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Road Maintenance Management Based on Geographic Information System (GIS)

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***Abstract*—This research implements GIS in transportation, specifically road maintenance. The system is built by utilizing 2D/3D models from aerial photographs using UAV as a base map. Attribute data such as the type and dimensions of road damage can be obtained by interpreting high-resolution 2D/3D models, which display each road damage, making it easier to measure the dimensions of road damage. The assessment of road conditions is done using the PCI method, which indicates that 51% of the roads fall under the category of people with low incomes to severely damaged category. These roads are prioritized on a map based on their area and cost of maintenance. The projection calculation of the amount of damage is analyzed with one do-nothing scenario, where the roads have not been maintained for ten years. The progression of the damage is observed each year, and the reactive maintenance cost is calculated from 2023 to 2032. The cost and duration are analyzed using three do-something scenarios: optimistic, moderate, and pessimistic. The research results show that the moderate scenario has the lowest cost among the other scenarios and is the most effective scenario, as it produces road conditions with an International Roughness Index (IRI) value of less than 6. This research can assist the government in making informed decisions regarding road maintenance.**

***Keywords*— Road maintenance management; geographic information system; maintenance cost.**

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I. Introduction

In the final quarter of January 2023, the central government allocated a budget of IDR 32 trillion to improve the percentage of reliable service conditions throughout Indonesia to enhance connectivity [1]. On average, countries worldwide spend only 20–50 percent of what they should spend on maintaining their road network [2]. A reliable road is a road segment with good and fair conditions due to its well-managed and maintained quality. Road inspections and maintenance must be carried out regularly to achieve road reliability in Indonesia because all road pavements will erode with time, no matter how adequately constructed. Hence, the timeliness of repair is critical because if road maintenance operations are carried out on time and by employing the most appropriate maintenance methods, not only is their destruction delayed, but also the operating costs of vehicles driving on them are reduced due to increased road surface quality [3]–[5]. Road maintenance is a road management activity in the form of prevention, maintenance, and repairs needed to maintain road conditions to reduce the degree of road deterioration so that they continue to keep up with the service level, bearing capacity, and traffic can operate without any interruption [6]–[9]. The availability of accurate data can support good road maintenance, and one of the essential data needed is the road pavement condition. Road pavement conditions should be accurately evaluated to identify the severity of pavement damages and types of pavement distress [10]. Pavement condition surveys are still manually done in the field, with surveyors filling out forms, gathering data, and compensating for time, weather, as well as accuracy, this traditional method is also subjective, expensive and leads to delays [11]–[13]. The road pavement condition is assessed using the Pavement Condition Index (PCI) method because PCI is one of the most effective approaches to evaluating pavement performance [14]. The PCI is widely acceptable to describe the overall pavement surface condition of a roadway section [15].

In 2019, the Ministry of Public Works began operating the Provincial/District Road Management System (PKRMS) application as a tool to support road planning, programming, and budgeting. This system utilizes QGIS as a geographic information system with roads depicted as vectors. GIS has great potential in the management of transport infrastructure. GIS is great for predicting future conditions of roads, allowing highway engineers to make cost-effective plans due to preventive road maintenance. Referenced to a geographic location [16]–[19]. Other research says that GIS software can visually display the results, enabling decision-makers to understand the area better and ensure efficient maintenance management [20]–[22].

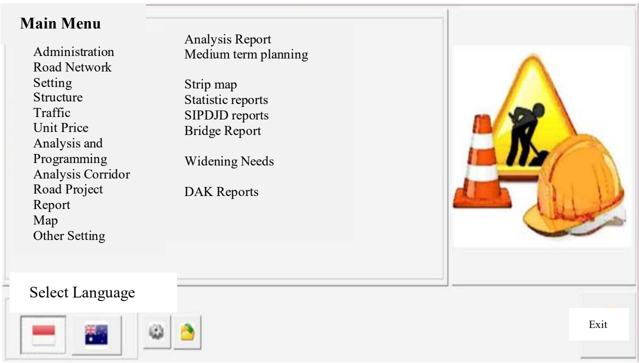

Fig. 1 Main Interface of PKRMS

Fig. 1 illustrates the main interface of PKRMS. One drawback of this system is that road condition data needs to be manually inputted based on the IKP road condition survey form. Additionally, the documentation that can be displayed only includes photos of the damage, making it difficult to determine their precise field locations. This research develops a Geographic Information System (GIS)-based maintenance management system that can generate IKP survey forms, detailed road condition information (raster maps), repair plans, cost estimates, and repair durations. This system is expected to facilitate the decision-making process related to road maintenance.

II. Materials and Methods

A. Materials

The data requirements are categorized based on their sources, which are primary and secondary, and based on the types of GIS data, namely geospatial data and textual data. The primary data used includes damage validation, LHR (Loadings of Heavy Vehicle), and CBR (California Bearing Ratio) obtained through location surveys. The primary secondary data are the maps and IKP survey result forms from April 2022. Other secondary data used include the 2023-unit price list for West Java, the cost of public road physical activities per kilometer for 2023, Provincial Road maintenance scenarios, and the Subang District Spatial Planning—Data Geospatial and Data Attributes from previous research.

The primary data required is geospatial mapping, obtained from aerial photographs using Unmanned Aerial Vehicles (UAVs) [Fig. 2, Fig. 3]. The aerial photos captured have high resolution, enabling easy assessment of road conditions without the need to visit the field. Utilizing UAVs for pavement condition assessment using the PCI method yields more data and information than the SDI method [23]. Geospatial mapping is the primary data obtained from aerial photographs taken using UAVs. The high-resolution aerial photos enable accurate assessment of road conditions that align with on-site conditions.

Fig. 2 Example of UAV Aerial Photo Results (2D)

Fig. 3 3D Model of Road Condition

Other data includes subgrade CBR data [Fig. 6], traffic data (Fig. 7), a regression model for the relationship between IRI and IKP values [24], and data for financing scenario calculations.

$$IRI = 12{,}905 - 0{,}119xPCI \quad (1)$$

In addition to spatial data, this research utilizes attribute data in documents containing IKP survey forms specific to the research locations. These IKP forms are used to calculate the area of each damage so that they can be classified for appropriate handling. The IKP forms used are the survey result forms based on aerial photos (UAV). The IKP forms contain categories of damage, severity levels, and the respective areas of each damage. This data calculates the extent of damage, which will then inform the subsequent handling procedures.

1) Validation of Road Damage Data: This survey was conducted to examine the changes in damages after a period of 1 year, from April 2022 to March 2023. The studied changes may include the enlargement in length and/or width of damage and the repairs carried out. Random samples were taken from each segment, representing the middle and near-shoulder lanes. The survey team consisted of 3 groups, each comprising 3-4 members. Each group covered an area of 500 meters. The dimensions of each damage sample were measured, recorded, and compared with the dimensions of the damages in 2022. A total of 73 samples were reviewed out of the total of 559 damages. Based on the survey, it was found that some damage had increased in size, while others had decreased compared to the previous year. For example, Figure 4 shows significant changes in lane damage and the same spot, with the appearance of holes accompanied by standing water. Therefore, the validation survey aims to document which damages have undergone shape changes, represented by several samples. The summary of the results is presented in Figure 5.

Fig. 4 Validation Survey of Road Damage

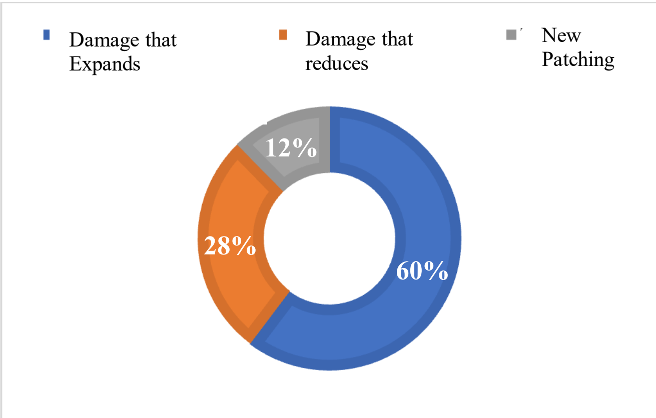

Fig. 5 Results of Validation of Road Damage Data Sample

The enlargement of each damage sample varied in percentage and occurred in several types of damage, such as Crocodile Cracks, Block Cracks, Depressions, Longitudinal/Transverse Cracks, Patching, Potholes, Slippage Cracks, and Raveling. On the other hand, the repaired damage with patching showed a similarity, as the size before the repair was relatively small, typically <10m2. The most commonly addressed damage was potholes.

The size of damaged samples can be reduced due to differences in surveyors' perception during measurement, which can be attributed to unclear boundaries of the damage. This often happens with damage with a relatively small decrease (<10%). On the other hand, damages with a significant decrease (>90%) can be caused by previous repairs that have been done, but further damage occurs at the same location. As for patched damages, the reduction in size can be attributed to the peeling of the patch.

2) California Bearing Ratio: DCP testing was conducted to determine the subgrade CBR (California Bearing Ratio) of the flexible pavement at the location. However, permission for core drilling was not obtained, so the assessment was conducted on the non-stabilized road shoulders. Eight testing points were distributed to represent the research object, with a distance of 200 meters between each point [25].

Fig. 6 Collection of CBR Data (Example at point 4)

TABLE I
DCP TEST RESULTS

No	Point	Coordinate (m)	CBR (%)
1	DCP 1-2	x= 791459 y=9250564	1.7326
2	DCP 3-4	x= 791572 y=9250745	1.9799
3	DCP 5-6	x= 791439 y=9250847	1.3300
4	DCP 7-8	x= 791377 y=9250932	3.3672
5	DCP 9-10	x= 791561 y=9250999	2.7592
6	DCP 11-12	x= 791722 y=9251072	1.1453
7	DCP 13-14	x= 791883 y=9251203	1.6671
8	DCP 15	x= 792007 y=9251270	1.4718

Since the CBR values were within the range of 1%-3.5% [26], soil improvement was carried out during the road construction at the study location. The thickness of the soil improvement was determined based on the values of each segment. As a result of the soil improvement, the CBR value increased to 6%

3) Traffic Volume: The survey was conducted for one week, starting from May 13, 2023, to May 19, 2023. Ideally, the survey should have been carried out for a full year to obtain an accurate representation. However, due to limited time and the availability of the last LHRT (Loadings of Heavy Vehicle by Axle Configuration) data from the relevant authority only for the year 2013, a one-week traffic survey was conducted to provide an estimate for the LHR in 2023. The survey methodology followed the Technical Guideline No.19 of 2004B on Manual Traffic Counting Survey with adjustments made through CCTV observations [27].

Fig. 7 Collection of Traffic Volume Data

The results obtained from the survey were then calculated to determine the average traffic volume, and projections were made for the next ten years (Table 2).

TABLE II
PROJECTION OF AVERAGE TRAFFIC FOR TEN YEARS

No	Year	Types of Vehicles						
		5A	5B	6A	6B	7A	7B	7C
1	2023	248	247	554	568	101	1	1
2	2024	257	256	574	588	105	1	1
3	2025	266	265	594	609	108	1	1
4	2026	276	274	615	631	112	1	1
5	2027	285	284	637	654	116	1	1
6	2028	296	294	660	677	120	1	1
7	2029	306	305	684	701	125	1	1
8	2030	317	316	708	726	129	1	1
9	2031	328	327	733	752	134	1	1
10	2032	340	339	760	779	138	1	1

B. Methods

This system was developed after the completion of attribute data processing and was built using ArcGIS 10.8 and a website.

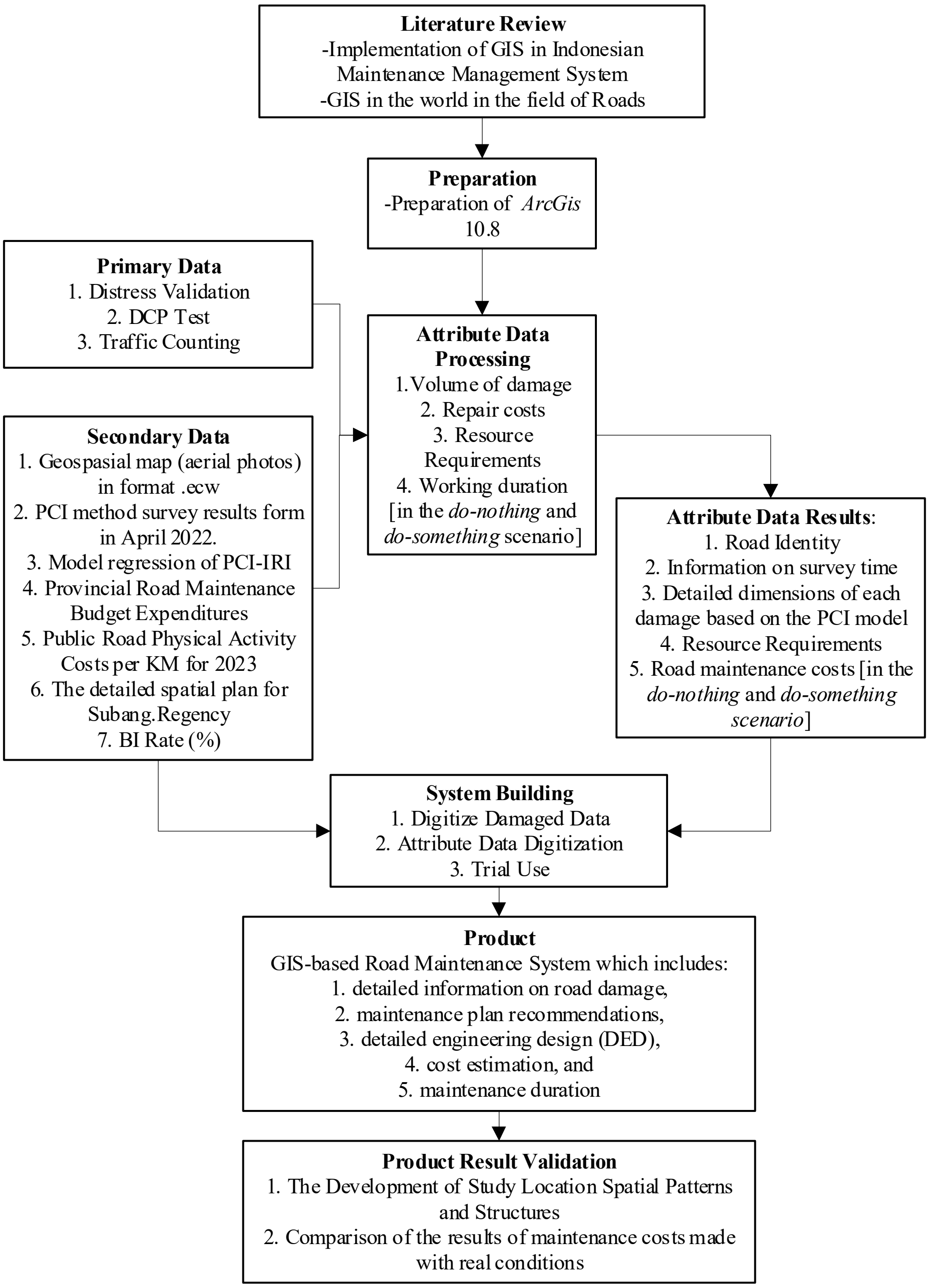

Fig. 8 Research Methodology

The road maintenance scenarios in this research consist of 3 handling scenarios, namely:

- Do-something scenario 1 (optimistic): a scenario aimed at maintaining an ideal reliable road condition with an International Roughness Index (IRI) value of less than 4 [23].
- Do-something scenario 2 (moderate): a scenario aimed at maintaining reliable road conditions within the range

of the highest and lowest average values between 4 and 8, with an IRI value of less than 6.

- Do-something scenario 3 (pessimistic): a scenario that maintains the minimal reliable road condition with an IRI value of less than 8.

The development stages of the system are divided into three phases: 1. Spatial Data Digitization, 2. Attribute Data Digitization, and 3. Usage Testing.

1) Spatial Data Digitization: contains information about road identity, survey time, predicted IKP values, maintenance costs for do-something scenarios 1, 2, 3, resource requirements, and maintenance duration for do-something scenarios 1, 2, 3.

2) Attribute Data Digitization: contains data such as the severity category of the damage, the name of the damage, sample unit (US) location, damage area, and photos of the damage.

3) Usage Testing: The final product, in the form of a system, is visible and capable of displaying detailed information about the damage, survey time, volume of damage, repair costs for both the "do-nothing" and "do-something" conditions, providing options for optimal repair implementation and repair duration. The expected system interface allows users to view handling prioritization for all segments.

III. Result and Discussion

A. Result

1) Area of Damage: The area of damage is obtained from the identification of damages in the model, categorized according to the same type and severity level within each segment. Crocodile Cracks are the most frequently encountered damage along the study location. The extent of the damage and its corresponding handling approach for STA 0+000 - 0+100 are shown in Table 3. An overview of the repair/maintenance based on the type of damage in each segment can be seen in Fig. 9.

TABLE III

AREA OF DAMAGE AND REPAIR TYPE FOR STA 0+000 – 0+100

STA		Damage Type	Damage Level	Wide	Repair	Area (m2)
		1	R	6.436581	Slurry Seal Type 1	8.103781
		1	S	1.6672	Slurry Seal Type 1	
		3	S	5.0076	Slurry Seal Type 1	5.0076
		6	S	5.061324	Patching	5.061324
		8	R	5.482	Slurry Seal Type 1	5.482
0+000	0+100	10	R	8.606	Slurry Seal Type 1	0.04303
		11	R	35.02842	-	
		11	S	5.967935	-	110.5569
		11	T	69.5605	-	
		13	R	0.912041	Patching	0.912041
		19	T	3.911	Slurry Seal Type 2	3.911

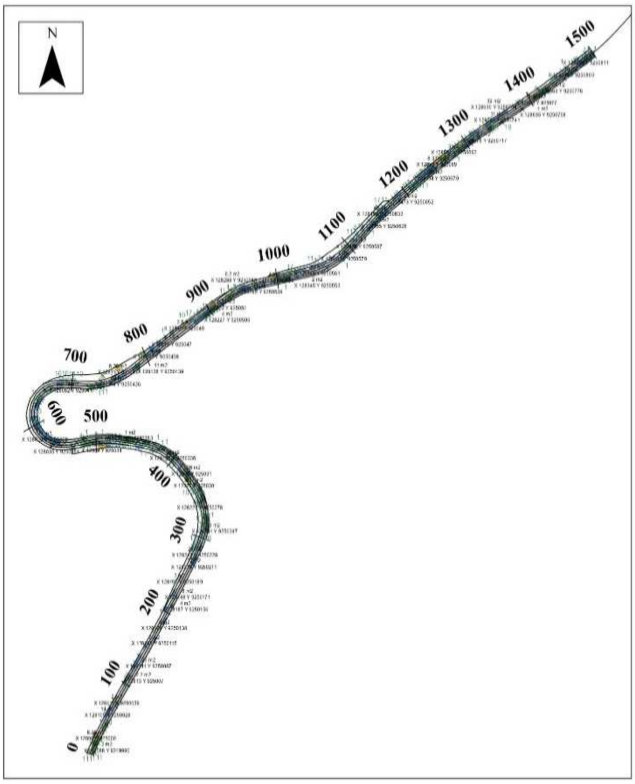

Fig. 9 Site Plan

2) Road Maintenance Scenario: Based on the analysis calculations using the 'Cost of Public Road Physical Activities per KM for the Year 2023' data by Bina Marga as the calculation data for the do-nothing scenario, reactive handling of road damages is only performed in 2032. However, the calculation analysis for the do-something scenarios yields different results.

- Do-Something 1. To achieve a good road condition with a target IRI<4, this scenario requires an overlay to be performed every 3 years.
- Do-Something 2. To achieve a fair road condition (moderate) with an IRI value of less than 6 within a 10-year period, the handling approach involves periodic maintenance (overlay) in the first year and routine maintenance every subsequent year.
- Do-Something 3. Similar to do-something 2, the handling approach involves periodic maintenance in the second year and mandatory routine maintenance every subsequent year. This scenario aims to achieve an IRI value of less than 8.

For the details of financing, please refer to the following table IV. It is important to note that the cost calculations above are based on material and labor prices sourced from the 2023 standard material and labor rates applicable at the study location. The calculations were conducted following the Unit Price Analysis 2023 procedure. Hence, it can be affirmed that this calculation is indeed correct and precise. However, it should be noted that the types of maintenance activities in this study are based on ideal conditions. Therefore, there may be differences compared to the maximum maintenance work prices issued by the Provincial Public Works Department (as a result of the focus group discussion on September 14, 2023).

TABLE IV
COMPARISON OF COSTS FOR FOUR SCENARIOS (FUTURE VALUE)

Year	Do Nothing	Do Something 1	Do Something 2	Do Something 3
2023	IDR-	IDR 6,128,398,765	IDR 6,586,887474	IDR 284.795.160
2024	IDR-	IDR 456,799,688	IDR 297,622808	IDR 7.068.710.712
2025	IDR-	IDR-	IDR 311,028236	IDR 311.028.236
2026	IDR-	IDR 5,542,323,245	IDR 325,037466	IDR 325.037.466
2027	IDR-	IDR 521,346,686	IDR 339,677695	IDR 339.677.695
2028	IDR-	IDR-	IDR 354,977345	IDR 354.977.345
2029	IDR-	IDR 6,325,468,116	IDR 370,966116	IDR 370.966.116
2030	IDR-	IDR 595,014,346	IDR 387,675048	IDR 387.675.048
2031	IDR-	IDR -	IDR 405,136578	IDR 405.136.578
2032	IDR 23,078,956,225	IDR 7,219,273,419	IDR 423,384605	IDR 423.384.605
Total	IDR 23,078,956,225	IDR 26,788,624,266	IDR 9,802,393.370	IDR 10.271.388.959

The maintenance cost in the do-something 2 scenario is the cheapest compared to other scenarios. This is because the do-something 2 scenario involves routine maintenance every year, starting with an overlay implementation in the first year. The routine maintenance cost for a road that has undergone overlay is lower compared to a road that has not been overlaid before. This is related to the Time Value of Money (TVM), which states that money has a higher value in the present year than the same amount in the future [28]. Therefore, road engineering experts argue that the sooner a road is repaired, the future losses can be minimized.

Compared to the maximum physical cost of routine maintenance activities in West Java Province, routine maintenance in the do-something 2 and do-something 3 scenarios only consume 8.18% of the maximum cost. As for periodic maintenance in the three do-something scenarios, it only consumes 8.22% - 11.48% of the maximum cost. The difference in handling implementation among the three scenarios also leads to variations in the duration of work and the resources used.

TABLE V
COMPARISON OF DURATION AND HUMAN RESOURCES

Scenario	Duration (Days)	Human Resources (People)
Do Something 1	354	654
Do Something 2	441	1092
Do Something 3	435	1081

TABLE VI
COMPARISON OF CONDITIONS BASED ON SCENARIOS

Scenario	IRI	IKP	Condition
Do Something 1	3.6	78	Good
Do Something 2	3.9	76	Good
Do Something 3	4.2	73	Good

Based on the table above, the average IRI value over 10 years in the do-something 2 scenario is less than 4. This means that the road condition is very good with relatively optimal cost expenditure compared to other scenarios.

3) System Interface and Priority Map

- System Interface

An example of attribute digitization results for STA 0+000 - STA 0+100 is shown in Fig 10. To apply data display similar to Fig 10, enable HTML Pop-up mode.

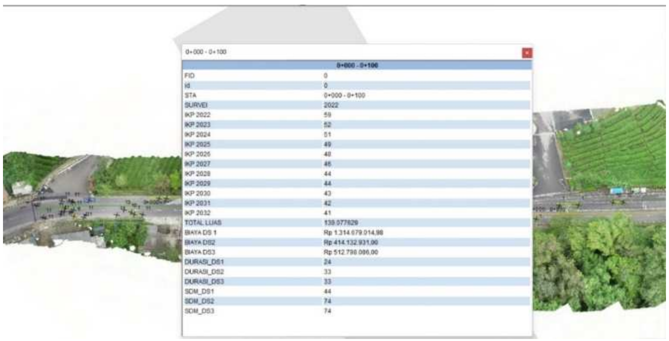

Fig. 10 Example of Attribute Digitization Results for STA 0+000 - STA 0+100

An example of digitization damage results is shown in Fig. 11. Fig 11 displays the location of a Patching damage point with a damage code of 11 in Sample Unit 1, categorized as Low severity, with an area of 5.11 m2.

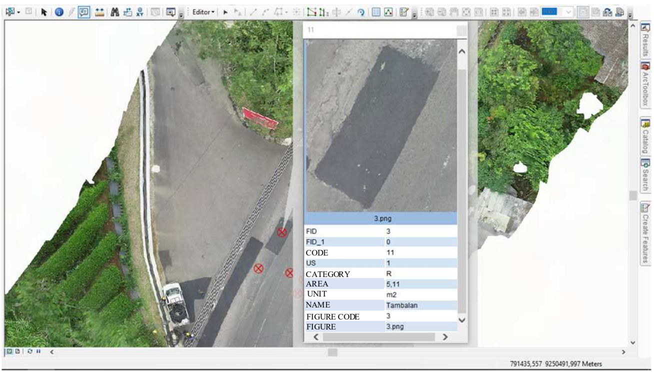

Fig. 11 Example of Digitization Damage Results

- Priority Map

Based on the processing and input of available data, priority handling can also be displayed in the system using several categories, namely based on the area of damage (Fig. 12) and the maintenance costs of the 3 scenarios (Fig. 14, Fig. 15 and Fig. 16). In the system, each 100-meter road segment will be shaded darker if the extent of damage is higher or redder if the maintenance cost is higher.

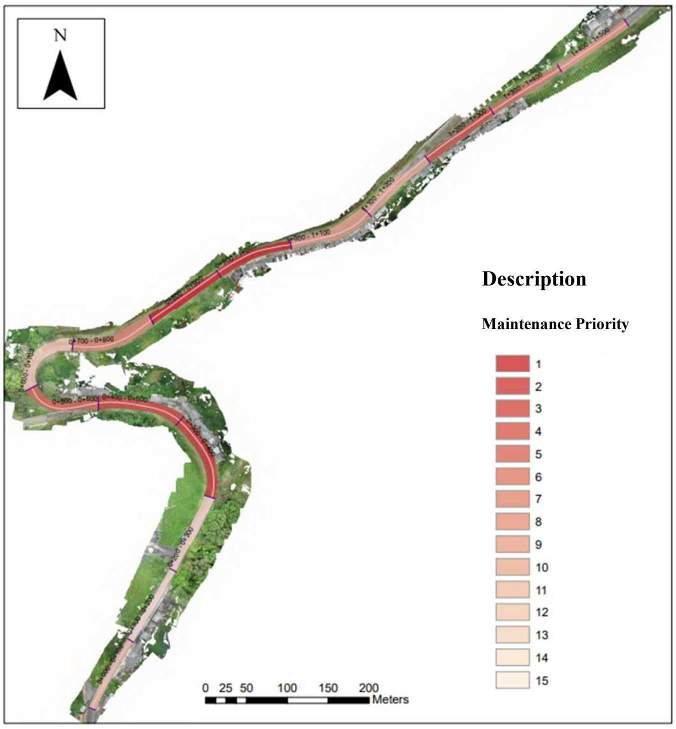

Fig. 12 Maintenance Priority Based on Area Damage

Fig. 12 shows the priority maintenance map based on the extent of damage in each segment. The segment with the highest extent of damage (STA 0+800 - 0+900) is marked with a dark red color and receives the highest priority ranking for maintenance.

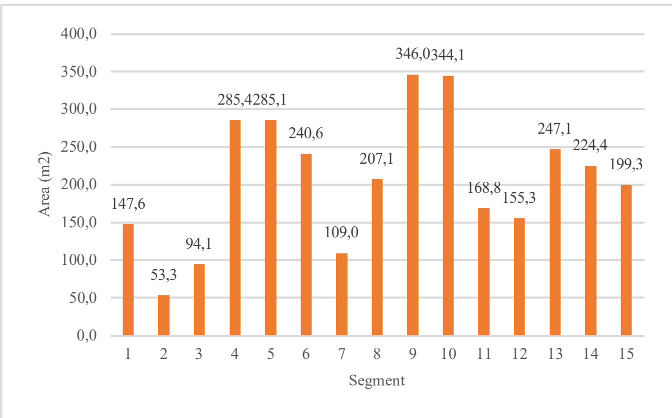

Fig. 13 Area of Damage for All Segments

Fig. 14, Fig. 15, and Fig. 16 are the priority maintenance maps based on the maintenance cost requirements of do-something 1 to do-something 3. Segments with the lowest cost requirements are marked dark green and receive the lowest priority ranking for maintenance. In the do-something 1 priority sequence, STA 1+000 - 1+100 occupies the top position because it requires the highest cost, which is IDR 2,241,172,610.42, while STA 0+700 - 0+800 occupies the bottom position because it requires the lowest cost, which is IDR 1,314,679,015.98.

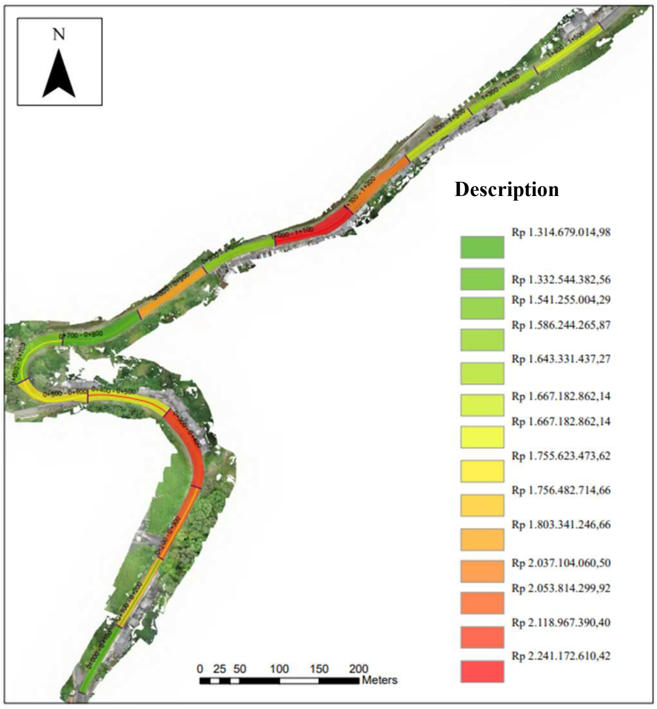

Fig. 14 Maintenance Priority Based on Do Something 1

In the do-something 2 priority sequence, STA 1+200 - 1+300 occupies the top position due to requiring the highest cost, which is IDR 874,348,464.00, while STA 0+000 - 0+100 occupies the bottom position due to requiring the lowest cost, which is IDR 396,388,605.00.

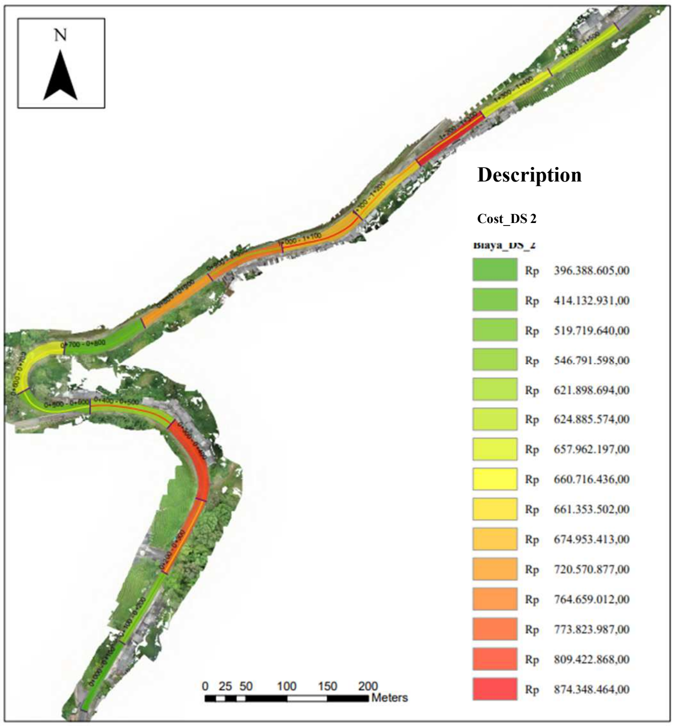

Fig. 15 Maintenance Priority Based on Do Something 2

In the do-something 3 priority sequence, STA 1+200 - 1+300 occupies the top position due to requiring the highest cost, which is IDR 940,616,228.00, while STA 0+000 - 0+100 occupies the bottom position due to requiring the lowest cost, which is IDR 492,691,721.00.

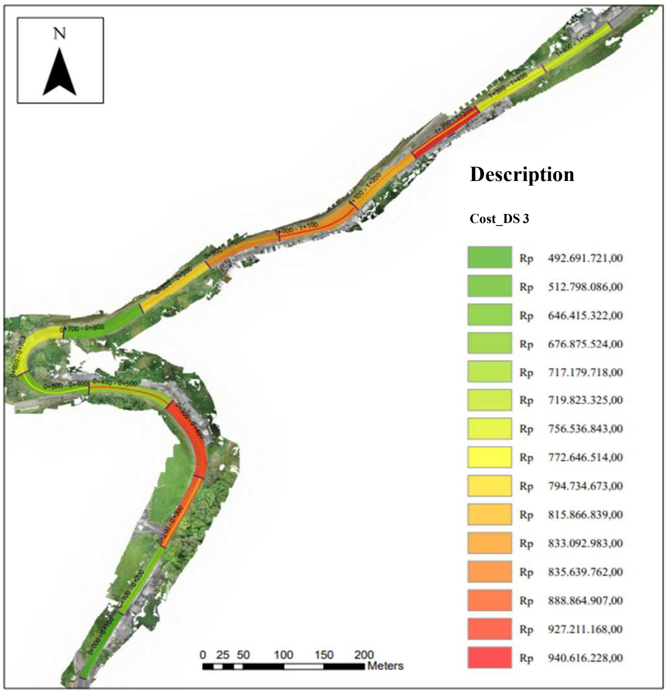

Fig. 16 Maintenance Priority Based on Do Something 3

Based on the mapping of the analysis results, the segment from STA 0+800 to 0+900 needs to be addressed first using the do-something 2 financing scenarios. The handling of this segment is based on the largest extent of damage, which will worsen over time and result in increased costs if not addressed promptly. The percentage of damage area does not influence the maintenance priority based on the "do something" scenario but is solely determined by the damage category and the width of the road in the respective segment. As a result, this leads to a distinct prioritization sequence, differing from the maintenance priority based on the extent of damage.

B. Discussion

When compared to the expenses incurred by the government, the government is estimated to require a budget of 1.66 billion to repair or maintain 1 km of provincial road per year, or a total of 16.6 billion for 1 km of provincial road over 10 years [29]. However, using the do-something 2 scenarios, it is estimated to only require a budget of 9.8 billion for 1.5 km of the study location's road over 10 years. Therefore, the use of this scenario is expected to save over 6 billion in government expenditure for road maintenance.

To establish an effective road maintenance management system, the completeness and validity of input data need to be considered, as there may be slight differences between the data used and the actual field conditions. Essential data to be collected from the field include geospatial maps, pavement surface conditions, Average Annual Daily Traffic (AADT), California Bearing Ratio (CBR), and pavement layer thickness.

Furthermore, the approach taken by the Provincial Public Works Department for provincial roads is reactive, whereas, in this research, the approach is preventive. This is due to budget allocations that are only sufficient for repairing already damaged roads. Therefore, in the future, it is hoped that there will be a design for preventive financing scenarios that can be more effective than this research so that budget allocations can be adequately met.

IV. Conclusions

This system can be a starting point for utilizing Digital Twin Technology concepts, particularly road maintenance [30]. Furthermore, this GIS-based Road Maintenance Management System is already capable of displaying preventive road maintenance costs, making it a valuable input for the Provincial/District Road Management System (PKRMS).

Acknowledgment

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