MARKOV DECISION PROCESS FOR DEVELOPMENT OF HIGHWAY MINIMUM STANDARD PERFORMANCE

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This thesis is dedicated with a great love to my dear parents. I also dedicate it to the light of my life; my wife, Ati Utami, SE, family who always supported me till I finish Doctor of Philosophy Degree by Research. To my supervisor and mentors, Prof. Madya Ts. Dr-Ing. Joewono Prasetijo for consistent encouragement, guidance and support throughout the research journey. To supporting company, Universitas Mercu Buana Jakarta, for their direct and indirect support in completing various stages of this research.

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ABSTRACT

Poor road conditions can cause discomfort, endanger safety, and disrupt the smooth flow of traffic. After the road is opened, it is start influenced by traffic and environmental loading, and as time goes by, road performance will decrease. The damage that occurs is different with various types of conditions on the road surface, within the time limit of maintenance, it is very important to maintain it optimal conditions. If this situation is not addressed, maintenance costs will continue to increase to repair further damage. This study aimed to identify the value of the condition of the road pavement and the model of the remaining life of the road, referring to the minimum service standard and the development of a road damage model. Additionally, it involved the prediction of pavement conditions with the Markov Chain model and simulations for optimizing future financing in maintenance management. The data needed for research, such as information on traffic volume and its projected growth, were gathered and aggregated as the study's method. For the following stage, the International Roughness Index (IRI) was established. Road age and condition estimates can be made using traffic volume prediction algorithms and IRI values. In this study, development of a Markov chain prediction model is to obtain the pattern of road maintenance and the proportion of this condition, which was expressed in the Transition Probability Matrix (MPT) of the 2019-2029 road condition transition. The development of a predictive model with the Markov chain application resulted in a fairly good maintenance pattern, where the type of handling program continued to shift from heavy work to light work for the next 10 years. The results were 52.6% in good condition, 47.4% in moderate condition, and scenario I was more in good condition reaching 92% in steady condition at the end of the design life.

ABSTRAK

Keadaan jalan raya yang rosak boleh menyebabkan ketidakselesaan, membahayakan keselamatan dan mengganggu kelancaran lalu lintas. Selepas jalan dibuka, ia dipengaruhi oleh lalu lintas dan beban persekitaran, seiring dengan berlalunya masa, prestasi jalan akan menurun. Kerosakan yang berlaku adalah berbeza dengan pelbagai jenis keadaan di permukaan jalan. Dalam had masa penyelenggaraan adalah sangat penting untuk mengekalkan keadaan optimum. Jika keadaan ini tidak dilakukan secara automatik kos penyelenggaraan akan terus meningkat untuk membaiki kerosakan selanjutnya. Kajian ini bertujuan untuk mengenal pasti nilai keadaan turapan jalan dan model baki hayat jalan merujuk kepada standard perkhidmatan minimum, membangunkan model kerosakan jalan dan meramalkan keadaan turapan dengan model Markov Chain untuk pengoptimuman. pembiayaan masa hadapan dalam pengurusan penyelenggaraan. Kaedah ini mengumpul data untuk analisis, seperti kadar trafik dan data pertumbuhan dan data IRI. Data tersebut digunakan untuk membangunkan model ramalan berdasarkan kadar trafik dan nilai IRI untuk meramal jangka hayat dan prognosis keadaan jalan raya. Model ramalan rantai Markov dibangunkan untuk mendapatkan corak penyelenggaraan jalan dan perkadaran keadaan yang dinyatakan dalam Matriks Kebarangkalian Peralihan (MPT) peralihan keadaan jalan bagi tahun 2019–2029. Keputusan analisis menunjukkan model hayat turapan sisa adalah sesuai dan boleh digunakan untuk meramalkan baki hayat jalan raya. Berdasarkan kadar trafik, didapati terdapat penurunan sebanyak satu tahun daripada hayat reka bentuk. Pembangunan model ramalan dengan aplikasi rantai Markov menghasilkan corak penyelenggaraan yang agak baik, di mana jenis program pengendalian terus beralih daripada kerja berat kepada kerja ringan untuk 10 tahun akan datang, hasilnya adalah 52,6% dalam keadaan baik, 47,4 % dalam keadaan sederhana dan senario saya lebih baik keadaan mencapai 92% dengan keadaan mantap pada akhir hayat reka bentuk.

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LIST OF SYMBOLS AND ABBREVIATIONS

a_0	-	Initial vector
a_t	-	Distribution of conditions at time t
ADT	-	Average Daily Traffic
ARRB	-	Australian Road Research Board
CESAL	-	Cumulative Equivalent Standard Axle Load
DGH	-	Director General of Highway
ESAL	-	Equivalent single axle load
HD	-	Heavily damaged
IRMS	-	Inter-Urban Road Management System
i	-	Growth factor
IP	-	Surface Index
IRI	-	International Roughness Index
LD	-	Lightly damaged
MPT	-	Transition Probability Matrix
MSS	-	Minimum Service Standards
NAASRA	-	National Australian Association of State Roads Authority
N_i	-	The number of road segments that are in condition i before the transition occurs
N_{ij}	-	the number of road segments that move from condition i to state j in one cycle
P	-	Period
P'	-	Desired condition
P_{ij}	-	Transition probability
PSI	-	Present Serviceability Index
P^t	-	Improved MPT with control at time t
PCU	-	Passenger car units
PTV	-	Planned traffic volume

PUPR	-	Pekerjaan Umum Perumahan Rakyat
R2	-	R-squared
RL	-	Remaining life
SN	-	Structural number
SNC	-	Structural number capacity
SPM	-	Minimum Service Standards
t	-	Elapsed time in years
VDF	-	Vehicle damage factor
WHO	-	World Health Organization

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CHAPTER 1

INTRODUCTION

1.1 Background

The road is a means of transportation that has a vital role in life. It can facilitate the economy, culture, distribution of goods and services, become an access link between regions, and improve the people's economy and standard of living (Shrestha & Khadka, 2021a). It is a land transportation infrastructure that includes all parts of the road, including complementary buildings and equipment intended for traffic, which is on the ground (Ministry of PUPR, 2012).

The road network is a crucial land transportation infrastructure, especially for the sustainable distribution of goods and services (Nugroho & Nicholas, 2018). Transportation intentionally moves goods and services from one place to another (Fatimah, 2019). The existence of an excellent level of road service facilitates the movement of people and goods. So, road damage can affect economic activity, quality of life, and the environment in an area (Ruiz & Guevara, 2020). Optimization in road maintenance is needed to obtain a proper pavement condition even with limited funds using a knowledge-based planning strategy (Jurkevičius *et al*., 2020).

The primary function of road pavement is to spread the wheel load to the surface area so that it can provide a solid structure for support traffic loads, a flat surface, and skid resistance on the pavement surface (Hardiyatmo, 2019). Pavement damage is caused by exceeding the capability limits of each road pavement element (Yoder & Witczak, 1991). Road conditions must remain prime to provide safety and comfort for users (Prasetijo *et al*., 2020). According to the WHO, nearly one million people are killed annually, three million are disabled for life, and thirty million are injured in road accidents. By 2020, road accidents are expected to be the third most important contributor to the global burden of disease and injury (Prasetijo *et al*., 2017).

The pavement layer can experience a decrease in structural function according to increasing age and traffic load (Wang *et al*., 2003). Its age is generally determined based on the cumulative equivalent standard axle (CESA) expected to pass (DGH, 2017). The process of decreasing road life is not linear. The overall decline in road performance is a function of the increase in traffic volume and load, changes in environmental conditions, etcetera (Haas & Hudson, 2015).

A common phenomenon in developing countries is the presence of excessive loads that result in structural damage to the pavement before the design life is reached (Rifai, Pereira, *et al*., 2015). Repeated conditions result in significant damage that alters service life and the environment. The financing of continual overloads is a direct factor to the increase in maintenance costs (Pais *et al*., 2013). The maintenance costs required for this condition are not only for grazing the function of the top pavement layer but also must consider the sub-base layer (Hadiwardoyo *et al*., 2012). This condition is often a problem in almost every big city in Indonesia (Angreni *et al*., 2018). Due to vehicle traffic and temperature change, roads expand/shrink and crack, leading to potholes, which can cause accidents, uncomfortable journey, and damage to the vehicle's wheels (H. Huang *et al*., 2022).

Maintaining good road conditions is essential to support continued economic and social activities (Hankach *et al*., 2019). The road pavement management system continues to develop with limited costs, but users are increasingly demanding to ensure good quality, safety, and comfort in driving (Santos & Ferreira, 2012). An essential part of the road pavement management system is excellent and sustainable planning and rehabilitation.

Over time the system continues to evolve to meet higher expectations (Rifai, Pereira, *et al*., 2015). The latest approach, assisted by modern mathematics and computer technology, allows budget allocation as one of the resources for system improvement to be implemented efficiently (Yarmukhamedov *et al*., 2020), Optimization is carried out on all components: pavement performance, construction costs, maintenance costs, user costs, and the residual value of the structure. These components must be interpreted and predicted precisely and accurately. The interpretation process approach used is the artificial intelligence (AI) approach carried out by several researchers (Cortez, 2010), (Govindarajan *et al*., 2020), (Hu *et al*., 2021),(Chowdhury *et al*., 2021). Furthermore, model development using IRI predictions (Mazari & Rodriguez, 2016), (Shrestha & Khadka, 2021b), (Fakhri & Shahni Dezfoulian, 2019), and (Alatoom & Al-Suleiman, 2021). A pavement will change from one condition to another in a cycle. One of the methods available for this purpose is the Markovian technique, which is a probabilistic technique that has proven to be an effective tool in predicting future pavement performance. The transition probability matrix (MPT) is part of the Markov process that changes the initial conditions of the pavement under study. In addition, MPT functions to display changes in the condition of one state to another in the future. Several model developments to maximize maintenance cost decision-making using linear formulations were carried out through the MPT approach (Prasetijo, 1996), (Tjan & Pitaloka, 2005), (Bakó & Horváth, 2004), (Mandiartha *et al*., 2017), and (Handayani, 2018).

1.2 Problem statement

The common condition in the road pavement management system is maintaining the best road performance while maintaining the lowest possible maintenance costs. After the road is opened, road performance will decrease over time, influenced by traffic and environmental loading. The damage that occurs varies with various types of conditions. There are still vehicles with excess loads and the increasing volume of vehicles resulting in structural damage to the pavement before the design life is reached.

Maintenance is essential to maintain optimal road conditions, and maintenance costs will continue to rise if roads are not repaired promptly. Some of the difficulties in optimizing maintenance costs are due to the complexity of the road damage process. Based on a probabilistic analysis of road deterioration, it is necessary to develop a model capable of estimating road maintenance costs, and a model capable of predicting pavement performance as accurately as possible. Prediction of future pavement degradation is done using a Markov Chain Process, which requires estimation of transition probabilities using historical damage rating data, both to predict damage ratings in the absence of maintenance and to predict pavement ratings when maintenance activities are performed.

Experience shows that using pavement modeling methods like pavement deterioration models is the only reliable way to manage pavement performance (Parkman *et al*., 2003), Several highway organizations all over the world are currently assessing pavement performance using the IRI (Pérez-Acebo *et al*., 2020). The IRI can be used in pavement rehabilitation and management applications and provides a summary measure of the longitudinal surface profile obtained from surface elevation data collected using a mechanical profilometer (Abaza, 2004). However, its use is only restricted to those agencies that can obtain and calibrate a suitable mechanical profilometer (Byram *et al*., 2012; Sayers, 1995). The provision of road conditions that comply with minimum service standards (SPM) is expressed through the road surface roughness value (IRI). Data, which is the result of measurements every semester, is available quite massively at the Directorate General of Highways Indonesia. So far, this data has only been used for the benefit of programming, but there has been no attempt to measure and predict damage in the future using the Markov process model.

Model development is significant in optimizing road maintenance. Based on the literature search, until now, the Markov process approach is still used as a predictive model of road performance for optimization of road maintenance management with limited costs, which still meets the minimum road service standards applicable in Indonesia. Because the number and length of roads in Indonesia total 532,817 km (Direktorat Jendral Bina Marga, 2020) and with the limited condition of human resources in the field of technology, especially in forecasting and optimizing road pavement management, the selection of models using the Markov chain application is easier to understand and apply.

1.3 Research questions

Based on the background and problem identification above, the formulation of the problem is how to:

(i) Using the minimum service standard, determine the level of damage to the pavement and the model for the remaining life of the road.
(ii) By interpreting existing data, develop a road damage model and pavement condition prediction based on the Markov chain model.
(iii) Simulate future financing optimization in maintenance management.

1.4 Research objectives

The common objectives of this research are to:

(i) To determine the level of damage to the road pavement and the model of the remaining life of the road referring to the minimum service standard.
(ii) To develop a model to predict pavement conditions based on the Markov Chain Model by interpreting the existing data.
(iii) To estimate simulate future maintenance management scenarios.

1.5 Research scope

The focus of this research:
(i) The performance of the road pavement discussed is specifically for flexible pavement.
(ii) The data used includes road surface conditions, budget availability, prioritization, and the function of road use.
(iii) The road status is 34 national roads in the West Java region.
(iv) Develop a logical model for increasing minimum service standards and predicting future damage conditions with Markov chains and matrix transitions.

1.6 Significant of the study

The development of an optimal model can provide alternative recommendations for maintenance work, cost control, work implementation, and time and location scenarios to meet Minimum Service Standards (SPM). The optimal road maintenance pattern system is vital for planning maintenance and predicting future work and the costs incurred in its implementation.

1.7 Structure of thesis

This thesis consists of five chapters specially arranged to achieve the research objectives. The research provides a clear picture at each stage of the work. The introductory chapter includes eight sub-topics, background, problem formulation, research questions, objectives, scope, significance, thesis structure, and summary.

Chapter two, as a literature review, discusses the basic theory of road maintenance management systems and their various models. It also includes definitions and concepts related to topics and government regulations in Indonesia regarding Road Minimum Implementation Standards. There is the presentation of several related previous studies for reference. Research methodology helps guide the process, steps, procedures, and techniques for assessing the success of the data. This chapter discusses research design, methodology flowchart, sample population, data collection, and data analysis.

The research findings obtained through data analysis are in chapter four. Finally, chapter five discusses the discussion, conclusions, and recommendations. In addition, there are deductions about the results to make recommendations for further research objectives.

1.8 Summary

This chapter has introduced the research topic by providing a general and comprehensive overview of the value of road pavement conditions, road maintenance management, and models produced by previous researchers have developed. It shows the research problem, the formulation of research questions, the objectives, and an overview of the scope and significance of the research.

CHAPTER 2

LITERATURE REVIEW

This chapter discusses the basic theory of pavement management, the development of a road maintenance optimization model, the International Roughness Index (IRI), the Present Service Index, and predictive modeling using the Markov chain model. It consists of definitions and concepts related to topics to meet minimum service standards for roads in Indonesia. In addition, some previous related studies related to this topic are also presented as a basis for reference studies.

2.1 Road management

Recent road management policies have been influenced by changes in the mechanism due to the implementation of regional autonomy. National road operators are ministers or officials appointed to implement them, including toll roads. Generally, its performance is related to several policies that underlie the concept (Ministry of PUPR, 2012). In general, the authority is the central government and local government, but the control of the road rests with the state.

Roads can be classified according to class based on Law No. 22 of 2009 based on the network system, function, and road status (Republic of Indonesia, 2009). The following Tabel 2.1 shows the relationship between each road classification:

Table 2.1: Type of roads based on class (Republic of Indonesia, 2009)

Road Class	Function	Motorized Vehicle Size	MST
Class I	Arterial Road Collector Street	Width ≤ 2.500 mm Length ≤ 18.00 mm Height ≤ 4.200 mm	10 Ton
Class II	Arterial Road Collector Street Local Street Neighborhood Road	Width ≤ 2.500 mm Length ≤ 12.00 mm Height ≤ 4.200 mm	8 Ton
Class III	Arterial Road Collector Street Local Street Neighborhood Road	Width ≤ 2.100 mm Length ≤ 18.00 mm Height ≤ 3.500 mm	8Ton
Special Class	Arterial Road	Width ≤ 2.500 mm Length ≤ 18.00 mm Height ≤ 4.200 mm	> 10 Ton

The primary system is a road network system for the distribution of goods and services to develop all regions at the national level. It is done by connecting all distribution service nodes as activity centers. In comparison, the secondary system is a method for distributing goods and services in urban areas (Direktorat Jendral Bina Marga, 2020). Figure 2.1 depicts the road function scheme in the road network system:

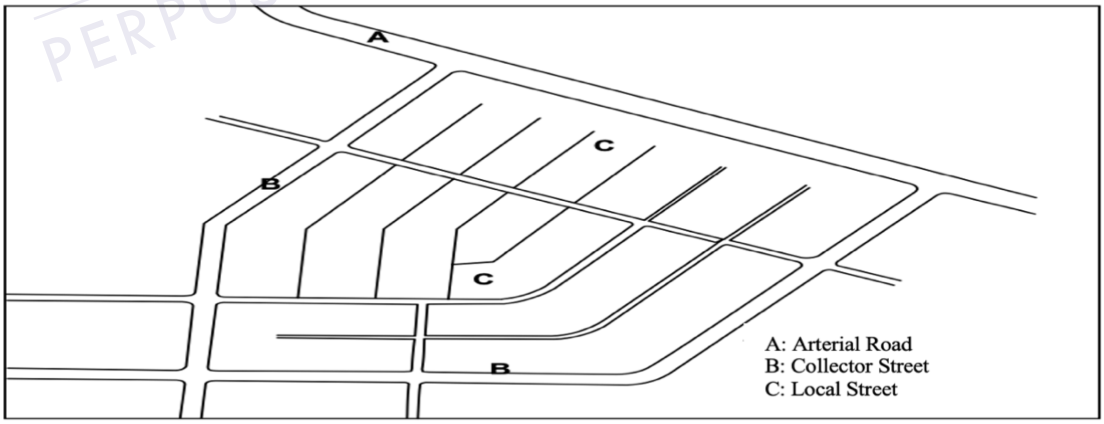

Figure 2.1: Road function scheme (Direktorat Jendral Bina Marga, 2020)

2.2 Road handling

In the condition of a constrained budget available, the prioritising road handling activities for assets preservation is a reasonable step. However, if it is financially feasible, asset enhancement can be carried out. If the available funds are substantial, asset expansion is necessary.

The need for road management funds comes from various sources, such as the primary source of funds and assistance (Direktorat Jendral Bina Marga, 2016). Road handling aims to maintain the physical and operational conditions so that it remains in good shape to provide services as it should (Putri, 2011). The handling of national road network infrastructure based on working areas is proposed to be divided into two groups: preservation and development. Handling preservation ensures the road network remains in optimal condition where the work is grouped into two types: road maintenance and rehabilitation. Meanwhile, the handling of development increases the quantity both in the longitudinal and the transverse direction.

2.2.1 Road maintenance

All types of work are needed to maintain and repair roads to keep them in good condition or jobs related to both. It is to prevent a decrease in quality with the rate of change that occurs immediately after construction is carried out (Khan *et al*., 2016).

Therefore, road maintenance is the highest priority program. It is carried out with the principle of effective and efficient economic profit through a minimum budget so that optimum road conditions can make people happy because transportation costs are low (Augeri *et al*., 2019). Figure 2.2 ilustrates the maintenance model relating to time and cost:

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