Simulation of road treatment costs based on life-cycle cost analysis

A Mulyawan¹, S M Saleh² and R Anggraini²

¹Civil Engineering postgraduate program, Department of Civil Engineering, Universitas Syiah Kuala, Banda Aceh, Indonesia
²Department of Civil Engineering, Universitas Syiah Kuala, Banda Aceh, Indonesia

Corresponding e-mail: mulya.mulyawan2@gmail.com

Abstract. Flexible pavement is the most widely used type of road pavement in Indonesia. The main factors in the selection of flexible pavements are the low initial cost and the limited budget for road maintenance. This study aims to examine the level of comparison of road treatment costs based on life-cycle cost analysis (LCCA) rigid and flexible pavement for 40-years analysis period. The road treatment simulation uses road deterioration models based on the equation in the second version of the HDM-4 manual with the International Roughness Index (IRI) and the treatment period as the main variable. Based on the LCCA, The NPV analysis showed that the rigid pavement treatment cost ratio is 0.818 or more economical 18.20% at a 10% discount rate and 0.915 or more economical 8.48% at a 12% discount rate than the flexible pavement. Meanwhile, the EUAC analysis result showed that the rigid pavement treatment cost ratio is 0.847 or more economical 15.31% at a 10% discount rate and 0.862 or more economical 13.79% at a 12% discount rate compared to flexible pavement. The results showed that the rigid pavement treatment cost was more efficient 8.48% - 18.20% compared to flexible pavement.

1. Introduction

Flexible pavement is generally used for road treatment in Indonesia compared to other road pavements. The main factors in choosing this pavement are cheaper initial costs, limited road maintenance budget, relatively faster implementation time, and demand for equitable development. The flexible pavements do have cheaper initial costs, but in the long term period, the flexible pavements maintenance costs will increase annually, so the total cost of flexible pavements will be more expensive and less economical compared to the rigid pavements. Another aspect to be considered in determining pavement type beside maintenance costs is pavement endurance against heavy traffic. There are still many overloading vehicles in Indonesia that will cause an impact on service capability or performance life of the pavement. According to Saleh [1], the excess of the truckload of up to 50% can affect maintenance costs 2.5 times higher than the annual maintenance plan costs in the service life span. In addition, Syafriana [2] also stated that the total number of vehicles violating the allowable weight (JBI) was 31.50% per day of the total number of goods vehicles on the eastern national road cross-section of the Aceh Province.

This study aims to examine the comparison of road treatment cost based on life-cycle cost analysis (LCCA) rigid pavement and flexible pavement for 40-years plan of the analysis period. Road deterioration modeling used the equation in the second version of the HDM-4 manual with the International Roughness Index (IRI) and the treatment period as the main variable. The benefits cost or
user cost in this study for the two types of pavement is assumed to be the same so that the value of benefits can be ignored. The total road treatment based on LCCA will also be correlated with the level of road stability in accordance with the standards of the Directorate General of Highways of the Ministry of Public Work and Housing, so the most economical and efficient road treatment costs can be discovered.

2. Literature review and analysis methods

2.1. Road treatment and life cycle cost analysis
Life-cycle cost analysis (LCCA) is an analysis technique, based on well-founded economic principles, used to evaluate the overall long-term economic efficiency between the alternate investment options [3]. LCCA is typically used as a means to evaluate and compare the cost to the agency of any number of alternate pavement alternatives, including variations of concrete and asphalt pavement solutions.

![Generalized illustration of pavement condition over time and the financial implications of such through the calculation of total cost.](image)

**Figure 1.** Generalized illustration of pavement condition over time and the financial implications of such through the calculation of total cost [3].

2.2. Pavement design and road deterioration model
Pavement design in this study refers to Directorate General of Highways’s Road Pavement Design Manual for 2017. Ditjen Bina Marga [4], states that the service life of flexible pavement plans is 20 years while the rigid pavement is 40 years. The ratio of traffic volume to road capacity (RVK) is a maximum of ≤ 0.85 [5]. The value of RVK or the degree of saturation will be used as an indicator of the need to increase road capacity. Morosiuk [6] states that there are several main components in analyzing the decline in road conditions based on IRI values. The components can be seen in the following equation:

\[ \Delta RI = \Delta RI_s + \Delta RI_c + \Delta RI_r + \Delta RI_p + \Delta RI_e \]  \hspace{1cm} (1)

**Description:**
- \( \Delta RI \): Total incremental change in roughness during analysis year, in m/km IRI.
- \( \Delta RI_s \): Incremental change due to structural deterioration during analysis year, in m/km IRI.
- \( \Delta RI_c \): Incremental change due to cracking during analysis year, in m/km IRI.
- \( \Delta RI_r \): Incremental change due to rutting during analysis year, in m/km IRI.
- \( \Delta RI_p \): Incremental change due to potholing during analysis year, in m/km IRI.
- \( \Delta RI_e \): Incremental change due to the environment during analysis year, in m/km IRI.

The following is the equation used to analyze the IRI value on the rigid Joint Plain Concrete Pavement (JPCP) type according to ERES (1995) [6]:

![Equation for IRI calculation.](image)
IRI = IRI₀ + 0.00265(TFAULT) + 0.0291(SPALL) + 0.15×10⁻³(TRACK³)  \hspace{1cm} (2)

Description:
IRI = International Roughness Index, in m / km IRI.
IRI₀ = Initial roughness at construction, in m / km IRI.
TFAULT = transverse joint faulting, in mm/km.
SPALL = spalled joints, in per cent.
TCrack = transverse cracks, in no/km
L = 10 CRACKING / L CRACKING.

2.3. Evaluation of economic values based on LCCA
ACPA [3] states that the real discount rate, also known as the real interest rate, is commonly used in engineering economics to refer to the rate of change over time in the true value of money, taking into account fluctuations in both investment interest rates and the rate of inflation. Road treatment costs are calculated using the real discount rate as the discount factor value of road treatment costs during the analysis period. The equation of the real discount rate in the adaptation of Thuesen and Fabrycky is shown below [3].

\[ d = \frac{1 + i_{int}}{1 + i_{inf}} - 1 \]  \hspace{1cm} (3)

Description:
d = real discount rate, %.
i_{int} = the interest rate, %.
i_{inf} = the inflation rate, %.

Walls III [7] states that NPV is computed by assigning monetary values to benefits and costs, discounting future benefits and costs using an appropriate discount rate, and subtracting the sum total of discounted costs from the sum total of discounted benefits. Walls III [7] also states that equivalent uniform annual costs represent the NPV of all discounted costs and benefits of an alternative as if they occur uniformly throughout the analysis period. EUAC is a particularly useful indicator when budgets are established on an annual basis. The NPV and EUAC equations used in evaluating project economics based on LCCA are as follow [7]:

\[ NPV = Initial \ Cost + \sum_{k=1}^{N} \ Rehab \ Cost \ k \left[ \frac{1}{(1+i)^{n_k}} \right] \]  \hspace{1cm} (4)

\[ EUAC = NPV \left[ \frac{1}{(1+i)^{n}} \right] \]  \hspace{1cm} (5)

Description:
i = discount rate, %.
n = year of expenditure.

2.4. Analysis methods
The research location is the national road section of ‘Bts Bireuen / Aceh Utara - Bts. Lhokseumawe City /Bts. Aceh Utara (N.01.007.2)’. The road has a configuration of 2/2 undivided roads with a total length of 16.32 Km and a road width of 7.0 m. This study uses secondary data from ‘Balai Pelaksanaan Jalan Nasional I (BPJN I)’ and ‘Satker Perencanaan dan Pengawasan Jalan Nasional Provinsi Aceh (Satker P2JN)’. Data collected data includes general information data, traffic volume, CBR subgrade, unit prices
in 2017, and routine road maintenance unit prices in 2018. The inflation value used in this study is 3.51% which is an average value inflation rate for the period 2016 - 2018 from the Bank of Indonesia website. The interest rate used in the calculation of treatment costs is 10% during the period analysis using the real discount rate as an economic indicator, while the discount rate used in the economic analysis of LCCA is 10%, 12%, and 15%. Data processing is done with the help of laptops and Microsoft Word and Excel software.

2.5. Types of treatment for sealed roads based on IRI values

The following is the road conditions category index based on IRI values according to Directorate General of Highways which is a policy on road management in Indonesia:

- Good condition: IRI ≤ 4 m/km
- Fair condition: 4 < IRI ≤ 8 m/km
- Poor condition: 8 < IRI ≤ 12 m/km
- Bad condition: IRI > 12 m/km
- Road steadiness: Good condition + Fair condition

| Types of Road Treatment             | Type of Simulation Criteria for Road Treatment |
|-------------------------------------|-----------------------------------------------|
| Routine Maintenance                 | Model SF01: 0 < IRI < 4                      |
|                                     | Model SF02: 0 < IRI < 4                      |
|                                     | Model SF03: Every year                      |
| (unless there are other treatments) |                                               |
| 1st minor rehabilitation (overlay 40 mm) | 4 ≤ IRI < 6                                 |
| 2nd minor rehabilitation (overlay 60 mm) | 6 ≤ IRI < 7                                 |
| 1st major rehabilitation (overlay 100 mm) | 7 ≤ IRI < 8                                 |
| Reconstruction                      | IRI ≥ 8                                     |
|                                     | IRI ≥ 10                                    |
|                                     | Model SF03: years 20th                      |

Note: - SF01 and SF02 use treatment trigger criteria based on IRI values.
- The SF03 model uses treatment trigger criteria based on performance life every 5 years.

The work road effect is calculated based on the IRI value. The IRI value after road treatment, especially the major rehabilitation, is 3.0 m/km IRI. While the reduction in IRI value after road treatment, such as road routine maintenance and minor rehabilitation, is 0.01 (the default value from the HDM-4 manual). The reduction was analyzed using the road deterioration analysis results with reduced sensitivity of IRI value,

| The handling simulation | Model SR01 | Model SR02 | Model SR03 |
|-------------------------|------------|------------|------------|
| Trigger Criteria of Road Treatment | service period | service period | service period |
| every 5 years           |            | every 8 years | every 10 years |

| Types of Treatment                  | Model SR01                                  | Model SR02                                  | Model SR03                                  |
|-------------------------------------|---------------------------------------------|---------------------------------------------|---------------------------------------------|
|                                    | Repairing of transfer fault with dowel replacement | Repairing of concrete spalling | Repairing of concrete cracking |
|                                    | Surface roughness maintenance with diamond grinding for at years 10th and years 30th | | |
|                                    | Surface drainage maintenance with diamond grooving at year 20th | | |
2.6. Data processing methods
The data processing methods used in this study are as follow:
- The manual design of pavement thickness for both types of pavement based on the results of secondary data processing, which are traffic data, soil carrying capacity (CBR) data, analysis of Degree of Saturation (DS), and Cumulative Equivalent Standard Axle (CESA) analysis.
- Analysis of road deterioration model for both types of pavement.
- Calculation of material quantities requirements and road treatment costs for both types of pavement.
- Calculation of the economic value of road treatment costs for each year during the analysis period using a real discount rate economic indicator as a discount factor.
- Analysis of the economic value based on Life Cycle Cost Analysis (LCCA) by using economic indicators Net Present Value (NPV).
- Comparison of LCCA results between rigid pavement and flexible pavement.

3. Results and discussion

3.1. Road pavement thickness design
Based on the calculations and analyzes results that have been carried out, the results of flexible pavement thickness design are as follow:

a. AC-WC : 40 mm
b. AC-BC : 60 mm
c. AC-Base (initial development) : 210 mm
d. AC-Base (for 1st & 2nd reconstruction) : 245 mm
e. Sub-base coarse aggregate : 300 mm
f. Foundation layer : 300 mm

The Rigid pavement of the analysis is JPCP with dowel as the load transfer system. The analysis results of rigid pavement thickness design are as follow:

a. Concrete thickness f’c 35 MPa : 305 mm
b. Dowel size : D 38 mm - distance 300 mm
c. Binding Reinforcement Size (assumption) : 4 D16 and stirrup Ø10-250 mm
d. Concrete shoulder : Not counted in simulation
e. Lean Mix Concrete Foundation Layer : 150 mm
f. Sub Base Course Aggregate : 300 mm (as drainage layer)
g. Foundation layer : 300 mm (CBR 3.0%)

The results of the degree of saturation analysis show that in the 23rd year (in 2042) the value of the degree of saturation has reached 0.88 (DS > 0.85) so that the road capacity is increased from 2/2 divided to 4/2 divided. The Degree of saturation value in the 40th year of the analysis is still below the maximum allowable value of 0.81 (DS < 0.85) so road widening is not needed.

3.2. Analysis results of flexible pavement simulation
The poor condition on the SF01 only occurred once during the analysis period which is in the year of 23rd (IRI = 9.16 m/km) with the road steadiness level of 98 %. SF01 has a life-cycle with a performance life of 23 years before the reconstruction takes place in the year of 24th. The initial cost of SF01 is the same as SF02 and SF03, which is Rp. 219.90 billion. The total pavement treatment cost during the analysis period is Rp. 2,301.75 billion.
Both SF02 and SF03 have the same analysis. The poor condition on the SF02 occurs twice which is in the year 20\textsuperscript{th} and the year 26\textsuperscript{th} with an IRI value of 8.72 m/km IRI and 11.96 m/km and with the road steadiness level of 95 \%. The Total pavement treatment cost during the analysis period of the SF02 model is Rp. 2,652.17 billion. Besides, the poor condition on the SF01 occurs once which is in the year 18\textsuperscript{th}, but the bad condition on the SF02 occurs twice in the year of 39\textsuperscript{th} (IRI = 12.46 m/km). In the year 27\textsuperscript{th}, major rehabilitation was carried out because the IRI value was above 12 m/km. SF03 road steadiness level is 93 \% with the requirement of total treatment cost during the analysis period is Rp. 2,475.20 billion. The graph of the relationship between annual treatment costs and the cumulative cost of model SF01 can be seen in figure 3 below.

3.3. Analysis results of rigid pavement simulation
The results of the analysis on the SR01 model indicate that poor conditions occurred at the end of the analysis period of 8.06 m/km IRI with 98\% of road steadiness level during the 40-year analysis period.
The initial cost for all of the rigid pavement model is Rp. 293.84 billion. The life-cycle age of rigid pavement is considered the same as that of the analysis period of 40 years.

![Figure 4. Relationship between Road Treatment Costs and IRI Values of SR01 Model.](image)

![Figure 5. Relationship between Annual Treatment Costs and Cumulatif Cost of SR01 Model.](image)

The same analysis was carried out on SR02 and SR03. The poor condition on the SR02 occurs three times which is in the year 38th (8.31 m/km), in the year 39th (8.88 m/km), and in the year 40th (9.53 m/km). SR02 road steadiness level is 95% with the total treatment cost during the analysis period of Rp. 841.44 billion. The poor IRI conditions on the SR05, occurring five times starting from the year 36th to the end of the analysis period, are 8.02 m/km, 8.54 m/km, 9.31 m/km, 9.79 m/km and 10.53 m/km. The total treatment cost of SR03 during the analysis period is Rp. 759.73 billion.

### 3.4. Results of rigid and flexible pavement base on life cycle-cost analysis

Table 3 below is a recapitulation of the results of LCCA analysis using NPV and EUAC indicators to evaluate the value of actual pavement treatment costs over the 40-year analysis period. Based on the NPV, SF03 has the highest pavement treatment costs at a discount rate of 10% and 12% with the total cost of Rp. 455.83 billion and Rp. 388.01 Billion. While SR03 also has the lowest pavement treatment costs.
costs at both discount rates of 10% and 12% with the total costs of Rp. 345.07 billion and Rp. 329.73 billion.

Furthermore, based on the analysis results of EUAC indicators, SF01 has the highest pavement treatment costs at a discount rate of 10% and 12% with the total cost of Rp. 498.09 billion and Rp. 478.23 billion. While SR03 has the lowest pavement treatment costs also at both discount rates of 10% and 12% with total costs of Rp. 325.91 billion and Rp. 321.90 billion.

### Table 3. Results of LCCA Analysis with NPV and EUAC.

| No. | Model | Net Present Value (NPV) | Equivalent Uniform Annual Cost (EUAC) |
|-----|-------|-------------------------|---------------------------------------|
|     |       | Discount Rate 10% | Discount Rate 12% | Discount Rate 10% | Discount Rate 12% |
| 1   | SF01  | 422.60          | 359.09          | 498.09          | 478.23          |
| 2   | SF02  | 408.79          | 345.96          | 408.56          | 392.29          |
| 3   | SF03  | 455.83          | 388.01          | 333.84          | 322.55          |
| 4   | SR01  | 358.09          | 337.89          | 376.15          | 365.09          |
| 5   | SR02  | 349.80          | 332.74          | 348.56          | 341.54          |
| 6   | SR03  | 345.07          | 329.73          | 325.91          | 321.90          |

### 3.5. Discussion

Based on the table of the relationship between road treatment costs and the road steadiness below, the SR01 rigid pavement is the best model with a total treatment cost of Rp. 1,020.14 billion with 98% of the road steadiness level. Even though SR01 costs are not the cheapest costs, but in terms of cost and road steadiness level, the SR01 model is the best choice. SF01 has the same steadiness level as SR01 but has a much more expensive cost which is Rp. 2,301.75 billion; however, the SR01 road treatment costs are more efficient at 1.26 times compared to the SF01. The total average of road treatment costs of rigid pavement model saves more 1.83 times than the flexible pavement model. However, the average road steadiness of rigid pavement is lower 2% compared to the flexible pavement, which is 98%.

### Table 4. Relationship between road treatment costs and road steadiness.

| No. | Model | Road Steadiness | Road Steadiness | Total Cost (Rp. Billion) | Average of Treatment Cost (Rp. Milyar) | Comparison of Rigid and Flexible Pavement |
|-----|-------|-----------------|-----------------|--------------------------|----------------------------------------|------------------------------------------|
| 1   | SF01  | 98%             | 95%             | 2,301.75                 | 2,476.37                               | 183%                                     |
| 2   | SF02  | 95%             | 95%             | 2,652.17                 |                                        |                                          |
| 3   | SF03  | 93%             | 93%             | 2,475.20                 | 873.77                                 |                                          |
| 4   | SR01  | 98%             | 98%             | 1,020.14                 |                                        |                                          |
| 5   | SR02  | 93%             | 93%             | 841.44                   |                                        |                                          |
| 6   | SR03  | 88%             | 88%             | 759.73                   |                                        |                                          |

Figure 6 below is an LCCA analysis result using economic indicators of NPV and EUAC on both types of pavement. Based on figure 6, the treatment cost of rigid pavement based on NPV saves Rp. 78.09 billion (18.20%) at a discount rate of 10% and Rp. 30.90 billion (8.48%) at a discount rate of 12% compared to flexible pavement. Whereas based on EUAC calculation results, the treatment cost of rigid pavement saves Rp. 63.29 billion (15.31%) at a discount rate of 10% and Rp. 54.84 billion (13.79 %) at a discount rate of 12% compared to flexible pavement.
4. Conclusion
Based on the results of the analysis and discussion it can be concluded that the SR01 model is the most economical and efficient pavement model in terms of road treatment cost and road stability during the 40-year analysis period with a cost of Rp. 1,020.14 billion with 98% road steadiness level. The total average of rigid pavement road treatment cost is 1.83 times or 183% more efficient than the flexible pavement, but the average of rigid pavement road steadiness is lower 2 % compared to the flexible pavement’s, which is 98 %. Based on the LCCA analysis with NPV indicators, the road treatment cost of a rigid pavement ratio is 0.818 or more economical 18.20% at a discount rate of 10% and 0.915 or more economical 8.48% at a discount rate of 12 % than the flexible pavement. Besides, the EUAC indicator shows that the road treatment cost of rigid pavement ratio is 0.847 or 15.31% at a discount rate of 10% and 0.862 or 13.79% at a discount rate of 12% compared to flexible pavement.

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References
[1] Saleh S M, Sjafruddin A, Frazila R B and Tamin O Z 2009 Pengaruh muatan truk berlebih terhadap biaya pemeliharaan jalan Transportation J. of FSTPT 9 1 79
[2] Syafriana, Saleh S M and Angraini R 2015 Evaluasi umur layan dengan memperhitungkan beban berlebih di ruas jalan lintas timur Provinsi Aceh Transportation J. of FSTPT 15 2 115
[3] American Concrete Pavement Association 2012 Life Cycle Cost Analysis: A Tool for Better Pavement Investment and Engineering Decicions (Rosemont-Illinois: US) vii 1 p 6
[4] Direktorat Jenderal Bina Marga 2017 Manual Desain Perkerasan Jalan Nomor 02/M/BM/2017, Kementerian Pekerjaan Umum dan Perumahan Rakyat (Jakarta: Direktorat Jenderal Bina Marga Kementerian Pekerjaan Umum dan Perumahan Rakyat) 2-1
[5] Kementerian Pekerjaan Umum dan Perumahan Rakyat 2011 Peraturan Menteri PUPR Nomor:
19/PRT/M/2011 tentang Persyaratan Teknis Jalan dan Kriteria Perencanaan Teknis Jalan (Jakarta)

[6] Morosiuk G, Riley M J and Odoki J B 2004 *Highway Development & Management (HDM -4) Volume Six: Modelling Road Deterioration and Works Effect Version 2.* (Washington DC: The World Road Association (PIARC) on behalf of the ISOHDM Sponsors Paris and The World Bank) B 10-11 C 5-2

[7] Walls III J and Smith M R 1998 *Life-Cycle Cost Analysis in Pavement Design-Interim Technical Bulletin* (Washington: FHWA US) pp 4-5