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Are There Any Correlations Between the Functional and Structural Performance of Indonesian National Road Conditions?

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ABSTRACT: The deterioration of road conditions affects the safety and comfort of road users. The initial stage of implementing road rehabilitation and maintenance management involves conducting an inventory through routine assessments of pavement functional and structural conditions. Evaluating functional and structural conditions is essential for determining the appropriate rehabilitation and maintenance methods. However, evaluations are typically focused only on functional conditions. Therefore, it is necessary to investigate whether a relationship exists between the functional and structural conditions of roads to determine their correlation. This study aims to evaluate the functional and structural conditions of three national road sections: the Simpang Tiga East Ring Road – Pati/Kudus District Boundary, Lingkar Pati, and Wangon – Menganti. The functional conditions were assessed using the Hawkeye 2000 vehicle, which generates Pavement Condition Index (PCI) data for each road segment, providing the average PCI value and the condition of each segment. Meanwhile, the Falling Weight Deflectometer (FWD) was used to obtain deflection data, which was utilized to calculate the representative deflection value (D represented) and elastic modulus (E). This study concludes that there is either no correlation or only a weak correlation between the functional and structural conditions of national roads in the three sections analyzed. Therefore, it is recommended to evaluate both functional and structural conditions simultaneously to ensure that road rehabilitation and maintenance management achieves its objectives by providing safe and reliable roads.

KEYWORDS: Road Rehabilitation, Maintenance, Pavement Condition Index (PCI), Falling Weight Deflectometer (FWD).

I. INTRODUCTION

Roads are essential land transportation infrastructure required by communities to carry out activities outside the home to fulfill their daily needs. Every day, millions of people and goods necessary for human life move from their origin to their destination. The role of roads in human life is so vital that maintaining their availability in good condition is crucial.

Deteriorating road conditions significantly impact the safety and comfort of road users [1][2]. The initial step in implementing road rehabilitation and maintenance management involves conducting an inventory through routine assessments of the functional and structural conditions of the pavement. Evaluations of functional and structural conditions are performed to determine appropriate rehabilitation and maintenance methods. However, these evaluations often focus solely on functional conditions, neglecting structural conditions. Therefore, it is necessary to investigate whether a relationship exists between the functional and structural conditions of the road and to examine the correlation between the two.

Studies analyzing the relationship between the functional and structural conditions of roads, using IRI values and FWD deflection data, have shown that the two are not correlated. This is evidenced by a coefficient of determination (R^2) value of less than 0.5 [1]. These findings raised curiosity about whether replacing IRI data, which represents functional conditions, with PCI data might yield different results.

This research aims to evaluate the functional and structural conditions of three national road sections: the East Ring Road Simpang Tiga – Pati/Kudus Regency Border, Lingkar Pati, and Wangon – Menganti. The functional condition was tested using a Hawkeye 2000 vehicle, which generates Pavement Condition Index (PCI) data for each road section, providing average PCI values and overall road condition assessments. Meanwhile, the Falling Weight Deflectometer (FWD) tool was used to produce deflection data, which was subsequently utilized to calculate representative deflection values (D represented) and elastic modulus (E).

II. RESEARCH METHOD

This research employs a descriptive analytical method, utilizing secondary data for PCI values, FWD deflection, and Average Daily Traffic (ADT) obtained from National Road Implementation Agency Central Java. Meanwhile, primary data consists only of documentation of environmental conditions and road sections, as well as observations of vehicle types. The research was conducted on the Simpang 3 East Kudus Ring Road – Pati/Kudus District Boundary, Lingkar Pati, and Wangon – Menganti sections. The location and road network are depicted in the map shown in Figure 1.

Figure 1. Location and Road Network Map

A. Service life of pavement

Highways are transportation infrastructure whose structural value decreases over time, as illustrated in Figure 1. When the road is completed and ready for operation, the pavement index value is at its highest level (P_0). Due to traffic operations, the pavement index value gradually declines over time, following the planned curve, until it reaches a certain point at a specific service period limit (t), or the Pt value. At this point, the road can no longer adequately serve traffic or has reached its construction limit. In this condition, treatment in the form of road improvements is required to restore it to its original service level (P_0).

However, to ensure that road conditions align with the initial scenario—following the planned curve to the construction boundary—regular maintenance is essential. Maintenance activities are necessary to enable the road to provide the planned level of service. Without maintenance, the road will not reach its intended service life and may experience accelerated damage [1].

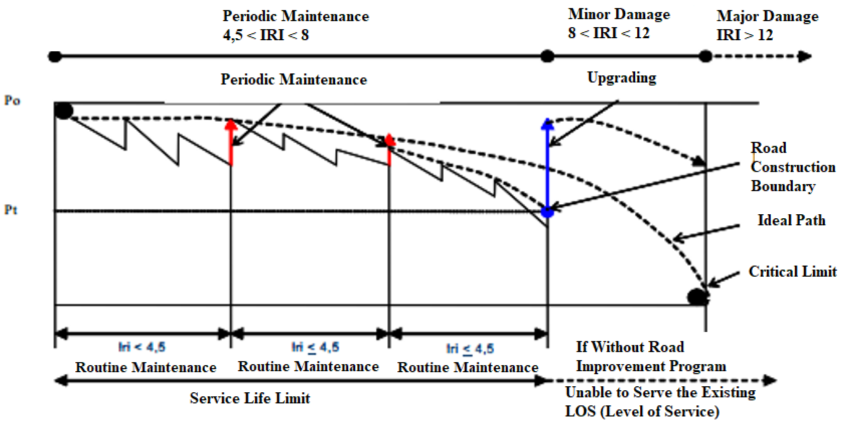

Figure 2. Relationship between condition, age and type of road service [2]

P_0 : Initial Serviceability Index

P_t : Terminal serviceability index

P_0 dan P_t values are highly dependent on road classification and ADT

B. Functional Performance of pavement

Road users essentially purchase a package of services and expect good and reliable facilities or services [2]. Asphalt road damage can be caused by human factors, the load of passing vehicles, and the volume of traffic [3]. To maintain Road conditions at the desired level of service, appropriate evaluation methods for road pavement are required [4]. Common evaluations include functional and structural evaluations.

Functional evaluation assesses the comfort level experienced by road users when using a road. Attributes influencing functional conditions include roughness, skid resistance, and grooves. If the road surface feels rough, slippery, or sways due to grooves, this indicates that the road is no longer functioning as intended. Even without visible potholes, roads with deteriorated functional conditions can reduce average speeds and result in decreased road capacity.

On the other hand, structural evaluation determines the pavement's capability to support vehicle traffic loads throughout its service life. Structural capacity decreases with damage to the pavement, such as cracking, potholes, deformation, surface grain loss (raveling), or surface curling (corrugation) [5].

The Pavement Condition Index (PCI) is one of several road pavement condition assessment systems, based on the type and severity of damage. The PCI method provides information on road pavement conditions at the time of the survey but does not predict future conditions. However, periodic condition surveys can help predict future performance and serve as input for more detailed measurements [6].

The PCI value ranges from 0 to 100, with criteria such as perfect, very good, good, fair, poor, very bad, and failed [5]. The PCI rating range follows ASTM D 6433-18 [7], as shown in Figure 3. PCI calculations are based on visual surveys of road conditions, identifying the type, severity, and quantity of damage. The PCI data collection uses the Hawkeye 2000 vehicle, shown in Figure 4, which is an integrated, modular, and scalable digital highway survey tool designed for road condition assessments. The Hawkeye 2000, developed by the Australian Road Research Board (ARRB), provides road condition values such as the International Roughness Index (IRI) and Surface Distress Index (SDI). Using the Hawkeye 2000 ensures data that is well-scaled and meets established standards.

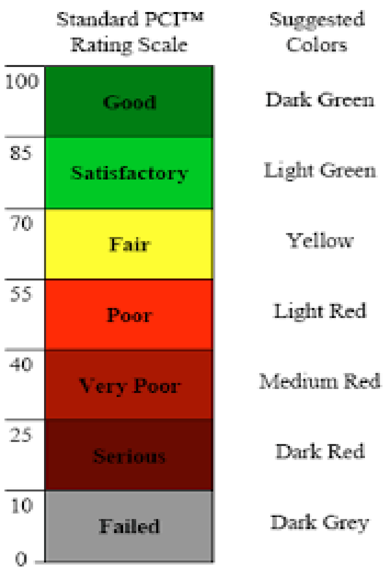

Figure 3. Pavement Condition Rating Based on PCI Value ASTM D 6433-18

Figure 4. Hawkeye 2000 Vehicle

C. Structural Evaluation of pavement

The structural condition of the road can be assessed by determining the residual strength of the pavement. Measuring the amount of deflection that occurs during a loading test is an indicator of the structural value. The known maximum deflection and the composition of the pavement layers assist in identifying changes in the pavement structure. The tool commonly used for this purpose is the Falling Weight Deflectometer (FWD).

The Falling Weight Deflectometer (FWD) is a device used to evaluate the stiffness of pavement and its layers. It is a trailer-mounted apparatus that operates by dropping a load onto the pavement and measuring the resulting deflection. The residual strength of the pavement is determined by analyzing the deflection caused by the load and the traffic load. The FWD is specifically designed to assess the structural performance of flexible pavements without causing damage to the road pavement construction.

The working principle of the FWD involves applying an impulse load to the flexible pavement through a round plate, simulating the effect of a vehicle. Figures 5 and 6 provide a representation of the Falling Weight Deflectometer tool.

Figure 5. Falling Weight Deflectometer tools

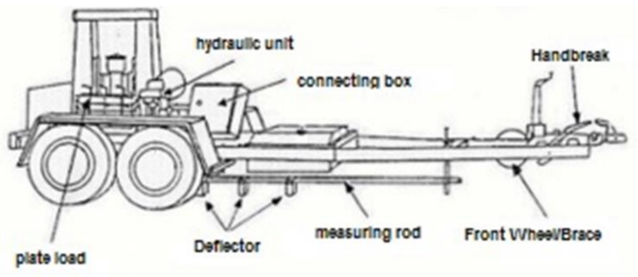

Figure 6. Falling Weight Deflectometer Tools (FWD)

Stages of Deflection Testing with FWD Tools. The stages of deflection testing on flexible pavement using the FWD tool are as follows:

- Testing can be conducted during the day or night. Traffic arrangements must be made to prevent traffic congestion during the testing process.
- Deflection testing points are located on the outer wheel tracks, between the wheel tracks, and on the inner wheel tracks.
- For road sections with two or more lanes, the minimum length of the road being tested is 1,500 meters, with a maximum distance of 500 meters between test points. Testing is carried out for each lane.
- The road surface to be tested must be clean and level to avoid interference with the FWD tool while it collects data.
- All relevant information for each section being tested must be recorded, including the road name/section number, the operator's name, the date and time of testing, and the pavement temperature.
- A load of 41 kN is used for testing on flexible pavement.
- A minimum of two load drops is required. The first load drop is used as an 'adjustment' to properly position the loading plate on the surface.

D. Deflection with Falling Weight Deflectometer (FWD)

Deflection refers to the amount of vertical downward movement of the pavement surface caused by a load. The FWD tool applies dynamic loading and is non-destructive. According to [8] Pd.T-05-2005B, the deflection used is the load center deflection (df1). This deflection value must be adjusted using the groundwater level factor (seasonal factor), temperature correction, and the test load correction factor (if the test load deviates from the standard 4.08 tons).

In analyzing structural condition values, it is essential to calculate the representative deflection value (Drep). This value is crucial to determine the amount of elastic deformation experienced by the flexible pavement being evaluated. Prior to calculating the representative deflection value, the direct deflection value (dL) must first be determined.

III. RESULT AND DISCUSSION

A. Functional Condition Analysis using the Pavement Condition Index (PCI) Method

The first step in road maintenance efforts is to conduct a survey to obtain accurate road condition data, which serves as the basis for implementing appropriate maintenance actions [9]. On the Simpang Tiga Ring Kudus Timur – Pati/Kudus Regency Boundary Road (STA 0+000 – 1+030), the types of damage observed include polished aggregate, rutting, and bleeding. These damages are caused by heavy vehicles stopping on the road shoulder and the area's extreme weather conditions. On the Wangon – Menganti Road Section (STA 0+000 – 11+600), the types of damage identified include potholes, shoving, polished aggregate, bumps and sags, and bleeding.

B. Structural Condition Analysis using the Falling Weight Deflectometer (FWD)

On the Simpang 3 Ring Kudus Timur – Pati/Kudus Regency Boundary Road (STA 0+000 – 1+030), the maximum deflection value in the right lane is 2.4635 mm, while the minimum modulus of elasticity (E) is 108.5980 MPa. Similarly, in the left lane, the maximum deflection value is also 2.4635 mm, and the minimum modulus of elasticity (E) is 108.5980 MPa. The FWD values arise due to several factors. High traffic flow on this road section significantly impacts its functional condition. Heavy vehicles passing through this section contribute to various types of damage, including potholes, polished aggregate, rutting, and bleeding. Additionally, damage is exacerbated by heavy vehicles stopping on the road shoulder.

C. Correlation between Functional and Structural Conditions

The following are the results of calculations and analysis of the correlation between functional and structural conditions on the three road sections studied, using the Pavement Condition Index (PCI) method and Falling Weight Deflectometer (FWD):

1. *Jalan Simpang 3 Ring Kudus Timur – Pati/Kudus Regency Boundary (STA 0+000 – 1+030).*
   The correlation between the deflection value (Dangkat) and the PCI value on the right lane yielded r = -0.257, which indicates a weak correlation. Similarly, the correlation between the elastic modulus (E) value and the PCI value resulted in r = 0.388, also classified as a weak correlation. On the left lane, the correlation between the deflection value (Dangkat) and the PCI value yielded r = -0.072, which indicates "no correlation." Similarly, the correlation between the elastic modulus (E) value and the PCI value was r = -0.041, which also indicates "no correlation."
2. *Pati Ring Road Section (STA 0+000 – 1+254).*
   Similar to the previous section, the correlation analysis on the right lane between the deflection value (D Deputy) and the PCI value yielded r = 0.204, classified as a "weak correlation". The correlation between the elastic modulus (E) value and the PCI value resulted in r = -0.242 , also a "weak correlation". On the left lane, the correlation between the deflection value (D Deputy) and the PCI value yielded r = 0.229 , classified as a "weak correlation." Meanwhile, the correlation between the elastic modulus (E) value and the PCI value resulted in r = -0.081, which indicates "no correlation."
3. *Wangon – Menganti Road Section (STA 0+000 – 1+160).*
   On the right lane, the correlation between the deflection value (Dklik) and the PCI value yielded r = 0.032, which indicates "no correlation". Similarly, the correlation between the elastic modulus (E) value and the PCI value

was r = 0.153, which also indicates "no correlation." On the left lane, the correlation between the deflection value (Dklik) and the PCI value yielded r = 0.303, classified as a "weak correlation." Meanwhile, the correlation between the elastic modulus (E) value and the PCI value resulted in r = -0.031, which indicates "no correlation." Based on the results of the correlation analysis between functional and structural conditions on the three road sections in this study, the outcomes predominantly indicated "no correlation" and "weak correlation."

Integrating pavement structural and surface data allows for easier identification of the causes of pavement failure, providing a powerful tool for managing pavement conditions and supporting robust infrastructure maintenance strategies. The unique capability of continuous high-accuracy and high-resolution data enables infrastructure managers to pinpoint areas where pavement structure is deficient and prone to failure [10][11].

Previous studies have examined the correlation between functional and structural pavement conditions. For instance, a study in Islamabad found that a developed regression model showed a significant relationship between deflection and the International Roughness Index (IRI) [12]. In Medan City, Indonesia, the relationship between PCI and IRI was reported to be quite strong [13]. Additionally, findings from a study in Bandung City, Indonesia, revealed that the PCI correlation coefficient with SDI was greater than the PCI correlation coefficient with PSI.

IV. CONCLUSIONS

Correlation of Functional Conditions (PCI) with Structural Conditions (D Deputy):

At Simpang 3 Lingkar Kudus Timur – Pati/Kudus Regency Boundary, the correlation for the right lane is weak, while there is no correlation for the left lane. On the Pati Ring Road, there is no correlation for the right lane, and a weak correlation for the left lane. For the Wangon – Menganti Road section, there is no correlation on one lane and a weak correlation on the other.

Correlation of Functional Conditions (PCI) with Structural Conditions (Modulus of Elasticity):

At Simpang 3 Lingkar Kudus Timur – Pati/Kudus Regency Boundary, the correlation for the right lane is weak, while there is no correlation for the left lane. On the Pati Ring Road, both the right and left lanes show weak correlation or no correlation. Similarly, for the Wangon – Menganti Road section, there is no correlation on one lane and a weak correlation on the other.

Thus, it can be concluded that there is no significant correlation between the functional and structural conditions of the national roads across the three sections studied. In instances where a correlation exists, the relationship is weak.

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