

# A Conceptual Pavement Optimization Considering Costs and M&R Interventions (Learn from Long Segment Maintenance Contract)

*Hermanto, Dardak<sup>a</sup>, HerryTrisaputra, Zund<sup>b</sup>, Andri Irfan, Rifai<sup>c</sup>,*

*<sup>a</sup>Universitas Pancasila, Indonesia,*

*<sup>b</sup>Ministry of Public Work & Housing, Indonesia,*

*<sup>c</sup>UniversitasInternasionalBatam*

**Abstract**-Highly deteriorated road infrastructure in a developing country, major budgetary restrictions and the significant growth in traffic have led to an emerging need for improving the performance of highway maintenance concept. Due to the financial government problem, in Indonesia, as in many other countries, the trend of budgetary pressures on highway agencies is increasing. Simultaneously, road users are increasingly demanding in terms of highway quality, comfort, and safety. To meet these challenges highway agencies are looking for more cost-effective methodologies for pavement management at project-level. This paper presents a concept new pavement design optimization model with new contract model, called Long Segment Maintenance Contract (LSMC), which considers pavement performance, construction costs, maintenance and rehabilitation costs, long network, the residual value of the pavement at the end of the project analysis period, and preventive maintenance and rehabilitation interventions.

**Keywords:** Long segment maintenance contract, Optimization, Interventions.

## Introduction

Highly deteriorated road infrastructure in a developing country, major budgetary restrictions and the significant growth in traffic have led to an emerging need for improving the performance of highway maintenance concept. Pavement condition prediction modeling is a critical component of a pavement management system (PMS). Accurate prediction models assist agencies in performing cost-effective maintenance or rehabilitation at the proper time, thus most efficiently improving the overall pavement condition under specific budget limits. The evaluation of pavement performance is a complex task and it is important for pavement design, rehabilitation, and management. In a typical "top-down" pavement management system (PMS), network-level decisions (e.g., long-term network performance prediction and preservation programming) are made first, followed by project-level decisions (e.g., life-cycle cost analysis and design of individual projects). The network-level decisions include pavement preservation and rehabilitation programming to develop budgets and allocate resources over the entire network, followed by project selection to identify which projects should be carried out in each year of the programming period [1]. These projects are further developed at the project level. Decisions made at the programming level have a great impact on the effectiveness of the decisions made at the project selection and project levels.

The programming level decisions often involve multi-objective consideration and must address competing objectives. For example, a transportation agency may wish to find suitable maintenance strategies that minimize the agency cost while simultaneously maximizing network performance. However, any strategy that maximizes pavement performance would require that pavements be maintained at a high level of service, which in turn will increase agency costs significantly. Traditional single-objective optimization frameworks consider one single objective while imposing competing objectives to serve as constraints in the optimization formulation [2]. These approaches exhibit at least one of the following limitations: (1) among the competing objectives, how to justify that the selected objective is the one that deserves the most attention; and (2) how to determine the proper range values for those objectives that are not included in the objective function but instead set as constraints. Such limitations in some cases may lead to suboptimal solutions concerning those derived directly from multi-objective considerations [3]. Moreover, while a few applications have made use of multi-objective optimization techniques [3] and [4]. The constraints are often deterministic, which usually leads to a single deterministic result that may exclude information that could improve the decision.

The Pavement is a layer in between the vehicle traffic load and ground base, which is more constructive so that the load can be supported by subgrade. Therefore, the pavement needs to be managed well and appropriately in terms of human resources quality control arrangements, the application of technology (tools, materials, methods of work), efficient funding, and research for better maintenance modeling. Currently, funding for the maintenance of more stringent budget limitations in many countries while increasing traffic growth requires extraordinary measures in making better pavement management to maintain the service life by using the available budget [5].

Long-term planning is needed to respond to the needs for the sustainable service life of the national roads. Traffic data collection causes of damage and repair history will greatly assist the process of optimizing long-term maintenance [6]. This happens also in Indonesia, before the fiscal year 2004, the Directorate General of Highway, Ministry of Public Works, has set three national pavement management models, such as the construction of new roads, improved roads, and road maintenance. Since that fiscal year until now, the pattern has been applied to the management of provincial and district roads, while the national roads are more focused on aspects of road maintenance (routine and periodic) and improvement. Division of the road management authority divides the responsibility, but it still provides an optimal maintenance policy that can minimize the overall life cycle cost of road networks [7]. The same thing was presented by [8], stating that pavement maintenance can be optimized by leveling up an available road network.

In its development through the process of testing implementations, Directorate General of Highway (DGH) Indonesia to implement the Long Segment Maintenance Contracts (LSMC) in 2015 to improve the standard of maintenance and replacing the self-management approach based on direct labor applied. These contracts include elements of compensation results is fundamental in the approach of Performance-Based Maintenance Contract (PBMC) but the duration is shorter. Therefore, some of the difficulties associated with the contract form like PBMC can be avoided. It is expected with this LSMC, the pavement management system in Indonesia is getting better. The performance of the main road became the main parameter in measuring the sustainability of LSMC requires special attention.

This paper presents a new pavement design optimization model considering costs and preventive interventions with long segment road network, called LSMC, developed and programmed to help pavement designers to choose the best pavement structure for a road or highway. The paper is divided into three sections. The first section contains a detailed description of the LSCM system. The second section presents the results obtained with the application of the LSCM system to the pavement maintenance of the Indonesia Manual. The final section consists of a synthesis of the conclusions reached so far and a statement of prospects for future research.

### **Long Segment Maintenance Contract**

Long Segment Maintenance Contract (LSCM) is the handling of road preservation within one continuous segment length (can be more than one segment) which is carried out to get uniform road conditions, namely steady and standard roads throughout the segment. To support the contractor to take over the routine maintenance tasks, since the beginning of the LSMC was designed to reduce the risks and the financial exposure; using low-risk pricing structure with a combination of lump-sum payments and the payments that adjust as PI for routine maintenance (similar to PBMC) and a payment schedule based on the rates for major maintenance work.

This LSMC should be carried out continuously, especially the type of construction of flexible pavement and rigid pavement. Other activities are; Maintenance of road and building complementary facilities and their supporting facilities. Road maintenance can be done regularly or periodically. Road maintenance is routinely carried out as soon as possible and continuously throughout the year against damage that is still light so that the cost of repairs is relatively low. The road maintenance is regularly carried out on a steady and periodic road, which includes maintenance and repairs to widespread minor damage. Supervision and control of road maintenance need to be done to find out how to deal with road damage and to detect damage that occurs based on the volume and type of damage. The large projects with strong competition, long duration and extension periods, long outsourced road sections that incorporate crack sealing, pothole repair, illumination repair/maintenance, and mowing activities, favor outsourcing under PBC [8].

Routine maintenance, periodic maintenance, rehabilitation or reconstruction of roads and road complementary structures are included in road preservation activities. Dividing the length of national roads into long (50-150) km segments by considering the range of control of the Project Officer as a section manager is an LSCM. LMSC requires a culture shift service provider. Technical capability and innovation service providers to be competitive. The pattern of construction services business will also change with the increasing integration of the stages of design, construction, operation, and maintenance. LSMC also requires a change in the culture of service users, given that most risks can occur due to the behavior of service users.

For this reason, with the existence of the LSCM, it is expected that the overall condition of the existing roads can be well maintained according to the age of the plan, so that road stability can be increased and the potential for

accidents can be reduced. Also, future maintenance costs can be reduced to be more efficient. Through the work of maintaining the condition of existing roads to be kept in a steady state. Thus, the minimum level of service following the Minimum Service Standards, also the design life of the road can be met as well as the performance of the road will be restored to the initial condition at the time of construction. To maintain the service road, streamline maintenance of roads and ensuring the maintenance costs, we need a contract innovation such as a performance-based contract, the expected implementation constraints that would be solved.

### **Decision Support System**

In a public decision-making context (e.g., pavement management system), there is often more than one objective that needs to be achieved. These multiple, often conflicting, objectives are often not only incommensurate but also may have significantly different impacts on the resulting solutions. Single-objective optimization identifies the best feasible solution in terms of a single measure of value. Decision-makers are given the choice of either accepting or rejecting this single solution without learning anything about how the solution compares to other feasible solutions. In contrast, the multi-objective optimization problem involves finding a vector of decision variables that satisfies constraints and optimizes various objective functions.

Decision Support System (DSS) is needed to provide support for the decision-makers in making accurate decisions, as revealed by [14] with the DSS approach through the development of a new decision with intervention used to improve decision-making optimization of pavement maintenance and rehabilitation strategies. Any activity, including infrastructure development and maintenance activities of road pavement, needs a support system that can provide an invaluable tool in making decisions. The decision support tool has a tiered and neatly structured nature. Some types of decisions can be described as follows strategic planning decisions: decision-making related to policy and the highest goal; Management control decisions: decisions made to utilize available resources effectively and efficiently; (3) Operational control decisions: decisions made for effective performance during execution; and (4) Operational performance decisions: decisions taken in implementing daily activities.

Decision support models have been widely used in various disciplines including industrial infrastructure [15] and [16]. The decision-making process in infrastructure industries has increased due to the high level of inherent uncertainty. This is illustrated by the increasing complexity of the needs of decision support models, tools and systems to assist the process. It should also be applied to road infrastructure investment. It is impossible to know exactly how accurate a particular investment decision is; therefore, decision support tools can assist in improving the decision-making process.

The further strategic decision-making process is related to the level of interest in wisdom or higher management, whereas operational decisions related to the performance of routine decisions are related to a task. It is quite important in this classification that the consequences of decisions made by a higher level are more frequent than the consequences of a decision made by the lower level [24]. The series of highway management is a process that accompanies some of the steps of activities involving planning, design, construction, operation, maintenance, and development and research. Each of these activities requires decisions that are not infrequently ambiguous and dubious in approach. Also, it is because of uncertainty as well as subjective decision-makers, political and social elements, and no completely objective way of finding the best solution. Thus, in implementing effective management processes, a critical decision support system should be available and can be implemented [17].

### **Pavement Maintenance Optimization**

To perform the optimization of pavement maintenance, several approaches have developed in different countries. Ranging from the traditional approach to modern approaches. Each method has advantages and disadvantages on its own. Over time, the optimization method becomes more complete and possesses 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 [20]. Genetic Algorithms (GA) is an approach that considered practical and has been widely used in various fields of science.

Through the GA approach, it is hoped that the unexpected future variables such as traffic growth uncertainty and excess loading on the national road network will be able to be mapped from the beginning as a consideration for the policyholder. The combination of stochastic simulation and GA allows the development of a project-based network-level maintenance plan that can explicitly consider the uncertainty of future pavement conditions in the decision-making process [21].

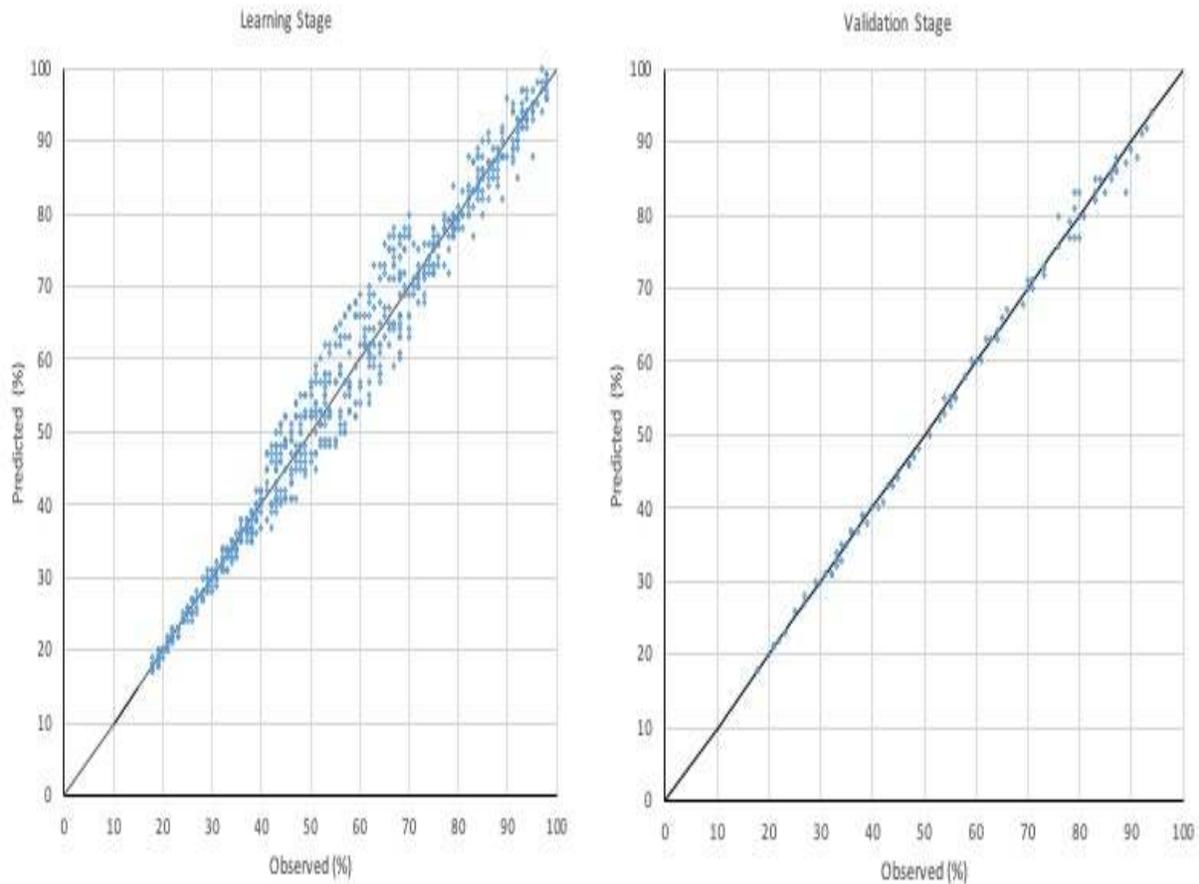
### **Case Study: LSCM**

As the case study, the national road network in the Central Sulawesi – Indonesia is selected. The road network in Central Sulawesi has a complete characteristic. The eastern part is characterized by the presence of the eastern corridor of Sulawesi Island that serves as the main transportation lines and this corridor is passed by all types of vehicles. Central Sulawesi eastern coastline connecting the south Sulawesi with other cities in Sulawesi such as

Luwuk, Gorontalo, and Manado. Also, there is a western corridor marked by anurban areawith a mountain transportation character.

### **PI Prediction Model**

Using Data Mining with the SVM model will result in the predictive PI value obtained for each road segment on the national road network in Central Sulawesi. In this work, we used the rminer package of the R tool to train the SVM model. For each model, a total of 1.000 runs of a 20 cross-validation procedure were applied. The predictive results (measured over unseen data) are shown in terms of observed versus predicted scatterplots. In such scatterplots, the better the predictions, the closer they are to the diagonal line (perfect model). Figure 1 the scatterplots of PI predictive models, revealing a good fit.



**Figure 1.** Target PI values versus SVM PI outputs (Learning & Validation stage)

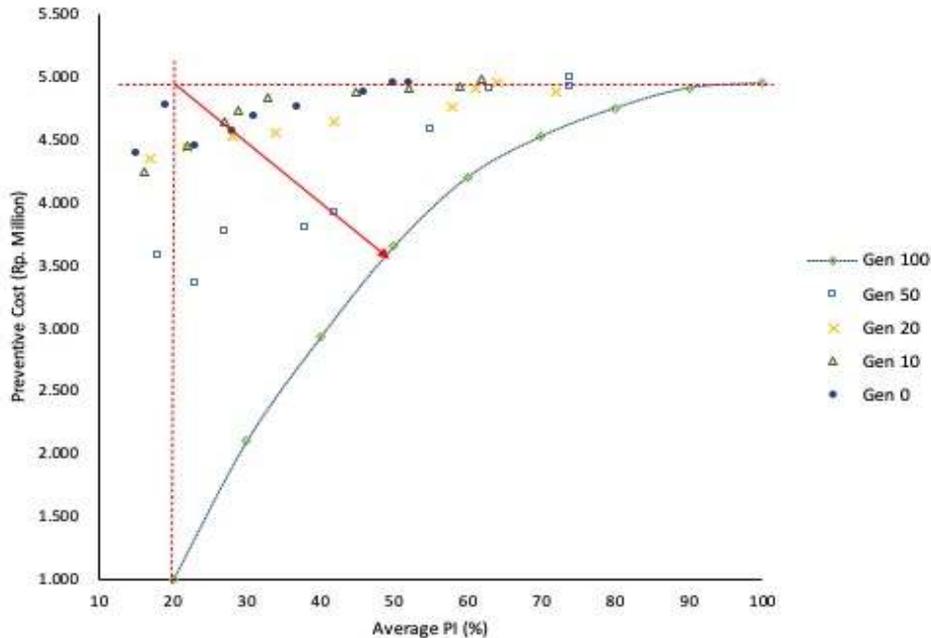
Figure 1 (learning stage) is some scatterplots showing the results of the learning stage modeling learning stage with a total amount of 700 data, and Figure 1 (validation stage) is an iteration for the validation stage. The computed regression error metrics, in terms of the Mean Absolute Deviation (MAD)  $0.61 \pm 0.02$ , Root Mean Squared Error (RMSE)  $0.75 \pm 0.01$  and coefficient of determination (R2)  $0.91 \pm 0.01$ . The lower the MAD and RMSE values, the better the predictive model, while a perfect model should have an R2 value close to 1.0. The results are presented in terms of the average of the runs and with the respective 95% confidence intervals according to a t-student distribution. Analyzing the results, a good fit was achieved by the SVMs model.

### **The Developed Optimization Model**

The main problems of road maintenance are optimization of the decision-making process, specified on budget constraints; and the prioritization maintenance method which guarantees the implementation with the level of road

stability. Therefore, a comprehensive hierarchal system in the decision-making process is needed to formulate with several elements, aspects, and variables of the implementation of road maintenance policy, so that the optimum funding and proper prioritization can be achieved

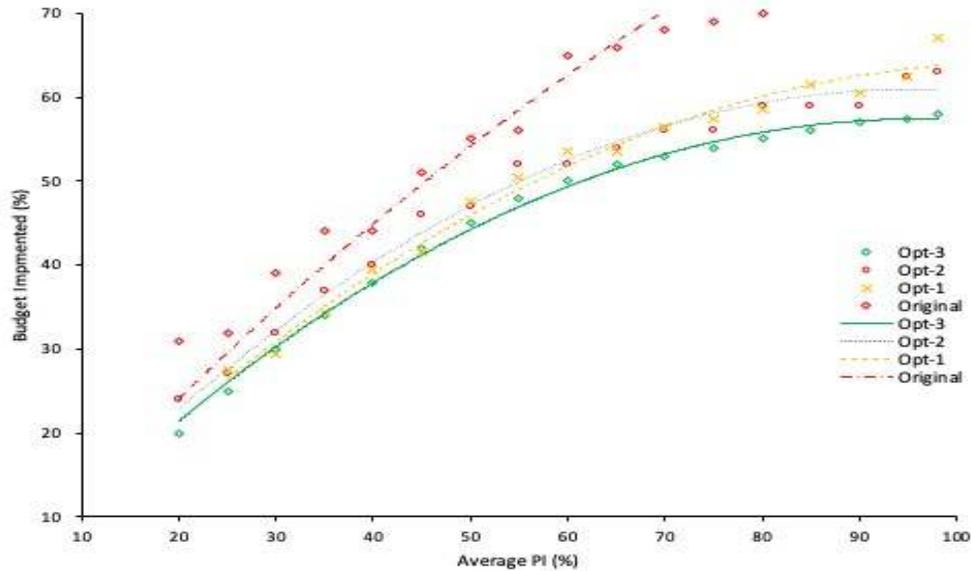
Optimization in road preservation must be implemented from the beginning of operation so that influential success factors, such as technical data, can be noted, archived, and evaluated, so irrelevancy of road usage. Stochastic Optimization approach can be used to determine the model of Pareto Solution to obtain the optimization of PI value and the maintenance costs. The post-optimization decision making or the methods used to choose the final solution are also illustrated by the model application. In this paper, 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 choosing the pattern of maintenance with the farthest distance to the axis 0 (Fig.2).



**Figure 2.** Pareto Optimality

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 DGH standard scenario, in sequence and then combined to achieve the optimum point is called the Pareto optimality and the shortest normalized distance.

In this optimization stage, the scenario maintenance is performed by iterating utilizing the tools provided by R-tools by conducting simulation tiered generation. The pattern of the Pareto optimization approach is done by transformation with the first generation. This is consistent with Pareto's theory, that a small percentage (20%) of the causes of the problems giving a potential settlement of the majority (80%) issues. To simplify the optimization scenario in this research approach road conditions with 4 types of handling LSMC. Maintenance chose to achieve the best PI and use the available budget. With the Pareto approach provided by optimx on R, obtained pattern maintenance activities of each segment and the prediction value predicted PI on each segment. The estimated value of PI obtained in the LSMC period before (original) and after optimization (Opt-1, Opt-2, Opt-3) can be seen in figure 3.



**Figure 3.** PI and budget implemented optimization

Simulations carried out by iterating dynamically linked with the performance prediction model part way through iteration SVM models. The second main part is mutually connected and controlled with the constraint. PI value to become a target in the simulation is the average value of PI's most optimal road network with due regard to the optimum value PI on each segment. Iteration models show that the necessary steps to achieve this jump. 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 figure 3, in sequence and then combined to achieve the optimum point is called from the Pareto approach and the farthest normalized distance. To simplify the optimization scenario in this study with the LSCM concept, the maintenance model is developed with 3 optimizations. Type of optimization maintenance is chosen to achieve the highest PI and lowest budget

## Conclusion

This paper developed a model of multi-objective optimization using an LSCM approach to generate an optimal scenario of pavement maintenance. A two-objective optimization model considers maximum PI and minimum maintenance costs. Both objectives are achieved simultaneously. Through the DM approach to obtain predicted PI, maintenance optimization is then performed by load factors that are received in each group of highway networks. The results showed the optimization type preventive pavement maintenance scenario produces the most optimal financing. This study only measures the performance of the PI values. Moreover, it can also be developed maintenance scenario with other approaches, aside from the standard scenario that has been selected in this study

The pavement maintenance optimization system proposed in this paper, called LSCM, can solve the problem of making LCCA for typical maintenance, to compare different condition solutions in terms of global costs for the final choice of the pavement maintenance for a national road. Additionally, the LSCM system has the capability of making LCCA with or without optimization and using only corrective rehabilitation operations or using both preventive and corrective M&R operations. The LSCM system provides a good solution to the pavement design problem considering not only design criteria but also construction costs, maintenance costs, user costs and the residual value of pavement structures.

## References

- [1]. Haas, R., Hudson, W. R. & Ziewski, J., (1994). *Modern Pavement Management*. Florida: Krieger Publishing Company, Malabar.
- [2]. Grivas, D., Ravirala, V. & Schultz, B., (1993). State Increment Optimization Methodology for Network-Level Pavement Management. *Journal on The Transportation Research Board*, pp. 25-33.

- [3]. Fwa, T., Chan, W., & Hoque, K. (2000). Multiobjective Optimization for Pavement Maintenance Programming. *Journal of Transportation Engineering*, ASCE Vol 119 No. 3, 419-432.
- [4]. Wang, F., Zhang, Z., & Machemehl, R. B. (2003). Decision-Making Problem for Managing Pavement Maintenance and Rehabilitation Projects. 82nd TRB Meeting, (pp. 1-10). Washington D.C.
- [5]. Fallah-Fini, S., Triantis, K., de la Garza, J. M., & Seaver, W. L. (2012): Measuring the efficiency of highway maintenance contracting strategies: A bootstrapped non-parametric meta-frontier approach. *European Journal of Operational Research*, p134-145.
- [6]. Zhang, X., & Gao, H. (2012). Road Maintenance Optimization Through a Discrete-Time Semi-Markov Decision Process. *Reliability Engineering and System Safety*, p 110-119.
- [7]. Moazami, D., Muniandy, R., Hamid, H., & Md. Yusoff, Z. (2011). The use of the analytical hierarchy process in priority rating of pavement maintenance. *Scientific Research and Essays*, 2447-2456.
- [8]. J. M. Akyildiz, S., Bish, D. R., & Krueger, D. A. (2011). Network-level optimization of pavement maintenance renewal strategies. *Advanced Engineering Informatics*, article in press.
- [9]. Ede A. Nkem, (2014), Cumulative Damage Effects of Truck Overloads on Nigerian Road Pavement, *International Journal of Civil & Environmental Engineering IJCEE-IJENS* Vol: 14 No: 01
- [10]. Sianipar C. P. M., Dowaki K., (2014), Eco-burden in pavement maintenance: Effects from over traffic growth and overload, *Sustainable Cities and Society* 12, 31–45
- [11]. Pais, J., Amorim, S., and Minhoto, M. (2013). "Impact of Traffic Overload on Road Pavement Performance." *J. Transp. Eng., ASCE*, 139(9), 873–879.
- [12]. Jeong, H. O., Chen, D., Walubita, L., & Wimsatt, A. (2011). Mitigating seal coat damage due to superheavy load moves in Texas low volume roads. *Construction and Building Materials*, 3236-3244.
- [13]. Hadiwardoyo, S., Sumabrata, R. & Berawi, M., (2012). Tolerance Limit for Trucks with Excess Load in Transport Regulation in Indonesia. *Makara Journal of Technology*, Volume 16 No.1, pp. 85-92.
- [14]. Zhou, G., & Wang, L. (2012). Co-location decision tree for enhancing decision-making of pavement maintenance and rehabilitation. *Transportation Research*, 287-305.
- [15]. Gluch, P., & Baumann, H. (2004). The life cycle costing (LCC) approach: a conceptual discussion of its usefulness for environmental decision-making. *Building and Environment* 39 (5), 571-580.
- [16]. Rahman, S., & Vanier, D. J. (2004). Life cycle cost analysis as a decision support tool for managing municipal infrastructure. Toronto, Ontario.
- [17]. Fedra, K., & Reitsma, R. (1990). *Decision Support and Geographical Information Systems*. Dordrecht, the Netherlands: Kluwer Academic Publishers.
- [18]. Tinoco, J., Correia, A.G. & Cortez, P., (2011). Application of data mining techniques in the estimation of the uniaxial comprehensive strength of jet grouting columns over time, *Construction and Building Material* 25, pp. 1257-1262.
- [19]. Rifai, A., I., Hadiwardoyo, S., P., Correia, Gomes A.G., Pereira, P., Cortez, P, (2014) Implementasi Data Mining Untuk Mendukung Sistem Manajemen Perkerasan Jalan Di Indonesia, *Konfransi Regional Teknik Jalan Ke-13, Makassar*
- [20]. Elhadidy A. A., Elbeltagi E. E., Ammar M. A., (2015) Optimum analysis of pavement maintenance using multi-objective genetic algorithms, *HBRC Journal* 11, 107–113
- [21]. Chootinan p., Chen A., Horrocks M. R., Bolling D., (2006) A multi-year pavement maintenance program using a stochastic simulation-based genetic algorithm approach *Transportation Research Part A* 40, 25–743
- [22]. Biatna, D., Denny, & Dhandy. (2005). Studi Standard Teknik Sampling dan Ukuran. *Jurnal Standardisasi*, 41-45.
- [23]. [23] Anderson, S. D., & Russell, J. S. (2001). *Guidelines for Warranty, Multi-parameter, and Best Value Contracting*. Washington, D.C.: NCHRP Report 451, National Research Council
- [24]. [24] Haseeb, M., Lis, M., Haouas, I., & Mihardjo, L. W. W. (2019). The mediating role of business strategies between management control systems package and firms stability: Evidence from SMEs in Malaysia. *Sustainability (Switzerland)*. <https://doi.org/10.3390/su11174705>