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PRESERVATION STRATEGIES OF PAVEMENT BASED ON ROUGHNESS INDEX AND LIFE CYCLE COST

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ABSTRACT: The design life, traffic volume, regional conditions, quality specifications, and other factors are all taken into consideration by the pavement design standards implemented in several nations. The design eventually leads to the pavement's ability to serve as access to designated locations. For various reasons, the relationship between planning and operation often falls apart. However, the lack of comprehensive preparation for preservation and rehabilitation throughout road service life is one notable cause. After designating and forecasting the periods and expenses required during the pavement's service life, this study aims to offer an alternative perspective on planning. Both rigid and flexible pavements in new condition with a 40-year design life are the pavements that will be observed. In this instance, the International Roughness Index (IRI) will be used to estimate the pavement's functional bearing capacity. Preservation strategy is chosen to extend the service life of pavement to be 50th years. The Life Cycle Cost Analysis (LCCA) approach and the IRI value will be combined to create forecasts of the costs and schedule that will be incurred throughout the road's service life. The LCCA will utilize agency cost and user cost values. Compared to rigid pavements, agency costs are higher when flexible pavements are reconstructed. Rigid pavements are typically more costly than flexible pavements when considering other factors, including user cost. According to the research, rigid pavements are more effective for long-term pavement construction. Furthermore, this study would help stakeholders make decisions on road pavements.

Keywords: Preservation, IRI, Life Cycle Cost, Maintenance and Rehabilitation Schedule

1. INTRODUCTION

Design pavement generally has not considered the value of structural and functional reactions of the pavement. Although in the reality, that when you observe the field, there is a necessary for an approach that is both structurally and functionally related to the preservation function of the road. Road preservation aims to maintain the service capacity of the road during its service life. One of the key factors for consideration is the functional performance of the pavement, which impacts the safety and comfort of driving. One approach that can be utilized to determine the functional value of the pavement is the IRI value. The International Roughness Index (IRI) is one of the most crucial approaches to determine pavement performance and suggests that ride quality is the primary aspect that defines functional performance. Nevertheless, most of the forecast models currently in use for the IRI in rigid pavements depend on basic machine learning methodologies including linear regression, that require for improvements in learning effectiveness and interpretability [1]. Mechanistic Empirical Pavement Design Guide (MEPDG) integrates distresses including cracking, rutting, faulting, and punchouts as the primary variables that influence the loss of pavement roughness with the aim to estimate IRI incrementally over the course of the design period. Numerous studies have been performed to predict IRI for both rigid and flexible pavements utilizing the MEPDG [1-2]. In the MEPDG, pavement distress and IRI are influenced by a variety of traffic materials, and climatic influences. Modulus of Reaction (MR) refers to the stiffness of the pavement's unbound layer system under repeated traffic loads. Previous study stated that the higher the MR value in the soil layer, the lower the IRI value and the lesser the pavement deterioration [3]. The pavement load bearing capacity for traffic will probably decrease and will be correlated with the duration of time required for preservation and rehabilitation. Therefore, the correlation of that study to be related to the pavement life cycle cost function, which needs further analysis.

Pavement is the fundamental asset for meeting distribution demands, but it requires periodic repair and will eventually deteriorate. Road authorities are facing difficulties with project budgets due to limited resources, as most expenditures are inadequate under typical circumstances. Additionally, road authorities prioritize to minimizing the budgets and increasing efficiency. In the proposed circumstance, the author aims to present an alternative view based on Life-cycle cost analysis. Life-cycle cost analysis (LCCA) is established to rank various pavement designs or determine maintenance and rehabilitation (M&R) criteria in a better approach, which leads Departments of Transportation (DoTs) to improve pavement performance within limited budgets. LCCA can be known from the planning period to predict the value or time required to carry out preservation and rehabilitation actions. Determining the rehabilitation schedule, which includes preservation and rehabilitation actions and time, is a crucial methodological aspect for LCCA.

LCCA will also utilize the rehabilitation schedule based on the IRI value forecast. Using a set schedule is the simplest operational method [4]. Research that combines IRI values with LCCA remains scarce, particularly in Indonesia. This research will influence the authorities' perspective on pavement selection by informing their decision on the type of pavement to use. The existing circumstance until now, the financing of pavement Maintenance and Rehabilitation (M&R) has been based on a reactive approach when damage occurs, rather than on well-planned, scheduled, and measured financing. The situation will impact the expenditure and implementation, which will be less coordinated. Therefore, this research is expected to fill the existing gap in research and implementation with better suggestions and solutions.

2. RESEARCH SIGNIFICANCE

The present rehabilitation expense will be significantly decreased given the condition of the Bogor pavement and the area that requires Maintenance and Rehabilitation (M&R). Furthermore, this pavement faces an annual increase in traffic flow. It has been suggested that preservation strategies based on functional condition, which include IRI and LCCA values, provide appropriate considerations for managing the agency's or stakeholder's current resources, including establishing the agency's budget and schedule. The transportation agency will be assisted in determining the most appropriate pavement type by employing the application of LCCA in the pavement management system. This study aims at finding preservation solutions based on IRI value and LCCA among rigid and flexible pavements in order that transportation departments can determine how much to allocate on preservation.

3. METHODOLOGY

The data required for pavement design including daily traffic volume, material specifications, subgrade, and climate conditions, are utilized for parameters in manual design. Preservation strategies include IRI data, LCCA data, and other relevant parameters in accordance to preservation that will be utilized for forecasts. Relevant parameters also will be assumed using previous research or valid regulations. Additionally, in this study the unit price is determined by the relevant unit price on Bogor City. This study aims to planning and developing the preservation strategies for pavements based on the International Roughness Index (IRI) and Life Cycle Cost Analysis (LCCA). The preservation strategy to be utilized in this study includes M&R for a design life of 40 years. The development of preservation strategies is necessary to maintain the reliability of road conditions throughout the design life and to determine the costs that need to be prepared during M&R phase.

The main framework of this study begins with the design of road pavements, including the rigid and flexible pavements, establishing based on the Indonesian Pavement Design Manual [5]. Both types of pavements are chosen to compare the effectiveness and efficiency of design and preservation strategies. The IRI value will serve as a reference in determining the scheduling and types of M&R actions to be used during design life. LCCA is used to determine the life cycle of these two types of pavements in accordance to cost expenditures from the construction phase to the service life of the pavement. These costs can serve as one of the bases for decision-making by the stakeholder/agency in road pavement. The analysis results will also reveal the performance of the pavement related to the scheduling of M&R and reconstruction of the pavement.

3.1. Design and Preservation of Pavement

Design of flexible and rigid pavements is based on Indonesian Pavement Design Manual, this manual based on Mechanistic-Empirical Pavement Design Guide (MEPDG) [5]. The MEPDG method, being the most recent pavement design approach, integrates supplementary design criteria including longitudinal cracking, reflection cracking, and smoothness, which are essential in assessing pavement performance and thickness [6]. This stage determines the thickness of the road pavement and the initial construction cost. Generally, the design life of flexible and rigid pavements is 20 and 40 years, respectively. However, with the implementation of a road preservation program, this approach could extend service life. Therefore, the end of service life design for both types of pavements is 40 years. Flexible pavements, which initially had a maximum of 20 years of service life, can be extended to 40 years with the addition of a reconstruction phase scenario within those 40 years.

Road preservation is a series of long-term activities to maintain roads efficiently and effectively, to extend the service life of the road through various processes, and maintain the functional and structural condition of the road. According to Federal Highway Association 1998 [7] M&R is conducted every 5 years. In this study, routine maintenance is not included in the calculation because the cost and IRI value post-routine maintenance are not very significant. The treatment for flexible and rigid pavements differs according to the level of damage. M&R strategies for flexible pavement include chip seal, crack seal, slurry seal, patching, and thin overlays [8]. Rehabilitation includes partial or full depth rehabilitation, mill and Hot mix asphalt (HMA) overlays. Patching combined with mill and overlay every 10 years offers a sustainable and cost-effective approach [8]. The determination of the M&R schedule for road pavements is based on IRI predictions. The chosen treatment will be used to calculate the M&R cost.

3.2. International Roughness Index (IRI)

IRI will determine the value of road surface roughness based on the results of measuring the longitudinal pavement profile. IRI data can also be obtained from IRI prediction [9]. Indonesia has Integrated Road Management System (IRMS) program, which include the utilization of IRI data in determining the functional maintenance of pavement. The prediction equation for the IRI of flexible pavements refers to Patterson equation within the IRMS [10–12]. The prediction equation for the IRI values of rigid and flexible pavements are shown in Eq. 1 and 2.

$$IRI = IRI_t + C1 \times CRK + C2 \times SPALL + C3 \times TFAULT + C4 \times SF \quad (1)$$

IRI is predicted IRI of rigid pavement (in/mi), IRIt is initial smoothness measured as IRI (in./mi), CRK is percentage of slabs with transverse cracks (all severities), SPALL is percentage of joint with spalling (medium & high severities), TFAULT is total joint faulting cumulated per IRI (mi, in), C1 = 0.8203; C2 = 0.4417; C3 = 0.4929; C4 = 25.24

$$RI_t = RI_0 + 725\ (1 + SNC)^{-5}\ .NE_t)\ .e^{0.0153t} \quad (2)$$

RI_t is predicted IRI of flexible pavement (m/km), RI_0 is the initial IRI value, m/km, NE_t is ESAL value t (per 1 million ESAL/lane), SNC is the structure Number Capacity, which is determined by the AADT and IRI value according to Indonesian Road Management System [11]. The AADT value is 57,960 vehicles/day, thus the SNC value is 4.35.

This study will analyze the design of new pavements in order that the estimation of pavement preservation strategies will utilize the predicted IRI values through the specified design life. The IRI value will be utilized to determine the type and schedule of M&R, where the IRI value for new construction and rehabilitation is 2 m/km and 8 m/km, respectively. Maintenance will be performed within the range of 2 to 8 m/km [13].

3.3. Life Cycle Cost Analysis

Life Cycle Cost Analysis (LCCA) in the road pavement field are used as a instrument to evaluate the economic efficiency of road pavement design and preservation. LCCA is obtained by considering the values of agency cost and user cost. Agency cost includes construction cost and M&R cost. Meanwhile, user cost includes Vehicle Operational Cost (VOC), delay cost, and crash cost. LCCA can assist stakeholders in transportation authorities in making decisions by considering the life cycle of road pavements [14].

3.3.1. Agency cost

Agency cost refers to the expenses occur by the agency for initial construction and M&R. M&R treatments which include chip seals, crack seals, and thin overlays are effective to improving short-term pavement performance and delaying the need for major rehabilitation [15]. Properly planned M&R activities might be cost-effective because it can prevent severe damage, thereby avoiding more expensive rehabilitation or reconstruction in the future.

3.3.2. User cost

User cost is the cost that occur during the usage of pavement over the service life by user. User cost generally includes VOC, delay cost, and crash cost. Environmental impact is also considered part of the user cost [16–19]. In this study, the user cost does not account for the environmental impact.

VOC includes fuel consumption, tire usage, and vehicle maintenance. VOC can be calculated based on the IRI value. IRI indicates the roughness of the road surface; the higher the IRI, the higher VOC will be [20]. The relationship between IRI and VOC is shown in Table 1.

Table 1. Vehicle operational cost [21]

Type of vehicle	Fuel consumption ($/veh.mil)	Tire wear ($/veh.mil)	Repair and maintenance ($/veh.mil)
Medium car	0.0027*IRI + 0.0867	0.000021*IRI + 0.0021	0.024
SUV	0.0021*IRI + 0.0983	0.00021*IRI + 0.0017	0.032
Light truck	0.0016*IRI + 0.1568	0.000021*IRI + 0.0017	0.034

Delay cost is related to the work zone (WZ) during M&R or reconstruction. The more frequent the rehabilitation, the higher the delay cost will be. Delay costs are determined by multiplying the estimated delays to personal travel, business travel, truck travel, and freight inventory caused by the work zone by the unit cost ($/day) of travel time. The estimation of delay costs is based on the Federal Highway Administration [17]. In this study, the work zone time is from 08:00 am to 05:00 pm, or nine working hours. The calculation of delay time for all vehicles per day is shown in Eq. 3.

$$\frac{\sum\ [(\textbf{Delay time per hour}\ .\textbf{Traffic volume per hour})\ /\ \textbf{60}]}{\textbf{Traffic volume per day}} \quad (3)$$

The inventory cost is computed by multiplying the average payload of the truck by the average value of commodities transported by truck. The calculation of the cost of cargo inventory per day [17]. The cost of travel delay is estimated during the work zone, assuming that the work zone during M&R or reconstruction is 60 days.

Crash cost refers to the accident cost that occurs due to the presence of a work zone for M&R or reconstruction. The data required to determine crash cost during a work zone are the number of accidents, work zone crash rate, work zone exposure, and crash cost rate. The calculation of crash cost refers to Federal Highway Administration [17].

4. RESULT AND DISCUSSION

Newly pavement construction of 1 km with a design life of 40 years will be taken as primary data. The average annual daily traffic is 57,960 vehicles per day, with 5% of these being trucks. There are two lanes in each direction, each with a width of 6 meters. Two types of pavements are planned: flexible and rigid pavements, which are considered in pavement selection using LCCA. Given a planned 40-year service life period, a reconstruction phase for the flexible pavement is also considered. The result pavement design obtained a concrete slab layer with f’c 30 MPa and thickness of 250 mm and a subbase layer using lean concrete with a thickness of 100 mm. Flexible pavement contains a surface, base, and subbase layer with thicknesses of 70 mm, 80 mm, and 200 mm, respectively. A repair subgrade layer thickness of 500 mm will be used for flexible pavement in this study.

4.1. Pavement preservation

Preservation strategies include periodic maintenance conducted every 5 years [7] and rehabilitation based on IRI values [13]. The predicted IRI value that required for rehabilitation period of (the end of IRI) flexible and rigid pavement is 8 and 12 m/km, respectively [13]. It is assumed that after maintenance, the IRI value will decrease by 0.5 m/km [12], and after rehabilitation period (HMA overlay) the IRI value will equal to a newly pavement, both of flexible and rigid will have value of 3 and 4 m/km, respectively [13]. The IRI prediction over the service life is shown in Fig. 1.

Based on Fig. 1, the presence of an appropriate M&R schedule can extend the service life of the pavement from the originally planned 40 years to 50 years. This plan can be implemented if the present stakeholders consistently conduct inspections and proactively M&R the pavement. Rigid pavement requires periodic maintenance and treatment twice in its 5th and 10th years. Although routine and periodic maintenance has been carried out, over the 0 – 10 years period, the IRI value generated on the rigid pavement continues to show an increasing pattern. The pattern indicates a decrease in the comfort function and surface suitability of the pavement, therefore by the 40th year, rehabilitation is necessary to lower the IRI value.

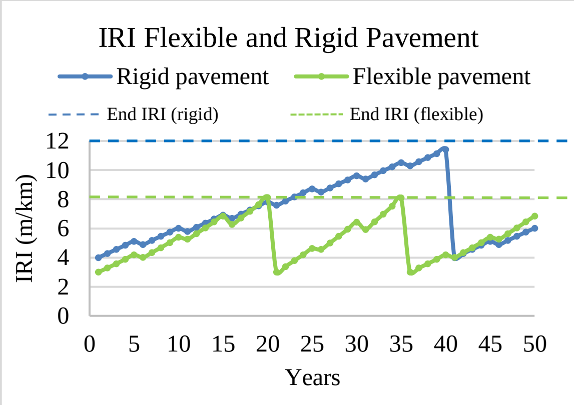

Fig 1. IRI flexible and rigid pavement

During its service life, rigid pavement requires one rehabilitation activity in the 40th year. The IRI value after undergoing rehabilitation, in the form of an overlay, has nonetheless not worked in restoring the IRI value reinstated at that of newly created pavement. However, its value tends to be low. After carrying out rehabilitation, the flexible pavement receives rehabilitation in the 20th years. The analysis shows that the performance of the pavement will significantly decrease, as shown by the increasing trend of periodic maintenance compared to reconstruction (new pavement) reaching 35th years. The trend of periodic maintenance on rigid pavements shows the same pattern which are before and after rehabilitation, namely that it is carried out annually, with a linear increase in IRI values. In the 50th year, the rigid pavement will get into the reconstruction phase. Based on Fig. 1, after periodic maintenance, the rigid pavement has a lower IRI value compared to before the maintenance was carried out, thus this analysis adequately represents the field conditions.

However, based on the prediction results using the IRI value, flexible and rigid pavement requires periodic maintenance every 5 years. After the IRI increases significantly, the flexible pavement is scheduled for rehabilitation due to its IRI value exceeds 8m/km. The flexible pavement requires one rehabilitation activity in the 20th year and one reconstruction in the 35th year. Periodic maintenance is carried out every 5 years. Although maintenance and treatment have been carried out, the IRI value of the flexible pavement continues to show a linear increasing pattern and will experience deterioration. A service life of 40 years is assumed, implying that the flexible pavement will be reconstructed from the surface layer to the Subbase layer. Without reconstruction, the flexible pavement will not reach the planned service life and is predicted only up to 35 years. M&R extends the service life beyond the planned lifespan. However, based on the IRI values of both types of pavements, flexible pavements require rehabilitation earlier, despite having the same maintenance schedule.

4.2. Life Cycle Cost Analysis (LCCA)

4.2.1. Agency cost

The cost comparison of the two types of road pavements based on initial construction costs and M&R is shown in Table 3. The cost up to a service life of 50 years shows that flexible pavement is more expensive than rigid pavement. The costs occur will include material and labor cost that adjusted to the Unit Price of Work in Bogor City, West Java, Indonesia. Agency cost is determined with 5% discount rate in accordance to Indonesia's Bank Rate. Furthermore, based on the periodic maintenance, rehabilitation, and reconstruction period, the Net Present Value (NPV) will be determined for each period with values of $46,900, $120,000, and $327,448, respectively. The value of agency cost from each period, with consideration of the discount rate, can be seen in Table 2.

Based on Table 2, every 5 years for periodic maintenance will cost $46,900 due to maintenance work of minor to moderate damage, as stated in the American Association of State Highway and Transportation Officials [9] also with predicted damage from the previous study. The rehabilitation period will cost $120,000 due to overlay work and repairing the defect. The reconstruction of the flexible pavement period will involve the work of replacing the surface layer, base layer, and subbase layer. Based on the occupation, during work time, the occupation will cause more expenses than the rehabilitation period. For providing the good quality of pavement, the expenditure from this occupation is included to be agency cost. When compared to rehabilitation and reconstruction during the 50th year of service between the flexible and rigid pavement, based on Table 2, the flexible pavement will be more costly than the rigid pavement.

Table 2. Agency cost breakdown

Years	Agency cost ($)			
	Rigid		Flexible	
0	C	1,433,300.00	C	1,310,700.00
5	M	59,857.00	M	59,857.00
10	M	76,395.00	M	76,395.00
15	M	97,501.00	M	97,501.00
20	M	124,439.00	R	318,395.00
25	M	158,820.00	M	158,820.00
30	M	202,699.00	M	202,699.00
35	M	258,701.00	RC	1,806,211.00
40	R	844,798.00	M	330,175.00
45	M	421,396.00	M	421,396.00
50	E	-	E	-
Total		3,677,909.00		4,782,152.00

USD $1 = IDR 16,271.49

Explaining activities on Table 2, C is construction, M is maintenance, R is rehabilitation, RC is Reconstruction, and E is end of service life. When compared between the flexible pavement with preservation period which expense $4,718,152 and without preservation period (repairing to newly pavement) with expense $5,626,004 with 50th years of service life, the difference between both of scenario will have 15% cost margin. The same pattern also occurs on, with 50th years of service life, rigid pavement with preservation which expense $3,677,909 and without preservation which expense $4,418,663, both of scenario will have 17% cost margin. However, the expenditure of rigid pavement will cost more less than flexible pavement, since there are rehabilitation and reconstruction that occur in the flexible pavement utilization.

The preservation strategy of pavement will have different approach. Reconstruction of the rigid pavement will only have once in 50 years of service life. However, to reach the 50 years of service life, the flexible pavement will have twice of major rehabilitation and once of reconstruction.

Based on the NPV, the agency cost for flexible and rigid pavement will have $2,098,748 dan $1,930,845, respectively. Based on the analysis that has been through, the flexible pavement will have higher expense than the rigid pavement. Therefore, the long-term investment should be rigid pavement in term of economically view.

4.2.2. User cost

The user cost scenario during the initial construction, when there is no vehicle traffic. During M&R, partial lane closures are implemented, allowing for vehicle traffic, and the work zone is considered during this period. 4.8% from Indonesia Pavement Manual Design 2024 will be utilized for traffic growth in this study. VOC are calculated based on the IRI value.

Table 3. VOC breakdown

Years	VOC ($)	
	Rigid	Flexible
50th	9.329.151,00	7.229.823,00

USD $1 = IDR 16,271.49

Based on Table 3, the VOC over the service life indicates that flexible pavement has lower costs than rigid pavement, specifically in terms of fuel consumption, tire wear, and repair & maintenance costs. The calculation of these parameters is based on the IRI value, thus the IRI value significantly influences the VOC. The VOC of flexible pavement is decreasing because of the reconstruction occurs in the 40th year, which reduces the IRI value of the flexible pavement, bringing it closer to the condition of a new pavement. The VOC of flexible pavement is always higher than that of rigid pavement before the reconstruction in the 40th year. Based on the analysis result, when the reconstruction occur in the pavement, there is decreasing IRI value, thus it will be impacted by decreasing the value of VOC.

The crash cost parameters calculated are the types and number of accidents, work zone crash rate, work zone exposure, and crash cost rate in the analysis year. The types and numbers of accident fatalities, injuries, and property damage are 1, 4, and 8, respectively. The data was obtained from accident data in the city of Bogor [23]. The calculation of the work zone crash rate follows the guidelines for determining work zone user cost [17]. The parameters used to calculate work zone exposure include work zone duration, annual average daily traffic in the analysis year, and the length of the rehabilitated road. The result of work zone exposure is stated in million vehicle miles traveled. The crash cost rate for fatalities, injuries, and property damage only in 2025 is $81.500, $19.600, and $9.800, respectively. The data obtained by calculation with an assumed inflation rate of 11% from the crash cost rate of Indonesia [22]. The costs in the guide need to be projected to the year of analysis. Crash cost is shown in Table 4. Due to the limited data on traffic accidents caused by road pavement rehabilitation work, the data used in this study are the average traffic accident data for Bogor city in 2020 [23]. When calculating crash costs, several factors influence them, including the type and number of accidents, the duration of the work zone, and the average daily traffic volume. The delay time is due to the presence of a work zone per day. For example, if the rehabilitation work lasts for nine hours, the delay time calculated is for nine working hours. Unit value involves personal travel, passenger car, business travel, and truck. Cargo inventory is calculated for single-unit trucks and combination trucks. It is necessary to estimate the percent of empty trucks in the cargo inventory. The percent of empty value is obtained from the work zone road user cost [17]. Delay cost can be seen at Table 4.

Table 4. Crash and delay cost

Type of pavement	Crash cost ($)	Delay cost per day ($)
Rigid	33.200	3.087
Flexible	93.300	15.919

Delay cost analysis is conducted when there is rehabilitation or reconstruction work. The rigid pavement work zone is carried out in the 25th year with a work zone duration of 60 days. Meanwhile, in the flexible pavement, there are two major activities: rehabilitation work in the 20th year and reconstruction work in the 40th year, respectively. The delay cost analysis, in Table 4, is closely related to the number of vehicles. Traffic volume increases every year. On the other hand, flexible pavements also have more major activities including rehabilitation and reconstruction. Thus, the delay cost of flexible pavement is higher than that of rigid pavement. Road users will incur higher costs. Per day on rigid pavement, road users will incur a cost of at least $3,087, whereas on flexible pavement, they will have a minimum cost of $15.919. There is a significant margin of $12.832 per day, which will result in road users suffering a loss. Based on the analysis results, it is recommended the usage of rigid pavement from the perspective of delay cost.

4.3. Discussion

LCCA analysis is important as an economic consideration in decision-making, especially in determining the type of road pavement. The considerations have been made that include not only the initial construction phase costs but also the estimation of M&R costs and user costs. The end of service life for the pavement is planned for 40 years. After forecasting the IRI to develop the M&R schedule (Fig.1), the result show that the service life of the pavement can be extended to 50 years. Consequently, the flexible pavement must undergo reconstruction, thus the 1 and 2 major activities are carried out on rigid and flexible pavements, respectively. The comparison of the two types of pavements is shown in Fig. 2 and 3.

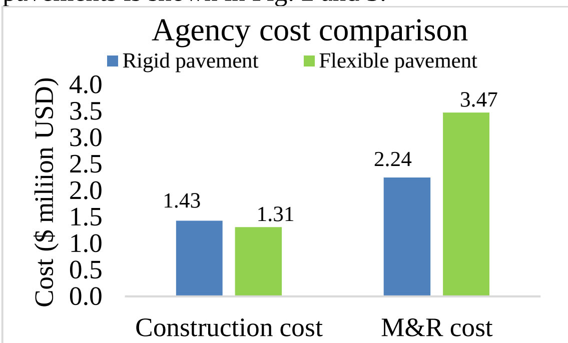

Fig 2. Agency cost comparison

Based on Fig. 2, the initial construction cost of rigid pavement is higher than that of flexible pavement. However, the M&R cost of rigid pavement is lower. The M&R schedule affects the cost. The total agency cost for rigid and flexible pavements is $3.677.909 and $4.718.152, respectively. Rigid pavement is more expensive in construction costs, but with reconstruction, flexible pavement becomes more expensive. The reconstruction of flexible pavement involves replacing the surface, base, and subbase materials along the road. Rigid pavement is more suitable for long-term pavement. Although the initial construction cost is higher than flexible pavement, rigid pavement has durability, a long service life, and requires little rehabilitation, thereby reducing agency costs [24]. VOC rigid pavement is more expensive. The fundamental to determining VOC is the IRI value, and rigid pavements have a higher IRI value. A high IRI value can cause tires to wear out quickly. Additionally, if the IRI increases, it indicates that the road surface is becoming more uneven, which can result in increased fuel consumption and vehicle maintenance [25].

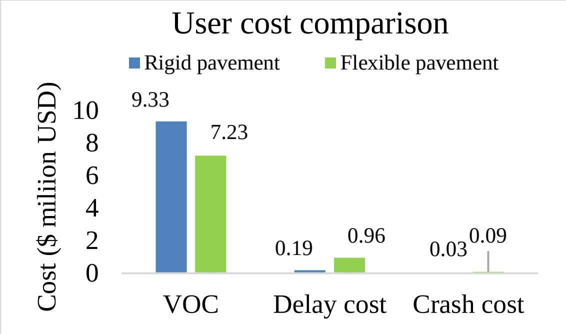

Fig 3. User cost comparison

From the aspect of crash cost, although the accident data includes traffic accidents from various causes and not specifically due to road rehabilitation work, the research results show that crash costs can occur during the work zone. The crash cost for flexible pavement is more expensive because two activities occur: rehabilitation and reconstruction, which increase the risk of accidents. Work zone duration, work zone length, and high traffic volume could potentially led to accidents [26-27]. Shorter work zones tend to have higher crash rates, indicating that crash rates increase more rapidly in shorter work zones [26]. Additionally, long work zones are associated with increased traffic conflicts and safety problems. Moreover, the type and number of accidents can also increase crash costs.

Table 5. Recapitulation of agency dan user cost

	Rigid	%	Flexible	%
Agency cost				
Construction	1.433.300,00	0,39	1.310.700,00	0,27
M&R	2.244.609,00	0,67	3.471.452,00	0,73
Total	3.677.909,00	-	4.782.152,00	-
User cost				
VOC	9.329.151,00	0,98	7.229.823,00	0,87
Delay	185.160,00	0,02	955.140,00	0,12
Crash	33.200,00	0,00	93.300,00	0,01
Total	9.547.511,00	-	8.278.263,00	-

The recap of agent in Table 5 shows that flexible pavement is more expensive for long-term pavements with a service life of 40-50 years. Flexible pavement more frequently major activities major activities such as rehabilitation. Even to achieve the planned long-term lifespan, reconstruction is necessary. The long duration of the work zone and the increasing frequency of rehabilitation can also increase delay costs. For example, flexible pavement is scheduled for two major activities: rehabilitation and reconstruction. Delay cost shows a quite significant cost difference. Economic considerations including the M&R and user cost need to be understood by the stakeholder thus they could make the right decisions. Based on agency costs, rigid pavement is more economical, but from the aspect of user cost, flexible pavement is more economical compared to rigid pavement, especially in terms of VOC.

5. CONCLUSION

This study focuses on preservation strategies based on IRI predictions and LCCA as considerations in decision-making by stakeholders, particularly the public works agency of Bogor City, specifically for road pavement. IRI prediction is used to determine the functional condition of the road and to schedule M&R. LCCA relates to the costs that need to be incurred by the agency and road users. Agency cost includes construction cost and M&R cost, while user cost includes VOC, delay cost, and crash cost. Both are important to know because agency cost is the perspective of the stakeholder or government, and user cost is the perspective of the road users. Based on the IRI prediction results with a planned 50 years of service life, the rigid pavement agency cost is more efficient from an economic perspective than flexible pavement. The user cost has a contradiction to agency cost; it can be seen that flexible pavement has more or less risk than rigid pavement from an economic viewpoint. Based on analysis results, the preservation strategy has fundamental role in order to reach economic efficiency, which can be seen from both of pavement can reach service lifetime until 50 years. Moreover, the analysis shows that the pavement with preservation strategies has less expense than without preservation strategic. Therefore, it is suggested to utilize the rigid pavement compared to the flexible pavement in accordance with the LCCA analysis in this study. The analysis shows rigid pavement is more suitable and efficient for long-term pavement for agency cost, however, it has more expense in the user cost. The results of this study can provide insights to the relevant stakeholders in decision-making regarding the decision of road pavement.

6. ACKNOWLEDGMENTS

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