Determining the priority criteria and ranking of provincial bridge maintenance in West Sumatra using a combination of the Fuzzy Analytical Hierarchy Process and VIKOR-Modification methods

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Abstract. There are many bridges that need to be maintained in a provincial road network, with limited funds for bridge maintenance, many bridge criteria (average daily traffic, economic benefits, fund budget, technical conditions, bridge hierarchy, spatial planning, flood potential, type of damage, erosion potential, age and surface concrete, etc.), and various levels of conditions, are a number of criteria that are taken into account in the decision making by the government as an institution responsible for the functioning of roads and bridges. The selection of bridge maintenance priorities in West Sumatra Province was decided through a coordination meeting between agencies, and sometimes relatively without going through sufficient technical analysis. This research initiated, the selected criteria to be taken into consideration, the order of the important criteria in the selected network segment. This study involved a number of road and bridge maintenance experts at the Ministry of Public Works, Road and Bridge Research and Development Institutions, as well as the Department of Public Works and Spatial Planning of West Sumatra Province. A combination of Fuzzy Analytic Hierarchy Process (to determine weighted criteria) and VIKOR-Modification methods (to determine the order of choice of bridges to be handled) are selected. There are eight criteria that can be used in determining the priority of bridge maintenance, and the priority sequence of the most important are: bridge technical conditions, aging of the bridge, average daily traffic, economic benefits, road function, budget, disaster risk (Flood, Landslides, Tsunamis) and Spatial Plans.

1. Introduction

Bridges are an important sections of the road infrastructure network, which becomes part of the passage of a vehicle in crossing a river, road or otherwise. The condition of the bridge must be maintained, which provides a safe way. Over time, due to usage, aging and other aspects, the existing bridges have been reduced in conditions. Regarding the maintenance of bridges, the limited of a budget is an important issue for the government, so that it is impossible for all bridges with less conditions to be handled at once period in a short time. So far the priority of selecting bridges, for
example: only decided through coordination meetings between relevant agencies without going through consideration and measurable technical analysis based on a number of variable conditions of the bridge, so that sometimes in determining which bridge should be repaired first, it is considered inappropriate choice. For this reason, priority handling is needed, so that the implementation of bridge maintenance is effective and efficient.

In 2017, the Department of Public Works and Spatial Planning (DPWSP) of West Sumatra Province recorded 612 bridges on 58 roads, which are part of the provincial road network, to maintain functions in accordance with the service requirements. But in the year was also recorded, were only 394 bridges (64%) with good condition, while 218 bridges (36%) with poor conditions [2]. With the number of hundreds of bridges that are not in a good condition, and with insufficient funding to carry out the maintenance and repair of existing bridges, it is necessary to analyze the criteria that represent the conditions and the right assessment in determining the choice of the bridge which must be prioritized to be handled first.

In bridge maintenance, various criteria are used as analysis parameters for appropriate decision making. The criteria used differ depending on needs. According to Directorate General of Highways, MPWPH [3] several criteria commonly used for bridges include: bridge conditions, bridge hierarchy, average daily traffic, budget funds, economic benefits, traffic conditions / impacts, conditions of strategic areas (spatial layout), types damage, strength of surface concrete, bridge aging, flood potential, erosion potential, maintenance costs, time / duration of work and emergency situation.

Previous research and the opinions of several experts on bridge maintenance in Indonesia, in certain areas sometimes there is a discrepancy in the choice of bridges to be maintained. This article tries to use the method by relying on the understanding of experts who have experienced working in bridge maintenance in Indonesia. The possibility of determining the criteria and priority choice of the bridge that will be chosen to be maintained first will be obtained. This article provides another perspective for decision makers in determining the choice of criteria and ranking for bridge maintenance.

2. Indonesian Bridge Maintenance System
Since 1993, the Ministry of Public Works and Public Housing (MPWPH) of the Republic of Indonesia used the Bridge Management System (BMS) method, which was adopted from the Australian BMS, to plan bridge maintenance activities.
Activities of the BMS starting from inspection, program planning and technical planning to implementation and maintenance, so that the bridge is in a safe condition to be passed [3]. This system makes it possible to make plans systematically and provide uniform procedures for all bridge activities at the National and Provincial levels with the help of the Management Information System (BMS-MIS). The Indonesia BMS component is shown in Figure 1. However, this system has not been implemented optimally, so that relatively many bridges are not maintained, rehabilitated and repaired [4]. A research is needed in determining the priority of handling bridges, so that priority outputs for handling bridges are precise.

3. Multi Criteria Decision Making
Multi Criteria Decision Making (MCDM) is a method of decision making to determine the best alternative from a number of alternatives based on certain criteria. Criteria can be in the form of measurements, rules or standards for making decisions. MCDM is classified into two categories [5]; Multi Attribute Criteria Decision Making (MADM) and Multi Objective Decision Making (MODM). MADM is used to explain the same class or category in the desk. Methods including MADM include Simple Adaptive Weighting (SAW), Weighted Product (WP), Analytical Hierarchy Process (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), VIšekriterijumsko Kompromisno Rangiranje (VIKOR); And, MODM is used to solve problems in continuous space. The method that includes is Fuzzy.

3.1. Fuzzy Analytic Hierarchy Process
One of the priority determination analysis methods that is often used is the AHP method. This method starts to be widely used by many researchers and decision makers, when Saaty [6] explained in detail the basic principles and stages of decision making. The problem of the complex will be formed into groups so that it becomes a hierarchical model. The main input of this method is human perception [7]. Edwin et al [8], have conducted on determining the priority of criteria in handling bridges of South Sumatra Province. The criteria used are five; that the order of criteria is average daily traffic, economic benefits, fund budget, technical conditions of bridges, bridge hierarchy. Sudradjat, et al [9] determined three criteria, and the weighting of criteria for consecutive considerations was: bridge
conditions, traffic and spatial planning. Bakamwesiga et al [10] conducted a similar study, used five criteria and criteria weighting sequentially from the highest value are; flood potential, type of damage, erosion potential, bridge age and strong surface concrete.

Although it has several advantages, the AHP method also has limitations, such as the dependence of the AHP model on its main input, the perception of an expert that sometimes tends to be subjective, or an expected expert who has many experiences related to things selected using the AHP method; besides that the model becomes meaningless if the expert gives a wrong assessment; only mathematical methods without statistical testing, so that there is no confidence limit from the correctness of the model formed. The weakness of the AHP method in determining priorities from the decision making of vague decision makers can be overcome by linguistic variables and Triangular Fuzzy Number (TFN).

Fuzzy Analytical Hierarchy Process (FAHP) is a combination of AHP method with Fuzzy concept approach. FAHP method focuses on the fuzzification of the previous pairwise comparison matrix on the AHP in the form of a classical number. The concept of fuzzy logic was first introduced by Zadeh [11]. Fuzzy means "blurred" or "vague". Fuzzy sets are the development of strict set theory (crisp). A firm set, has two possible memberships, namely being a member or not a member. Whereas, the fuzzy set has a fuzziness value. If the firm set knows black or white then in the fuzzy set can recognize black, gray and white. Each fuzzy set can be expressed by a membership function, which is a curve that shows the mapping of data input points into its membership value (membership degree) which has intervals between 0 and 1. Membership values are obtained through a function approach. There are several functions that can be used, including Linear, Trapezoid (Trapezoidal), and Triangle (Triangular) Representations [12]. In this case use the function of TFN which is used certainty denoted by (l; m; u) to describe linguistic variables. TFN is represented in the form of a triangular curve as in Figure 2.

![Figure 2. Triangular curve of TFN](image)

The linguistic variables used to make the pairwise comparisons were those associated with the standard 9-unit scale [13] that shown by Table 1. Number of researchers studied FAHP given the proof that FAHP gives more suitable description of this type of decision making process. One of the stages in the use of FAHP is the one compiled by Ahari, Ghaffari-Nasab, Makuib and Ghodsypour [14], where network structure is structured to define problems into the identification of existing dependency interaction relationships, so that the problem becomes clearer and more detailed. and weighting each element. Fuzzy logic helps to capture the fuzzy information in the minds of people and make them into crisp numbers despite the vagueness of human thought.

| Number of Preference (Numerical Value) | Definition (Verbal Scale) | Triangular Fuzzy Number | Reciprocal |
|---------------------------------------|---------------------------|-------------------------|------------|
| 1                                     | Equally Important (just equal) | (1, 1, 1)               | (1, 1, 1)  |
| 2                                     | Medium (Intermediate)      | (1/2, 1, 3/2)           | (2/3, 1, 2) |
| 3                                     | Moderately Important; weak preference of one over other | (1, 3/2, 2)           | (1/2, 2/3, 1) |
| 4                                     | Medium (Intermediate)      | (3/2, 2, 5/2)           | (2/5, 1/2, 2/3) |
| 5                                     | Strongly Important; essential or strong preference | (2, 5/2, 3)           | (1/3, 2/5, 1/2) |
| 6                                     | Medium (Intermediate)      | (5/2, 3, 7/2)           | (2/7, 1/3, 2/5) |
3.2. **VIKOR Analysis**

VIKOR is a decision-making technique that can optimize multicriteria problems. This method has an advantage in the ranking process by having a preference value for ranking and can overcome the ranking of conflicting criteria, and the results are closer to the ideal solution. In the VIKOR method the multicriteria rank index is based on consideration of the proximity between ideal and non-ideal alternatives [15]. In fuzzy VIKOR, to evaluate alternatives according to established criteria, we use linguistic variables [16] as in Table 2. Linguistic preferences can be converted to fuzzy numbers. The steps to complete the VIKOR method were used by the methods developed by Kaya and Kahraman [17].

| 7   | Very strongly Important; demonstrated preference | (3, 7/2, 4) |
|-----|--------------------------------------------------|-------------|
| 8   | Medium (Intermediate)                            | (7/2, 4, 9/2) |
| 9   | Extremely Important; absolute preference         | (4, 9/2, 9/2) |
| 2,4,6,8 | Intermediate values between the two judgements | (2/9, 1/4, 2/7) |

| Numeric Scale | Linguistic Variables | Fuzzy Value |
|---------------|----------------------|-------------|
| 1             | Very bad             | (0,0,1)     |
| 2             | Bad                  | (0,1,3)     |
| 3             | Bad enough           | (1,3,5)     |
| 4             | Medium               | (3,5,7)     |
| 5             | Pretty good          | (5,7,9)     |
| 6             | Good                 | (7,9,10)    |
| 7             | Very good            | (9,10,10)   |

4. **Method**

There were several stages were conducted,

1. The first stage is the identification of the necessary criteria to be considered, these criteria are obtained from previous studies of similar research literature. which here is a consequence of a semi-structured interview with bridge experts. Consideration of respondents is an expert (expert) who participate directly either directly or indirectly in the handling of bridges in the Road Area of West Sumatra Province. Based on the perception of 27 bridge experts, with details of thirteen from Ministry of Public Works, two from Research and Development Center and twelve from Department of Public Works and Spatial Planning of West Sumatera Province.

2. The sampling technique is used is Purposive Sampling, by determining the ways in which bridges in the West Sumatra Province are carried out.

3. Then compile comparisons between criteria on the AHP scale. FAHP has been used to determine the weights of a precise number of criteria selected from literature. Then the value is transformed to the TFN comparison scale (which consists of three numbers, namely l (lowest value), m (middle value) and u (highest value), which refers to the Chang scale [13].

   - After the mean value of l, m, u each criterion is obtained, it is arranged into a pairwise comparison matrix of the defuzzyfication results of the average paired comparisons of the expert.
   - Then form the normalization matrix W from the division of each element in matrix A.
   - Forming an AR matrix (mean line normalization matrix) "priority vector".
   - Specifies the "Number of Weight Vectors" by multiplying the "Origin Pairwise Comparison Matrix" with the "Normalized Eigenvector Vector" (multiplication matrix of element A with AR).
   - Calculate eigenvalues maximum value (λ max), value Consistency Index, Consistency Ratio, fuzzy synthesis value,
Add the rows for each criterion, the column for all criteria, determine the inverse of the column sum.
Calculating the degree of probability, calculating the ordinate value is the lowest value for each SC compared to other SCs.
Weight normalization vector.

4. Selecting of several bridges in West Sumatra provincial roads network.

5. The next stage is the VIKOR method, which is used to determine the order of alternative bridges to be maintained first:
   - Determine how to assess / score each criterion using secondary data,
   - Assessment results in the form of numeric numbers are transformed to TFN numbers and matrix,
   - Determine the best Fuzzy and worst Fuzzy values,
   - Calculate matrix normalization,
   - Multiplying the normalization matrix with the criteria weight,
   - Determine the utility measures of each alternative (Si and Ri),
   - Calculate the index value of VIKOR,
   - Determine the VIKOR index for each alternative examined,
   - TFN Qi deficiency and alternative priority by Qi index.

6. Priority sequence for bridge maintenance is obtained.

5. Analysis and Result
The data used consist of secondary data and primary data. Secondary data obtained from the Department of Public Works and Spatial Planning of West Sumatra Province that are BMS data; list of use of budget (DIPA) Bridge Rehabilitation Work and average daily traffic data 2014, 2015, 2017. While the Primary data were obtained from questionnaires conducted on 27 bridge experts. According to the bridge experts, the important criteria considered in making decisions for bridge maintenance from the analysis using a combination of F-AHP and VIKOR-modification methods in this study, there were eight criteria (Table 3). The analysis also ranks the priority criteria with the highest to lowest scores: Technical Conditions of Bridges (0.424), Bridge Age (0.211), Average Daily Traffic (0.156), Economic benefits (0.106), Road Functions (0.050), Budget funds (0.046), Disaster Impacts (Floods, landslides, Tsunamis) (0.004) and the last Spatial Condition (0.003), (hereafter eight criteria C1, C2, C3, C4, C5, C6, C7 and C8).

Table 3. Criteria selected

| Experts                                      | Number of expert | The order of the selected criteria                                                                 |
|----------------------------------------------|------------------|-----------------------------------------------------------------------------------------------------|
| Ministry of Public Works                     | 13               | technical condition, age of bridge, average daily traffic, economic benefits, road function, budget fund, disaster impact, spatial conditions |
| Research and Development Center              | 2                |                                                                                                    |
| Department of Public Works and Spatial Planning of West Sumatera Province | 12               |                                                                                                    |
| Total                                        | 27               |                                                                                                    |

For the application in this study, a number of Provincial Bridges in West Sumatra were reviewed. The selection of provincial road segments whose observations and data were collected, were adjusted to eight criteria. This study was conducted on a total of 12 (twelve) bridges, 10 (ten) bridges located at Link P.075 Ketaping - Pariaman Road and 2 (two) bridges located at Link P.028 Sicincin - Kurai Taji Road (both road segments are in Padang Pariaman Regency). This road section was chosen because it is a Provincial road which is an important segment for areas that are relatively vulnerable to some types of disasters and potential to occur in West Sumatra. Technical data from bridges on the road sections selected for analysis are shown in Table 4.
Table 4. List of bridges and technical data.

| Number | Segment Number | Segment Name | Bridge Name                  | Length (m) | Width (m) | Number of spans | Year Built |
|--------|----------------|--------------|------------------------------|------------|-----------|-----------------|------------|
| 1      | P.028          | Sicincin-    | Bari                         | 12.5       | 6.1       | 1               | 1986       |
| 2      |                | KuraI Taji   | Sampan                       | 69.8       | 6.0       | 2               | 1984       |
| 3      |                |              | Ketaping II                  | 6.1        | 7.1       | 1               | 2012       |
| 4      |                |              | Pauh II                      | 12.1       | 6.3       | 1               | 1986       |
| 5      |                |              | Ketaping                     | 30.6       | 6.0       | 1               | 1986       |
| 6      |                |              | Talua Busuak I               | 9.5        | 2.5       | 1               | 1984       |
| 7      | P.075          | Ketaping-    | Talua Busuak II              | 6.5        | 4.8       | 1               | 2014       |
| 8      |                | Pariaman     | Tiram                        | 60.8       | 6.0       | 1               | 2009       |
| 9      |                |              | Ulakan I                     | 41.0       | 7.0       | 2               | 2011       |
| 10     |                |              | Ulakan II                    | 16.6       | 7.0       | 1               | 2004       |
| 11     |                |              | Manggopoh                    | 14.0       | 5.0       | 2               | 2010       |
| 12     |                |              | Ujung                        | 60.8       | 6.0       | 1               | 1996       |
|        |                |              | Sunur                        |            |           |                 |            |

Source: [2]

The data were collected and obtained from the Department of Public Works and Spatial Planning of West Sumatra Province. The data collected consisted of: BMS data (year 2014, 2015, 2017), budget (DIPA) for provincial bridge maintenance in West Sumatra (year 2014-2017) and average daily traffic data (year 2014, 2015, 2017).

The criteria as the study result implemented to those bridges, so there will be rank of priority among those bridges. Then the twelve bridges selected were assessed for conditions for each criterion, of the eight criteria that had been sorted (Table 5). Determination of the value for each criterion in each bridge is based on the assessment of the bridge expert. The VIKOR method is used in the twelve bridge which has priority set. The hierarchical structure in determining bridge maintenance priorities is shown in Figure 3.

Table 5. List values for each criterion of the bridge

| Bridge Name           | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 |
|-----------------------|----|----|----|----|----|----|----|----|
| Bari                  | 2  | 4  | 1  | 3  | 1  | 1  | 5  |    |
| Ketaping              | 2  | 4  | 1  | 4  | 5  | 1  | 5  |    |
| Ketaping II           | 2  | 1  | 1  | 4  | 5  | 2  | 1  | 5  |
| Manggopoh Ujung       | 2  | 1  | 1  | 4  | 5  | 4  | 1  | 5  |
| Pauh II               | 2  | 4  | 1  | 4  | 5  | 1  | 1  | 5  |
| Sampan                | 2  | 4  | 1  | 3  | 5  | 6  | 1  | 5  |
| Sunur                 | 2  | 3  | 1  | 4  | 5  | 6  | 1  | 5  |
| Talua Busuak I        | 3  | 4  | 6  | 4  | 5  | 5  | 1  | 1  |
| Talua Busuak II       | 2  | 1  | 1  | 4  | 5  | 3  | 1  | 1  |
| Tiram                 | 2  | 1  | 1  | 4  | 5  | 3  | 3  | 3  |
| Ulakan I              | 2  | 1  | 1  | 4  | 5  | 2  | 1  | 3  |
| Ulakan II             | 2  | 2  | 1  | 4  | 5  | 4  | 1  | 3  |

Table 5 shows the value of each criterion of each bridge. The next step is to use the VIKOR Method to determine the priority order of the bridge that will be repaired first compared to the other bridges. The results of the analysis of the order of maintenance priorities from the twelve selected bridges are: beginning with the Bari bridge, and so on Sampan Bridge, Ketaping II, Pauh II, Ketaping Talua Busuak I, Talua Busuak II, Tiram, Ulakan I, Ulakan II, Manggopoh Ujung and finally Sanur bridge (Figure 3).
6. Conclusion

To determine criteria and priority order for bridge maintenance, various methods can be used, one of which may be relatively good is to use a combination of FAHP and VIKOR modification methods. From a number of possible criteria to be used as criteria for choosing a bridge that is prioritized to be repaired, then for the provincial bridge in West Sumatra eight criteria can be used. Of the eight criteria used in determining the priority of the bridge by FAHP analysis, the highest priority criteria were obtained, the Bridge Technical Conditions and the lowest weighting of Spatial Conditions, with the order from the highest to the lowest; Technical Conditions of Bridges, Bridge Age, Average Daily Traffic, Economic Benefits, Road Functions, Budget of funds, Impact of Disasters (Floods, landslides, Tsunamis), and finally Spatial Conditions. And get the order of the bridge selected to be repaired from a number of bridges in the road segment

The VIKOR method has provided convenience in determining the priority order of bridges to be repaired first compared to other bridges. The maintenance priorities from the twelve selected bridges are: beginning with the Bari bridge, and so on Sampan Bridge, Ketaping II, Pauh II, Ketaping Talua Busuak I, Tallua Busuak II, Tiram, Ulakan I, Ulakan II, Manggopoh Ujung and Sanur.

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