded vehicles is enormous compared to vehicles with the legal maximum load and very significant compared to vehicles in actual traffic. Unlike [29], which found that the effect of overloaded vehicles is not very large compared to vehicles complying with the maximum legal load. This difference is due to variations in vehicle density, weight, and axle load regulations in different countries. The phenomenon of overloading often occurs in developing countries, while the research conducted by [29] in developed countries thus obtained different results.

Due to the direct impact of excessive vehicle load in Fig. 6, which is very sensitive to the asphalt surface and the quality of asphalt material, which are essential factors in the performance and durability of asphalt pavement, in addition to considering the vehicle weight distribution, it is also necessary to consider the additives, fiber reinforcement, and aggregate quality on the asphalt surface to ensure better performance and durability [30–32].

The increase in road handling costs is up to 7 % higher than in the absence of excess vehicles passing by based on Fig. 7. It affects the increase in handling fees that will be burdensome compared to conditions in the absence of extra vehicles, with a rise in the expenses exceeding 20 % in excess vehicle conditions shown in Fig. 8.

Based on Fig. 9, 170–205 mm thickness is obtained to anticipate overloading of vehicles using Arizona local calibration because it is considered to have a freezing index of 0, which is in line with Indonesia [33]. Where the results of this additional layer thickness allow it to be a solution for road administrators when compared to the design of road construction against overloading carried out by [34] because currently, the roads that have been built are more dominant than the construction of new roads, so as a solution for road management, especially vehicle overloading this is beneficial.

Fig. 10 shows that overloading will harm road users and operators as the road will experience functional failure. Overloaded vehicles significantly increase the damage to the road, which affects the driving comfort and safety of road users. This is confirmed by the correlation between vehicle overloading and accidents and their severity [35].

Based on Fig. 11, there is an excess of vehicle fuel consumption based on the pavement smoothness level of up to 22 % in year 10. Excess vehicle fuel consumption will increase emissions and cause air pollution and global warming. This excess fuel consumption is also influenced by driving habits and traffic conditions, which have negative environmental and economic impacts [36, 37].

The limitation of this research is that traffic calculations still use the Equivalent Single Axle concept, resulting in the weakness of calculations that are less accurate than the Axle Load Spectra concept related to the use of MEPDG, and local calibration is needed to improve the accuracy of its application at each location. To support this, assistance from the government and road administrators is required. The assumptions related to mechanical damage and alpha exponents are based on only one type of damage, namely fatigue. Still, many types of damage occur on flexible pavements based on limitations related to using models that can only review a kind of damage. Hence, it needs to be studied because every damage assumption produces different outputs.

7. Conclusions

1. The highest truck factor based on overloading conditions is achieved by vehicle 6B, followed by 6A; these vehicles are single-axle dual-wheel and single-wheel vehicles, compared to vehicles 7A, 7B, and 7C, which have a higher percentage increase in truck factor due to overloading but lower truck factor values. This proves that vehicle axes impact overloading and pavement losses, so it is necessary to use axes with a broader footprint to reduce the effects of this overloading.

2. The overloading of vehicles traveling on flexible pavements dramatically influences the thickness of the asphalt layer and the material strength of the asphalt compared to the granular thickness and subgrade strength. Increasing the thickness of the asphalt layer from 0.06 m to 0.36 m significantly reduces the truck factor value for all types of vehicles. Similarly, improving the modulus value of asphalt in vehicle 6B, which has the highest truck factor value, can be achieved by enhancing the quality of the asphalt mixture. So, to reduce the effect of overloading, it is necessary to focus on asphalt quality in new road construction and maintenance.

3. The need for additional layer thickness and increased costs on flexible pavements increases by more than 7 % due to overloading; an alternative solution for recommending different layer thicknesses due to overloading is 170–205 mm. This indicates the need for increased costs in road maintenance due to overloaded vehicles.

4. Overloaded vehicles have been shown to consume more fuel than customarily loaded vehicles based on road roughness. This will increase energy use and increase emissions that impact the environment. So, there is a need for significant treatment of overloaded vehicles.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

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Data availability

The manuscript has no associated data.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

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