Assessment of Pavement Surface Quality using TOPSIS Method

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Abstract. The pavement surface quality (PSQ) is the most significant element of highways. To assure PSQ, it is necessary to check its performance periodically. The data from field test carried on Link road, near Samrala Chowk, Ludhiana by using Falling Weight Deflectometer (FWD) was collected for analysis. It is a non-destructive testing device that is used for the determination of the deflection value of damaged surfaces that may be in the form of potholes, isolated cracked areas, ruts, raveling, etc. This system only provides the deflection values. Therefore, it is necessary to use a decision-making technique to assess the quality of pavement surfaces at a particular location. In this paper, an alternative method based on the technique for order preference by similarity to ideal solution (TOPSIS) is considered for ranking of PSQ. The results presented that chainage 500 m has good PSQ as it has been ranked one. Similarly, the chainage 5000 m ranked two because the PSQ of this chainage was less good as compared to the chainage 500 m and followed by chainage 4000 m, 1500 m, 0 m, 6000 m, 2000 m, and 1000 m respectively. The study also helps to decide maintenance requirements according to the surface condition of the pavement.

Keywords: Deflection; PSQ; FWD; TOPSIS, MCDM

1. Introduction

Rods are considered an important infrastructure part of any country and the cost of their maintenance is significant. As we know that the use of another mode of transportation is dependent on road transportation because of its flexibility and also it provides door-to-door services to road users. Due to rapid industrial development in the last twenty years, a tremendous increase in highway traffic volume was reported. This increased volume resulted in highway pavement failure which occurs in the form of potholes, isolated cracked areas, ruts, raveling, etc. Therefore, it is essential to ensure its surface quality periodically by suitable mechanical methods. Falling Weight Deflectometer (FWD) [1] is one of the non-destructive testing (NDT) devices, which imparts a load pulse equal to the load produced by a rolling vehicle wheel on the pavement surface. The load is produced by dropping a large weight, through a circular load plate to the pavement surface, which provides the deflection values corresponding to the various distresses. In the present study field test carried on Link road, near Samrala Chowk, Ludhiana for the first 6 km has been taken for analysis which showed that the pavement surface was under distress condition. The analysis of the data was done by using the multi-criteria decision-making (MCDM) technique of order preference by similarity to ideal solution (TOPSIS) for evaluation of PSQ. This method is simplest among all available MCDM methods such as simple additive weighting (SAW), analytic hierarchy process (AHP), VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR), etc. The parameters such as potholes, isolated cracked areas, localized depression due to settlement, ruts, raveling, corrugations, edge breaking, alligator cracking, and wavy surface [2] are considered in the analysis to provide a more reliable solution.

Wang et al. [3] used the response surface method (RSM) and TOPSIS for MCDM problems and showed that this method is in a good decision concerning the other researcher studies. Ouma et al. [4] compared the Fuzzy AHP and Fuzzy TOPSIS methods for prioritization of road pavement maintenance and illustrated that two methods provided nearly the same ranking of prioritization. Sun [5] used Fuzzy AHP for Subjective weightage calculation by triangular fuzzy numbers and used Fuzzy TOPSIS for the evaluation of performance in a fuzzy environment that helps industrial practitioners to take a more accurate and effective decision. Jahanshahloo et al. [6] considered the extended TOPSIS for decision-making problems by taking an example of bank branches in Iran which presented that for better ranking there should be less distance from a positive ideal solution and more distance from a negative ideal solution. Ertuğrul et al. [7] proposed FAHP for the weight of the criteria calculation and TOPSIS method for the

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selection of fifteen Turkish cement firms by using their financial ratios. Wang et al. [8] proposed the TOPSIS method to select initial training aircraft which helps the Air Force Academy in Taiwan to take the comprehensive decision in a fuzzy environment where the weight of each criterion is presented by triangular fuzzy numbers.

Jozaghi et al. [9] proposed a comparative analysis of the TOPSIS and AHP method for dam site selection in the Baluchestan and Sistan region of Iran based on geographic and water quality criteria. Their study showed that the TOPSIS method is best suited for dam site selection problems. Garg and Maji [10] used the Fuzzy TOPSIS approach in the optimal noise barrier selection and also suggested that it is a very supportive approach for the selection of noise barriers to reduce the nuisance due to road traffic noise. Qiu et al. [11] presented the use of the TOPSIS method in pavement condition ranking based on 18 parameters that involve four major aspects of pavement condition are roughness, surface distress, structural capacity, and safety characteristic. Pal et al. [12] proposed the TOPSIS and RIDIT method for the prioritization of state highways including the AHP method for the calculation of weightage that helps the policymakers to identify various sections which need improvement based on the above prioritization. Zhongyou [13] applied the TOPSIS method in the quantitative evaluation of the competitive ability of the foreign player in CBA games. Ardielli [14] applied the TOPSIS method for evaluating the Governance of European Union countries and identified that the Nordic countries like Denmark, Finland, and Sweden have been efficacious in the related subject and other countries like Romania, Greece, and Bulgaria have various shortcomings.

2. Methodology

The TOPSIS (technique for order preference by similarity to ideal solution) method was firstly proposed by Hwang and Yoon in 1981 [15] and has varieties of application, that helps the decision-maker to take an effective and comprehensive decision. The TOPSIS method consists of the following steps [15-16]:

Step I: A decision matrix has been created after identifying the number of alternatives and performance defining criteria of the problem. If X is the number of alternatives and Y is the performance defining criterion then the decision matrix having an order of $X \times Y$ is represented as:

$$D_{X \times Y} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1N} \\ a_{21} & a_{22} & \cdots & a_{2N} \\ \vdots & \vdots & \ddots & \vdots \\ a_{M1} & a_{M2} & \cdots & a_{MN} \end{bmatrix} \quad (1)$$

Where an element $a_{ij}$ represents the actual value of the $i_{th}$ alternative having $j_{th}$ performance defining criterion.

Step II: The decision matrix is now normalized and the normalized value calculated as:

$$r_y = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{M} (a^2_{ij})^{1/2}}} \quad (2)$$

Step III: Determine the positive ideal solution and the negative ideal solution based on weighted normalized ratings are as:

$$A^+ = (r_1^+, r_2^+, \ldots, r_N^+) \quad \text{and} \quad A^- = (r_1^-, r_2^-, \ldots, r_N^-) \quad (3)$$

Where

$$r_j^+ = \frac{(\max_{i} r_{ij})}{(\min_{i} r_{ij})} \quad (\text{if } j \text{ is benefit criteria})$$

and

$$r_j^- = \frac{(\min_{i} r_{ij})}{(\max_{i} r_{ij})} \quad (\text{if } j \text{ is the cost criteria})$$

for $j = 1, 2, \ldots, N$
Step IV: The separation measures are calculated by using Euclidian distances between each of the alternatives. The separation measures for the positive ideal solution and the negative ideal solution are calculated by using the equation as shown below:

\[
D_i^+ = \sqrt{\sum_{j}^N (r_{ij}^+ - r_{ij}^-)^2} \quad \text{and} \quad D_i^- = \sqrt{\sum_{j}^N (r_{ij}^+ - r_{ij}^-)} \quad \text{for } i = 1, 2 \ldots M
\]

Step V: Finally, the overall preference or relative closeness index (RCI) of the alternatives is calculated. All the alternatives are then arranged in descending order according to the value of their relative closeness index. The alternative at the top of the list is the most preferred one. The relative closeness index (RCI) of the alternatives is calculated by using the equation as shown below:

\[
\text{RCI} = \frac{D_i^-}{D_i^- + D_i^+} \quad \text{for } i = 1, 2 \ldots M
\]

Step VI: The overall preference of all the alternatives now can be ranked by the descending order of the RCI.

3. Application

For the analysis purpose data from the field study conducted on Link road, near Samrala Chowk, Ludhiana for the first 6 km has been taken. Table 1 presents the decision matrix of field data on various chainage points of the selected locations in which D_1, D_2, D_3, D_4, \ldots, D_n represents the deflection data in mm in terms of potholes, isolated cracked areas, localized depression due to settlement, ruts, raveling, corrugations, edge breaking, alligator cracking, and wavy surface which showed that the pavement surface was under distress condition.

Table 1. Decision matrix for pavement surface quality ranking

| Chainage (m)/D (mm) | D_1  | D_2  | D_3  | D_4  | D_5  | D_6  | D_7  | D_8  | D_9  |
|---------------------|------|------|------|------|------|------|------|------|------|
| 0                   | 150.99 | 125.86 | 104.60 | 84.38 | 70.86 | 56.03 | 44.22 | 34.96 | 29.95 |
| 500                 | 405.45 | 334.60 | 270.27 | 208.76 | 163.95 | 98.57 | 68.29 | 49.24 | 39.33 |
| 1000                | 129.98 | 105.87 | 87.45  | 66.72 | 50.62 | 31.62 | 19.47 | 15.13 | 13.20 |
| 1500                | 166.29 | 143.01 | 125.22 | 101.55 | 86.88 | 62.75 | 48.64 | 36.68 | 25.17 |
| 2000                | 125.32 | 103.75 | 89.43  | 74.54 | 64.61 | 48.96 | 38.75 | 29.87 | 25.10 |
| 4000                | 251.46 | 207.34 | 156.75 | 113.48 | 82.89 | 54.40 | 36.68 | 28.39 | 23.72 |
| 5000                | 206.83 | 157.97 | 125.32 | 98.02 | 60.33 | 59.74 | 47.24 | 37.03 | 29.58 |
| 6000                | 237.70 | 187.81 | 139.34 | 88.10 | 60.33 | 35.24 | 25.95 | 20.97 | 17.04 |

Table 2. Normalized Decision matrix

| Chainage (m)/D (mm) | D_1  | D_2  | D_3  | D_4  | D_5  | D_6  | D_7  | D_8  | D_9  |
|---------------------|------|------|------|------|------|------|------|------|------|
| 0                   | 0.235 | 0.240 | 0.250 | 0.265 | 0.281 | 0.335 | 0.359 | 0.379 | 0.391 |
| 500                 | 0.633 | 0.639 | 0.646 | 0.656 | 0.651 | 0.589 | 0.555 | 0.533 | 0.551 |
| 1000                | 0.203 | 0.202 | 0.209 | 0.209 | 0.201 | 0.189 | 0.158 | 0.164 | 0.184 |
| 1500                | 0.259 | 0.273 | 0.299 | 0.319 | 0.345 | 0.325 | 0.395 | 0.363 | 0.352 |
| 2000                | 0.195 | 0.198 | 0.213 | 0.234 | 0.256 | 0.292 | 0.315 | 0.323 | 0.351 |
| 4000                | 0.391 | 0.396 | 0.374 | 0.356 | 0.329 | 0.328 | 0.298 | 0.307 | 0.332 |
| 5000                | 0.323 | 0.302 | 0.299 | 0.308 | 0.322 | 0.357 | 0.384 | 0.401 | 0.414 |
| 6000                | 0.371 | 0.359 | 0.333 | 0.276 | 0.239 | 0.210 | 0.211 | 0.227 | 0.238 |

Table 3. The matrix of the positive and the negative ideal solution

| Chainage (m)/D (mm) | D_1  | D_2  | D_3  | D_4  | D_5  | D_6  | D_7  | D_8  | D_9  |
|---------------------|------|------|------|------|------|------|------|------|------|
| 0                   | 0.633 | 0.639 | 0.646 | 0.656 | 0.651 | 0.589 | 0.555 | 0.533 | 0.551 |
| Positive (Max)      | 0.633 | 0.639 | 0.646 | 0.656 | 0.651 | 0.589 | 0.555 | 0.533 | 0.551 |
Table 4. The matrix of the distance between the score for each alternative and the matrix of positive ideal solutions

| Chainage (m)/D (mm) | D₁   | D₂   | D₃   | D₄   | D₅   | D₆   | D₇   | D₈   | D₉   | D₁₀  |
|---------------------|------|------|------|------|------|------|------|------|------|------|
| 0                   | 0.158| 0.159| 0.157| 0.153| 0.137| 0.065| 0.038| 0.024| 0.017| 0.953|
| 500                 | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| 1000                | 0.185| 0.191| 0.191| 0.199| 0.203| 0.160| 0.158| 0.136| 0.135| 1.248|
| 1500                | 0.139| 0.134| 0.120| 0.114| 0.094| 0.069| 0.026| 0.029| 0.039| 0.874|
| 2000                | 0.192| 0.194| 0.187| 0.178| 0.156| 0.088| 0.058| 0.044| 0.040| 1.066|
| 4000                | 0.059| 0.059| 0.074| 0.090| 0.104| 0.069| 0.257| 0.051| 0.048| 0.901|
| 5000                | 0.096| 0.114| 0.120| 0.121| 0.108| 0.054| 0.029| 0.017| 0.019| 0.823|
| 6000                | 0.069| 0.078| 0.098| 0.144| 0.169| 0.144| 0.118| 0.094| 0.098| 1.036|

Table 5. The matrix of the distance between the score for each alternative and the matrix of a negative ideal solution

| Chainage (m)/D (mm) | D₁  | D₂  | D₃  | D₄  | D₅  | D₆  | D₇  | D₈  | D₉  | D₁₀ |
|---------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 0                   | 0.002| 0.002| 0.002| 0.003| 0.006| 0.021| 0.040| 0.027| 0.055| 0.396|
| 500                 | 0.192| 0.194| 0.191| 0.199| 0.203| 0.16  | 0.158| 0.136| 0.135| 1.173|
| 1000                | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    | 0    |
| 1500                | 0.004| 0.006| 0.008| 0.012| 0.021| 0.018| 0.056| 0.039| 0.028| 0.435|
| 2000                | 0    | 0    | 0    | 0    | 0.003| 0.011| 0.025| 0.025| 0.028| 0.303|
| 4000                | 0.038| 0.039| 0.027| 0.022| 0.016| 0.018 | 0.019 | 0.020 | 0.022 | 0.471 |
| 5000                | 0.016| 0.011| 0.008| 0.009| 0.015| 0.028| 0.051| 0.056| 0.053| 0.498|
| 6000                | 0.031| 0.026| 0.015| 0.005| 0.001| 0    | 0.003| 0.004| 0.003| 0.352|

Table 6. Determine the preference value for each alternative

| Chainage (m)/D (mm) | D₁   | D₂   | RCI  | Rank |
|---------------------|------|------|------|------|
| 0                   | 0.953| 0.396| 0.294| 5    |
| 500                 | 0    | 1.173| 1.000| 1    |
| 1000                | 1.248| 0    | 0    | 8    |
| 1500                | 0.874| 0.435| 0.332| 4    |
| 2000                | 1.066| 0.303| 0.221| 7    |
| 4000                | 0.901| 0.471| 0.343| 3    |
| 5000                | 0.823| 0.498| 0.377| 2    |
| 6000                | 1.036| 0.352| 0.254| 6    |

As per Table 6, the chainage 500 m has been ranked one based on RCI value as 1 that was very close to the positive ideal solution. This is followed by the chainage 5000 m has been ranked two that was the second-highest value of RCI as 0.377, the chainage 4000 m was ranked three having RCI value 0.343, the chainage 1500 m was ranked four because the RCI value of that chainage was 0.332, and the chainage 0 m, 6000 m, 2000 m, and 1000 m has been ranked five, six, seven and eight based on RCI value which was nearer to negative ideal solution. Chainage 2000 m and 1000 m have very poor PSQ as these have the least ranked.

4. Conclusion

Roads are the important infrastructure of any country because a country’s economic growth is supported by its transportation system. Road transport is the most widely adopted system of transportation. So, in addition to the wide and efficient road network, the quality of the roads should meet the standards laid by IRC. Due to the increased volume of traffic in recent years the pavement failure occurs in the form of potholes, isolated cracked areas, ruts, raveling, etc. Therefore, it is essential to ensure its surface quality periodically by suitable mechanical methods. In this context, Falling Weight Deflectometer (FWD) is used to determine the distresses of the pavement of Link road,
near Samrala Chowk, Ludhiana. For the analysis of FWD readings, the TOPSIS multi-criteria decision-making method is used to identify the PSQ of the Link road. On the basis of the study, it is found that

- The chainage 500 m has ranked one as the PSQ was good for this chainage and also resulted to very close to the positive ideal solution.
- This is followed by the chainage 5000 m, ranked two because the PSQ of this chainage was less good as compared to the chainage 500 m and then 4000 m, 1500 m, 0 m, 6000 m, 2000 m and 1000 m that was nearer to negative ideal solution.
- Chainage 2000 m and 1000 m has poor PSQ as these have the least ranked.
- This method also helps to make a decision regarding maintenance requirements according to pavement surface quality.
- As per the PSQ ranking, chainage 500 m required less maintenance than other chainage points.

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