Estimation of Highway Maintenance Costs due to Heavy Truck Traffic

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Abstract

This article aims to study the pavement damage forecasting model suitable for highways in Thailand. with damage results sufficient to charge long-term maintenance costs and analyze the damage cost covering the cost of maintaining the road structure as a guideline for calculating truck fees in the future. The study authors modeled the asphalt road structure by using HDM-4 program [3] using the data of Highway 344, Rayong-Ban Bueng. which is located not far from the truck weighing station in the modeling. The model was built with a length of 1 km and a total of four lanes. Tests were carried out using four types of heavy truck models, simulating the damage caused by heavy trucks over a period of 20 years: cracking, ravelling, potholes and rut depth. relationship between structural strength Truck quantity and road section It tends to indicate future damage. The maintenance cost will be charged as per standard axles.

Keywords: hdm-4, heavy truck, maintenance, fee

1. Introduction

Each year, the Department of Highways and the Department of Rural Roads lose a lot of budgets to be used for road maintenance. Due to damage caused by overweight trucks, these problems cause huge losses to the country's economy. Therefore, it is necessary to investigate and solve problems to reduce the loss of the public sector. reduce the loss of operators reduce the loss of the people Reduce resource waste including reducing injustice in society.

Violations for trucks due to the interests of operators. By carrying weight that exceeds the standard, resulting in damage to roads and bridges. The reason may be that the adjustment setting is too low. Therefore, the entrepreneur is worth the risk of violating the law. Or willing to pay, it's still worthwhile to continue driving [2]

In many countries, heavy truck tolling systems are in place. To support industrial and economic growth, it is the source of the fee for heavy-duty vehicles. to bring the money to repair that road directly. [5, 7]

Recently, a policy for truck tolls by weight has been implemented in China. However, this policy ignores the external environmental costs of heavy trucks. Referring to the German HGV toll policy, similar toll schemes were implemented in the country. Including truck tolls according to the weight model have been optimized to account for the external cost of environmental pollution. [1]

Foreign studies show that the strength of the structure of the construction. The stronger the structure as a result, the damage rate from heavy trucks decreased. including reduced fees [6]

Collecting truck fees helps the Department of Highways reduce significant budget losses in pavement maintenance due to damage from the use of heavy trucks. Including collecting truck information used in the network, such as the route truck type cargo for the benefit of future fee adjustments. [8]

Therefore, this research aims to study the appropriate fee rates in the highway network in Thailand. Calculating fees based on and demonstrating a rational process for allocating license fees. To allow policy makers to make more informed decisions about the cost of license fees. Because Thailand does not collect fees for overweight trucks.

2. Information and programs used in the research

2.1 Network and traffic information

Department of Highways, National Highway No. 344, Chonburi - Klaeng Road, is a road constructed to shorten the distance from Chonburi Province to Chanthaburi and Trat Provinces. without passing through the city of Rayong It is a road with asphalt concrete surface, size 4 lanes throughout the line. Start from Sukhumvit Road Mueang Chonburi District through

Chonburi bypass road Bangkok-Chon Buri Road Ban Bueng Phatthana Intersection (M16 Intersection), Ban Bueng District, Nong Prue Intersection and Nong Yai District enter Rayong province through Wang Chan District Ends at Sukhumvit Road around Phiban Pattana Intersection (Klaeng Intersection), Klaeng District, Rayong Province, a total distance of 102.181 kilometers, which is the route under the responsibility of Chonburi Highway District 1 and Rayong Highway District. In summary, the traffic volume and road cross-sections are in accordance with Tables 1 and 2.

Table 1 Heavy truck traffic

vehicle type	AADT
Medium Truck	1,327
Heavy Truck	1,214
Semi-Trailer	1,412
Full Trailer	1,312

Table 2 Cross-sectional format, km. 20+000 – 25+000

road section	thickness (mm.)
Surface (AC) + AC Overlay	150
Base	200
Subbase	300

2.2 Falling Weight Deflectometer (FWD) data

The data used in this analysis was provided courtesy of the Highway Office 14, Department of Highways on Highway No. 344, Nong Ri to Nong Plue section, during the test km range 20+000 – 32+150 on the test date 18 July 2017. To be used in the analysis of the Structural Number (SN) in order to bring the obtained value to create a model of the road structure as in equations (1), (2) and (3).

$$M_r = \frac{0.24P}{d_r r} \quad (1)$$

when $M_r(psi)$ is Subgrade field $M_R(psi)$ P is FWD Load (lbs) typ. 9000 lbs d_r deflection (not adjusted) at distance r (in) r is should use r > 36 in. (91.44 cm.)

$$d_0 = 1.5pa\left\{\frac{1}{M_r\sqrt{1+\left(\frac{D}{a}\sqrt[3]{\frac{E_P}{M_R}}\right)^2}}\right\} \quad (2)$$

when E_p is effective modulus $d_0(in.)$ is deflection at load center (adjusted for 9000 lbs.) M_R is Subgrade field $M_R(psi)$ D is pavement total thickness above subgrade (in.) P is plate pressure (psi) (700 kPa = 101.506 psi) a is Plate radius (in.)

$$SN_{eff} = 0.0045D^3\sqrt{E_p} \quad (3)$$

when SN_{eff} is effective structural number D is pavement total thickness above subgrade (in.) E_p is effective modulus

2.3 HDM-4 program.

The tool used for modeling and predicting damage in this research is HDM-4. It is the main tool for analysis, planning, management and evaluation of future road maintenance with inputs and outputs. in Figure 1

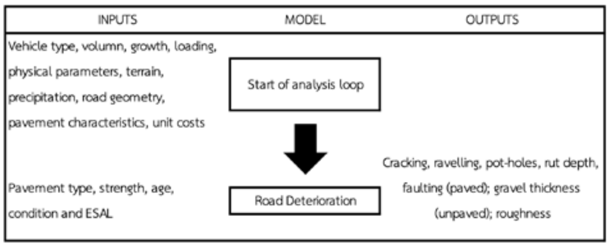

Fig. 1 Analysis procedure using HDM-4 program.

A model of predicting pavement deterioration over time and under traffic. The occurrence of the damage pattern is shown in Figure.2

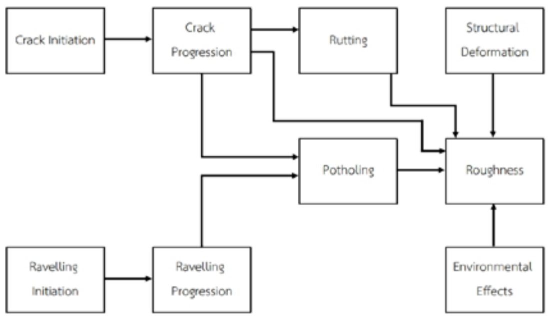

Fig. 2 Procedure for damage using the HDM-4 program.

3. Research Process

conducting research the researcher divided the main modeling into 4 parts, namely the first part of the data. is a modeling of the structure by using FWD data from Highway 344 to calculate the strength of the road structure to be used to create a model in the HDM-4 [4] program. The second part is a calibration factor for suitability in terms of topography, material quality and quality of construction work the third part is the preliminary construction cost and pavement maintenance form determination. The fourth part is Net Present Value (NPV) analysis.

3.1 Modeling with HDM-4

Modeling using HDM-4 requires 3 parts of information: the first part is vehicle model such as vehicle characteristics, number and Truck Factor (TF). Environmental patterns such as average annual precipitation, temperature, and the third part is the condition of the integrity of the road, such as damage on the pavement. structural strength All 4 models were created as shown in Table 3.

Table 3 Model and conditions used to create.

No. of Model	Condition
Model 1	No Calibration Factor
Model 2	Calibration Factor
Model 3	Calibration Factor and increase SN 20%
Model 4	Calibration Factor and increase SN 40%

3.2 Calibration Factor

Calibration for road deterioration model There are 3 levels of application, verification and adaptation for paved roads, all of which are data dependent. and continuity in data collection in this research, the first level, Application, was used due to the limitation of available data and the damage of the pavement was not continuously collected. At this level, three factors of deterioration are corrected: roughness caused by age and environment. initiation of cracking and fracture progression as shown in Equations (4), (5) and (6).

$$m_{eff} = mK_m \qquad (4)$$

when m_{eff} is effective environmental coefficient K_m is material adjustment and drainage m is recommended value of environmental coefficient

$$K_{gm} = \frac{m_{eff}}{0.023} \qquad (5)$$

when K_{gm} is roughness – age – environmental factor.

$$K_{cp} = \frac{1}{K_{ci}} \qquad (6)$$

when K_{cp} is Cracking progression adjustment factor K_{ci} is adjustment factor cracking initiation

By Calibration Factor, crack formation is considered from 3 conditions: bitumen quality, local weather conditions, and construction quality as shown in Table 4.

Table 4 Level 1 Adjustment factor cracking initiation

Construction Quality	Bitumen quality	Oxidizing climate		
		High	Medium	Low
High	High	1.0	1.2	1.5
	Low	0.8	1.0	1.1
Medium	High	0.8	**1.0**	1.1
	Low	0.6	0.8	0.9
Low	High	0.6	0.8	0.9
	Low	0.4	0.6	0.7

3.3 Configuration and maintenance intervals

After 20 years of running the model on the condition that there was no maintenance on the asphalt concrete surface, it was possible to know the damage and changes that occurred over time. Therefore, the form of maintenance has been determined as shown in Table 5 to achieve the most appropriate and cost-effective model based on the model conditions that have been adjusted for the Calibration Factor.

Table 5 Maintenance criteria and costs

Maintenance model	Condition	Price per unit (Baht/sq.m.)
Mill and Replace (Milling of existing asphalt concrete surface 5 cm. thick + Asphalt concrete wearing course 5 cm. thick)	IRI ≥ 2.8 IRI m/km	322.79 บาท = 8.39 USD
Slurry Seal	Interval 5 Year	111 บาท = 2.89 USD

3.4 Preliminary calculation of paved road construction

This section shows basic construction costs such as foundation work, pavement layer, pavement layer and asphalt concrete work. By considering the price of materials used in construction, distance, transportation costs, transportation costs, operation costs, depreciation costs. Then calculate the price used for road construction, shown in Figure 3.

Summary form of middle price for road construction

Project name Construction cost for Model HDM-4 Highway No. 344 Chonburi - Rayong
Construction site Chonburi
Project Owner Chulalongkorn University
Drawing No. -
Calculate the median price by Mr. Panupong Yencham **Date** 1-Jan-65

No.	Description	Unit	Working Unit	Unit price	Cost price	FN	Unit price X FN	Cost Estimate
1	Road structure improvement work							
	1.1 Soil aggregate subbase compected, thk. 30 cm.	m3	3,450.00	453.31	1,563,919.50	1.3012	589.84	2,034,940.78
	1.2 Crushed rock soil aggregate type base and compacted, thk. 20 cm.	m3	2,150.00	572.09	1,229,993.50	1.3012	744.39	1,600,442.94
2	Pavement work							
AC 5 cm.	2.1 Prime coat work	m2	10,450.00	32.12	335,654.00	1.3012	41.79	436,746.27
	2.2 Asphalt concrete pavement 5 cm.	m2	10,450.00	268.85	2,809,482.50	1.3012	349.82	3,655,642.44
AC+AC Overlay 15 cm.	2.3 Tack coat work	m2	10,450.00	14.70	307,230.00	1.3012	19.13	399,761.53
	2.4 Asphalt concrete pavement for Overlay 5 cm.	m2	10,450.00	265.29	5,544,561.00	1.3012	345.19	7,214,471.88
							Total	15,342,005.84

① The total cost of construction work	11,790,840.50
② Factor F value for construction work	1.3012

Fig. 3 Items, quantities and prices used in road construction.

3.5 NPV Analysis

Finding the difference between the present value of future returns expected over the life of the project and the present value of money paid out of that model. By setting the discount rate at 3% to be used in determining the best alternative, where the NPV is positive, or the highest value indicates that the model is worth investing as in Equation (7).

$$NPV = \sum_{t=0}^{n} \frac{MC_t}{(1+i)^t} \tag{7}$$

when NPV is Net Present Value MC is maintenance costs t is year of analysis i is Discount Rate

A 20-year period from 2022 to 2041 was established where the construction costs in Model 1 and Model 2 were the same, with a difference in maintenance intervals shown in Figure 4 and 5. In Model 3 and 4 There is a higher construction cost respectively from increasing the thickness of the pavement by the Overlay method to increase the strength of the pavement structure. therefore, making the maintenance intervals differ shown in Figure 6 and 7.

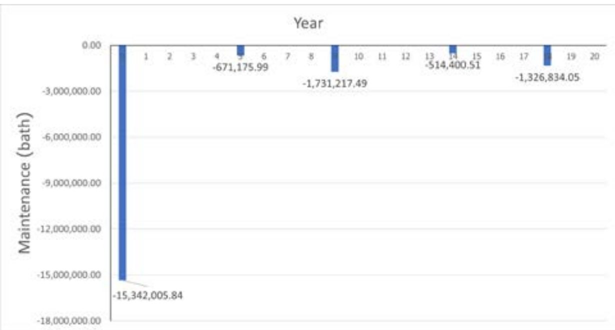

Fig. 4 Maintenance Interval Graph Model 1

Fig. 5 Maintenance Interval Graph Model 2

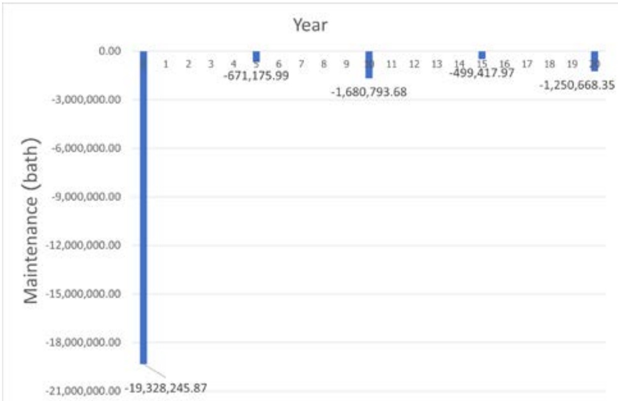

Fig. 6 Maintenance Interval Graph Model 3

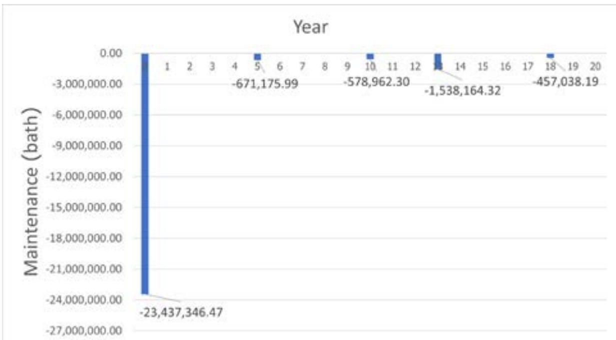

Fig. 7 Maintenance Interval Graph Model 4

After obtaining the model for the period during which the maintenance was carried out, Therefore, the NPV values of all 4 models were calculated. The results are shown in Table 6.

Table 6 NPV value derived from construction and maintenance costs at different years.

No. of Model	NPV value (baht per kilometer)
Model 1	-19,585,633.88
Model 2	-19,625,438.90
Model 3	-23,430,301.85
Model 4	-26,682,687.27

Consider the fee for heavy truck from construction and maintenance costs over 20 years per ESAL accumulated over 20 years as shown in Table 7-10

Table 7 Results of 20-year maintenance cost analysis for model 1

Detail Model 1	Cost	Unit
Construction and maintenance costs over 20 years	19,585,633.88	Bath/km
ESAL accumulated over a period of 20 years	41,170,000	ESAL
Construction and maintenance costs over 20 years	0.48	Bath/ESAL/km

Table 8 Results of 20-year maintenance cost analysis for model 2

Detail Model 2	Cost	Unit
Construction and maintenance costs over 20 years	19,625,438.90	Bath/km
ESAL accumulated over a period of 20 years	41,170,000	ESAL
Construction and maintenance costs over 20 years	0.48	Bath/ESAL/km

Table 9 Results of 20-year maintenance cost analysis for model 3

Detail Model 3	Cost	Unit
Construction and maintenance costs over 20 years	23,430,301.85	Bath/km
ESAL accumulated over a period of 20 years	41,170,000	ESAL
Construction and maintenance costs over 20 years	0.57	Bath/ESAL/km

Table 10 Results of 20-year maintenance cost analysis for model 4

Detail Model 4	Cost	Unit
Construction and maintenance costs over 20 years	26,682,687.27	Bath/km
ESAL accumulated over a period of 20 years	41,170,000	ESAL
Construction and maintenance costs over 20 years	0.65	Bath/ESAL/km

4. Conclusion

The selection of the best maintenance alternative and forecasting the maintenance budget requirement for a selected road network depend on the criteria that a planner adopts. The planning criteria may be maximizing the NPV or keeping the road in an acceptable condition. The following conclusions have been drawn from the analysis.

To charge the truck from the maintenance cost, the NPV maintenance value analysis was used and the maintenance cost per standard axle was considered. The maintenance costs are the maintenance costs caused by all 4 types of trucks. However, the damage to the pavement will be more or less. It depends on the quality of pavement materials and construction quality. As for the fees that trucks must pay, it depends on overloading the specified rate per driving distance.

The researcher hopes that This study will provide a guideline for Related agencies such as the Department of Highways, the Department of Rural Roads, etc., consider using the HDM-4 program to predict road structure damage. and as a guideline for collecting truck fees in the future.

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Reference

[1] Wang et al., (2018). Optimization of the freeway Truckway toll by weight policy, including external environmental costs. pp.220-226. **(In case of Journal of Cleaner Production 184(2018))**

[2] Prozzi, J., Murphy, M., Loftus-Otway, L., Banerjee, A., Kim, M., Wu, H., Prozzi, J.P., Hutchison, R., Harrison, R., Walton, C.M., Weissmann, J., Weissmann, A. (2012). Oversize/Overweight Vehicle Permit Fee Study **(In case of Report No. FHWA/TX-13/0-6736-2(2018))**

[3] Shah Yogesh U. (2014). Adaptation of HDM-4 tool for strategic analysis of urban roads Network. pp. 71-81. **(In case of Transportation Research Procedia 17(2016))**

[4] Justin D. Warner (2016). An Evaluation of Reclaimed Asphalt Shingles for Beneficial Reuse in Roadway Construction. **(In case of Journal of ASTM International 9(1):103665 DOI:10.1520/JAI103665)**

[5] Abdelazim S. et al., (2020). Pavement damage cost by truck class and economy of scale relative to increased loading. **(In case of International Journal of Pavement Engineering : DOI: 10.1080/10298436.2020.1832221)**

[6] Cesar Tirado et al., (2010). Process to estimate permit costs for movement of heavy trucks on flexible Pavement. **(In case of Transportation Research Record Journal of the Transportation Research Board : DOI: 10.3141/2154-19)**

[7] Ehsan Dehghan-Niri et al., (2020). Simplified comparison of oversize and overweight vehicles permits fee structure in the U.S. western states. **(In case of International Journal of Transportation Research Record Journal of the Transportation Research Board : DOI: 10.1177/0361198120932569)**

[8] Osman Erman Gungor et al., (2019). Development of an overweight vehicle permit fee structure for Illinois. pp. 26-35 **(In case of International Journal of Transportation Policy Volume 82)**