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Optimization of Construction Type and Cost Efficiency on Irrigation Inspection Roads: A Planning Study of DI Panca Jaya

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Abstract: The construction of inspection roads in irrigation areas is a vital supporting infrastructure in supporting the sustainability of the agricultural system, especially in the aspects of maintaining channel networks and access to crop distribution. This study aims to evaluate the most optimal type of inspection road construction from the perspective of cost efficiency and structural resilience, with a case study on the technical planning of the Panca Jaya Irrigation Area (DI) in Muara Kaman District, Kutai Kartanegara Regency. The method used is a descriptive-quantitative approach through comparative analysis of cost and service life of three road construction alternatives: (1) natural gravel, (2) water-bound macadam (WBM), and (3) WBM with bitumen coating. Data were obtained from technical planning documents, the results of topographic surveys, basic soil CBR tests, and building material market price surveys. Efficiency analysis was carried out using the formula of the ratio of cost per meter to the life of construction services (Rp/m/year). The calculation results show that WBM + bitumen pavement has the best annual cost efficiency, which is Rp 20,417/m/year with a plan life of 12 years. Meanwhile, natural gravel despite having a low initial cost, shows the worst efficiency because its lifespan is only 4 years (Rp 30,000/m/year). Based on the topographic conditions and bearing capacity of the soil at the study site, most of which have a CBR value of <10%, a type of construction with higher durability such as WBM+ bitumen is more recommended. In conclusion, the selection of the type of road construction inspection must consider long-term efficiency, especially in areas with fairly intensive agricultural vehicle traffic. The recommendations of the results of this study are expected to be a reference for planners and implementers of irrigation projects in determining economical, technical, and sustainable road specifications.

Keywords: Bitumen; Cost Efficiency; Irrigation Inspection Road; Road Construction; WBM

1. Introduction

The development of inspection road infrastructure in irrigation areas is one of the important elements in supporting the sustainability of the agricultural system, as it functions as an access route for the operation and maintenance of irrigation networks and the distribution of agricultural products (Bina Marga, 1970; Sugiyanto, 2019). Poorly designed inspection roads can cause damage to irrigation networks and reduce the efficiency of agricultural production (Putra et al., 2020). The Kutai Kartanegara Regency Government through the Public Works Office is committed to improving the accessibility and operational efficiency of irrigation areas through the inspection road construction program, as reflected in the DI Panca Jaya planning technical document (DPU Kukar, 2023). The determination of the right type of road construction must take into account topographic conditions, soil carrying capacity, traffic load, and long-term sustainability aspects

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(SNI 03-3430-1994; KP-04, 2006). Technical studies on the characteristics of subgrades and the use of pavement materials such as gravel, macadam, and bitumen layers are important so that road design not only meets technical standards but is also cost-efficient (ESCAP, 1981; Road Note 31, 1977).

Previous research has shown that the selection of suitable road pavement can reduce maintenance costs by up to 40% over the life of the road plan (Fajariyah & Wibowo, 2022), while the efficiency of project implementation is also highly determined by the accuracy of topographic data and other technical parameters (Nejatyan et al., 2023). In the context of area-based development, inspection roads also play a role as infrastructure to support village connectivity and local economic development (Bappenas, 2020). Therefore, the inspection road planning study in DI Panca Jaya is focused on optimizing construction types and cost efficiency based on geometric, technical, and rational analysis of the life of construction services (Mardiasmo, 2009; Chan & Pribadi, 2022; Saksena, 2024). With this approach, it is hoped that the resulting recommendations can be used as a basis for physical implementation that is efficient, durable, and in accordance with the characteristics of the local area

2. Materials and Methods

2.1 Research Location

This research was carried out in the Panca Jaya Irrigation Area (DI) located in Panca Jaya Village, Muara Kaman District, Kutai Kartanegara Regency, East Kalimantan Province. The site is within the scope of the administrative area with an area of ±3,410 km² and is geographically surrounded by the Mahakam River and its tributaries, which form the backbone of the local irrigation system. This area is dominated by agricultural land and has a population density of 95 people/km² in the village where the project is located, making it a strategic area for the development of irrigation supporting infrastructure. The topography of the area tends to be flat to undulating with an average elevation of 16 meters above sea level, as well as wet tropical climate conditions that have the potential to affect the durability of road structures (BPS Kukar, 2023).

Figure 1. Research Location

2.2. Research Design

The type of research used is descriptive-quantitative with a case study approach to the technical planning of inspection roads. This design was chosen to describe and evaluate the technical characteristics and cost efficiency of the planned alternative construction type, based on factual data obtained from documents and measurements in the field. This study also utilizes a comparative approach to analyze the ratio of cost to service life (life cycle cost) of each type of road construction (gravel, makadam WBM, and WBM + bitumen).

2.3. Data Collection Methods

The data used consists of primary and secondary data. Primary data was obtained through direct measurements in the field using Total Station and GPS to obtain topographic contours and elevation coordinate points. In addition, a CBR (California Bearing Ratio) survey was carried out on the subgrade soil layer to determine the carrying capacity of the soil along the road track. Secondary data were obtained from the final technical planning document (Final Report of the DI Panca Jaya Inspection Road), geometric design drawings, Cost Budget Plan (RAB), and technical standards from Bina Marga and KP-04 (2006). Market

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price surveys are also conducted to obtain actual information related to building materials, heavy equipment, and labor wages in the local area.

2.4. Research Instruments

The instruments used include measuring equipment (Total Station, waterpass, GPS), data processing software such as AutoCAD for road geometry mapping, as well as Microsoft Excel and engineering calculators to calculate work volume and cost efficiency. Technical reference standards include SNI 03-3430-1994 for road geometry, Irrigation Planning Standard KP-04 (2006), and Road Note 31 (1977) for flexible pavement layer analysis.

2.5. Methodology

The analysis was carried out by comparing three types of inspection road construction, namely:

- Natural Gravel Pavement (thickness 15 cm)
- Water Supply (WBM)
- WBM+ Bitumen Coating

Each type of construction is calculated for its cost efficiency using the formula:

$$\textbf{Cost Efficiency} = \textbf{Cost per meter}\ (\textbf{Rp/m}) \div \textbf{Service life}\ (\textbf{years}) \quad (1)$$

This ratio shows the annual cost incurred for each construction meter over the life of the road plan. Furthermore, the data is analyzed and visualized in the form of tables and bar graphs to facilitate the selection of the most efficient construction alternatives. The evaluation also considered the suitability of soil conditions (CBR value), elevation, and potential vehicle load traffic in the study area. The results of this method are used as a basis for compiling technical recommendations for optimal and sustainable irrigation inspection road construction in DI Panca Jaya.

3. Results

Inspection road planning in the Panca Jaya Irrigation Area (DI) in Muara Kaman District, Kutai Kartanegara, was carried out to support the operational mobility of irrigation networks and agricultural production transportation. Based on the results of the topographic survey and existing conditions in the field, the type of inspection road planned is a class III-IV road based on the classification of Highways (KP-04 and RSNI T.02-2005 Standards), with a road body width of 5.5 meters and a pavement width of 3-3.5 meters. The planned speed is set at 40 km/h, and the maximum gradient is 7%.

The two alternative types of pavement studied in this report are:

- Natural Gravel Pavement (for ordinary inspection roads)
- Water Bound Makadam Pavement (WBM) with a bitumen surface layer (for roads with higher vehicle loads)

Based on the results of the soil carrying capacity (CBR) and topographic elevation tests, the basis for subgrade classification with a minimum CBR value of 6%–20% was used. These results indicate that natural gravel pavement is still usable but less than optimal for heavy loads and humid areas, so an alternative to macadam with bitumen coating for long-term efficiency is considered.

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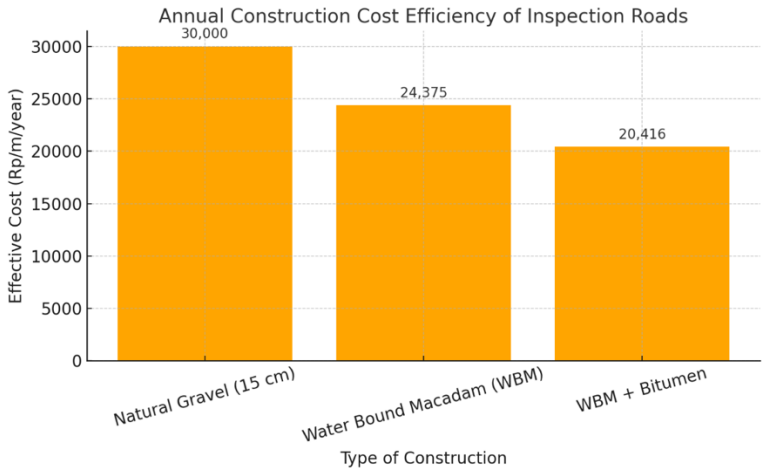

Figure 2. Inspection Road Construction Cost Chart Per Year

The cost efficiency graph of road construction inspection shows that the WBM + Bitumen type of pavement is the most economical choice in the long term, with an effective cost of Rp 20,417 per meter per year and a service life of 12 years. The type of makadam (WBM) is in a medium position with an efficiency of Rp 24,375/m/year and is 8 years old. Meanwhile, natural gravel pavement has the lowest initial cost, but it is also the least efficient annually (Rp 30,000/m/year) because it only lasts for 4 years. Thus, although it requires a larger initial investment, WBM + Bitumen pavement provides the best economic value in the horizon of the irrigation inspection road project in DI Panca Jaya.

4. Discussion

Inspection roads are vital supporting infrastructure in the irrigation system, serving to facilitate operational access and maintenance of channels and distribution of agricultural products (Bina Marga, 1970; Sugiyanto, 2019). Therefore, the design of road construction must consider the cost efficiency and durability of the structure to terrain conditions as well as the intensity of use. In the context of DI Panca Jaya, Muara Kaman District, inspection roads are not only used by irrigation officers, but also used by agricultural production vehicles with heavier loads, so a stronger and more durable construction design is needed (Putra et al., 2020; DPU Kukar, 2023).

The results of the evaluation showed that there was a significant difference between the annual cost efficiency of the three types of road pavement. Natural gravel pavement, although cheap at the beginning, only has a plan life of 4 years with a cost efficiency of Rp 30,000/m/year, making it less suitable for medium to heavy load paths. On the other hand, the makadam type (WBM) provides better performance with a service life of 8 years and a cost efficiency of Rp 24,375/m/year. The best type is shown by the construction of WBM with a layer of bitumen, which although it requires the highest initial cost (Rp 245,000/m), has a plan life of 12 years and the lowest cost efficiency of Rp 20,417/m/year.

This finding is in line with the study of ESCAP (1981) and Road Note 31 (1977) which stated that layered pavement structures (bituminous surfacing) are very suitable for application in wet tropical areas, because they are able to withstand weathering due to waterlogging and moderate to heavy traffic loads. In addition, WBM + bitumen pavement has been proven to be able to reduce the frequency of maintenance, which according to Fajariyah and Wibowo (2022) can reduce costs by up to 40% over the life of the project. This is relevant to the principle of value engineering in road construction projects (Mardiasmo, 2009), where the alternatives chosen are not only based on the initial cost, but also take into account the total cost throughout the road life cycle (life cycle cost).

The soil condition in locations that have a CBR value below 10% in some sections of the trase is also a strong reason to choose a stronger and more stable type of pavement. In accordance with the provisions of KP-04 (2006) and SNI 03-3430-1994, the selection of road structures must consider the carrying capacity of the soil (subgrade), road geometry, and traffic load classification. In this context, the selection of WBM + bitumen not only meets technical requirements but also shows economic efficiency, especially if the road doubles as a logistics and distribution route for agricultural products as driven by the region-based infrastructure development policy (Bappenas, 2020; Amir, 2024).

Taking into account all these parameters, it can be concluded that the selection of inspection road construction in DI Panca Jaya should not only consider the initial cost, but also take into account the annual

cost efficiency and long-term resistance to terrain conditions and traffic loads. Such a comprehensive approach is in line with the spirit of sustainable agricultural infrastructure development that is adaptive to local characteristics.

5. Conclusions

A technical planning study of inspection roads in the Panca Jaya Irrigation Area (DI), Muara Kaman District, shows that the selection of the right type of construction greatly determines the success of the road's function as an irrigation operational route as well as access to agricultural distribution. Based on the results of topographic measurements and soil bearing capacity (CBR) tests, it was found that most areas have soft soil characteristics that require a stable pavement structure that is resistant to traffic loads and wet tropical climatic conditions. The three alternative types of construction analyzed are natural gravel pavement, water-bonded macadam (WBM), and WBM with bitumen coating. From the results of the calculation of annual cost efficiency, the WBM + bitumen construction type shows the best performance with a cost of Rp 20,417 per meter per year and a planned life of 12 years. Despite the higher initial cost, this type of construction provides the best economic value in the long run and is suitable for high-use intensive road segments. Meanwhile, gravel pavement, although cheaper in terms of initial cost, has a shorter service life and requires more frequent maintenance, making it less efficient in the context of sustainable infrastructure development. Therefore, technically and economically, WBM+bitumen is recommended as the optimal inspection road construction for DI Panca Jaya.

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