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Economic Feasibility Analysis of National Road Maintenance Based on Vehicle Operating Cost and Greenhouse Gas Emission Cost Savings in Depok City

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Abstract

Urban national roads carry heavy traffic, which accelerates pavement deterioration and increases road user costs. This study analyzes the economic feasibility of maintaining three national road segments in Depok City, namely Jalan Ir. H. Juanda, Jalan Gandaria–Cilodong/Depok Border, and Jalan Margonda Raya, using savings in Vehicle Operating Costs (VOC) and vehicle greenhouse gas (GHG) emission costs as benefit variables. A with–without project approach (base case and project case) was applied over a five-year design period. Traffic volume, International Roughness Index (IRI), and vehicle speed were projected for each scenario; VOC was calculated using the Ministry of Public Works guideline, and GHG emissions were estimated using the IPCC 2006 method. Economic feasibility was assessed using Net Present Value (NPV), Benefit Cost Ratio (BCR), and Internal Rate of Return (IRR) at a 6.83% discount rate, complemented by a nine-scenario sensitivity analysis. The results show an NPV of IDR 37,601,607,538.88, a BCR of 2.05, and an IRR of 75.33%, far exceeding the prevailing interest rate. Maintenance becomes infeasible only when benefits decrease by 40% and maintenance costs increase by 40% simultaneously. Therefore, maintaining the three road segments is economically feasible and delivers tangible benefits to the community through reduced VOC and vehicle emissions.

Keywords: *Vehicle Operating Cost, Greenhouse Gas Emission, Economic Feasibility, Road Maintenance, Sensitivity Analysis*

INTRODUCTION

Roads are transportation infrastructure that play an important role in the economic, socio-cultural, and environmental sectors, as well as serving as distribution infrastructure for goods and services [1]. Well-functioning roads facilitate community activities, particularly economic activities, so that their performance directly affects the productivity of the regions they serve [2]. Urban national roads, such as the segments connecting Depok City and Bogor Regency, carry heavy traffic that causes pavement deterioration, which is commonly expressed through the International Roughness Index (IRI) [3–5]. Therefore, road maintenance is mandatory to preserve the level of service until the end of the design life [6].

Deterioration of the road surface affects not only the pavement structure but also the costs borne by road users. Surface damage and roughness have been shown to increase Vehicle Operating Costs (VOC) because vehicle speed decreases while the consumption of fuel, tires, and spare parts increases [7, 8]. Traffic conditions along the road, such as side friction, also increase VOC [9]. Timely routine maintenance results in lower VOC than deferred treatment [10], while Highway Development and Management (HDM-4) analyses show that active treatment scenarios reduce roughness and road user costs [11, 12]; the timing and type of treatment also determine life-cycle costs [13–15].

The economic feasibility of road projects in Indonesia is generally assessed using Net Present Value (NPV), Benefit Cost Ratio (BCR), and Internal Rate of Return (IRR), with VOC savings as the main benefit, for example in ring roads, underpasses, and flyovers [1, 16, 17]. Other studies add travel time savings as a benefit [18, 19], and recent research also includes indirect benefits such as increased regional revenue [20]. The same criteria are also applied in other construction investment analyses [21].

Nevertheless, most of these studies focus on new road construction and have not included environmental benefits. In fact, external benefits such as pollution reduction have begun to be considered in transportation investment appraisal [22]. Life-cycle assessment research shows that vehicle greenhouse gas (GHG) emissions decrease after pavement maintenance [23], and vehicle emissions on urban road segments in Indonesia can be

estimated using the IPCC 2006 method [24–26]. Hence, there is a research gap regarding the economic feasibility of maintenance works, rather than new construction, on urban national roads that combine VOC savings with the social cost of GHG emissions [27] and test the robustness of the results through sensitivity analysis [28].

This study aims to analyze the economic feasibility of road maintenance on Jalan Ir. H. Juanda, Jalan Gandaria–Cilodong/Depok Border, and Jalan Margonda Raya using VOC and vehicle GHG emission costs as benefit variables, with NPV, BCR, and IRR indicators over a five-year design period. This study also identifies the limits of changes in benefits and maintenance costs that still yield a feasible decision.

METHOD

This study is a quantitative case study using a with–without project approach, comparing the condition without maintenance (base case) and with maintenance (project case) over five years from the 2019 base year. The study locations are three national road segments in Depok City connecting Depok City and Bogor Regency (Table 1). Geometric and IRI data, as well as traffic data (average daily traffic, vehicle composition, and capacity), were obtained from the Directorate General of Highways [29], while vehicle speed data were obtained from the Depok City Transportation Agency [30]. Supporting data include the 2010–2018 traffic growth rate of Depok City of 11.72% per year, surveyed prices of vehicles, fuel, oil, tires, and spare parts, an economic growth rate of 5.49% per year for price projection, the unit cost of GHG emissions [27], and the 2019 Depok City Unit Price Analysis (AHSP).

Table 1 Geometric data of the studied road segments

No	Road Segment	Length (km)	Width (m)	Terrain	IRI (m/km)
1	Jln. Ir. H. Juanda	3.96	14.02	Hilly	4.15
2	Gandaria–Cilodong/Depok Border	8.20	12.11	Flat	3.90
3	Jln. Margonda Raya	1.64	18.98	Flat	3.73

Source: Directorate General of Highways, 2019

Traffic Condition Projection

Traffic volume, Volume Capacity Ratio (VCR), IRI, and vehicle speed were projected annually for both scenarios based on the traffic engineering module of the Ministry of Public Works [31]. The increase in IRI was predicted using the IRMS model, as applied in pavement life-cycle cost studies [14, 15], with Equation (1).

$$RI_t = (RI_0 + 725(1 + SNC)^{-5} NE_t) e^{0,0153t} \quad (1)$$

where RI_t is the roughness in year t (m/km), RI_0 is the initial roughness (m/km), NE_t is the cumulative equivalent standard axle load in year t (million ESAL/lane), and SNC is the structural number capacity of the pavement. In the project case, the initial IRI after maintenance was assumed to be 3.5 m/km (good condition). Vehicle speed was projected using linear regression between speed (dependent variable) and IRI (independent variable), considering that surface roughness affects vehicle operating speed [3, 32].

Calculation of Vehicle Operating Costs and Emission Costs

VOC was calculated for both scenarios based on the vehicle operating cost guideline of the Ministry of Public Works [33], which has also been used to assess changes in VOC due to roughness, speed, and traffic volume [8]. The running cost component was calculated using Equation (2).

$$BTT = BiBBM_j + BO_i + BP_i + BU_i + BB_i \quad (2)$$

where BTT is the running cost (IDR/km), $BiBBM_j$ is the fuel consumption cost, BO_i is the oil consumption cost, BP_i is the spare parts cost, BU_i is the maintenance labor cost, and BB_i is the tire consumption cost (all in IDR/km).

GHG emissions (CO_2, CH_4, and N_2O) were calculated according to the national GHG inventory guideline [34], which adopts the IPCC 2006 default emission factors, as applied in vehicle emission estimates on urban road segments [24, 25]. The approach based on fuel consumption and vehicle distance traveled is considered the most suitable for Indonesian conditions [26]. Emissions and energy consumption were calculated using Equations (3) and (4). The emission factors for gasoline are 69,300 kg CO_2, 33 kg CH_4, and 3.2 kg N_2O per TJ, while those for diesel are 74,100 kg CO_2, 4 kg CH_4, and 3.9 kg N_2O per

TJ, with calorific values of 0.000033 TJ/liter (gasoline) and 0.000036 TJ/liter (diesel) [34]. Emission costs were obtained by multiplying the emission mass of each gas by its social cost [27].

$$\text{GHG Emission (kg/day)} = \text{Energy Consumption (TJ/day)} \times \text{Emission Factor (kg/TJ)} \quad (3)$$

$$\text{Energy Consumption (TJ)} = \text{Fuel Consumption (liter)} \times \text{Calorific Value (TJ/liter)} \quad (4)$$

Determination of Maintenance Type and Cost

The maintenance type was determined based on road segment condition [6], assessed from the Road Condition Index (RCI), IRI, and annual average daily traffic [29], in line with the practice of prioritizing road treatment based on condition indices [35]. Layer thickness and material type for each maintenance type follow the urban road maintenance programming procedure [36]. Maintenance costs were calculated using AHSP with unit prices from the Depok City Public Works and Housing Agency.

Economic Feasibility and Sensitivity Analysis

Economic analysis evaluates the total benefits received by the community or the economy as a whole, regardless of who provides the funds or who receives the project outputs [37]. Benefits were defined as the difference in VOC and GHG emission costs between the base case and the project case, while costs were the maintenance costs. Feasibility was evaluated using Equations (5) to (7) [21, 37].

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \quad (5)$$

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+i)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+i)^t}} \quad (6)$$

$$\sum_{t=0}^{n} \frac{B_t - C_t}{(1+IRR)^t} = 0 \quad (7)$$

where B_t and C_t are the benefits and costs in year t, i is the discount rate, and n is the design period (5 years). The discount rate used was the 2019 Bank Indonesia policy rate of 6.83%. Maintenance is declared feasible if NPV ≥ 0, BCR ≥ 1, and IRR exceeds the discount rate [20]. Sensitivity analysis was conducted to determine the effect of changes in the basic variables on the feasibility indicators [28], through nine scenarios of decreased benefits and/or increased maintenance costs of 20%, 30%, and 40%.

RESULT AND DISCUSSION

Traffic Condition Projection

With a growth rate of 11.72% per year, the average daily traffic on Jalan Ir. H. Juanda increases from 26,510 to 46,138 pcu/day, on Jalan Gandaria–Cilodong/Depok Border from 14,979 to 26,069 pcu/day, and on Jalan Margonda Raya from 28,801 to 50,125 pcu/day in the fifth year. Consequently, the VCR of the three segments increases from 1.57, 1.27, and 2.04 to 2.73, 2.22, and 3.55, indicating that all segments operate under oversaturated conditions. The IRI and speed projections are presented in Table 2. In the base case, IRI continuously increases to 4.19–4.76 m/km, whereas in the project case IRI decreases to 3.50 m/km after maintenance and remains below 4.16 m/km until the end of the design period. This reduction in IRI increases the initial vehicle speed to 40.53 km/h on all three segments.

Vehicle Operating Costs and Greenhouse Gas Emission Costs

VOC was calculated from the consumption of fuel, oil, spare parts, tires, and maintenance hours multiplied by surveyed unit prices, then projected to the design year using the 5.49% economic growth rate. Table 3 shows that the project case VOC is lower than the base case VOC for all segments and all years. In the base year, maintenance reduces the VOC of the three segments by IDR 113.61 million per day (18.7%), with the largest savings on Jalan Gandaria–Cilodong/Depok Border, the longest segment. GHG emission costs are also lower in the project case (Table 4), decreasing by approximately IDR 0.21 million per day in the base year, with CO_2 accounting for more than 92% of emission costs.

Table 2 Projected IRI (m/km) and vehicle speed V (km/h) in the base case (BC) and project case (PC)

	Jln. Ir. H. Juanda				Gandaria–Cilodong/Depok Border				Jln. Margonda Raya			
Year	IRI BC	IRI PC	V BC	V PC	IRI BC	IRI PC	V BC	V PC	IRI BC	IRI PC	V BC	V PC
0	4.149	3.500	35.40	40.53	3.898	3.500	34.33	40.53	3.734	3.500	35.58	40.53
1	4.265	3.606	33.62	39.26	4.019	3.614	37.30	39.16	3.822	3.569	36.85	39.70
2	4.383	3.661	32.87	38.60	4.142	3.732	36.58	37.75	3.912	3.640	36.66	38.85
3	4.504	3.744	31.79	37.61	4.268	3.884	35.48	35.93	4.003	3.719	36.40	37.91
4	4.628	3.828	30.69	36.59	4.398	4.018	34.63	34.32	4.097	3.795	36.19	37.00
5	4.755	3.915	29.56	35.55	4.530	4.156	33.77	32.67	4.192	3.872	35.97	36.07

Source: Data analysis, 2021

Table 3 Vehicle operating costs (million IDR/day) in the base case (BC) and project case (PC)

	Jln. Ir. H. Juanda		Gandaria–Cilodong/Depok Border		Jln. Margonda Raya	
Year	BC	PC	BC	PC	BC	PC
0	233.55	185.14	282.10	230.53	92.70	79.06
1	279.62	222.64	339.26	279.52	110.70	94.73
2	335.49	267.59	408.05	338.41	132.33	113.49
3	402.71	321.52	490.82	409.27	158.24	135.98
4	483.67	386.27	590.50	494.62	189.28	162.93
5	581.35	464.06	710.72	597.51	226.51	195.25

Source: Data analysis, 2021

Table 4 Vehicle GHG emission costs, CO_2 + CH_4 + N_2O (thousand IDR/day), in the base case (BC) and project case (PC)

	Jln. Ir. H. Juanda		Gandaria–Cilodong/Depok Border		Jln. Margonda Raya	
Year	BC	PC	BC	PC	BC	PC
0	3,133.17	3,005.99	3,924.39	3,859.74	1,222.34	1,200.69
1	3,674.77	3,512.64	4,611.08	4,510.41	1,430.44	1,402.53
2	4,337.82	4,105.43	5,424.44	5,270.20	1,679.34	1,639.16
3	5,130.02	4,800.43	6,388.37	6,159.35	1,973.91	1,917.13
4	6,081.19	5,617.15	7,535.83	7,202.74	2,323.41	2,244.27
5	7,229.58	6,579.21	8,908.90	8,431.04	2,739.21	2,630.00

Source: Data analysis, 2021

Maintenance Costs

Based on IRI and average daily traffic, the three segments are in fair condition and therefore require periodic maintenance in the initial year, followed by routine maintenance from year 1 to year 5. The AHSP results show a unit price of IDR 159,310.65/m² for periodic maintenance (class A aggregate leveling, tack coat, and 3 cm HRS-WC wearing course) and IDR 113,045.80/m² for routine maintenance (tack coat and 3 cm cold mix asphalt), including a 10% profit. The total maintenance cost over the design period for each segment is presented in Table 5.

Table 5 Road condition, maintenance type, and total maintenance cost over the design period

Road Segment	ADT (pcu/day)	IRI (m/km)	Condition	Year-0 Treatment	Maintenance Cost (IDR)
Jln. Ir. H. Juanda	26,510	4.149	Fair	Periodic	11,056,706,566.91
Gandaria–Cilodong/Depok Border	14,979	3.898	Fair	Periodic	19,782,194,166.39
Jln. Margonda Raya	28,801	3.734	Fair	Periodic	6,197,631,901.79

Note: routine maintenance in years 1–5. Source: Data analysis, 2021

Economic Feasibility

The benefits and costs of the three segments were summed and discounted to the base year at a 6.83% discount rate (Table 6). In year 0, the BCR is only 0.44 due to the high periodic maintenance cost, but from year 1 to year 5 the BCR ranges from 8.45 to 10.83 because routine maintenance costs are much smaller than the benefits received. Overall, a positive NPV of IDR 37,601,607,538.88 and a BCR of 2.05 were obtained. The IRR (the discount rate at which NPV = 0) is 75.33%, far higher than the 2019 interest rate of 6.83%. Thus, maintenance is economically feasible.

Table 6 Economic feasibility analysis based on NPV and BCR (i = 6.83%)

Year	PV Benefit (IDR)	PV Cost (IDR)	NPV (IDR)	BCR
0	13,077,440,200.85	29,627,545,551.43	−16,550,105,350.58	0.44
1	13,465,497,207.65	1,243,160,251.52	12,222,336,956.12	10.83
2	13,071,696,453.71	1,225,173,803.99	11,846,522,649.72	10.67
3	12,385,261,320.53	1,207,447,590.25	11,177,813,730.29	10.26
4	11,362,919,551.32	1,189,977,845.13	10,172,941,706.18	9.55
5	9,904,858,705.13	1,172,760,857.98	8,732,097,847.14	8.45
Total	73,267,673,439.19	35,666,065,900.31	37,601,607,538.88	2.05

Source: Data analysis, 2021

Sensitivity Analysis

The results of the sensitivity analysis are presented in Table 7. A decrease in benefits of up to 40% with fixed costs, or an increase in costs of up to 40% with fixed benefits, does not change the feasibility decision; the BCR remains above 1.23 and the IRR above 20%. A combined change of 30% still yields a BCR of 1.11. Maintenance only becomes infeasible when benefits decrease by 40% and maintenance costs increase by 40% simultaneously, with an NPV of −IDR 5.97 billion, a BCR of 0.88, and an IRR of −0.05%.

Table 7 Sensitivity analysis of NPV, BCR, and IRR

Benefit	Cost	PV Benefit (IDR)	PV Cost (IDR)	NPV (IDR)	BCR	IRR
Fixed	Fixed	73,267,673,439.19	35,666,065,900.31	37,601,607,538.88	2.05	75.33%
−20%	Fixed	58,614,138,751.35	35,666,065,900.31	22,948,072,851.04	1.64	46.64%
−30%	Fixed	51,287,371,407.43	35,666,065,900.31	15,621,305,507.12	1.44	32.69%
−40%	Fixed	43,960,604,063.51	35,666,065,900.31	8,294,538,163.20	1.23	20.45%
Fixed	+20%	73,267,673,439.19	42,799,279,080.37	30,468,394,358.82	1.71	50.19%
Fixed	+30%	73,267,673,439.19	46,365,885,670.40	26,901,787,768.79	1.58	41.56%
Fixed	+40%	73,267,673,439.19	49,932,492,260.43	23,335,181,178.76	1.47	34.49%
−20%	+20%	58,614,138,751.35	42,799,279,080.37	15,814,859,670.98	1.37	28.55%
−30%	+30%	51,287,371,407.43	46,365,885,670.40	4,921,485,737.03	1.11	13.11%
−40%	+40%	43,960,604,063.51	49,932,492,260.43	−5,971,888,196.92	0.88	−0.05%

Source: Data analysis, 2021

VOC Savings as the Determinant of Feasibility

VOC savings are the dominant benefit component, consistent with studies showing a strong relationship between road damage and VOC [7] and studies finding that changes in roughness and speed affect toll road VOC [8]. The benefit-cost ratio in this study (2.05) is higher than that of a new road construction study in West Lombok with a BCR of 1.017 [19] and a flyover in Banda Aceh with a BCR of 1.23 [17]. This is reasonable because maintenance requires much smaller investment than new construction, while its benefits are directly enjoyed by already heavy traffic. These results are also consistent with HDM-4 studies concluding that national road treatment is economically feasible and that a combination of routine and periodic maintenance is the most efficient strategy [10–12].

Contribution of Environmental Benefits

The reduction in GHG emission costs accounts for only about 0.2% of the total daily savings in the base year, so its contribution to feasibility is relatively small; however, its direction is consistent with the finding that pavement maintenance reduces vehicle emissions during the use stage [23]. Because high-volume segments generate the largest emissions [24, 25], this benefit is relevant for congested segments. The small value is also

influenced by the emission unit price used [27]; more recent estimates of the social cost of carbon could increase its weight, as pollution externalities can determine the feasibility of transportation projects [22].

Robustness of the Feasibility Decision

The sensitivity analysis shows that the feasibility decision is highly robust to uncertainty. This differs from new construction projects, whose feasibility decisions change easily with the discount rate [17] or depend on indirect benefits [20]. This supports the argument that timely maintenance is more efficient than deferring treatment [13–15]. This study has limitations: travel time value was not included, the design period is only five years, and speed projection depends solely on IRI, whereas speed on oversaturated segments is also affected by traffic characteristics [4, 9]. Future studies are recommended to use periodically measured IRI data [5, 32] and to include travel time value as a benefit variable.

CONCLUSION

Maintenance of Jalan Ir. H. Juanda, Jalan Gandaria–Cilodong/Depok Border, and Jalan Margonda Raya, which connect Depok City and Bogor Regency, is economically feasible, with an NPV of IDR 37,601,607,538.88, a BCR of 2.05, and an IRR of 75.33%, far higher than the 2019 interest rate of 6.83%. This feasibility mainly results from vehicle operating cost savings, supplemented by reduced vehicle greenhouse gas emission costs. The feasibility decision is robust and only becomes infeasible when benefits decrease by 40% and maintenance costs increase by 40% simultaneously. Road authorities are advised to prioritize timely maintenance of high-volume urban national roads and to include environmental benefits in the economic evaluation of maintenance.

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