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Pavement Maintenance Optimization Strategies for National Road Network in Indonesia Applying Genetic Algorithm

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Abstract

In Indonesia, the national road has an important role to increase the region's economy, the road has the function to preserve inter-provincial or inter-provincial and regencies/cities. Road network in Indonesia has a significant length, of approximately 516,239 kilometers, where the majority presents lack of information related to monitoring data and evaluation. As a consequence, road maintenance is not appropriated. The objective of this paper is to describe the development of a Genetic Algorithm (GA) based on multi objectives programming of pavement and to investigate the optimal maintenance strategy options applied as function of road surface distress conditions. This is supported by database of an Integrated Road Management System (IRMS) and taking into account of both road network condition and agency costs. The optimization strategies provided by the developed soft computing tool can help solving agency problems; minimizing costs and maximizing road services.

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Keywords: data mining, genetic algorithm, multi objective, optimization

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1. Introduction

In Indonesia, the national road has an important role to increase the region's economy, the road has the function to preserve inter-provincial or inter-provincial and regencies/cities. Road network in Indonesia has a significant length, of approximately 516,239 kilometers, where the majority presents lack of information related to monitoring data and evaluation. The classification of roads upon overall length consists of residence / Kabupaten road 423,578 or 82.05% and national road 47,017 or 9.11% and provincial road 423,578 km or 8.84%. It is not deniable that the national road infrastructures provide significant contribution in economic society through sustainable goods and services distribution. (Hamdi et. al, 2017a). The National Road consist of an arterial road and collector road in the system of primary road network. This road connects between the provincial capital, national strategic road and highway. The responsibility of the development of national roads is in the hand of the central government. As of acquiring the national roads being more lengthened, the government faces the need of maintenance budget for road assets increased from 38,569 km in 2014 up to 47,017 in 2015, or being developed up to 17,97%. In the other side, the government is captured on to budget limitation in the maintenance budget. Therefore, the effectivity and efficiency of the road management is required to provide optimum road asset performance for both budgeting and servicing on given availability budget.

Nomenclature

A	total operational option
AC	area crack
B_t	budget for year t
C_j	unit cost of *j* treatment
C_{min}	minimum maintenance cost
CW	crack width
f_a	cost function
GA	Genetic Algorithm
IRMS	Integrated Road Management System
L	length of pavement section
NSDI	New Surface Distress Index
P	pothole
Patch	patching
r	discount rate
R	rutting
SDI	Surface Distress Index
$\overline{SDI}$	warning level road condition
SDI_{jt}	surface distress index for *j* treatment option in year
SDI_{max}	maximum road condition
SDI_{min}	minimum acceptable level of SDI
T	total years of planning
X_{jt}	binary variable for section with j treatment option in year t

2. Purpose of study

The objective of this study is to develop the road asset management system complied to the condition and specification of the national road in Indonesia by simulating road maintenance through multi-objective optimization function. The optimization applied in this study is performed to minimize agency cost and maximize the road level serviceability to society during analytical period. Another objective being targeted in this study is to develop the optimization on road maintenance by applying Genetic Algorithm using data mining technique through Pareto model based on the budget limitation along with road assessment through surface distress index.

3. Literature Study

Many studies have been conducted on the optimization of road maintenance. The approach by Markov chain is applied on to predicting road condition and GA built in solving the multi-objective optimization. (Elhadidy, Elbeltagi, Ammar, 2014). The application of GA is also used to solve multi-objective on the level of maintenance road project and rehabilitation program by applying model of two optimization objectives, namely; the maximized road performance and minimized maintenance budget. (Chikezie, Olowosulu, Abejide, 2013). Hamdi et. al (2017b) uses life cycle cost analysis in the optimization, the study is applied on to model optimization with the scenario values on different initial values and traffic. Furthermore, GA uses an artificial intelligence technique applied on multi objective optimization (Hoque, Fang, Tat, 1999). An overview and tutorial method on multiple objective optimization using GA is introduced by Konak, Coit, Smith (2006). Far more exploring on different technologies integration in the earth work construction process is applied by Parente, Correia, Cortez (2015). The model is casted on evolution system of multi-criteria optimization tools in cost, duration, and environment effect. GA package is flexible functions method is also widely used through R (Srucca, 2013).

4. Methodology

4.1 Genetic Algorithm

GA, developed by Holland (1975), is computing algorithm inspired by evolution theory later adopted to be computing algorithm to find a solution on particular problem in more nature manner. One of algorithm genetic application is on the optimization combination where particular optimum value of solution on problem containing many solving probability is obtained. GA is a computation inspired by Darwin's evolution theory, defining the cycle life of particular creatures is on effect of those who are strong will survive (Goldberg, 1989). GA approach is practical, widely used in many disciplines. By applying GA approach, the unpredicted conditions such as the uncertain growth of distress condition on national road network is edible to be mapped on early stage as a consideration for decision makers.

The first step to set GA method is to formulate variable types and encoding being used on solving problem. Afterward, the formulating of fitness value is to be set up as objective function for optimization. The crossover and mutation, then, are the next step to be performed. After some generations, the genetic algorithm will obtain generations as many as expected. The steps being required in selecting GA are shown in Figure 1.

The optimization applied in this study is performed to minimize agency cost and maximize the road level serviceability to society during analytical period. Six (6) main pavement distress types are considered in study i.e. area crack (AC), crack width (CW), pothole (P), rutting (R), patching (Patch) and depression. The purpose deterioration model for this work is based on the equation as follow:

$$NSDI = (AC\,x\,1.68) + (CW\,x\,1.13) + (P\,x\,2.91) + (R\,x\,1.06) + (Patch\,x\,0.02) + (Dx\,3.38) - 1.26 \quad (1)$$

where $NSDI$ is New Surface Distress Index

Genetic Algorithm in R is used on 100 m pavement section in making hypothetical problem of pavement maintenance. The multi-objective optimization function applied in this study is performed to minimize agency cost and maximize the road level serviceability.

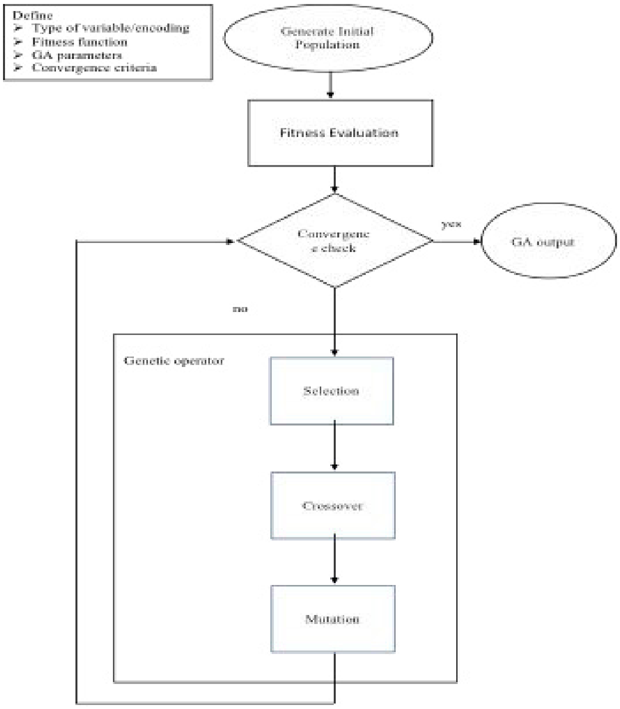

Fig. 1. Flow chart of a Genetic Algorithm (source Scrucca, 2016).

The problem parameters are as shown by Table below:

Table 1. The Problem Parameter and Descriptions.

Parameter	Description
Length	100 m
Period	5 years
Warning level:	
Area crack	30 % per 100 m
Crack width	5 mm
Pothole	50 pothole per 100 m
Rutting	30 mm
Patching	30 % per 100 m
Depression	30 % per 100 m

4.2 Performance Indicator

In order to face of limited highway budgets constraint, the priority of surface distress scale is required. Table 2. show roads condition is classified in good, fair, poor; bad condition, based on SDI rating DGH, 2006 in Hamdi. Et. al, 2017a.

Table 2. Scale of SDI rating.

Surfacing Rating	SDI scale	Description
Good	SDI <= 50	Excellent and good condition, some minor problem for routine maintenance
Fair	50 < SDI <= 100	Minor section loss, periodic maintenance
Poor	100 < SDI <= 150	Deterioration, advance section loss, rehabilitation
Bad	SDI > 150	Beyond corrective action, reconstruction

The model of optimization is considered as of having two objective optimizations, the minimization of cost over planning time span and maximization of road surface condition. The purpose of this objective function is to minimize the cost for maintenance works, which can be formulated by equation (2) as follows:

$$C_{min}(Min.Cost) = \sum_{i=1}^{T}(1+r)^{-1}\sum_{j=1}^{A}X_{jt}.c_j.L \quad i=1,2,3\ldots n; j=1,2,3\ldots n \tag{2}$$

where, Cmin is minimum maintenance cost, T is total years of planning time span, r is discount rate, A is total operational option and Xjt equal zero if not operation applied and equal to one if operational j in year t, cj is unit cost of j treatment in initial year and L is length of pavement section.

This function uses surface distress as represent of road condition. The purpose of second objective function is to maximize the road condition of overall road network condition as shown by equation (3):

$$SDI_{max}(Max.Condition) = \sum_{i=1}^{T}\sum_{i=1}^{A}X_{jt}\left(SDI_{jt} - SDI_{min}\right).L \tag{3}$$

where, SDI_{max} is maximum road condition, $SDI_{it}$is the surface distress index for j treatment option in year t, SDI_{min} is minimum acceptable level of SDI.

The constraint optimization model of road condition function formulated by equation (4) - (6) expressing the road condition in each road segment and year as a set of functions of initial road and maintenance scenario used in the road segment. The warning level constrains defining the maximum of SDI level for the road condition is formulated by equation (4).

$$SDI_{jt} \leq \overline{SDI} \tag{4}$$

where SDI_{it} is the road condition for segments j in year t and $\overline{SDI}$ is warning level road condition. The Cost constraint equation (5) defined the costs for road agency cost functions involved types of operation to road segment in year as a function of the road condition in that segment and year. These costs are found by multiplying agency cost for maintenance operations.

$$C_j = (f_a)\, X_{jt}, SDI_{jt} \tag{5}$$

where (f_a) is the Cost function.

The annual budget constraints equation (6) defined as the maximum to be spent on budget on maintenance work in each year.

$$\sum_{i=1}^{T}\sum_{j=1}^{A}C_j\ .X_{jt} \leq\ B_t \tag{6}$$

where $B_t$is the budget for year t.

4.3 Cost Model

In this paper, the cost model is conducted on the optimization in routine maintenance, periodic maintenance, and reconstruction. Based on 4 different maintenance work, some actions were considered, each of maintenance actions can be applied on individual or combination or both. The maintenance work action ‘0’ is applied to do nothing, scope of routine maintenance is applied on '1' for patching, '2' f for crack sealing. The periodic maintenance can be applied on '3'. For the reconstruction can be applied on '4'. The types of maintenance of works, treatments, and unit cost are shown by Table 3.

Table 3. Type of unit cost for various maintenance work.

Maintenance Work	Treatment	Cost (IDR)^6
Do Nothing	'0'	0
Patching	'1'	2,500
Crack sealing	'2'	3,000
Periodic Maintenance	'3'	3,500
Reconstruction	'4'	7,000

The parameters such as: length, budget, resource constraints, objective function are required to develop the optimization model (Watanatada, et. al, 1987). In performing the model, the algorithm approach from the package in R, namely, mco package is used. Pareto solution is used to define the optimization model based on GA. The mentioned solution is arranged to generate optimization values of SDI and unit maintenance cost. The optimization result is used as of base of making decision which will be used as final solution illustrated on model application. Throughout by trial calculation using some parameters i.e. generation = 70, population size = 40, output dimension = 2, constraint dimension = 1255, discount rate (R) = 12%. Optimization will be performed by having several maintenance scenarios following Table 3. The optimal maintenance program is selected by using Pareto solution. The Pareto optimality used to arrange optimization model in road maintenance is shown in Figure 2. Minimization Function on multi dimension used in Pareto front and Pareto set are algorithm NSGA II. Each population taken from creating or offspring is previously picked from the best individual. The best individual is counted based on non-dominated sorting breaking ties using the crowding distance.

5. Results and Discussion

From the results as shown by Table 4 and Figure 2(a), National Road in Province of Jambi, Pareto concept is used to get optimized solutions. As shown by Table 4 chromosomes of 21023 could represent of 5-years maintenance strategies. If the value of SDI 6.6, so the handling treatment are the handling crack sealing in 1st year and 4th year, patching in 2nd year do nothing 3rd year and periodic maintenance in 5th year. Based on the results, it is shown on SDI 6.6 is along with the highest of agency cost with value Rp. 22.16 billion. Meanwhile if the agency spends the lowest budget or Rp 20.689 billion, it will obtain the highest SDI with value 7.3 with the handling treatment "do nothing on 1st and 4th year, patching on 2nd and 5th year and crack sealing on 3rd year.

Based on hypothetical test through the implementation of optimization model, it is found that multi objective model with Pareto optimality in generating 10, 20, 30, 40, 50, 60, and 70, providing a good optimization options. In Figure 2(a), the plots apparently tend to be convergent to some GA iterations. On generation 70th, there is a result found with well-defined Pareto Frontier. As of illustrating the multi-objective convergence, Figure 2(a) plots the evolution of solutions optimized by the NSGA-II towards the Pareto-optimal front complied to cost, road condition. In the plot, each point shows a possible solution as line segments are used to join points belong to optimization of Pareto method. Facilitating the analysis, a color scheme is used, ranging from dark blue referring to first generation to light blue as of last generation.

Table 4 Maintenance of Optimization Strategies.

Cost (Rp 10^6)	SDI	Maintenance 1st year 0,1,2,3,4	Optimization 2nd year 0,1,2,3, 4	Strategies 3rd year 0,1,2,3,4	4th year 0,1,2,3,4	5th year 0,1,2,3,4
22.160	6.6	2	1	0	2	3
21.706	6.9	1	0	2	1	1
21.599	6.8	1	0	1	1	2
20.689	7.3	0	1	2	0	1
21.859	6.7	1	1	2	1	1
20.644	7.2	0	0	1	2	0
20.906	7.2	0	0	1	2	1

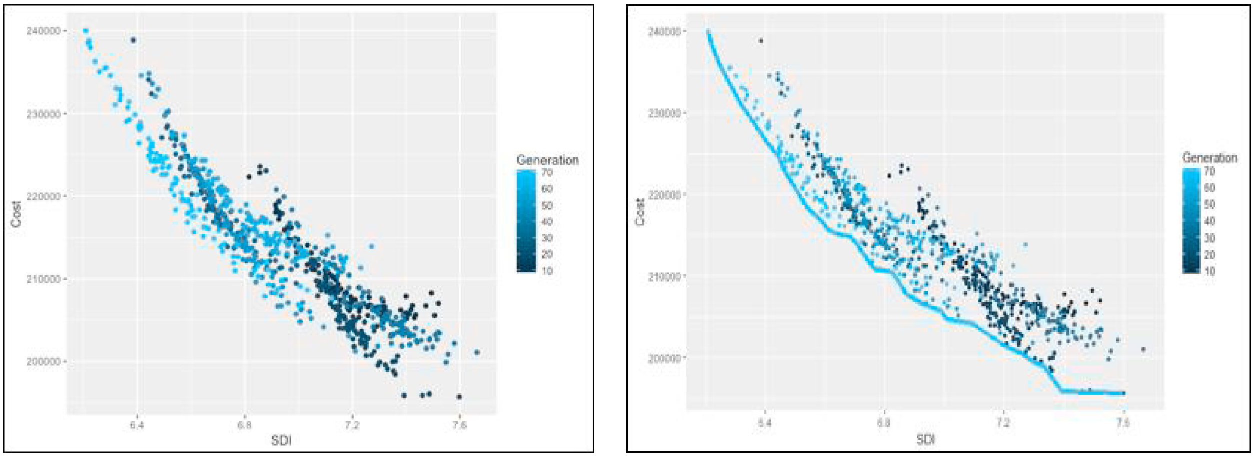

Fig. 2. (a) Optimization of Pareto Method; (b) Pareto Front.

Figure 2(b) Pareto Front shows that NSGA-II performs an initial fast convergence with substantial movements of the Pareto front towards the bottom left region, and then the algorithm converges more slowly towards the returned Pareto front, which is a convex which is adjacent to the bottom left region.

6. Conclusion

Based on the result in this research, accompanying thoughts being concluded on to some points, as follows:

- The development of optimization model in road maintenance is initiated by identifying objectives and constrains toward the problems in the road maintenance.
- Multi objective optimizations model with GA is chosen as optimization model considered appropriate to apply optimization in road asset management system.
- In the road maintenance, there are some objectives and constrains that have to be simultaneously identified.
- Pareto optimization is preliminary step on to determining total chromosomes and total running required in this optimization process.
- Based on Figure 2(a) there is a result found with well-defined Pareto Frontier on generation 70th. It is shown that optimum agency cost and maximum road level serviceability on SDI 6.6 is along with the agency cost with value Rp. 22.16 billion. GA optimization technic is able to be used in presenting problem in road asset management system.

- Based on results analysis chromosomes of 21023 could represent of following 5-years maintenance strategies; the handling crack sealing in 1st year and 4th year, patching in 2nd year do nothing 3rd year and periodic maintenance in 5th year.
- Based Figure 2(b) the optimization Pareto Front tends to move toward to axis point x and y: the optimization is found on the bottom of left region.

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