Analytical hierarchy process for mode choice model at Perumnas Palur, Karanganyar

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Abstract. The increasing need for transportation is influenced by the development of an area, including what happened at Perumnas Palur, Karanganyar. This residential area has a strategic location with many public facilities that easier people to do various movements with various modes of transportation. What mode is used by the Perumnas Palur society is inseparable from the criteria of mode choice. The linkage between the user reason criteria and the selection of these modes can be solved with an analytical hierarchy process (AHP). This study uses questionnaires that have been filled by the community selected as a sample. The questionnaire component includes travel characteristics and economic characteristics that are tailored to the conditions of the object. The dominance of the travel characters was obtained: motorcycle users (61%), work trips (44%), more than 5 trips per day (43%), 10-15 minutes of travel time (26%) and travel cost less than IDR 10,000 (43%). The percentage of mode types chosen according to the criteria of the reasons are Motorcycle (27%), Walking (26.6%), Car (18.5%), Bicycle (15%) and Bus (12.4%). The percentage of the vector priority each criterion of the reason is Safe (47.5%), Time (24%), Easy (17%), and Cost (11.5%).

1. Introduction
A model is a tool that can be used to accurately reflect and simplify a reality. The mode choice model is one of the four stages of the planning process, besides trip generation, distribution and route choice [1]. According to [2], there are several factors influencing the selection of modes, namely: characteristics of travelers, travel characteristics made, and characteristics of available transportation systems. Travel characteristics included travel destinations, distance, time, and travel expenses, departure times, weather conditions, and interconnection of different modes of transport [3].

The movements of people from origin to destination have different characteristics, generally affected by land use activities, and also car ownership. Sometimes, mode choice is also influenced by qualitative factors that are difficult to quantify. In this case, it could be analyzed by using the Analytical Hierarchy Process (AHP) method to describe multi-factor or criteria problems into a hierarchy [4]. Xi et al. [5] stated that AHP was a subjective assessment of decision makers using a combination of data between qualitative and quantitative analysis to help make decisions. Based on the above background, then the study of mode choice model at Perumnas Palur, Karanganyar is necessary.

Perumnas Palur is the first Perumnas in Central Java established around the 1975s. This study aims to determine the characteristics of travel, and socioeconomic conditions of people in the housing. In addition, the study also aims to create a mathematical model of AHP and determine the percentage...
of mode selection based on the criteria of reason. This study is expected to provide an overview of the use of AHP in modal mode analysis. This is evidence that factors influencing the selection of modes can be expressed either qualitatively or quantitatively.

2. Method
Decision-making with AHP can be divided into several steps, namely: define the problem, determine the desired solution, and create a hierarchical structure. This hierarchical structure was the composition of the network begins with the general goal, followed by the criteria and alternative options to be ranked. Networks were built on a comprehensive structure with regard to the issues to be developed [6]. The advantage of this method is the ability to combine qualitative and quantitative elements. Quantification of qualitative elements is done by providing a pair-wise comparison scaled perception. Comparisons are made on the judgment of the decision maker by assessing the level of importance of an element over other elements. The hierarchical structure used in this study can be seen in figure 1, whereas the rating scale is shown in table 1 and the process is shown in figure 2.

![Figure 1. The hierarchical structure.](image)

**Table 1. Scale of hierarchy assessment.**

| The intensity of interest | Definition of variable | Explanation |
|---------------------------|------------------------|-------------|
| 1                         | Equally important      | Both elements have the same effect |
| 3                         | Slightly more important| Assessment is slightly in favor of one element. |
| 5                         | More important         | Assessment is one-sided by one element. |
| 7                         | Very important         | Evidence that one of the elements is very influential and dominant |
| 9                         | Absolutely more important| Evidence that one element is more important than the others and very clear |
| 2, 4, 6, 8                | Middle rating between two scale options | A scale is given if there is doubt between two options |
| Reciprocal                |                        | If the comparison of elements i and j produces one of the values above then the comparison between the elements j to i will yield the inverse value |

The calculation process of the AHP method uses a comparison matrix (reciprocal) as shown in equation (1), ie if \( A_{ij} = a \), then \( A_{ji} = 1/a \). If \( A_i \) has the same interest with \( A_j \) then \( A_{ij} = A_{ji} = 1 \), for the special case, \( A_{ii} = 1 \) for all \( i \).

\[
A = \begin{bmatrix}
1 & a_{(1,2)} & \ldots & a_{(1,n)} \\
1/a_{(1,2)} & 1 & \ldots & a_{(2,n)} \\
\vdots & \vdots & \ddots & \vdots \\
1/a_{(1,n)} & 1/a_{(2,n)} & \ldots & 1
\end{bmatrix}
\] (1)
Figure 2. Analytical hierarchy process procedure.
The matrix in equation (1) is then normalized by dividing each element in a matrix into pairs with the total value of each column. The next step in the process of this analysis is: calculating the priority vector and checking for consistency. The procedure of AHP analysis can be seen in the following figure 2.

The data used in this study were collected from respondents in Perumnas Palur. Based on the data of Kelurahan Ngringo, the population of Perumnas Palur is about 1927 household. Referring to Slovin Formulas with 7.5% error rate, a minimum sample size was obtained. In this research, the total sample was 195 respondents.

\[
n = \frac{N}{1 + N(e)^2} = \frac{1927}{1 + (1927(0.075))^2} = \frac{1927}{11.839} = 162.762
\]

Where \(n\) = number of sample, \(N\) = number of population, and \(e\) = error tolerance.

3. Result and discussion
The characteristics of travel to be discussed are a number of the trip, type of destination trip, travel time, type of mode used, and travel cost. It was found 43% respondents made more than five trips a day, and around 44% dominant on a work trip. Travel time are dominated by the respondent with 10-15 minutes (26%), and majority using a motorcycle for their activities (61%). Besides above characteristic, this study also found that 14% of respondents have the lowest revenue (less than IDR 500,000), and 29% of them have more than IDR 2,500,000. The first step of the AHP process for the criterion is to set-up the matrix in pairs and then proceed it with the reciprocal matrix as shown in table 2. The values in table 2 are then normalized by dividing the elements of each column by the number of matrix columns (see table 3).

**Table 2. Reciprocal matrix of criteria of reasons**

|       | Safe  | Easy  | Cost  | Time  |
|-------|-------|-------|-------|-------|
| Safe  | 1.000 | 3.289 | 2.789 | 2.728 |
| Easy  | 0.304 | 1.000 | 2.316 | 0.483 |
| Cost  | 0.359 | 0.432 | 1.000 | 0.468 |
| Time  | 0.367 | 2.068 | 2.138 | 1.000 |
| Total | 2.029 | 6.789 | 8.243 | 4.679 |

**Table 3. Normalized matrix**

|       | Safe  | Easy  | Cost  | Time  |
|-------|-------|-------|-------|-------|
| Safe  | 0.493 | 0.484 | 0.338 | 0.583 |
| Easy  | 0.150 | 0.147 | 0.281 | 0.103 |
| Cost  | 0.177 | 0.064 | 0.121 | 0.100 |
| Time  | 0.181 | 0.305 | 0.259 | 0.214 |
| Total | 1.000 | 1.000 | 1.000 | 1.000 |

The next step after finding normalized matrix is to calculate the vector priority value of each criterion as follows:

\[
\text{Safe} = \frac{0.493 + 0.484 + 0.338 + 0.583}{4} = 0.475
\]
Data of the vector priority is then used to determine the weighting of each element. However, this value should be tested in advance as following steps:

Determining vector [K]

\[
[K] = \begin{bmatrix}
1.000 & 3.289 & 2.789 & 2.728 \\
0.304 & 1.000 & 2.316 & 0.483 \\
0.359 & 0.432 & 1.000 & 0.468 \\
0.367 & 2.068 & 2.138 & 1.000
\end{bmatrix} \times \begin{bmatrix}
0.475 \\
0.170 \\
0.115 \\
0.240
\end{bmatrix} = \begin{bmatrix}
(1.000 \times 0.475) + (3.289 \times 0.170) + (2.789 \times 0.115) + (2.728 \times 0.240) \\
(0.304 \times 0.475) + (1.000 \times 0.170) + (2.316 \times 0.115) + (0.483 \times 0.240) \\
(0.359 \times 0.475) + (0.432 \times 0.170) + (1.000 \times 0.115) + (0.468 \times 0.240) \\
(0.367 \times 0.475) + (2.068 \times 0.170) + (2.138 \times 0.115) + (1.000 \times 0.240)
\end{bmatrix} = \begin{bmatrix}
2.010 \\
0.698 \\
0.471 \\
1.013
\end{bmatrix}
\]

Finding the Eigen Value (E) by dividing vector [K] with the vector priority of reason criteria.

\[
[E] = \begin{bmatrix}
2.010/0.475 \\
0.698/0.170 \\
0.471/0.115 \\
1.013/0.240
\end{bmatrix} = \begin{bmatrix}
4.236 \\
4.096 \\
4.083 \\
4.226
\end{bmatrix}
\]

Above value then is used to calculate the average value of all elements, as follows:

\[
\lambda_{max} = \frac{4.236 + 4.096 + 4.083 + 4.226}{4} = 4.160
\]

Determining the index of consistency (CI).

\[
CI = \frac{\lambda_{max} - n}{n - 1} = \frac{4.160 - 4}{4 - 1} = 0.054
\]

Calculating the ratio of consistency (CR). To determine the value of CR, it is needed to know about the random index (RI) value that can be found from table 4 as follow.

**Table 4.** The value of RI [4]

| Matrix size (n) | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   |
|----------------|------|------|------|------|------|------|------|------|------|------|------|
| Random index (RI) | 0.00 | 0.58 | 0.90 | 1.12 | 1.24 | 1.32 | 1.41 | 1.45 | 1.49 | 1.51 |      |

\[
CR = \frac{CI}{RI} = \frac{0.054}{0.9} = 0.059 \leq 0.1
\]

Based on the value of CR, it can be stated that the value is adequate. Therefore, the vector priority can be used in the analysis. The percentage of the vector priority each criterion of the reason is Safe (47.5%), Time (24%), Easy (17%), and Cost (11.5%). Besides the AHP analysis conducted on the
criteria of reason, it was also conducted on the Mode Choice used. Using the same process of analysis, the results of mode selection are shown in table 5 – table 8.

**Table 5. The AHP analysis of mode choice based on safe criteria**

|          | Walking | Bicycle | Motorcycle | Car    | Buses | Vector Priority |
|----------|---------|---------|------------|--------|-------|-----------------|
| Walking  | 1.000   | 3.035   | 2.841      | 3.128  | 2.665 | 0.353           |
| Bicycle  | 0.329   | 1.000   | 2.807      | 0.327  | 0.339 | 0.139           |
| Motorcycle| 0.352   | 0.356   | 1.000      | 2.991  | 3.177 | 0.202           |
| Car      | 0.320   | 3.061   | 0.334      | 1.000  | 3.148 | 0.182           |
| Buses    | 0.375   | 2.949   | 0.315      | 0.318  | 1.000 | 0.124           |

$\lambda_{max} = 5.200$  $CI = 0.050$  $RI = 1.12$  $CR = 0.04$

**Table 6. The AHP analysis of mode choice based on easy criteria**

|          | Walking | Bicycle | Motorcycle | Car    | Buses | Vector Priority |
|----------|---------|---------|------------|--------|-------|-----------------|
| Walking  | 1.000   | 3.007   | 0.305      | 3.426  | 3.421 | 0.241           |
| Bicycle  | 0.333   | 1.000   | 0.266      | 3.310  | 3.073 | 0.157           |
| Motorcycle| 3.281   | 3.762   | 1.000      | 4.219  | 4.512 | 0.443           |
| Car      | 0.292   | 0.302   | 0.237      | 1.000  | 3.210 | 0.100           |
| Buses    | 0.292   | 0.325   | 0.222      | 0.312  | 1.000 | 0.059           |

$\lambda_{max} = 5.470$  $CI = 0.118$  $RI = 1.12$  $CR = 0.10$

**Table 7. The AHP analysis of mode choice based on cost criteria**

|          | Walking | Bicycle | Motorcycle | Car    | Buses | Vector Priority |
|----------|---------|---------|------------|--------|-------|-----------------|
| Walking  | 1.000   | 3.227   | 3.528      | 3.713  | 3.532 | 0.416           |
| Bicycle  | 0.310   | 1.000   | 3.419      | 3.830  | 3.429 | 0.262           |
| Motorcycle| 0.283   | 0.292   | 1.000      | 3.327  | 3.017 | 0.161           |
| Car      | 0.269   | 0.261   | 0.301      | 1.000  | 0.395 | 0.063           |
| Buses    | 0.283   | 0.292   | 0.331      | 2.532  | 1.000 | 0.098           |

$\lambda_{max} = 5.467$  $CI = 0.117$  $RI = 1.12$  $CR = 0.10$

**Table 8. The AHP Analysis of Mode Choice Based on Time Criteria**

|          | Walking | Bicycle | Motorcycle | Car    | Buses | Vector Priority |
|----------|---------|---------|------------|--------|-------|-----------------|
| Walking  | 1.000   | 0.170   | 0.142      | 0.148  | 0.250 | 0.038           |
| Bicycle  | 5.897   | 1.000   | 0.358      | 0.230  | 0.273 | 0.114           |
| Motorcycle| 7.026   | 2.794   | 1.000      | 2.070  | 2.027 | 0.356           |
| Car      | 6.756   | 4.342   | 0.483      | 1.000  | 3.016 | 0.311           |
| Buses    | 4.002   | 3.669   | 0.493      | 0.332  | 1.000 | 0.182           |

$\lambda_{max} = 5.457$  $CI = 0.114$  $RI = 1.12$  $CR = 0.10$
All values of vector priority each type of mode are recapitulated in a new matrix. This matrix is then multiplied by the result of vector priority of reason criteria as shown in table 9.

**Table 9. Recapitulation of the AHP Analysis of Mode Choice Based on Reason Criteria**

|      | Safe | Easy | Cost | Time | Vector Priority |
|------|------|------|------|------|-----------------|
| Walking | 0.353 | 0.241 | 0.416 | 0.038 | 0.475 × 1.075 |
| Bicycle | 0.139 | 0.157 | 0.262 | 0.114 | 0.170 |
| Motorcycle | 0.202 | 0.443 | 0.161 | 0.356 | 0.115 |
| Car | 0.182 | 0.100 | 0.063 | 0.311 | 0.240 |
| Buses | 0.124 | 0.059 | 0.098 | 0.182 | 0.124 |

The result of calculation on Table 9 can be presented as follows:

Walking = 0.353 Safe + 0.241 Easy + 0.416 Cost + 0.038 Time = 26.6%
Bicycle = 0.139 Safe + 0.157 Easy + 0.262 Cost + 0.114 Time = 15%
Motorcycle = 0.202 Safe + 0.443 Easy + 0.161 Cost + 0.356 Time = 27%
Car = 0.182 Safe + 0.100 Easy + 0.063 Cost + 0.311 Time = 18.5%
Buses = 0.124 Safe + 0.059 Easy + 0.098 Cost + 0.182 Time = 12.4%

Above result shows that the ranked of mode choice based on reason criteria are Motorcycle (27%), Walking (26.6%), Car (18.5%), Bicycle (15%) and Bus (12.4%).

4. Conclusion

The dominance of the travel characters in Perumnas Palur was obtained: motorcycle users (61%), work trips (44%), more than 5 trips per day (43%), 10-15 minutes of travel time (26%) and travel cost less than Rp10,000.00 (43%). The majority of respondents are housewives (26%) and the highest percentage of income is greater than Rp2,500,000.00 (29%). The percentage of mode types chosen according to the criteria of the reasons are Motorcycle (27%), Walking (26.6%), Car (18.5%), Bicycle (15%) and Bus (12.4%). The percentage of the vector priority each criterion of the reason is Safe (47.5%), Time (24%), Easy (17%), and Cost (11.5%).

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