Genetic Algorithm Applied for Optimization of Pavement Maintenance under Overload Traffic: Case Study Indonesia National Highway

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Abstract. National Road Network which consists of a traditional road structure and modern roads, require planned maintenance and should be in accordance with the needs. The limited choice of available national road network and the deviation of the overloading encourage the government to be more responsive to carry out maintenance management. The institution in charge of road maintenance is often constrained by the limited budget available. A two-objective optimization model considers maximum roughness and minimum maintenance cost for used road network with overload. The study was conducted on the entire national road network in West Java which are paved with flexible pavement. In the proposed approach, data mining model are used for predicting the roughness index over a given period of time. Routine and periodic maintenance are chosen in this study. Multi-objective optimization model was developed based on Genetic Algorithms. Budget constraints and overloading are the two constraints in the developed model. Based on the R-Tools result, the Pareto optimal solutions of the two objective functions are obtained. From the optimal solutions represented by roughness index and cost, an agency more easily obtain the information of the maintenance planning. Results of the developed model has been implemented through the selection of maintenance on the road network scenarios with different levels of overload.

Introduction

Indonesia has experienced a rapid increase in term of development of national road infrastructure in the past few decades. In addition to developing a network of new roads with modern pavement structure, Indonesia also possess road network with traditional road structure developed starting in 1808 [1]. Both types of road structures certainly require a good pavement management system with adequate funding. Proper pavement management system will results in the good level of road serviceability in accordance with the needs of road users. Directorate General of Highways (DGH), Ministry of Public Works and Housing is a goverment agencies that have full responsibility in conducting the development, construction and maintenance of national roads in Indonesia. In conducting pavement management system, since the 1990s, DGH has developed a modern pavement management system called Indonesian Integrated Road Management System (IIRMS). Along with the development of technology and of the vast scope of the road pavement management system requirements, IIRMS needs to further developed to achieve a more optimal result [2].

The system was designed to conduct data collection, data processing, planning and determination of the cost of implementation, as well as to control the implementation process. Budget planning recommendation for the policy holder in DGH is an important part in this system, used as the basis for determining the amount of the budget with the consideration of priorities, road’s function and road networks through economic principles. The budget modeling conclude that roads with high traffic volume gain priority funding, and vice versa. The limitations of the available budget will cause the low priority roads to get some delays in the maintenance. Another consideration in determining maintenance priority is the scale of time. Often, the road that should be immediately
addressed did not obtain any funding due to inappropriate period of time. Delay in treatment due to timescale is roads which are damaged by the overloading.

Overload is a condition that is common in developing countries [3]. This happens continuously and it is very hard to prevent. Due to limited modes of transport and minimizing transport costs, causing premature road damage. Overloading far above the acceptable limit and repeated load effect will cause significant damage to the road. An observed cause interpreted as the biggest contributor in road life-performance decrease is overload phenomena [4]. Continuous overloading will directly lead to high maintenance costs. Permitting heavier loads can increase the rate at which pavement damage accumulates, thus increasing the cost of maintaining good pavement conditions [5].

Budget limitation, overloading, wide national road network, priority maintenance, time scale, and scheduling, as well as the influence of the environment are the challenges in realizing a reliable road serviceability levels. IIRMS have the same concept, compared with the pavement management system and other infrastructure management system in the world. Infrastructure management systems have been developed to apply the life-cycle costing approach to optimize maintenance decisions at both network and project levels and achieving network/project performance requirements under financial constraints [6]. IIRMS needs to be develop further, especially for optimizing the existing budget module.

To perform the optimization of pavement maintenance, several approaches has developed in different countries. Ranging from the traditional approach to modern approaches. Each method has advantages and disadvantages on their own. Over the time, optimization method becomes more complete and possess various options that can be adjusted to the existing conditions and characteristics. Over the year there have been successful applications and implementations of multi-objective optimization problems using genetic algorithms (GA) [7]. GA is an approach that considered practical and has been widely used in various fields of science. GA are robust, practical, and general-purpose stochastic search-based optimization techniques that can provide a comparable level of accuracy while being more efficient than conventional optimization techniques [6]. Through the GA approach, it is hoped that the unexpected future variables such as traffic growth uncertainty and overloading on the national road network will be able to be mapped from the beginning as a consideration for the policy holder. The combination of stochastic simulation and GA allows the development of a project-based network level maintenance plan that can explicitly take into account the uncertainty of future pavement conditions in the decision-making process [8].

Optimization with GA approach is chosen as the main tool to create a model for pavement management system. The national road network in West Java is chosen to illustrate the results of modeling and then validated on roads with overloading problem. Optimization is conducted with the optimization of the financing and road conditions. The number of variables in the pavement management system will encourage policy holders to conduct multi-objective optimization. Pavement maintenance planning and programming requires optimization analysis involving multi-objective considerations [9].

The objective of this study is to develop a national road maintenance optimization with GA approach. The proposed approach is expected to improve the capability and efficiency of the optimization module in the existing pavement management system. This research is specifically conducted to optimize the application of routine maintenance, periodic maintenance and special maintenance. Proper maintenance pattern is expected to maintain life performance of existing roads, especially roads with overloading. The first section of this study presents the proposed formula based on the maintenance optimization problem. The second part presents a solution to this problem using a GA. The last section shows the feasibility of the proposed approach by the example of a national road network with overload study.

Pavement Management System

**Development Indonesian Integrated Road Management System.** In accordance with the needs of modern management system, DGH continues to improve its system by refining the existing Pavement Management System (PMS). According to the DGH annual report it explained that a
management system comprises a series of processes which will assist the managers in their business [10]. In the case of highway agency, it refers to the improvement and preservation of the road infrastructure. In its development, the system must be able to perform an automatic and thorough management approach as a refinement from the manual system. The PMS consists of a number of building blocks, some essential, some optional. Typically, the core processes in a PMS are collection of information on the infrastructure and the traffic using the data; storage and primary processing of that data; planning and programming of future road works; design and contract preparation; as well as implementation and progress monitoring.

The development of IIRMS been closely related to funding sources, notably the World Bank. Loans that are taken in the past have been used for different types of urban road, inter urban road and rural road. PMS development has consequently been targeted at these road types and separate systems have grown to suit their characteristics. Thus, four major systems have developed: Inter-urban Road Management System, this was revamped into a predominately as IIRMS; Inter-urban Bridge Management System; District Road Management System; and Urban Road Management System.

The unit costs and traffic growth rates are updated on an ad hoc basis. The updating however is not normally done at a detailed level but typically a nominal percentage increase is applied across the board. The updating of Vehicle Operating Cost (VOCs) has been performed following international standards, in 1997, 1999 and again in 2003. The Vehicle Damage Factors (VDFs) were last updated in 1997 using the results of the central weighbridge project 1992. PMS is a reliable system capable of conducting the accurate recording, evaluation and planning. The more reliable a certain system results in a more optimal use of the budget. Collection and analysis of pavement distress data is a significant component for effective long-term pavement performance. Accurate, consistent, and repeatable pavement distress type of evaluation can reduce a tremendous amount of time and money that has been spent each year on maintenance and rehabilitation for existing pavement distress [11]. Thus, the existing system should continuously develop so that the capacity to collect and process data can be considered as an accurate information for the decision maker.

**Pavement Condition.** Pavement surface condition in Indonesia is measured using the International Roughness Index (IRI). IRI was developed in 1986 by the World Bank which is a further development from NCHRP concept. IRI was first introduced in international road roughness experiment carried out in Brazil [12]. IRI is measured by collecting the output data from the test car or it is directly divided by the length of profiles to generate index of flatness. IRI has been accepted internationally as an indicator of the serviceability level of roads which can continuously calibrated for different regions and times.

Road management model formulated by Bennett [13], as by other author, in general, also use IRI data as an important indicator for road management. Periodic maintenance will be carried out if the IRI had reached 9.0 m/km (this is not a normal value; for this situation the current value will be of around 3.0 m/km), commonly occurring, while urgent maintenance for the quality improvement would be adopted if the IRI is greater than 12 m/km (current value for this situation would be about 4.0 m/km), which correspond to the end of pavement life [14].

In the implementation phase, on a regular basis, IIRMS record the yearly results of IRI value from the measurements in the field. There are still some incomplete data, but over time, the system will collect better and more complete IRI data. Changes in IRI value becomes the main indicator in determining the level of road serviceability in Indonesia, as well serves as main consideration for the policy makers in determining the amount of maintenance budget.

**Overload**

Road traffic served by the national road is marked with the number of different vehicle types with variations of vehicle load. Weak oversight from the government will lead to ignorance from the road users regarding the maximum axle load that have been determined. In Indonesia, overloads occur when the weight of the truck with overload the maximum allowable limit of 10 tons for road
class I or II, and 8 tons for road class III. The increase of vehicle overload cases on the national road will reduce road’s serviceability and at the same time increase the maintenance costs. These axles/vehicles overload causing significant damage to the pavements that increases the pavement construction and rehabilitation cost [5]. Efforts undertaken by DGH in recent times looks meaningless because the number of uncontrolled overloading cases on the national roads is increasing. Based on data recorded by weight-in-motion system (Fig. 1), the overload mostly occurs in the North Coast Corridor of Java Island, thus requiring special attention from the government [10]. The level of damage caused by overload in Indonesia is significantly influence the overall condition of the national road's pavement. The overloading of a vehicle affect the pavement in a different way. For example, 150% overloading of single, dual, and triple axle truck, will bring about 500, 135, and 122% level of damage respectively. The results of calculation using VDF also have the similar result namely 47.20, 10.30, and 7.99 times the capacity to deteriorated pavement respectively [15]. Similar with the condition in Indonesia, vehicle overloading has been identified as one of the major contributors to road pavement damage in Malaysia [16] as well as in Nigeria [3].

**Fig. 1. Overload in north coast corridor of Java Island [10]**

Damage to road pavement due to overload, not only affect the road’s surface, but also cause severe damage to the bottom layer of the road as well. Damage will further increase, in line with the increase of the repetition from vehicle with overload. The damage caused to the pavement due to the various axle load-groups depends on the respective loads, configuration and repetitions. It is possible to evaluate the damage caused by the repetitions of each axle load group [17]. Aside of imposing overload damage to the road, overload can also results in disturbance to the environment, such as pollution and declining road safety. Trucks exceeding axle load and gross vehicle weight limits can bring severe damage to infrastructure and increase the risk of traffic crashes [18].

**Methodology**

The basic principle of pavement management system is to maintain the serviceability level of the pavement with the available resources and budget. To obtain a good result, the policy maker efficiently utilize the existing resources, by optimizing the equipment, materials, personnel, methods, and costs. Moreover, policy maker can also plan a cost-effective and efficient method by
considering the priorities and the schedule of routine and periodic maintenance. But when faced with the extensive national road network and its constraints, this method of optimizing is considered as a difficult task. A systematic and well-concept effort is needed so that business-process maintenance management can run smoothly and measurable. The systematic process can be started with the identification of the problem, pavement performance prediction, deterministic formulation, and optimization process itself.

**Pavement Performance Prediction.** One of the basic issue in pavement management system is the development of performance or deterioration prediction models. Several performance prediction models have been proposed over the years, some of which are simple and others more complex. The highway performance prediction models into classes which indicate their basis as follows: empirical, mechanistic–empirical, and subjective [19]. The success of a maintenance management process depends on the performance prediction, executed by the system. To enhance the performance of PMS, successful prediction of pavement performance is of primary importance [20].

The researcher will conduct the IRI prediction models based on Support Vector Machines (SVM), which are empirical (data-driven) methods, while the occurrence of the fatigue cracking was predicted by a mechanistic-empirical procedure. SVM is one of them popular method approach in Data Mining (DM). DM aims at the extraction of useful knowledge from raw data and it is receiving an increasing attention by the both the research community and industry. Indeed, many case studies suggest that companies are increasingly investigating the potential of DM technology to deliver competitive advantage [21]. The success of the development of the IRI model can be used to use the existing data to support the management of the road network with the Pavement Management System in the road network of West Java [22].

Then, with SVM approach, IRI prediction is implemented to separate the road networks which affected by the normal load and overload. The model shows a great influence of the truck overloads identified on the road network evaluated [23]. DM in R-Project for statistical computing (R-Tools) is an open-source computational environment and high-level language that integrates powerful statistical and graphical features for data. R-Tools adopts a very flexible and object oriented design [24]. The tool can be easily extended by the creation of packages. IRI prediction model was develop from *rminer library* with the inclusion of several variables such as: age, crack, equivalent single axle load (ESAL), pothole, and rutting.

**Deterministic Formulations.** This study has a multi-objective, namely maximizing level of service as measured by the IRI and minimize the cost of maintenance. Further, the model developed by including the variables of overload and life cycle cost in a multi-year budget.

**Pavement Performance Maximization and Maintenance Cost Minimization.** As described in pavement condition section, smaller value of IRI is indicate better road roughness, as written in (Eq. 1). In addition to maximizing serviceability level road with a target value of IRI's smallest, the agency also have to minimize the budget that will be used for maintenance costs. In the (Eq. 2), it is described that the budget used for the maintenance of any treatment depends on the unit cost multiplied by the length of the segment roads.

Maximize: \[ \frac{1}{\sum_{i=1}^{n} d_i} \times \sum_{i=1}^{n} (d_i \times \sum_{t=1}^{m} IRI_{it}^{1} \times x_{it}) \leq \text{average}_{IRI} \]  
(1)

Minimize: \[ \sum_{i=1}^{n} \sum_{t=1}^{m} c_{it} \times x_{it} \leq B \]  
(2)

Where

- \( d_i \) = distance weight parameter to pavement segment \( i \)
- \( n \) = total number of pavement segment of the network
- \( m \) = total number of pavement management treatment options
- \( t \) = type of treatment options
- \( IRI_{it}^{1} \) = IRI value one year later for treatment \( t \) applied to pavement segment \( i \)
- \( x_{it} \) = if treatment \( t \) selected to pavement segment \( i \)
- \( \text{average}_{IRI} \) = predefined pavement network average IRI level
- \( c_{it} \) = cost parameter of treatment \( t \) selected to pavement segment \( i \)
To achieve these objectives, the researcher formulate a maintenance treatment formula with such approaches in table 1

<table>
<thead>
<tr>
<th>Code</th>
<th>Treatment type</th>
<th>Class</th>
<th>DGH Unit Cost (Billion Rupiah/Km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>t₀</td>
<td>Do nothing - 0</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>t₁</td>
<td>Minor Maintenance Routine 0.065</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t₂</td>
<td>Crack Sealing Preventive 0.12</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t₃</td>
<td>Patching Minor/Preventive 0.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t₄</td>
<td>Hot mix resurfacing Major 0.71</td>
<td></td>
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</tr>
<tr>
<td>t₅</td>
<td>Hot mill overlay Major 1.20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>t₆</td>
<td>Reconstruction Reconstruction 2.40</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: DGH [10]

**Experiment and Discussion**

As the case study, national road network in the province of West Java – Indonesia is selected. The road network in West Java has a fairly complete characteristics. The northern part is characterized by the presence of the northern corridor of Java Island that serves as the main transportation lines and this corridor is passed by all types of vehicles. West Java's northern coast line connecting the port city of Jakarta with other cities in Java such as Cirebon, Semarang and Surabaya. In addition there is south corridor marked by hilly terrain with high rainfall. The other corridor is middle corridor which serves as connecting lines and alternative roads.

**IRI Prediction Model.** Using DM with SVM model will results in predictive IRI value obtained for each road segment on the national road network in West Java Province. Each road segment has different characteristics with different axle-loading. The results of different IRI predictive SVM model (Fig. 2). Different loading and handling standards caused different decreasing rate of road’s serviceability on each roads. The picture shown that the IRI value will decrease faster when imposed by heavy overload compared with medium overload and normal loading. Road that is imposed by normal loading have a longer service life compared with the road that is imposed by over-loading.

![Fig. 2. IRI predicted SVM model](image)

**The Developed Optimization Model Based on GA.** GA approach can be used to determine the model of Pareto Solution to obtain the optimization of IRI value and the maintenance costs. The post-optimization decision making or the methods used to choose the final solution are also illustrated by model application. In this research, the optimization is conducted for various
maintenance scenarios. The optimal maintenance programs are selected by using the Pareto approach. Pareto approach is an approach to choose the pattern of maintenance with the closest distance to the axis 0 (Fig. 3).

In the optimization phase, the maintenance scenario is performed by iteration, utilizing the tools provided by the R-Tools by performing simulations tiered generation. Maintenance Scenario is conducted gradually refers to the scenario shown in Table 1, in sequence and then combined to achieve the optimum point is called the Pareto optimality and the shortest normalized distance. To simplify the optimization scenario in this study with the overload constraint, the maintenance model is developed with 3 types of loading in the national highway. Type of maintenance is chosen to achieve the lowest IRI and lowest budget. The loading conditions are as follows:

1. Normal Load. Maintenance scenario considering the traffic load over the road network is the load of 100-110% maximum load; for normal load segment, preventive maintenance option is preferred.

2. Medium overload. Maintenance scenario considering the traffic load over the road network is the load of 110-120% maximum load; for medium overload segment, preventive-major maintenance option is preferred.

3. Heavy overload. Maintenance scenario considering the traffic load over the road network is the load of 120-140% maximum load; for heavy overload segment, major-reconstruction maintenance option is preferred, considering the road’s structural condition.

With Pareto approach provided by the GA on R-Tools, types of maintenance for each year and predicted IRI value in the segments for each group loading are obtained. Predicted IRI obtained within 15 years after the optimization (Fig. 4).
Predicted IRI value based on the above-mentioned scenarios is chosen by IRI range which has been determined in advance. However, due to a limited budget, this optimization also provides priority options. In the early years, optimization is carried out against a group of selected road segments with different types of loading, and road reconstruction is conducted gradually in order to maintain maximum budget available. After the reconstruction, the types of maintenance applied are different up to the 15th year. Complete maintenance scenario and the optimization results generated (Fig. 5)

![Fig. 5. Maintenance type proposed](image)

Furthermore, to be able to convince stakeholders to pay attention to the effectiveness of maintenance based on loading groups and scenario of maintenance (Fig. 6). The results obtained from the simulation of long-term maintenance scenario of load factor and without load factor, as well as the optimization of preventive maintenance and non-preventive. Measurement is conducted by simulating 15 years data with a net present value.

![Fig. 6. Scenario of maintenance implemented](image)

**Conclusion**

This study developed a model of multi-objective optimization using a GA approach to generate optimal scenario of pavement maintenance. A two-objective optimization model considers maximum roughness and minimum maintenance cost. Both of these objectives are considered to be achieved simultaneously. Constraints faced is overload that can accelerate the decline in the level of roughness. Through the DM approach to obtain predicted IRI, maintenance optimization is then performed by load factor that are received in each group of highway networks. The results showed the load factor group with preventive pavement maintenance scenario produces the most optimal financing.
This study only measures the performance of the pavement’s roughness values. Further research is needed to see the impact of overload on other performance measures on the highway. Moreover, it can also be developed maintenance scenario with other approaches, aside from standard scenario that has been selected in this study.

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References


