Journal of the Eastern Asia Society for Transportation Studies, Vol.8, 2010

Analysis of Loss Cost of Road Pavement Distress due to Overloading Freight Transportation

Agus Taufik MULYONO
Associate Professor
Civil and Environmental Engineering,
Faculty of Engineering
Gadjah Mada University, Yogyakarta
E-mail: atm8002@yahoo.com

Danang Parikesit
Professor
Center for Transportation and Logistics Studies (PUSTRAL)
Gadjah Mada University, Yogyakarta
E-mail: dan-dan@indo.net.id

Max ANTAMENG
Directorate General of Highways
Ministry of Public Works
Jl. Patimura No. 20, Jakarta
E-mail: cenrma@yahoo.com

Rahmad RAHIM
Regional Development Planning Agency
Provincial Government of Riau
E-mail: adekrahim@yahoo.co.id

Abstract: This paper explains the analysis to calculate road pavement distress loss cost resulted from overloading and therefore the amount of loss cost the overload car users shall bear can be determined. Overloading heavy vehicle causes road pavement structural distress and service lifetime decreasing during design lifetime. The presence of overloading is indicated by the width area of rutting which is more than 60% of total road structural distress per km and by real maximum axle load (MAL) of the heavy vehicle which is larger than its standard MAL. The loss cost of road pavement distress due to overloading is calculated based on damage factor (DF) and deficit design life (DDL). The loss cost the overload car user shall bear is 60% of total DFC (damage factor cost) and DDLC (deficit design life cost), considering that not all pavement structural distresses are absolutely caused by overloading freight transport.

Keywords: *overloading, damage factor, deficit design life*

1. BACKGROUND

Technical management of national road networks is expectedly able to improve regional accessibility and inter-node population mobility which is wider than that of regency road network (National Development Planning Agency, 2003; Mulyono & Riyanto, 2005; Mulyono, 2007). National road network connects provinces and regions/cities. The management of national road network, therefore, cannot be separated from the application of quality standard to achieve serviceable road pavement quality (Mustazir, 1999; Ma'soem, 2006) and maximal axel load (MAL) control for freight vehicles (Mulyono, 2007). Currently, the problems of fund inadequacy and overloading are considered as the main reasons for road distress as the two factors can be easily proved by directly testing the real MAL compared to the permissible MAL.

In Indonesia, the growth of investment in road development and growth of traffic are not proportional to the improvement in road serviceability although the same quality standard is used (Mulyono, 2007). The fact found in national road performance from 2002 to 2006 showed that the greater number of investment has no direct impact on the decrease of IRI value. The IRI value presents the condition of road pavement performance; the greater the IRI value the worse the pavement serviceability, and the reverse. The IRMS (Integrated Road Management System) data from Directorate General of Highways, Ministry of Public Works (2006) in Mulyono (2007) showed that during 2002-2006 the amount of investment in national road management had increased about 7.42% per year. The amount is still smaller than the LHR increase, about 16.34% per year. The condition indicates that amount of distress road has increased about 4.79% per year while IRI value has increased about 13.29% per year.

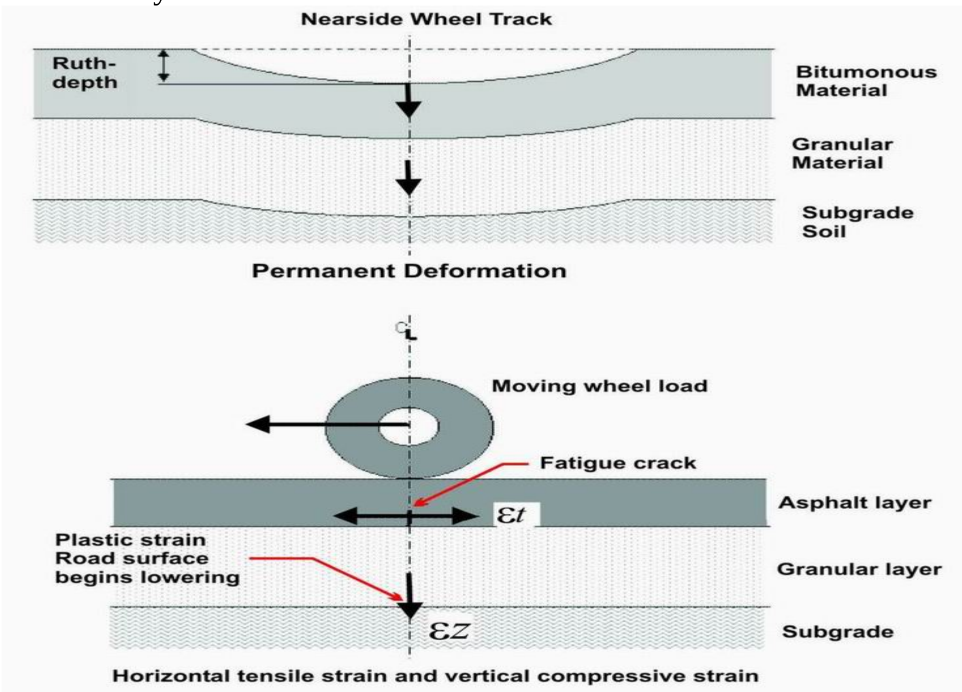
The phenomena sufficiently indicate that the decrease of road construction quality is caused by internal and external factors which contribute 45% and 55%, respectively, to the road pavement structural distress in Indonesia (Mulyono, 2008). The external factors are destructing variables outside the road construction, such as repetition of vehicle load and water puddle from spatial flood. The condition causes uncomfortability for traffic user, for example in Trans-North Coast of Java in which water puddle from spatial flood frequently happens and at the same time there are many overloading freight vehicles. The load repetition and overloading heavy vehicle have impact on the acceleration of road distress, meaning that the real service lifetime will be shorter than the design lifetime although the same quality standard is used during the road network construction related to freight transport distribution. Therefore, it is necessary to develop a model to analyze the impact of overloading freight transportation on the road distress.

Rahim (2000) had conducted an analysis of damage factor and deficit design life of road pavement due to overloading in several national road sections of Riau Province (Sumatera island). The road sections are part of Asia-ASEAN Highway. Meanwhile, Mulyono (2002) had analyzed the structural distress improvement on Manado-Bitung road section of North Sulawesi Province (Sulawesi island) which concluded that the width area of rutting was more than sixty percents of total distress width. This condition indicated that overloading had happened. However, the two studies did not analyze the loss cost of road pavement distress resulted from overloading. This technical study, therefore, focus more on the analysis of loss cost of road pavement distress which is based on damage factor and deficit design life due to overloading and therefore the amount of loss cost the overload car user shall bear can be determined.

2. LITERARY REVIEW

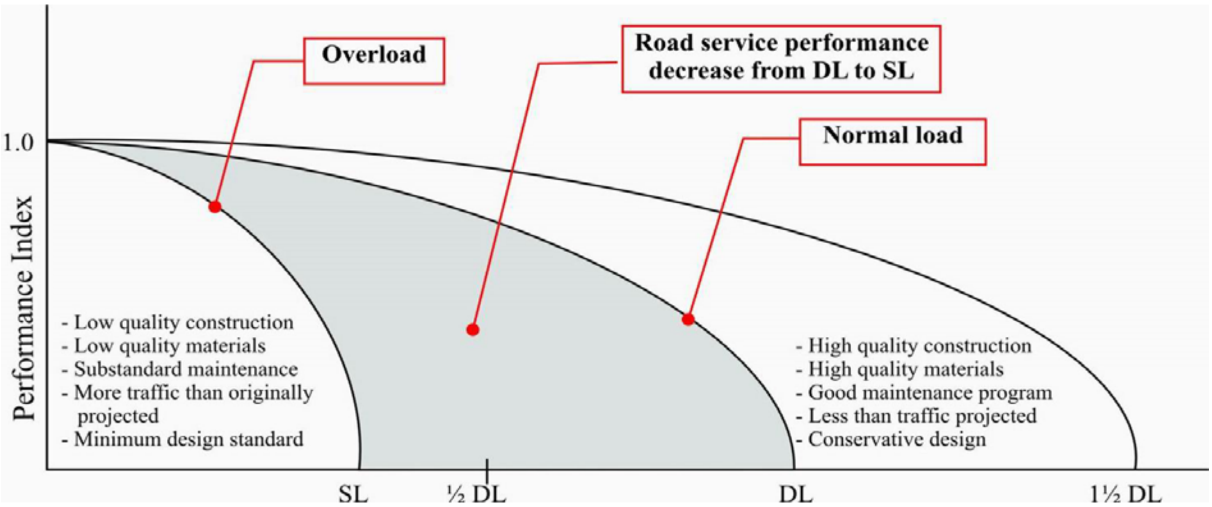
Brown & Brunton’s pavement thickness theory (1987) concluded that vehicle load supported by road pavement would result in two critical strains, i.e. (1) horizontal tensile strain (εt) occurred on the lower side of road surface; and (2) vertical compressive strain (εz) occurred on the upper side of subgrade. Figure 1 illustrates the two kinds of strains. If the existing tensile strain is larger than the inner horizontal tensile strain, pavement cracking will occur. Furthermore, if the vertical compressive strain is larger than the permissible ground vertical strain, plastic strain will occur that subsequently will initiate rutting and rut-depth. The plastic strain subsequently will cause permanent deformation on the pavement. The plastic strain is accelerated by long loading time due to slow speed of overloading freight vehicles. Based on the theory, Mulyono (2007) had stated that the greater the load repetition of overloading vehicles during the design lifetime, the increasingly lower the pavement performance. It is indicated by the decrease from the design lifetime (DL) to the service lifetime (SL), as indicated in Figure 2.

The Directorate General of Regional Infrastructure, Ministry of Settlement and Regional Infrastructure (2001), in Mulyono (2007), defined MAL as the vehicle axle load causing damage factor toward road pavement structure coming near or equaling to one. The Law Number 14 of 1992 of the Republic of Indonesia regarding Traffic and Road Transportation has clearly stated that capacities of road construction which are able to be provided include (1) less than 8 ton MAL, (2) 8 ton MAL and (3) 10 ton MAL. Figure 3 presents the typical configuration of heavy vehicle axle load.



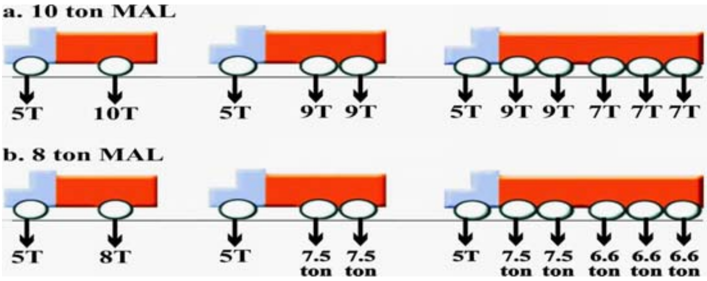
Source: Brown & Brunton (1987)

Figure 1 Illustration of horizontal tensile strain and vertical compressive strain as well as road surface deformation on flexible pavement due to vehicle load repetition



Source: Directorate General of Regional Infrastructure (2001) in Mulyono (2007)

Figure 2 Illustration of road pavement service quality decrease rate resulted from overloading vehicle



Source: Directorate General of Regional Infrastructure (2001) in Mulyono (2007)

Figure 3 Configuration of heavy vehicle axle load by MAL classification

Road pavement distress caused by vehicle weight and passage is stated in Equivalent Single Axle Load (ESAL), i.e. number showing the amount of single-axle passage of 8,160 kg (18,000 lbs) which possibly causes the same distress level if the axle load passes through for once (Directorate General of Highways, Ministry of Public Works, 1992). Furthermore, the formula of ESAL is categorized by axle type, i.e. single and tandem/tridem axle. ESAL is also called as damage factor (DF) value caused by overloading heavy vehicle as presented in Equation (1), Equation (2) and Equation (3). One of impacts resulted from overloading is the increase in equivalent number.

<u>Single axle (maximum axle load of 8 ton or 10 ton):</u>

$$\text{ESAL} = \left[\frac{\text{axle load (kg)}}{8160\ \text{kg}}\right]^4 \tag{1}$$

<u>Tandem axle (maximum axle load of 15 ton or 18 ton):</u>

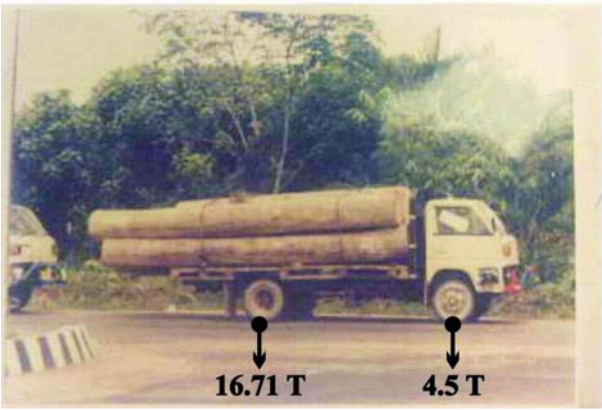
$$\text{ESAL} = 0.086\left[\frac{\text{axle load (kg)}}{8160\ \text{kg}}\right]^4 \tag{2}$$

<u>Tridem axle (maximum axle load of 20 ton or 25 ton):</u>

$$\text{ESAL} = 0.026\left[\frac{\text{axle load (kg)}}{8160\ \text{kg}}\right]^4 \tag{3}$$

On any vehicle axle type, freight transportation which exceeds the load capacity will increase the ESAL that subsequently increase the road distress level. For single-axle freight vehicle with 8 ton MAL, for example, the overloading of two times than the permissible load will increase the distress level by 16 times (see Equation (1)). Some illustrations of overloading vehicle are presented in Figure 4.

Road distress caused by overloading has resulted in additional cost on the distress management and vehicle operation. The Directorate General of Regional Infrastructure, Ministry of Settlement and Regional Infrastructure (2001) had determined that damage cost resulted from overloading per year for each ESAL can be calculated using Equation (4) and (5). Mulyono’s (2008) study concluded that pavement structural distress of majority national road in Indonesia which was caused by repetition of heavy vehicle load and road quality decrease was rutting. Furthermore, if the width area of rutting was more than sixty percents of total width area of distress per km of the surveyed road, it could be strongly concluded that the dominant cause was overloading vehicle. The rest (40%) was caused by other factors such as low quality construction, low quality material, substandard maintenance, and minimum design standard.

<table>
<tr>
<td>


</td>
<td>
<u>Standard Loading</u>
Load : 13.00 ton
Pay load : 8.25 ton
ESAL value : 0.1410 + 0.9238
: 1.0648
(8 ton MST)

<u>Overloading</u>
Load : 21.21 ton
Pay load : 12.69 ton (1.6 times of the standard
ESAL value : 0.0994 + 17.5853
: 17.6847 (16 times of the standard)
</td>
</tr>
<tr>
<td>


</td>
<td>
<u>Standard Loading</u>
Load : 21.00 ton
Pay load : 11.30 ton
ESAL value : 0.2923 + 0.9819
: 1.2743

<u>Overloading</u>
Load : 28.08 ton
Pay load : 18.38 ton (1.6 times of the standard
ESAL value : 0.4228 + 4.1446
: 4.5674 (3.61 times of the standard)
</td>
</tr>
</table>

Source: Directorate General of Regional Infrastructure (2001) in Mulyono (2007)

Figure 4 Illustrations of overload condition in Sikijang Mati – Sp. Lago – Sorek – Sp. Japura road section, Riau Province

$$DC_{NORMAL} = \frac{MC \times LOR}{\sum ESAL_{NORMAL}} \quad (4)$$

$$DC_{OVERLOAD} = \frac{MC \times LOR}{\sum ESAL_{OVERLOAD}} \quad (5)$$

$$DFC = DC_{OVERLOAD} - DC_{NORMAL} \quad (6)$$

where:
DFC = damage factor cost (Rp)
DC = damage cost of truck per ESAL
MC = maintenance cost per km per year (Rp)
LOR = length of road (km)
$ESAL_{NORMAL}$ = ESAL on normal axle load
$ESAL_{OVERLOAD}$ = ESAL on overload axle load

Overloading commonly will accelerate the road service decrease rate during the design lifetime. The decrease rate can be calculated using Equation (7), (8), (9), and (10).

$$SL = \frac{ESAL_{NORMAL}}{ESAL_{OVERLOAD}} \times DL \quad \textbf{(7)}$$

$$ESAL_{NORMAL} = DF \text{ x } AADT_{NORMAL} \quad (8)$$

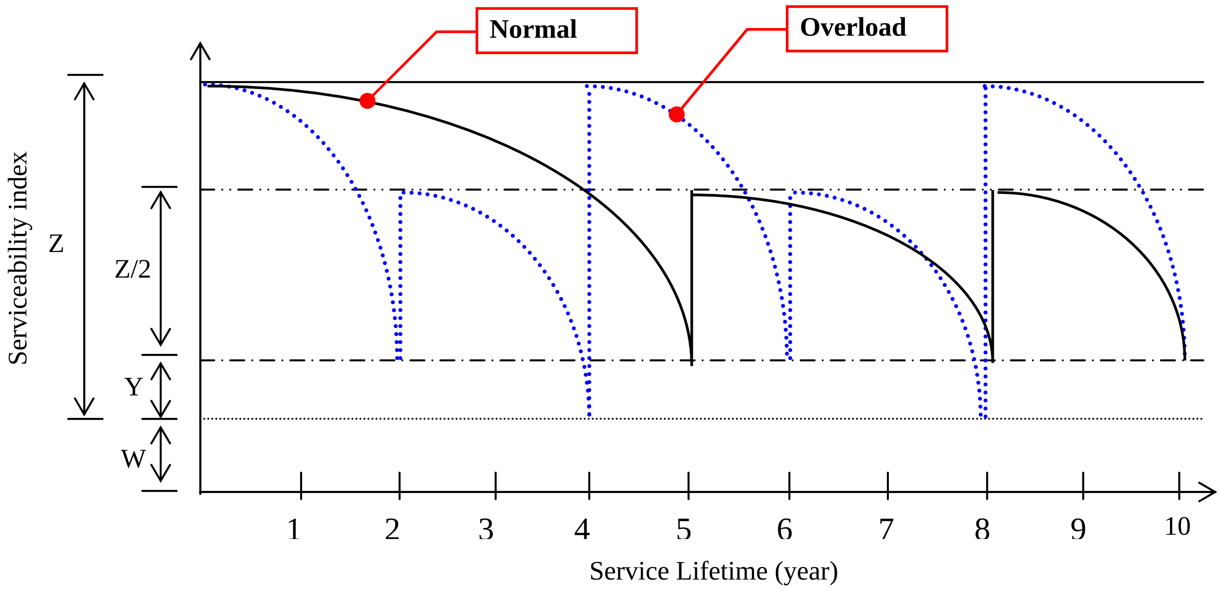
$$ESAL_{OVERLOAD} = DF \text{ x } AADT_{OVERLOAD} \quad (9)$$

where:
SL = service lifetime (year)
DL = design lifetime (year)
DF = damage factor
$ESAL_{NORMAL}$ = equivalent number on normal traffic
$ESAL_{OVERLOAD}$ = equivalent number on overload traffic
$AADT_{NORMAL}$ = AADT on normal condition
$AADT_{OVERLOAD}$ = AADT on overload condition

Road service lifetime decrease has significant impact on road improvement deficit cost from DL to SL, meaning that there will be additional cost during the current year (DL-SL). From investment point of view, it is a loss. Furthermore, to determine the loss cost, the following assumptions are used (see Figure 5): (1) on normal condition, routine maintenance is conducted on annual basis while periodic maintenance is conducted every 3-5 years in which the routine maintenance is not conducted in the same time as the periodic maintenance; (2) periodic maintenance can improve the road serviceability effect by a half of the road improvement; and (3) cost resulted from road service lifetime decrease from DL to SL during the current year (DL-SL) is stated as deficit design life cost (DDLC).

$$DDLC = (MC_{\mathbf{OVERLOAD}}) - (MC_{\mathbf{NORMAL}}) \tag{10}$$

where:
DDLC = deficit design life cost, loss cost resulted from decrease from DL to SL
MC_{NORMAL} = road distress improvement cost on normal load condition
$MC_{\mathbf{OVERLOAD}}$ = road distress improvement cost on overload condition



Normal condition	RM	RM	RM	RM	RM	PM	RM	RM	PM	RM
Overload condition	RM	RM	PM	RM	BM	RM	PM	RM	BM	PM

Source: Directorate General of Regional Infrastructure (2001) in Mulyono (2007)

Figure 5 Scenario of road serviceability decrease due to overloading vehicle

where:
W = lowest serviceability condition requiring betterment
Y = lowest serviceability condition requiring periodic maintenance
Z = targeted serviceability condition on betterment

Z/2 = number of road serviceability increase resulted from periodic maintenance
RM = routine maintenance; PM = periodic maintenance; BM = betterment

3. METHODOLOGY

This technical study to analyze the loss cost of road pavement distress due to overloading consists of three steps, i.e. (1) compilation of field and institutional data; (2) analysis of loss cost of road pavement distress; and (3) analysis of road distress betterment cost charged to overload car user.

The compilation of field and institutional data is started by classifying the road distress along with the causing factor in order to determine the type of dominant distress. In the case that the width area of rutting is more than sixty percents of total road pavement distress per km, it can be strongly concluded that the main reason is overloading and therefore the next analysis can be continued. Additionally the percentage of operating heavy vehicle by type and by freight is calculated. If the real MAL (maximal axle load) of the operating heavy vehicle is more than the standard MAL, it indicates that overloading happens in the surveyed road section.

The analysis of loss cost starts by investigating the damage factor (DF) of overloading vehicle and the deficit design life (DLL) of pavement performance of the existing road. If DF of overload vehicle is larger than DF of normal vehicle, there is pavement loss so that the analysis of damage factor cost (DFC) shall be conducted. The analysis of DF is performed using Equation (1), (2) and (3). Furthermore, the analysis of DFT is performed using Equation (4), (5) and (6). Subsequently, the data of road maintenance program on normal vehicle traffic (no overloading) is investigated and therefore routine maintenance can be performed every year, periodic maintenance every 3-5 years, and betterment at the end of the design lifetime (see Figure 5). If overload vehicle traffic exists, the normal scenario will change as the periodic maintenance is performed every 2 year and betterment every 4 year so that loss cost due to service lifetime decrease during design lifetime emerges (see Figure 5). The scenario is calculated using Equation (7), (8) and (9). Therefore, the deficit design life cost (DDLC) is the difference between maintenance cost (MC) per km on overload condition and MC on normal condition which is calculated using Equation (10). Eventually, the amount of loss cost of road pavement distress due to overload heavy vehicle is DFP plus DDLC.

Referring to Mulyono (2008), it is concluded that the road distress betterment cost charged to overload car user is sixty percents of total loss cost of road pavement distress due to overloading vehicle (60%(DFC + DDLC)). The systematic process of analyzing loss cost resulted from overloading freight transport is presented in Figure 6.

4. DISCUSSION AND EXAMPLES OF CALCULATION

The example of calculation is based on the data from Directorate General of Regional Infrastructure, Ministry of Settlement and Regional Infrastructure (2001) for the Trans-Eastern Sumatera, in Riau Province, which is focused on Sikijang Mati – Sp. Lago – Sorek – Sp. Japura road sections along 140.63 km. The road sections consist of Sikijang Mati – Sp. Logo section (25.36 km), Sp. Lago – Sorek section (50.32 km) and Sorek – Sp. Japura section

(64.95 km). The location is selected considering the highest level of rutting resulted from overloading freight transportation vehicle.

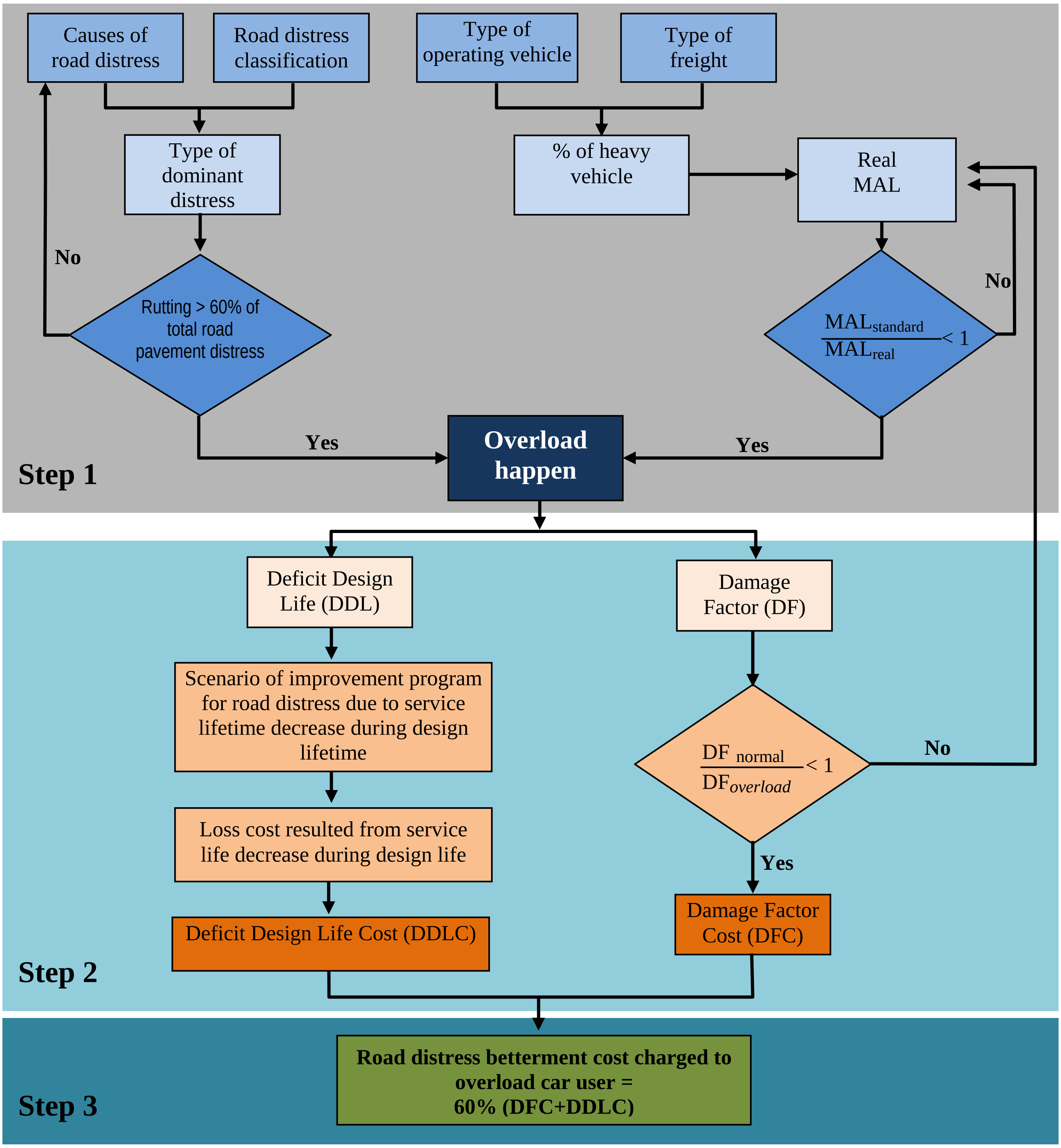


Figure 6 Analysis of road distress betterment cost due to overloading heavy vehicle

The number of operating cargo vehicle is 6,305 vehicles of truck type (see Table 1), consisted of wood and non-wood heavy vehicle, amounting 44.58% and 55.42%, respectively (see Table 2). Table 3 shows that Sikijang Mati – Sp. Lago road section is dominated by three-axle vehicle (64.59%), followed by two-axle vehicle (29.18%) and six-axle vehicle (6.23%). Furthermore, Sp. Lago – Sorek road section is also dominated by three-axle vehicle (52.48%), followed by two-axle vehicle (32.36%) and six-axle vehicle (15.5%). Sorek – Sp. Japura road section is dominated by three-axle vehicle (63.64%), followed by two-axle vehicle (14.43%) and six-axle vehicle (21.92%). The recapitulation of survey result and typical heavy vehicle is presented in Table 4 and Figure 7.

Table 1 Traffic of Operating Freight Vehicle

Road Section Name	Vehicle Type Light Vehicle	%	Heavy Vehicle	%	Number (Vehicle.)
Sikijang Mati – Sp.Lago	4,137	73.01	1,529	26.99	5,666
Sp. Lago – Sorek	6,783	74.12	2,368	25.88	9,151
Sorek – Sp. Japura	7,008	74.43	2,408	25.57	9,416
Total	17,928	73.85	6,305	26.15	24,333

Source: Directorate General of Regional Infrastructure (2001) in Mulyono (2007)

Table 2 Comparison of wood transporting vehicle to non-wood transporting vehicle

Road Section Name	Vehicle Type Non-wood Vehicle	%	Wood Vehicle	%	Number (vehicle)
Sikijang Mati – Sp. Lago	562	36.76	957	63.24	1,529
Sp. Lago – Sorek	1,168	49.32	1,200	50.68	2,368
Sorek – Sp. Japura	1,081	30.98	1,327	69.02	2,408
Total	2,811	44.58	3,494	55.42	6,305

Source: Directorate General of Regional Infrastructure (2001) in Mulyono (2007)

Table 3 Number of heavy vehicle by axle type

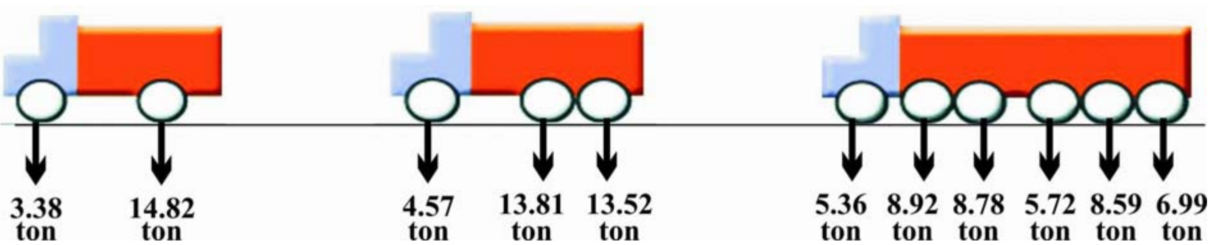
Road Section Name	Vehicle Type 2-axle Vehic.	%	3-axle Vehic.	%	6-axle Vehic.	%	Number (vehic.)
Sikijang Mati–Sp.Lago	164	29.18	363	64.59	35	6.23	562
Sp. Lago – Sorek	378	32.36	613	52.48	177	15.15	1,168
Sorek – Sp. Japura	156	14.43	688	63.64	237	21.92	1,081
Total LHR	698	24.83	1,644	59.20	449	15.97	2,811

Source: Directorate General of Regional Infrastructure (2001) in Mulyono (2007)

Table 4 MAL of operating heavy vehicle (wood truck)

No.	Axle number	MAL in the real field (ton) Sb. 1	Sb. 2	Sb. 3	Sb. 4	Sb. 5	Sb. 6
1	2-axle single	3.38	14.82				
2	3-axle tandem	4.57	13.81	13.52			
3	6-axle tandem-tridem	5.36	8.92	8.76	5.72	8.59	6.99

Source: Directorate General of Regional Infrastructure (2001) in Mulyono (2007)



Source: Directorate General of Regional Infrastructure (2001) in Mulyono (2007)

Figure 7 Types of operating heavy vehicle (wood truck)

The percentages of damage factor excess for each axle type are as follows:

a. Two-axle single truck

$$\%\_overload = \frac{(14.82 - 8.16)}{8.16} x100\% = 81.62\%$$

b. Three-axle tandem truck

$$\%\_overload = \left[\frac{(13.81 + 13.52) - 15}{15}\right] x100\% = 82.20\%$$

c. Six-axle Tandem-tridem truck

$$\%\_overload = \left\{\left[\frac{(8.92 + 8.76 + 13.52) - 20}{20}\right] + \left[\frac{(8.59 + 6.99) - 15}{15}\right]\right\} x100\% = 20.96\%$$

Table 5 presents the cost allocated for road maintenance, both routine and periodic maintenance, per kilometer for 10 years service lifetime in normal traffic condition. The Shadow unit price of road maintenance for 10 years service lifetime amounts for Rp 268,000,000 per kilometer, or averagely Rp 26,800,000 per km-year.

Table 5 Scenario and cost of road maintenance in normal traffic condition

Year	1	2	3	4	5	6	7	8	9	10
Maintenance	RM	RM	RM	RM	RM	PM	RM	RM	PM	RM
Cost (Rp. million/km)	6.5	6.5	6.5	6.5	6.5	108.0	6.5	6.5	108.0	6.5
Cumulative (Rp. Million/km)	6.5	13.0	19.5	26.0	32.5	140.5	147.0	153.5	261.5	268.0

RM= routine maintenance; PM=periodic maintenance

Source: Directorate General of Regional Infrastructure (2001) in Mulyono (2007)

4.1. Damage factor (DF) and deficit design life (DDL)

The road damage factor resulted from overloading truck vehicle can be calculated as follows:

a. 2-axle single truck

$$\text{DF} = \left(\frac{3.38}{8.16}\right)^4 + \left(\frac{14.82}{8.16}\right)^4 = 0.0294 + 10.8801 = 10.9095\_ESAL$$

b. 3-axle tandem truck

$$\text{DF} = \left(\frac{4.57}{8.16}\right)^4 + 0.086\left(\frac{13.81 + 13.52}{8.16}\right)^4 = 0.0984 + 10.8217 = 10.9201\_ESAL$$

c. 6-axle tandem-tridem truck

$$\text{DF} = \left(\frac{5.36}{8.16}\right)^4 + 0.086\left(\frac{8.59 + 6.99}{8.16}\right)^4 + 0.026\left(\frac{8.92 + 8.78 + 5.72}{8.16}\right)^4$$

$$= 0.1862 + 1.1429 + 1.7643 = 3.0934\_ESAL$$

The percentage of damage factor (DF) increase for each maximum axle load (MAL) of truck vehicle is presented in Table 6.

Table 6 The excess of overloading and damage factor

MAL type	Overloading excess (%)	DF excess (%)
Single axle	81.62	988.01
Tandem axle	82.20	1,001.92
Tridem axle	20.96	104.42

Design lifetime (DL) is the number of years calculated since the road starts servicing traffic to the time when betterment is needed or new surface layer seems necessary. In Indonesia, the design lifetime is commonly determined for 10 years. Furthermore, service lifetime (SL) is the number of years in which the road section truly serves traffic until betterment is needed. Service lifetime of 10 years means that the road section is able to serve the traffic in accordance to the design lifetime.

The traffic composition for heavy vehicle (truck) and the normal equivalent number (ESAL) for each truck vehicle type in inter-city arterial road section is presented in Table 7. The result of damage factor and ESAL analysis for overloading truck vehicle is presented in Table 8, 9 and 10.

Table 7 Normal ESAL for operating truck vehicle

Vehicle type	AADT composition (%)	*Damage factor* *)	ESAL – Normal
1	2	3	4 = (2) x (3)
2-axle single	15	1.0650	0.1597
3-axle tandem	8	1.0375	0.0830
6-axle tandem-tridem	7	4.9361	0.3450
Total	30%		0.5882

**) Source: Directorate General of Highways, Ministry of Public Works (1992)*

Table 8 ESAL for overloading truck vehicle (Sikijang Mati – Sp. Lago road section)

Vehicle type	AADT Vehicle	(%)	*Damage factor* (DF)	ESAL – *Overloading*
1	2	3	4	5 = (3)x(4) x 30%
2-axle single	164	29.18	10.9095	0.9551
3-axle tandem	363	64.59	10.9201	2.1160
6-axle tandem-tridem	35	6.23	3.0934	0.0578
Total	562	100%		3.1289

Table 9 ESAL for overloading truck vehicle (Sp. Lago - Sorek road section)

Vehicle type	AADT Vehicle	(%)	*Damage factor* (DF)	ESAL – *Overloading*
1	2	3	4	5 = (3)x(4) x 30%
2-axle single	378	32.36	1.09095	1.0592
3-axle tandem	613	52.48	1.09201	1.7194
6-axle tandem-tridem	177	15.15	3.09340	0.1406
Total	1,168	100%		2.9192

Table 10 ESAL for overloading truck vehicle (Sorek – Sp. Japura road section)

Vehicle type	AADT Vehicle	(%)	*Damage factor* (DF)	ESAL – *Overloading*
1	2	3	4	5 = (3)x(4) x 30%
2-axle single	156	14.43	1.09095	0.4723
3-axle tandem	688	63.64	1.09201	2.0850
6-axle tandem-tridem	237	21.92	3.09340	0.2035
Total	1,081	100%		2.7608

Based on ESAL for operating truck vehicle, the service lifetime for each road section is as follows:

a. Sikijang Mati-Sp. Lago road section

$$\text{SL} = \left(\frac{0.5882}{3.1289}\right) x10 = 1.88 \approx 2 \text{ years}$$

b. Sp. Lago-Sorek road section

$$SL = \left(\frac{0.5882}{2.9192}\right) x10 = 2.01 \approx 2 \text{ years}$$

c. Sorek-Sp.Japura road section

$$SL = \left(\frac{0.5882}{2.7608}\right) x10 = 2.13 \approx 2 \text{ years}$$

Therefore, the service lifetime for Sikijang Mati – Sp. Lago – Sorek – Sp. Japura road sections has decreased by 8 years or 80% from the targeted design lifetime, meaning that DDL equals to 8 years for each surveyed road section.

4.2. Damage factor cost (DFC) and deficit design life cost (DDLC)

DCF is cost emerging as the result of road distress caused by vehicle traffic. In this study, the calculation of damage factor is based on overloading heavy trucks. To calculate the DFC, firstly the damage cost (DC) of truck per ESAL in normal condition is calculated. DFC is the multiplication of DC to repetition of overloading truck for 1 (one) year in Sikijang Mati – Sp. Lago – Sorek – Sp. Japura road sections. The DC in normal traffic condition for each road section is presented in Table 11, 12, 13 and 14.

Furthermore, the loss cost per normal ESAL (DC_normal) per year for Sikijang Mati – Sp. Lago road section (25.36 km) is as follow:

$$\text{DC\_normal} = \frac{(\text{Rp } 26{,}800{,}000 \ x \ 25.36)}{214{,}501.92} = \text{Rp } 3{,}168.49 / \text{ESAL\_year}$$

For Sp. Lago – Sorek road section (50.32 km), the loss cost per ESAL normal (DC_normal) per year is as follow:

$$\text{DC\_Normal} = \frac{(\text{Rp } 26{,}800{,}000 \ x \ 50.32)}{481{,}748.57} = \text{Rp } 2{,}799.34 / \text{ESAL\_year}$$

For Sorek – Sp. Japura road section (64.96 km), furthermore, the loss cost per ESAL normal (DC_normal) per year is as follow:

$$\text{DC\_normal} = \frac{(\text{Rp } 26{,}800{,}000 \ x \ 64.96)}{495{,}655.39} = \text{Rp } 3{,}709.25 / \text{ESAL\_year}$$

The loss cost of road pavement distress due to overloading truck for each road section is presented in Table 14.

Table 11 Total normal ESAL (Sikijang Mati – Sp. Lago road section)

Vehicle type	AADT	ESAL_normal/vehicle	ESAL_normal/year
1	2	3	4 = (2)x(3)x365
2-axle single	164	1.0000	59,350
3-axle tandem	363	0.9820	130,110
6-axle tandem-tridem	35	1.9203	24,532
Total	562	3.9023	213,992

Table 12 Total normal ESAL (Sp. Lago – Sorek road section)

Vehicle type	AADT	ESAL_normal/vehicle	ESAL_normal/year
1	2	3	4 = (2)x(3)x365
2-axle single	378	1.0000	137,970
3-axle tandem	613	0.9820	219,718
6-axle tandem-tridem	177	1.9203	124,061
Total	1,168	3.9023	481,749

Table 13 Total normal ESAL (Sorek - Sp. Japura road section)

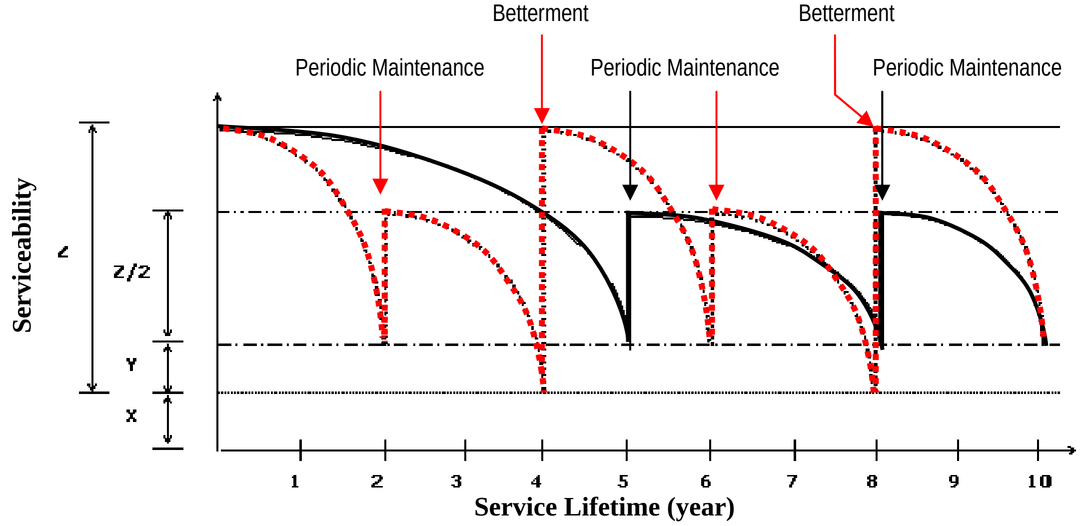
Vehicle type	AADT	ESAL_normal/vehicle	ESAL_normal/year
1	2	3	4 = (2)x(3)x365
2-axle single	156	1.0000	56,940
3-axle tandem	688	0.9820	246,600
6-axle tandem-tridem	237	1.9203	166,116
Total	1,081	3.9023	469,656

Table 14 Damage factor cost (DFC) by vehicle axle type

Vehicle type	AADT (vhc.)	Normal ESAL (per year)	Overload ESAL (per year)	ESAL difference (per year)	Normal DFC (Rp/vhc.)	Overload DFC (Rp/vhc.)	DFC (Rp/vhc.)
Sikijang Mati – Sp. Lago (25.36 km):							
2-axle	164	59,860	653,043	593,183	3,168.49	31,398.17	28,229.68
3-axle	363	130,110	1,466,859	1,316,749	3,168.49	31,488.78	28,320.29
6-axle	35	24,532	39,518	14,986	3,168.49	3,716.87	548.38
Sp. Lago – Sorek (50.32 km):							
2-axle	378	137,970	1,505,184	1,367,214	2,799.34	27,740.07	24,940.73
3-axle	613	219,718	2,443,308	2,223,600	2,799.34	27,820.12	25,020.78
6-axle	177	124,061	199,849	75,788	2,799.34	3,283.90	484.56
Sorek – Sp. Japura (64.96 km):							
2-axle	156	56,940	621,187	564,247	3,706.25	36,727.09	33,020.84
3-axle	688	246,600	2,742,256	2,495,656	3,706.25	36,833.09	33,126.84
6-axle	237	166,116	267,595	101,479	3,706.25	4,347.80	641.55

Budget for road improvement is commonly allocated to deal with one section road in such a way that the section road can serve traffic for 10 years (design lifetime). Nevertheless, overloading vehicle has made the design lifetime of the road unreachable or the service lifetime is smaller than the targeted design lifetime. To determine the amount of loss resulted from overloading heavy vehicle, several criteria have been established, including (a) in normal condition (underload), routine maintenance is conducted on annual basis while periodic maintenance is conducted in the second, sixth and eighth year of the service lifetime; (b) the periodic maintenance gives effect on road serviceability by a half of the road improvement work while routine maintenance has no effect on road improvement; and (c) loss cost due to decrease of road service lifetime from the design lifetime (deficit design life cost) is calculated based on the decrease of road service lifetime from 10 years to 2 years (deficit by 8 years), as presented in Figure 8.

Road improvement cost resulted from overloading is obtained using the scenario as presented in Figure 8, the result is then presented in Table 15. The deficit design life cost is obtained from road improvement cost in overloading condition (Table 16) minus road improvement cost in normal condition (Table 5), the result can be seen in Table 17. For 10 years road design lifetime, cumulative loss cost resulted from overloading truck which makes the service lifetime decrease to 2 years amounts for Rp 419,000,000 per kilometer or Rp 41,900,000 per kilometer-year. The total loss cost for the road section surveyed in the study (140.63 km long) amounts for Rp 47,139,176,000 per year or Rp 335,200,000 per kilometer-year for 8 years period of road serviceability decrease. The loss cost for each road section is presented in Table 17. Furthermore, Table 18 presents the per year cost by vehicle axle type resulted from overloading which causes decrease in service lifetime to 2 years.



Normal condition	RM	RM	RM	RM	RM	PM	RM	RM	PM	RM
Overload condition	RM	RM	PM	RM	BM	RM	PM	RM	BM	RM

Figure 8 Improvement scenario of road distress resulted from design lifetime decrease

Table 15 Improvement cost resulted from overloading (million rupiah)

Year	1	2	3	4	5	6	7	8	9	10
Improvement	RM	RM	PM	RM	BM	RM	PM	RM	BM	RM
Cost	6.5	6.5	108	6.5	216.0	6.5	108.0	6.5	216.0	6.5
Cumulative Cost	6.5	13	121	127.5	343.5	350.0	458.0	464.5	680.5	687.0

Table 16 Loss cost resulted from service lifetime decrease (million rupiah)

Year	1	2	3	4	5	6	7	8	9	10
Normal Cost	6.5	6.5	6.5	6.5	6.5	108.0	6.5	6.5	108.0	6.5
Overload Cost	6.5	6.5	108.0	6.5	216.0	6.5	108.0	6.5	216.0	6.5
Loss Cost	0.0	0.0	101.5	0.0	209.5	-101.5	101.5	0.0	108.0	0.0
Cumulative Loss Cost	0.0	0.0	101.5	101.5	311.0	209.5	311.0	311.0	419.0	419.0

Table 17 Deficit design life cost (DDLC)

Road Section Name	Length (km)	DL (year)	SL (year)	SL decrease	Loss cost (Rp/km-year)	Total loss cost (Rp)
Sikijang Mati – Sp. Lago	25.36	10	2	8	41,900,000	8,500,672,000
Sp Lago - Sorek	50.32	10	2	8	41,900,000	16,867,264,000
Sorek – Sp. Japura	64.95	10	2	8	41,900,000	21,771,240,000
Total	140.63					47,139,176,000

Table 18 Deficit design lifetime cost (DDLC) by vehicle axle type

Vehicle type	Axle load (ton/vhc.)	AADT (vhc.)	(%)	DDLC (Rp/vhc.)
Sikijang Mati – Sp. Lago (25.36 km)				
2-axle	18.2	164	29.18	1,511.62
3-axle	31.9	363	64.59	3,345.83
6-axle	44.6	35	6.23	322.60
Sp. Lago – Sorek (50.32 km):				
2-axle	18.2	378	32.36	1,600.55
3-axle	31.9	613	52.48	2,595.59
6-axle	44.6	177	15.15	749.46
Sorek – Sp. Japura (64.96 km):				
2-axle	18.2	156	14.43	995.34
3-axle	31.9	688	63.64	4,389.73
6-axle	44.6	237	21.92	1,512.16

Loss cost the overload car user shall bear is the sum of DFC and DDLC that is subsequently multiplied by 60%, as presented in Table 19.

Table 19 Structural distress improvement cost the overload car user bears

Vehicle type	AADT (vhc.)	DFC (Rp/vhc.)	DDLC (Rp/vhc.)	user responsibility (Rp/vhc..) *)
2	4	5	6	7= 0.6 ((5)+(6))
Sikijang Mati – Sp.Lago (25.36 km):				
2-axle	164	28,229.68	1,511.62	17,844.78
3-axle	363	28,320.29	3,345.83	18,999.67
6-axle	35	548.38	322.60	522.59
Simpang Lago – Sorek (50.32 km):				
2-axle	378	24,940.73	1,600.55	15,924.77
3-axle	613	25,020.78	2,595.59	16,569.82
6-axle	177	484.56	749.46	740.41
Sorek – Simp. Japura (64.96 km):				
2-axle	156	33,020.84	995.34	20,409.71
3-axle	688	33,126.84	4,389.73	22,509.94
6-axle	237	541.55	1,512.16	1,232.23

) If the road distress is **merely caused by overloading vehicle*

5. CONCLUSION

Overloading heavy vehicle causes road pavement structural distress and service lifetime decreasing during design lifetime. The presence of overloading on the surveyed road is indicated by the width area of rutting which is more than 60% of total road structural distress per km and by real maximum axle load (MAL) of the heavy vehicle which is larger than its standard MAL.

The loss cost of road pavement distress due to overloading is calculated based on damage factor (DF) and deficit design life (DDL). The damage factor cost (DFC) is the difference between damage cost of truck per ESAL (DC) on overload condition and DC on normal condition. Furthermore, the deficit design life cost (DDLC) is the difference between maintenance cost (MC) per km per year on overload condition and MC on normal condition.

The loss cost the overload car user shall bear is 60% of total DFC and DDLC, considering that not all pavement structural distresses are absolutely caused by overloading freight transport, there are other factors such as low quality construction, low quality material, substandard maintenance, and minimum design standard.

6. SUGGESTION

The Government of Indonesia may use this method of analysis of loss cost of road pavement distress to determine the amount of fine the overload car user shall pay in the effort to realize road reservation fund as stipulated in Law Number 22 of 2009 regarding Traffic and Road Transport. Therefore, the quality of pavement and the load of heavy vehicle shall be audited.

REFERENCES

Brown, S. F., and Brunton, J. M. (1987) **An Introductions to the Analytical Design of Bituminous Pavement**, Part II, 4th edition. University of Nottingham.

Directorate General of Regional Infrastructure. (2001) **The Mechanism for Private to Involve in the Road Maintenance as Anticipation of Road Fund Program.** Ministry of Settlement and Regional Infrastructure, Jakarta.

Gedafa, D., S. (2006) "Present Pavement Maintenance Practice: A Case Study For Indian Conditions Using HDM-4", Fall Student Conference Midwest Transportation Consortium, Ames, Iowa.

Directorate General of Highways. (1992) **Guideline for Flexible Pavement Thickness Design using Component Analysis Method**. Ministry of Public Works, Jakarta.

Ma'soem, D.M. (2006) The Luster of Our Road Construction, **Dinamika Riset**. Research and Development Agency, Ministry of Public Works, Jakarta.

Mulyono, A.T. (2002) The Analysis of Betterment of Road Structural Distress due to Overloading Heavy Vehicle, **Media Teknik, No. 1, Tahun XXIV**, Yogyakarta, 21-26.

Mulyono, A.T. (2007) **Monitoring and Evaluation Model of the Enforcement of Systemic Approach to Road Pavement Quality Standard**, Doctor Dissertation, Civil Engineering, Graduate Program of Diponegoro University, Semarang.

Mulyono, A.T. (2008) Dominant Factors Influencing Road Pavement Structural Strength in Indonesia, **Jurnal Transportasi, Volume 8, Edisi Khusus No. 1**, FSTPT, Bandung, 1-14.

Mulyono, A.T., and Riyanto, B. (2005) Technical Analysis on the Pavement Quality Performance of National and Provincial Road, **Forum Teknik**, **Vol. 29, No. 2,** FT-UGM, Yogyakarta, 79-90.

Mustazir. (1999) An Idea in Formulating Issuance of License for the Passing Through Super Heavy Traffic in the Main Route, **Jalan dan Transportasi, No. 094, Tahun XX**, PT. Pola Aneka, Jakarta, 45-51.

National Development Planning Agency. (2003) **Indonesia Infrastructure**, State Ministry for National Development Plan, Jakarta.

Rahim, R. (2000) **Calculation of Damage Factor and Deficit Design Live of Road Pavement due to Overloading Heavy Vehicle (Case Study in Riau Province)**, Master Thesis, Master Program of Transportation System and Engineering, Gadjah Mada University, Yogyakarta.