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Mathematical analysis of ROC-TOPSIS method for prioritizing road repair decisions

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Abstract

Determining the priority of road damage in road construction typically relies on assessments using Pavement Condition Index (PCI) method. However, the PCI classification does not provide specific criteria to differentiate between road sections within the same classification, making it challenging to identify sections in the worst condition. To address this issue, multi-criteria decision-making (MCDM) methods can be used to prioritize road sections for repair. One effective approach integrates the Rank Order Centroid (ROC) and Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) methods. The analysis revealed that the road sections prioritized for repair were located at Location III: Alternative 70, Alternative 80, and Alternative 42. Based on the Pearson correlation coefficient between the ranking orders of the pavement assessment using PCI and ROC-TOPSIS, there is a 65% similarity. Consequently, ROC-TOPSIS can serve as an alternative method for determining priority repairs, as it aligns with the results of the road pavement assessment.

Keywords: Multi-Criteria Decision-Making (MCDM), Rank Order Centroid (ROC), Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS)

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Introduction

Road infrastructure is a crucial component for advancing land transportation and requires special attention from the government. To ensure smooth transportation, roads should remain in good condition and free from damage. When roads are damaged, it disrupts traffic flow, which in turn impacts other sectors (Zahra et al., 2024). Unfortunately, many roads in Indonesia, including those in Tanah Laut Regency, South Kalimantan, remain in poor condition. This highlights the importance of studying the causes of road damage (Sur et al., 2024). Damage can result from various factors, such as poor construction materials, unstable climate and soil conditions, excessive traffic loads, and road planning or execution that fails to meet specifications, among other possible causes (Farhan, 2022).

In addition to identifying the factors that cause road damage, it is crucial to classify the types of damage to prioritize which road sections need repair. Types of road damage include cracks, potholes, patches, sinking, rutting, shoving, and various other forms of deterioration (Mandaya, 2020). In road construction, this damage is assessed through direct inspections and investigations, where the type and extent of the damage are measured based on the affected area. The Pavement Condition Index (PCI) method is then used to classify the severity of the damage into categories such as Failed, Very Poor, Poor, Fair, Good, and Very Good (Elhadidy et al., 2021). However, PCI classifications alone do not provide sufficient detail to prioritize which roads should be repaired when multiple sections are in the same category (Hafizyar & Mosaberpanah, 2018). For example, if both Road Section 1 and Road Section 2 are classified as Very Poor, there are no specific criteria to determine which section is in worse condition.

Mathematical analysis using multi-criteria decision support systems can rank road damage data based on the extent of damage (Ezzati et al., 2021). These methods help prioritize road sections, which cannot be determined solely by the PCI classification of road damage. Several previous studies have applied decision support methods in the fields of road and bridge engineering.

The study by (Han et al., 2020) utilized the Analytic Hierarchy Process (AHP) decision support system (DSS) method for road selection. The results indicated that, compared to manual road selection methods, the AHP DSS method provided greater accuracy, making it a valuable tool for facilitating road selection. Additionally, (Putu et al., 2023) employed the AHP-TOPSIS DSS method to prioritize bridge repairs within the provincial road network in East Java. Their research ranked bridge repair priorities based on criteria such as bridge condition scores, degree of saturation, and strategic area condition scores. The study's findings included rankings based on input from 10 bridge experts to determine which bridges should be prioritized for repair.

The study by (Stević et al., 2022) utilized the IMF SWARA method, a multi-criteria decision-making (MCDM) approach, to identify the most at-risk road segments based on bus safety and Annual Average Daily Traffic (AADT). This research employed seven criteria and analyzed six alternative road segments. However, the simulations produced varied ranking results, indicating the need for a larger number of alternatives.

This paper employs the ROC-TOPSIS decision support method to prioritize roads requiring repair based on identified types of damage. The study evaluates a larger number of alternatives, specifically assessing 80 road damage extents using seven criteria for types of road damage.

The ROC-TOPSIS method has previously been employed to determine recipients of the Family Hope Program, utilizing five criteria and seven recipient alternatives. This method aims to obtain the weights of the criteria for program recipients and rank the best alternatives (Syam & Rabidin, 2019; Valentine et al., 2022). The study by (Varshney et al., 2024) employed ROC to determine weights for sub-objective functions, specifically addressing the issue of automatic generation control (AGC) within a two-area interconnected power system. This research demonstrates that, in general, the ROC method offers a practical and effective approach to criteria weighting in multi-criteria decision making (MCDM), achieving a balance among the criteria. However, no research has applied ROC-TOPSIS to prioritize road repairs using types of road damage as criteria. This study aims to identify which road segments should be prioritized for repair, using 80 road damage extents as alternatives and seven types of damage as criteria.

Methods

This study utilized primary data collected by researchers through an investigative survey of road damage assessments at three locations in Tanah Laut Regency from April to June 2024: Location I, the road to Swarangan Beach; Location II, the road to Turki Beach; and Location III, the road to Jorong Beach. These three locations were chosen because the beaches are popular tourist destinations in Tanah Laut Regency. However, the damaged roads have diminished tourist interest in visiting the area. The determination of road repair priorities is based on the type of damage that occurs, such Cracking (X_1), Bumb and Sags (X_2), Depression (X_3), Patching and Potholes (X_4), Polished Agregat (X_5), Rutting (X_6), and Swell (X_7). This study identified 15 damaged road segments at Swarangan Beach (Location I), 20 at Turki Beach (Location II), and 45 at Jorong Beach (Location III). The prioritization of road sections for repair was determined using ranking results based on the multi-criteria decision-making method ROC-TOPSIS. The ROC method was used to determine the weighting of each criterion, while TOPSIS was employed to rank the alternatives (Sholihaningtias, 2023). Before carrying out analysis using the ROC-TOPSIS method, data on road damage cases is first generated. Decision Matrix $[X]_{m\times n}$ with m is the number of alternatives or number of experts, n is the decision criterion, and x_{ij} is data evaluation of alternatives i under the decision criteria j, with $i = 1,2,\ldots,m$ and $j = 1,2,\ldots,n$. The MCDM matrix as (1).

$$X = \begin{matrix} \\ a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_m \end{matrix} \begin{matrix} \begin{matrix} c_1 & c_2 & c_3 & \cdots & c_n \end{matrix} \\ \begin{bmatrix} x_{11} & x_{12} & x_{13} & \cdots & x_{1n} \\ x_{21} & x_{22} & x_{23} & \cdots & x_{2n} \\ x_{31} & x_{32} & x_{33} & \cdots & x_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ x_{m1} & x_{m2} & x_{m3} & \cdots & x_{mn} \end{bmatrix} \end{matrix} \quad (1)$$

The analysis steps for the ROC-TOPSIS method are as follows.

Step 1: Obtaining the attribute values based on priority level of each criterion (C_r) based on order and priotiry level. The ROC is able to formulate as follows (Lubis et al., 2020).

If,

$$C_{r1} \geq C_{r2} \geq C_{r3} \geq \cdots \geq C_{rn} \quad (2)$$

then

$$W_1 \geq W_2 \geq W_3 \geq \cdots \geq W_n \quad (3)$$

with

C_r = Criteria of Decision Making

W_k = Weighting of criteria

$k = 1,2,\ldots,n$ is the number of criteria, so:

$$W_1 = \frac{1+\frac{1}{2}+\frac{1}{3}+\cdots+\frac{1}{k}}{k} \quad (4)$$

$$W_2 = \frac{0+\frac{1}{2}+\frac{1}{3}+\cdots+\frac{1}{k}}{k} \tag{5}$$

$$W_3 = \frac{0+0+\frac{1}{3}+\cdots+\frac{1}{k}}{k} \tag{6}$$

$$\vdots$$

$$W_k = \frac{0+\cdots+0+\cdots+\frac{1}{k}}{k} \tag{7}$$

Step 2: Calculate the weighting of attributes using ROC weights based on (Ahn, 2011):

$$W_k = \frac{1}{k}\sum_{i=1}^{k}\left(\frac{1}{i}\right) \qquad i = 1,2,\dots,k \tag{8}$$

Step 3: Use the weighting value of ROC as weighting value of criteria (w_j), where $j = 1,2,\dots,n$ is the number of criteria to rank the alternatives using TOPSIS.
Step 4: Create the normalized matrix with entries R_{ij}, where $i = 1,2\dots,m$ is the number of alternatives and $j = 1,2,\dots,n$ is the number of criteria. Entries R_{ij} obtained as Formula 9 (D. Liu et al., 2020).

$$R_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \tag{9}$$

Step 7: Create the weighted normalized matrix with entries Y_{ij} where $i = 1,2\dots,m$ is the number of alternatives and $j = 1,2,\dots,n$ is the number of criteria. Entries Y_{ij} obtained as:

$$Y_{ij} = R_{ij} \times w_j \tag{10}$$

Step 8: Identify the positive ideal solution matrix A^+ and negative ideal solution matrix A^- based on (Chakraborty, 2022) with:

Positive Ideal Matrix $A^+ = (y_1^+, y_2^+, \dots, y_n^+)$ (11)
Negative Ideal Matrix $A^- = (y_1^-, y_2^-, \dots, y_n^-)$ (12)

where: $$y_j^+ = \begin{cases} max\, y_{ij}\, , if\ j\ is\ profit\ criteria \\ min\, y_{ij}\, , if\ j\ is\ cost\ criteria \end{cases}$$

and $$y_j^- = \begin{cases} max\, y_{ij}\, ,, if\ j\ is\ cost\ criteria \\ min\, y_{ij}\, ,\ if\ j\ is\ profit\ criteria \end{cases}$$

$i = 1,2,\dots,m,$ index of alternatives
$j = 1,2,\dots,n,$ index of criteria

Step 9: Calculate the separation between each alternative with the positive and negetive ideal solution using Euclidean distance (S. Liu et al., 2021) :

$$S_i^+ = \sqrt{\sum_{j=1}^{n}\left(y_{ij} - y_j^+\right)^2} \tag{13}$$

$$\text{and } S_i^- = \sqrt{\sum_{j=1}^{n}\left(y_{ij} - y_j^-\right)b^2} \tag{14}$$

where: $i = 1,2, \dots, m,$ index of alternatives
$j = 1,2, \dots, n,$ index of criteria

Step 10: Determine the Closeness of Ideal Solution each alternatives (Beheshtinia & Sayadinia, 2021) :

$$C_i^+ = \frac{S_i^-}{S_i^+ + S_i^-} \tag{15}$$

with $i = 1,2, \dots, m$
The most prioritized solution is the alternative with the largest value of C_i^+

Results

Road damage assessment results

The road damage assessment data is based on an investigative survey conducted at three locations: Location I (Swarangan), Location II (Turki), and Location III (Jorong). There are 80 alternatives, comprising 15 road sections from Location I, 20 road sections from Location II, and 45 road sections from Location III. The extent of damage for each alternative, categorized by seven types of damage criteria, is presented in Table 1 below.

Table 1. Summary of Road Damage Assessment

Location	Alternatives	Road Section	Extent of Damage Types (m^2)						
			C_1	C_2	C_3	C_4	C_5	C_6	C_7
	1	0+000 s.d 0+100	3.5	0	0	0	2	0	0
	2	0+101 s.d 0+200	17	0	0	3.2	19	0	0
	3	0+201 s.d 0+300	58	0	0	0.8	3.9	0	0
I	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
	13	4+601 s/d 4+700	5	0	0	0	0	0	0
	14	4+701 s/d 4+800	5	0	0	0	0	0	0
	15	4+801 s/d 4+900	6.1	4.6	4	0	0	0	0
	16	0+000 s.d 0+100	15.5	1.5	9.4	29	1.9	1.7	37.6
	17	0+101 s.d 0+200	19.57	0	0	5.45	1	0	0
	18	0+201 s.d 0+300	14.81	23.09	6.30	24.13	0.00	0.00	0.00
	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮
II	33	1+701 s/d 1+800	0	0	21.6	392	0	0	0
	34	1+801 s/d 1+900	102.25	0	0	161.68	0	20	0
	35	1+901 s/d 4+985	56	0	1.44	55.54	0	13.6	
	36	0+000 s.d 0+100	0	0	0	25.55	0	0	0
	37	0+101 s.d 0+200	0.00	0	0	0.00	266.6	0	0
	38	0+201 s.d 0+300	89.99	0.00	0.00	0.00	0.00	0	0
III			⋮	⋮	⋮	⋮	⋮	⋮	⋮
	78	4+201 s/d 4+300	52.36	0	0	0	0	0	0
	79	4+301 s/d 4+400	73	0	0	17.4	0	0	0
	80	4+401 s/d 4+500	52.36	0	0	0	0	0	0

Descriptions:

C_1 : Cracking
C_2 : Patching and Potholes
C_3 : Polished Agregat
C_4 : Depression
C_5 : Bumb and Sags
C_6 : Swell
C_7 : Rutting

The data of Table 1 in decision matrix of the road damage asessment based on (1) obtained as

$$X = \begin{matrix} \\ a_1 \\ a_2 \\ a_3 \\ a_4 \\ \vdots \\ a_{80} \end{matrix} \begin{matrix} c_1 & c_2 & c_3 & c_4 & c_5 & c_6 & c_7 \\ \end{matrix} \begin{bmatrix} 3,5 & 0.0000 & 2 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 17 & 3.2 & 19 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 58 & 0.8 & 3.9 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \\ 11.2 & 0.0000 & 0.0000 & 12.8 & 0.0000 & 0.0000 & 0.0000 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 800 & 800 & 0.0000 & 0.0000 & 0.0000 & 0.0000 & 0.0000 \end{bmatrix} \quad (16)$$

ROC-weighting results

To make decisions regarding the prioritization of road repairs, specific criteria are required. This study used seven criteria to establish a priority order for repairs based on the total area of damage that has occurred. The order of priority for the types of road damage can be determined based on Table 1. The extent of road damage is illustrated in Figure 1.

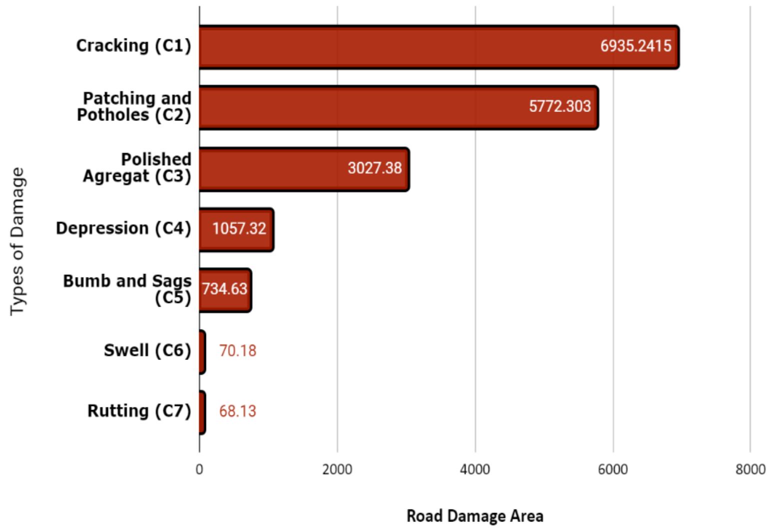

Figure 1. The Order of Road Damage Area

Based on the order of road damage extent, the ranking of criteria obtained from equation (2) are C_1 = Cracking, C_2 = Patching and Potholes, C_3 = Polished Agregat, C_4 = Depression, C_5 = Bumb and Sags, C_6 = Swell, and C_7 = Rutting.

The weighting of criteria using ROC based on (8) obtained as

$$W_1 = \frac{1 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5} + \frac{1}{6} + \frac{1}{7}}{7} = 0.37041$$

$$W_2 = \frac{0 + \frac{1}{2} + \frac{1}{3} + \frac{1}{4} + \frac{1}{5} + \frac{1}{6} + \frac{1}{7}}{7} = 0.22755$$

$$W_3 = \frac{0+0+\frac{1}{3}+\frac{1}{4}+\frac{1}{5}+\frac{1}{6}+\frac{1}{7}}{7} = 0.15612$$
$$W_4 = \frac{0+0+0+\frac{1}{4}+\frac{1}{5}+\frac{1}{6}+\frac{1}{7}}{7} = 0.10850$$
$$W_5 = \frac{0+0+0+0+\frac{1}{5}+\frac{1}{6}+\frac{1}{7}}{7} = 0.07279$$
$$W_6 = \frac{0+0+0+0+0+\frac{1}{6}+\frac{1}{7}}{7} = 0.04422$$
$$W_7 = \frac{0+0+0+0+0+0+\frac{1}{7}}{7} = 0.02041$$

The weighting value of ROC as weighting value of criteria (w_j), where $j = 1,2,\ldots,7$ is the number of criteria to rank the alternatives using TOPSIS.

TOPSIS-alternative ranks

Based on the decision matrix (16) , he matrix normalization is calculated according to equation (9), and the results are as follows.

$$R_{80\times7} = \begin{bmatrix} 0.00238 & 0.00000 & 0.00186 & 0.00000 & 0.00000 & 0.00000 & 0.00000 \\ 0.01158 & 0.00190 & 0.01771 & 0.00000 & 0.00000 & 0.00000 & 0.00000 \\ 0.03952 & 0.00048 & 0.00364 & 0.00000 & 0.00000 & 0.00000 & 0.00000 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0.54508 & 0.47562 & 0.00000 & 0.00000 & 0.00000 & 0.00000 & 0.00000 \end{bmatrix}$$

By using the ROC criteria weights, $w_1 = 0.37041$, $w_2 = 0{,}22755$, $w_3 = 0.15612$, $w_4 = 0.10850$, $w_5 = 0.07279$, $w_6 = 0.04422$, $w_7 = 0.02041$, the weighted normalization matrix is obtained based on equation (10) as follows:

$$Y_{80\times7} = \begin{bmatrix} 0.00088 & 0.00000 & 0.00029 & 0.00000 & 0.00000 & 0.00000 & 0.00000 \\ 0.00429 & 0.00043 & 0.00276 & 0.00000 & 0.00000 & 0.00000 & 0.00000 \\ 0.01464 & 0.00011 & 0.00057 & 0.00000 & 0.00000 & 0.00000 & 0.00000 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0.20190 & 0.10823 & 0.00000 & 0.00000 & 0.00000 & 0.00000 & 0.00000 \end{bmatrix}$$

The next step is to identify the positive ideal solution matrix A^+ and the negative ideal solution matrix A^- based on Equation (11) and (12). In this study, since all the criteria are types of damage, the greater the area of road damage in each type, the higher the priority for the road to be repaired. Therefore, criteria $C_1, C_2, C_3, C_4, C_5, C_6,$ and C_7 are categorized as profit criteria. The following results are obtained:

$$A^+ = [0.20190 \quad 0.16468 \quad 0.11298 \quad 0.08736 \quad 0.07234 \quad 0.04032 \quad 0{,}01260]$$
$$A^- = [0.00000 \quad 0.16468 \quad 0.11298 \quad 0.08736 \quad 0.07234 \quad 0.04032 \quad 0{,}01260]$$

Based on the ideal solution matrix, we can calculate the separation between each alternative by equation (13)(14). The results are presented in Table 2.

Table 2. Summary of Road Damage Assessment

Alternatives	S_i^+	S_i^-
A1	0.30802	0.00093
A2	0.30467	0.00512
A3	0.29906	0.01465
A4	0.30582	0.00468
A5	0.30012	0.01242
⋮	⋮	⋮
A78	0.30022	0.01321
A79	0.29568	0.01857
A80	0.17493	0.22908

The last step is determine the Closeness of Ideal solution (C_i) each alternative based on Equation (15), The summary of Closeness Ideal Solution of road damage can be presented by Figure 2.

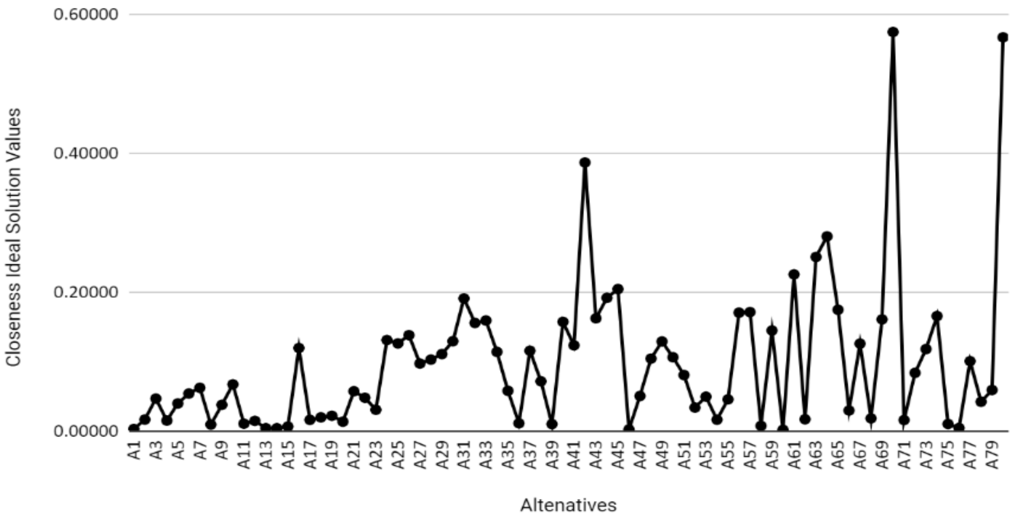

Figure 2. The Summary of Closeness Ideal solution

Based on C_i^+ values we can sorted the rank of alternatives with the largest C_i^+ become the most prioritized for repair. The results are as shown in Table 3.

Table 3. Summary of Road Damage Assessment

Ranking	Alternatives (i)	C_i^+
1	A70	0.57474
2	A80	0.56702
3	A42	0.38676
4	A64	0.28034
5	A63	0.25071
⋮	⋮	⋮
78	A1	0.00301
79	A46	0.00235
80	A60	0.00176

Based on the results of the alternative ranking in Table 3, the most prioritized road sections for repair are as follows: the road sections on Alternative A70 (Jorong Beach, STA 3+401 to STA 3+500), Alternative A80 (Jorong Beach, STA 4+401 to STA 4+500), Alternative A42 (Jorong Beach, STA 0+601 to STA 0+700), and Alternative A64 (Jorong Beach, STA 2+801 to STA 2+900). The next prioritized road sections are on Alternative A60

(Jorong Beach, STA 2+401 to STA 2+500), Alternative A46 (Jorong Beach, STA 1+001 to STA 1+100), and Swarangan Beach (STA 0+000 to STA 0+100)

Discussion

The ranking results of 80 road sections using ROC-TOPSIS show that Alternative A70 (Jorong Beach: STA 3+401 to STA 3+500) is the most prioritized road section for repair, while Alternative A60 (Jorong Beach: STA 4+401 to STA 4+500) is the least prioritized road section for repair. Comparing these rankings with a manual analysis based on the Pavement Condition Index (PCI), as outlined by Pinatt (Pinatt et al., 2020), reveals that the pavement condition of A70 is classified as "Very Poor," whereas A60, the lowest-priority section, is classified as "Excellent."

The Pavement Condition Index (PCI) is a numerical scale ranging from 0 to 100, where 0 indicates "Failed" pavement and 100 signifies "Excellent" pavement (Hafizyar & Mosaberpanah, 2018). PCI evaluation is based on visual surveys that assess the types, quantities, and severity of pavement distresses. It is designed to quantify the structural integrity and surface serviceability of pavement (Zafar et al., 2019).

Based on the visual survey of the 80 road sections, the pavement assessment results can be compared with the alternative rankings of road damage using the ROC-TOPSIS method.

Table 3. Summary of Road Damage Assessment

Alternatives (i)	PCI values	Pavement Condition	Rank of ROC	Rank of PCI
A70	11	Very Poor	1	2
A80	38	Poor	2	11
A42	6	Failed	3	1
A64	39	Poor	4	11
A63	55	Fair	5	39
⋮	⋮	⋮	⋮	⋮
A1	87	Excellent	78	77
A46	91	Excellent	79	79
A60	91	Excellent	80	80

Next, the similarity in the ranking order of road damage prioritized for repair will be determined using the correlation coefficient (Ali & Al-Hameed, 2022). One commonly used correlation coefficient for determining the similarity between two variables is the Pearson correlation. The Pearson correlation measures the strength and direction of the relationship between two variables (El-Hashash & Shiekh, 2022). The coefficient ranges from -1, indicating a strong negative relationship, to +1, indicating a strong positive relationship. The closer the value is to zero, the weaker the linear correlation, signifying a smaller degree of association (Jebli et al., 2021).

Based on the results of the pavement assessment using PCI in Table 4, it is observed that the ranking order from ROC-TOPSIS shows a 65% similarity with the ranking order from the road pavement assessment based on PCI values, as determined by the Pearson correlation coefficient. With this similarity value, it can be concluded that the road damage assessment can serve as an alternative method for determining priority repairs, given its alignment with the results of the road pavement assessment.

Conclusion

The research concludes that multi-criteria decision-making (MCDM) methods, specifically ROC and TOPSIS, are effective decision support tools for calculating weight values and ranking alternatives based on specific criteria. These methods facilitate the identification of road repair priorities, with Alternative A70 being the highest priority (C_i =0.57474), followed by A80 (C_i = 0.56702), and A42 (C_i = 0.38676), among all the road sections of Jorong Beach. The ROC-TOPSIS methods simplify the process of prioritizing road damage and support decision-making based on assessments of road pavement conditions. Further research could explore alternative decision support system methods to enhance effectiveness in determining repair priorities for road damage.

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Declarations

Author Contribution	:	WAAS: Conceptualization, Writing - Original Draft, Editing, Visualization, Analysis, and Validation. ISM: Writing - Reviewing & Editing, Formal analysis, Correspondence.
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Conflict of Interest	:	The authors declare no conflict of interest.

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