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New Optimization Strategies of Pavement Maintenance: A Case Study for National Road Network in Indonesia Using Integrated Road Management System

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Abstract. A road network requires timely maintenance to keep the road surface in good condition onward better services to improve accessibility and mobility. Strategies and maintenance techniques must be chosen in order to maximize road service level through cost-effective interventions. This approach requires an updated database, which the road network in Indonesia is supported by a manual and visual survey, also using NAASRA profiler. Furthermore, in this paper, the deterministic model of deterioration was used. This optimization model uses life cycle cost analysis (LCCA), applied in an integrated manner, using IRI indicator, and allows determining the priority of treatment, type of treatment and its relation to the cost. The purpose of this paper was focussed on the aspects of road maintenance management, i.e., maintenance optimization models for different levels of traffic and various initial of road distress conditions on the national road network in Indonesia. The implementation of Integrated Road Management System (IRMS) can provide a solution to the problem of cost constraints in the maintenance of the national road network. The results from this study found that as the lowest as agency cost, it will affect the increasing of user cost. With the achievement of the target plan scenario P1000 with initial value IRI 2, it was found that the routine management throughout the year and in early reconstruction and periodic maintenance with a 30 mm thick overlay, will simultaneously provide a higher net benefit value and has the lowest total cost of transportation.

INTRODUCTION

The road infrastructure contributes in facilitating the distribution of goods and services to improve the quality of human life. A road network requires treatment in the form of maintenance to keep the road in good condition so that it can serve as the provision of access and convenience. Road maintenance should always be planned to provide maximum safety for road users with cost-effective. It is important for the person in charge of the road to use the budget efficiently and effectively in maintaining roads in good condition during the services. The obstacle is apparently often occurred to those who are responsible for the road when it must be decided on the level of damage and the type of maintenance.

PURPOSE OF STUDY

The goal of optimization is set in order to minimize the sum of agency cost (AC) and road user cost (RUC) in present value or to maximize the net benefit to people over the analysis period. The aim of this study was to propose pavement maintenance management by means of optimization models of maintenance costs for different levels of traffic volume. The proposed maintenance optimization strategy is refining the previous version of the IRMS. By using this model, the optimization of maintenance costs and RUC costs can be performed on the optimal maintenance strategy options, appropriately applied into various initial of road distress conditions. This paper
presents a new approach to set initial IRI to provide the maximum level of services and results of saving on sum AC and RUC.

LITERATURE REVIEW

In order to integrate the strategic plan and maintenance work of pavement, it requires a pavement management system (PMS). According to [1], PMS is defined as a system that consists of a set of engineering tools for performing pavement condition surveys and condition prediction and developing work plans with the objective of optimizing spending. The main function of PMS is to increase efficiency in decision-making, and the scope of management. PMS is a way to overcome the problem of how to get the maximum road conditions with minimum cost [2]. Otherwise, the method of PMS has provided feedback to the consequences of decisions, and ensures the consistency of decisions made by the organization at different levels [3]. PMS is designed to provide objective information from existing data and analysis so that policy makers can give a decision in cost savings [4]. At this time, the optimization techniques have been widely adopted for planning and programming of road maintenance, such as integer linear programmed by [5]. Otherwise, [6] applied techniques of multi-objective decision aid tool to obtain maintenance optimization model. HDM-4 model has used Net Present Value (NPV) for calculating a wide range of appropriate options [7],[8] has used the IRMS for the management of the road network with the aim of planning, programming, and budgeting to be more effective and efficient. IRMS is a part of system policy, which has provided a way to managers that can make decisions faster, better, and sustainable [9].

METHODOLOGY

The IRMS is constituted by the following components: strategy analysis, work program analysis, and project analysis. In this paper, the deterministic model of deterioration was used to forecast road condition during analysis period based on the expected impact of each applied treatment technique, and without treatment on the road condition. The output of the model is fully determined by the parameter values and the initial conditions. Therefore, the older data IRI and traffic will be modelled on current year to the less one year. The main component of IRMS is the methodology used to select the best option of maintenance and rehabilitation taken into account in the coming planning period. The method applied in this IRMS is based on economic ranking by IRI as a present road condition and indicative cost for maintenance and reconstruction, where the treatment cost is based on the treatment selected. The economic ranking is determined by comparing the total cost of maintenance alternatives to the basic cost alternative. The basic cost is a minimum standard and routine maintenance [10].

In this paper, the net benefit was computed to people, and it is based on simulation of roughness scenario on difference level of traffic to the total cost transportation during project period in present value. The scenario analysis in this research was divided into two simulating different levels of traffic, namely P1000 and P5000. Where P1000 is AADT from 0 ≥ 1000 and P5000 are more than 1000 vehicles per day. This level is chosen to look at the maintenance of optimal strategies in order to deliver net benefits in its high. Besides, the P1000 and P5000 are taken as a form of innovation in providing better services in the long term and can save transportation costs. The selection process for P1000 and P5000 is used by using three alternative scenarios as follows: Scenario I multi-objective optimization with unconstraint budget, Scenario II multi-objective optimization between unconstraint and constrained budgets AC, Scenario III multi-objective optimization with constrained budget scenarios. Analyses of the budget in this scenario used the value of the discount rate of 12%. This optimization model uses LCCA, applied in an integrated manner, and allows determining the priority of treatment, type of treatment and its relation to the cost, the concept of LCCAs based on determining the best the lowest cost way to accomplish the maintenance scenario. IRMS optimization strategies use the iterative procedure heuristically, and the combination of several strategies to produce in accordance with the optimization capabilities specified a budget.

Type of Maintenance Operations

In this study, the road maintenance was based on 8 different types of maintenance operations, applied as individual or combination of several types. Table 1 shows the types of operations and costs, which T0 is do nothing and T1 to T3 are handling patching, crack sealing and asphalt concrete overlay 1 layer with thickness of 30 cm. This type is used for routine maintenance. T4 to T7 are periodic maintenance using asphalt concrete thickness of 40 cm, 50 cm, 60 cm and 70 cm. T8 is reconstructed by using asphalt concrete with a thickness of 80 cm.
### TABLE 1. Type of Maintenance Operations.

<table>
<thead>
<tr>
<th>Maintenance Work</th>
<th>Treatment action</th>
<th>Cost (IDR)^9</th>
<th>Maintenance Work</th>
<th>Treatment action</th>
<th>Cost (IDR)^9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do Nothing</td>
<td>T0</td>
<td>0</td>
<td>Overlay 50 mm</td>
<td>T5</td>
<td>2.25</td>
</tr>
<tr>
<td>Drainage works for every year</td>
<td>T1</td>
<td>0.2</td>
<td>Overlay 60 mm</td>
<td>T6</td>
<td>2.27</td>
</tr>
<tr>
<td>Patching, Crack sealing, cracking</td>
<td>T2</td>
<td>0.25</td>
<td>Overlay 70 mm</td>
<td>T7</td>
<td>3</td>
</tr>
<tr>
<td>Overlay 30 mm</td>
<td>T3</td>
<td>0.3</td>
<td>Overlay 80 mm</td>
<td>T8</td>
<td>3.5</td>
</tr>
<tr>
<td>Overlay 40 mm</td>
<td>T4</td>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Data Sources

This paper uses data obtained from a database IRMS. The database has been made up on the results of a survey of visual observation and with the aid of NAASRA. From the results of the survey, it is found that AADT of 12 types of vehicle and axle load calculated in millions ESA, has been classified into 5 groups of vehicles (motorcycle, passenger car, medium trucks, large buses and heavy trucks). Motorcycle type was not included in the calculation of the ESA.

In Table 2, it can be seen the separation between P1000 and P5000, the difference for P1000 is AADT 679 and P5000 AADT 4930. The group of P1000 composition was dominated by motorcycle of 95% in compared to the P5000 of only 55.52%, while the composition and the rate of traffic growth of each group varied. The rate growth of such vehicles has been calculated for traffic prediction during 10 years. ESA calculations have been obtained for P1000 subsequently determined by MESA 280.29x10^7, whereas the P5000 was determined by MESA 351.17x10^7.

### TABLE 2. Composition and Annual Growth Rate of Traffic

<table>
<thead>
<tr>
<th>Traffic class</th>
<th>Motorcycle</th>
<th>Passenger Car</th>
<th>Medium truck</th>
<th>Large Bus</th>
<th>Heavy truck</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>AADT 1000</td>
<td>13172</td>
<td>372</td>
<td>161</td>
<td>55</td>
<td>86</td>
<td>679</td>
</tr>
<tr>
<td>P100 (composition, %)</td>
<td>95</td>
<td>2.68</td>
<td>1.62</td>
<td>0.2</td>
<td>0.5</td>
<td>100</td>
</tr>
<tr>
<td>Annual Growth Rate</td>
<td>10.38</td>
<td>7.2</td>
<td>1.43</td>
<td>2.02</td>
<td>1.6</td>
<td></td>
</tr>
<tr>
<td>AADT 5000</td>
<td>6153</td>
<td>3172</td>
<td>1238</td>
<td>262</td>
<td>254</td>
<td>4930</td>
</tr>
<tr>
<td>P5000 (composition, %)</td>
<td>55.52</td>
<td>28.62</td>
<td>11.19</td>
<td>2.38</td>
<td>2.29</td>
<td>100</td>
</tr>
<tr>
<td>Annual Growth Rate</td>
<td>12.72</td>
<td>8.92</td>
<td>1.11</td>
<td>3.4</td>
<td>1.41</td>
<td></td>
</tr>
</tbody>
</table>

### DEVELOPMENT OF MAINTENANCE OPERATION MODEL

#### The Proposed Maintenance Optimization Model

To develop optimization model, several parameters were required such as: length of the analysis period, budget periods, objective function, and resource constraints for each funding period [11]. The modeling of optimization considered two objectives, namely the minimization of AC and minimization of RUC over planning time span. The AC constraint defined the costs for AC. Objectives function can be formulated by equation (1) and equation (2) as follows:

\[
\min AC = \sum_{t=1}^{T}(1 + r)^{-1}\sum_{n=1}^{N}\sum_{m=1}^{M} A_{t_{nm}} \cdot x_{t_{nm}}
\]  

where \(\min AC\) is minimum agency cost, \(T\) is total years of planning time span, \(t\) is in year \(t\), \(r\) is the discount rate, \(N\) is total segment, \(n\) is segment, \(M\) is total operational option and \(m\) is operational option and \(x_{t_{nm}}\) is equal zero if not operation applied and equal to one if operational \(m\) to segment \(n\) in year \(t\). The calculation of minimization RUC did not include the cost of traffic motorcycle users.
\[
\text{Min RUC} = \sum_{t=1}^{T} (1 + r)^{-1} \sum_{n=1}^{N} RUC_{tn}. 
\] (2)

where, Min RUC is minimum user cost, T is total years of planning time span, t is in year t, r is the discount rate, N is total segment, n is segment. The constraint optimization model of road condition, function formulated by equation (3)-(7), expressing the road condition in each road segment and year as a set of functions of initial road and maintenance scenario used to the road segment. This function uses roughness as represent of road condition. The warning level constraints defined the maximum of IRI level for the road condition is formulated by equation (3).

\[
IRI_{tn} \leq \overline{IRI} 
\] (3)

where \(IRI_{tn}\) is the road condition for segments \(n\) in year \(t\) and \(\overline{IRI}\) is warning level road condition for segment \(n\). The AC constraint equation (4) defined the costs for road agency cost functions involved types of operation to road segment in year as the the a function of the road condition in that segment and year. These costs are found by multiplying agency cost for maintenance operations.

\[
AC_{tnm} = (f_a) x_{tnm}, IRI_{tn} 
\] (4)

where \((f_a)\) is the AC function. The RUC constraint equation (5) defined as the costs for RUC functions involved types of operation to road segment in year as a function of the vehicle operational cost in that segment and year.

\[
RUC_{tn} = (f_a) V O C_{tn} 
\] (5)

where \((f_a)\) is the RUC function and \(V O C_{tn}\) is the annual RUC charges for type of vehicle. The vehicle operational cost for the annual year is formulated by equation (6).

\[
V O C_{tn} = k_1 + \frac{k_2}{V} + k_3.V^2 + k_4.IRI + k_5.IRI^2 
\] (6)

where \(k_{1-5}\) is constant and \(V\) is speed of vehicle. The annual budget constraints equation (7) defined as the maximum to be spent on budget on maintenance work in each year.

\[
\sum_{t=1}^{T} \sum_{n}^{N} AC_{tnm} \cdot x_{tnm} \leq B_t 
\] (7)

where \(B_t\) is the budget for year \(t\). The modelling of road condition function on IRMS which applied to evaluate the roughness progression using equation (11) by [8] as follows:

\[
IRI(t) = e^{0.023.t}[IRI(0) + 263(1 + SNC)^{-5}.NE_4(t)] 
\] (8)

where \(IRI\) is roughness in year \(t\), \(e\) is exponential 2.278, \(IRI(0)\) is roughness in year \(t\), \(SNC\) is modified structural number of pavement strength, \(NE_4(t)\) is the value of ESAL cumulative to year of \(t\) million (load damage power 4). The relationship between modified structural number of pavement strength and deflection using the equation (9) by [11].

\[
SNC = 3.2x(DEF^{-0.63}) 
\] (9)

where DEF is benkelman beam deflection (mm).

**Performance Indicators**

To prioritize highway pavement projects according to limited highway budgets, pavement distress rating was made, in one form or another. Performance indicator for a road pavement is the term for technical characteristics that indicate the condition of road. In this paper, the road condition was rated based on the roughness value that was
classified into four categories. The pavement is stated in good condition if the IRI <= 4, fair 4 < IRI <= 8, poor 8 < IRI <= 12, bad 12 < IRI [12].

RESULTS AND DISCUSSION

Maintenance Optimization for Different Levels of Traffic

The simulation resulted the three scenarios using P1000 and P5000, AC, UC, Total Transport Cost, NPV and IRI, the results were subsequently obtained, as shown in Table 3. Based on all the scenarios, scenarios I to P1000 has the higher agency cost of 1.67 billion IDR instead of II and III. The scenario III has the lowest user cost of 70.46 billion IDR instead of I and II, while the scenario II has the lowest value of total cost is 72.1 billion IDR instead of I and III. The scenario I has the higher NVP value is 10.96 instead of scenario II and III, while the scenario I has the lowest IRI is 3.1 instead of scenario II and III. As can be seen in Table 3 and Figure 1(a) scenario III is the lowest agency cost, allowing saving of approximately 56.89% to scenario I. This is a good finding to show that the scenario I is always avoided since it provided the implication of an increasing investments (agency cost) in order to maintenance of road condition. On the other hand, the scenario II would increase 56.20% to scenario III, related with the user cost is much higher when considering scenario III instead of scenario I and scenario II. The scenario II is the lowest user cost scenario, allowing saving of approximately 2.65% to scenario I and 0.38% to scenario III.

Table 3 and Figure 1(b) for the all scenario on P5000 shows that scenario I has the higher value of agency cost 87.27 billion IDR in compared to scenario II and III. While, the scenario II has the lowest user cost 81.07 billion IDR instead of scenario I and III, thus the scenario II has the lowest total cost 85.23 billion IDR instead of scenario I and III. The scenario I has the higher NVP value is 10.96 instead of scenario II and III, while the scenario I has the lowest IRI is 3.1 instead of scenario II and III. Scenario III is the lowest agency cost, allows saving 83.81% to scenario I. Moreover, the scenario II an increase 78.37% to scenario III. This mean to reduce of total cost it is necessary to allocate more in the maintenance of road condition. The scenario II is the lowest user cost, allowing saving of approximately 5.60% to scenario III and 0.88% to scenario I. Similar with scenario P1000, on P5000 the lowest total cost of transportation is the scenario II, instead of scenario I and III.

<table>
<thead>
<tr>
<th>No.</th>
<th>Scenario</th>
<th>Agency Cost</th>
<th>User Cost</th>
<th>Total Transport Cost</th>
<th>NVP</th>
<th>IRI</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>P1000</td>
<td>P5000</td>
<td>P1000</td>
<td>P5000</td>
<td>P1000</td>
</tr>
<tr>
<td>1</td>
<td>I</td>
<td>1.67</td>
<td>5.56</td>
<td>70.73</td>
<td>81.71</td>
<td>72.4</td>
</tr>
<tr>
<td>2</td>
<td>II</td>
<td>1.64</td>
<td>4.16</td>
<td>70.46</td>
<td>81.07</td>
<td>72.1</td>
</tr>
<tr>
<td>3</td>
<td>III</td>
<td>0.72</td>
<td>0.90</td>
<td>72.38</td>
<td>85.95</td>
<td>73.1</td>
</tr>
</tbody>
</table>

Figure 2(a) presents the value of annual IRI predictions for P1000. Simulation in scenario I, II and II have a final value of IRI of 3.10, 3.20 and 5.30, respectively, which the lowest value is scenarios I and the scenario III has the highest IRI value. This can be explained by Fig. 3(a) that the year 1st to year 5th on graphics, scenarios I, II and III appear in positions coincide, where the costs budgeted by the agency is relatively the same. In the 6th year budget allocation for scenario I is slightly greater than the scenario II and scenario III. Then in the 8th year and 9th year, scenario I and II got a portion of a larger budget than the scenario III so that the value of IRI scenarios I and II be decreased. In the 10th year scenario III got the biggest budget compared to scenarios I and II but the value of IRI scenario III still does not decline, the final value of IRI is 5.30 which in this condition the road is in fair condition. The value of IRI predictions for P5000 is shown by Fig. 2(b). In this figure the scenario I, II and III have a final value of 3.10, 3.60 7.00, respectively, which the lowest value is scenarios I, and scenario III has the highest IRI. This can be explained by Fig. 3(b) that the 1st year to the 4th year the graph of scenario I, II and III in positions coincide. The agency is an allocated budget by the same relative. In the 6th year, budgets allocation for the scenario I is slightly larger than the scenario II. The scenario III budget is the same until the end of the planning. It seems that the IRI for scenario III is increasing by the year-end planning. In the 9th year cost budgeted for scenario III is greater when compared to scenario I and II, but it was not declined on to IRI value, with the final value of IRI is 7.00, meaning that roads in fair condition.
To provide the maximum level of service and the results of saving on sum AC and RUC, two values AADT and five initial values for IRI have been developed. In this model, scenario II multi-objective optimization between unconstraint and constrained budgets agency cost is applied, based on the assumption that the scenario II on P1000 and P5000 have the lowest total cost of transportation, instead of scenario I and III. By using optimization model for
various initial of IRI, the person in charge of road can decide how much IRI value is taken as a baseline to use the budget efficiently and effectively in maintaining roads during those services.

The results of running the optimum operation of the IRMS for the maintenance on P1000 can be seen in Table 5 and Figure 4 (a). The initial value of IRI 2, the handling routine throughout the year, reconstruction of 80 mm carried out in 2015, and T3 carried out in 2018 and 2020, while the T4, T5 and T6 carried out in 2020 - 2023. The net benefit obtained value is 6.41. The initial value of IRI 4, the handling of routine throughout the year, T5 carried out in 2015 and T6 carried out in 2016 - 2019. The net benefit obtained is 0.22. The initial value of IRI 6, routine management throughout the year, T7 in 2015 and 2017, while T8 was carried out in 2015. The net benefit obtained is 0.24. The initial value of IRI 8, handling routine maintenance throughout the year, T7 and T8 in 2015. The net benefit obtained is 0.26. The initial value of IRI 12, handling routine throughout the year, T7 is performed in 2015. The net benefit obtained is 0.36. Figure 4 (a) show if the initial value is used IRI 2, 4, 6, 8 and 12 produces the final IRI 3.1, 3.3, 3.3, 3.3 and 3.4, respectively. Based on all scenario above showed that initial IRI 2 produce the lowest final IRI 3.1 and has higher net benefit 6.41 instead of initial IRI 4, 6, 8 and 12.

TABLE 5. Optimum Maintenance Option P1000 and P5000

<table>
<thead>
<tr>
<th>Initial IRI</th>
<th>P1000</th>
<th>P5000</th>
<th>Operation Option T (year)</th>
<th>Net Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>18</td>
<td>22</td>
<td>T1(2015-2025); T2(2016, 2017); T4(2019, 2020); T6(2017, 2021, 2022, 2023)</td>
<td>6.41, 0.17</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
<td>14</td>
<td>T5(2015); T6(2015, 2017); T8(2015)</td>
<td>0.22, 0.2</td>
</tr>
<tr>
<td>6</td>
<td>14</td>
<td>12</td>
<td>T7(2015, 2017); T8(2015)</td>
<td>0.24, 0.24</td>
</tr>
<tr>
<td>8</td>
<td>14</td>
<td>12</td>
<td>T1(2015-2025); T7, T8(2015)</td>
<td>0.26, 0.25</td>
</tr>
<tr>
<td>12</td>
<td>12</td>
<td>12</td>
<td>T1(2015-2025); T7(2015)</td>
<td>0.36, 0.39</td>
</tr>
</tbody>
</table>

FIGURE. 4 (a) Predicted roughness progression for optimal Maintenance option under P1000; (b) Predicted roughness progression for optimal Maintenance option under P1000.

The results of running the optimum operation on P5000 can be seen in Tables 5 and Figure 4 (b). If the initial value of IRI 2, the handling routine throughout the year, T2 performed in 2016 and 2017, T4 carried out in 2019 and 2020, while T5 is performed continuously in 2019 - 2022, T8 carried out in 2017, 2021 - 2023. The net benefits obtained value is (the least of all scenario) 0.17 and the last final IRI 3.1. If the initial value of IRI 4, the handling of routine throughout the year, T5 made in 2016 and T6 made in 2017 and 2018. The net benefits obtained value is lowest is 0.22 and the last final IRI 3.4. If the initial value of IRI 6, routine management throughout the year, T7 in
2016 and the last final IRI 3.5. If the initial value of IRI 8, routine management throughout the year, T8 carried out in 2015 and the last final IRI 3.3. If the initial value of IRI 12, handling routine maintenance throughout the year, T8 carried out in 2015. The net benefit obtained value is the highest of 0.39 and the last final IRI 3.5. The net benefit is the maximum net benefit over analysis period of the optimum maintenance option and defined as allowing saving on sum agency cost and road user cost. The value of progressive IRI in P5000 with several scenarios show that the initial IRI 2 has the lowest final IRI 3.1, instead of initial IRI, 4,6,8 and 12. This indicates that at the end of the scenario, roads in good condition. From the comparison between the P1000 and P5000 shows that on P1000 and P5000 with initial IRI 2 has the similar lowest final IRI 3.1 and on P1000 with initial IRI 2 has higher net benefits 6.41 compared to other scenarios.

CONCLUSIONS

On the P1000 and P5000, it is found that scenario III has the lowest AC that will affect the increase of RUC. The finding show that the scenario I is always avoided since it provides the implication of an increasing investments (AC) in order to maintenance of road condition. Three funding scenarios in this paper were examined, it found that the scenario II has the lowest total cost of transportation in compared to scenario I and III. The scenario III on P1000 with constant budget pattern until the 5th year, will provide the condition of roads in good condition. However, in the 6th year, allocation will give higher costs in order to maintain the roads in good condition. In scenario III where the budget on P5000 is given constantly until 8th year, the road conditions will be in good condition. However, if in the year 9th budgeted cost is larger, it will not decline the IRI value. With the achievement of the target plan scenario P1000 with initial value IRI 2, it is found that the routine management throughout the year and in early reconstruction and periodic maintenance with a 30 mm thick overlay will provide a higher net benefit value and has the lowest total cost of transportation among all scenarios. In the near future, we propose the significance of pavement management system to apply the other performance indicators and maximization of residual value of pavement.

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