Fuzzy AHP – DEMATEL Methods To Investigate Passengers' Decision Factors On Using Public City Bus In An Indonesian Region

by Editor Opsi

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ABSTRACT

An advanced public transportation system becomes an indicator for a country. Accordingly, it is essential that the decision-makers (DMs) conduct an initial study based on passengers' view in order to improve the public transportation services. Since involving multi factors, the problem is often solved using the multi-criteria decision-making (MCDM) approaches. This study aims to examine significant factors on passengers decision making to use public transportation using Fuzzy AHP and DEMATEL. The Fuzzy AHP method is proposed to determine criteria weights so that significant critera are obtained, then the causal relations including the criteria are visualized using DEMATEL. This study demonstrates the integration of the two MCDM methods in a BRT system in the region of Yogyakarta, Indonesia, and invites passengers and the DMs. The result indicated that 21 criteria are identified, while the 11 significant criteria are selected based on the Fuzzy AHP weight – α-cut screening. Besides, the DEMATEL has succeeded in describing the influence relationship for the criteria, where firstly, the significant criteria are classified into cause and effect group and secondly, the two criteria, namely coverage to strategic points and on time arrival, should be put on the top priority list. This study enables the DMs to solve public transportation problems more effectively. However, the follow-up study should be carried out by including other factors such as economic and sustainability to strengthen the decision-making process.

Keywords: public transportation; MCDM, Fuzzy AHP; DEMATEL

1. INTRODUCTION

In today's connected world, many countries have increased their commitment to massively provide adequate public transportation served to their people. This becomes a priority particularly in developing countries in which public awareness on using public transportation has not been an interest as well as poor infrastructure. In Indonesia, for instance, people in 2019 who use public transportation in the capital city which has the most connected transportation modes nationwide have only reached 30% of the 60% target despite an increase in passengers from 47.5 million per day in 2015 to 88 million per day in 2019 (Lova, 2019). On the other hand, there was a considerable growth in the number of private vehicles with an average increase of 10.58% for private cars and 5.07% for motorbikes between 2014 and 2018 (*Informasi Transportasi 2018*, 2019). This indicates that Indonesian people prefer to use private vehicles rather than to take public transportation.

Many factors have caused poor public interest, particularly in Indonesia, in using public transportation. Aminah (2018) stated that modest accessibility, service, and the high costs caused people to be reluctant to choose public modes. Further, Azali et al (2018) in the initial survey explained that uncertainty of time and lack of information were service factors which cannot be provided in a public transportation system in a city. In fact, there are many benefits when people use public transportation in terms of financial efficiency, environment risks reduction, and good impacts on people's health ("8 Keuntungan", 2019). Therefore, to support the decision-makers (DMs) to improve public access, this study aims to evaluate what key factors affect a passengers' decision when choosing public transportation and the relationship among these factors.

This study proposes multi-criteria decision-making (MCDM) approaches including fuzzy analytic hierarchy process (Fuzzy AHP) to determine the most significant passenger decision factors and the DEMATEL method to examine the causal relations among the significant factors illustrated by the digraph. Previously, MCDM methods have been taken by many scholars to evaluate the decision-making process in transportation sector. Zapolskytė et al (2020) evaluated the urban mobility system's smartness level using AHP. Moslem et al (2020) conducted a comparative study using the two MCDM methods, namely analytic hierarchy process (AHP) and best-first method (BWM), to obtain the significant service quality criteria of public transportation. The study involved four criteria at level 1 including service quality, transport quality, tractability, and fare, 14

criteria at level 2, and 10 criteria at level 3. The extended AHP for public transportation decision-making has also been carried out by Duleba and Moslem (2018) and Nassereddine and Eskandari (2017). Duleba and Moslem (2018) developed an AHP combined with Kendall rank to introduce a new model of public transportation development in a Turkish city involving three distinct stakeholders, which are: passengers, potential passengers, and local government. Meanwhile, Nassereddine and Eskandari (2017) assessed passengers' satisfaction level when using several transport modes in Tehran, such as metro, taxi, BRT bus, and van. Then, the study proposed group analytic hierarchy process (GAHP) and preference ranking organization method for enrichment of evaluation (PROMETHEE). By identifying six criteria, namely travel cost, travel time, waiting time, suitability, accesibility, and safety, the result indicated that metro was the most preferred mode.

More specific studies on public transportation performance evaluation using MCDM techniques have also been carried out by several researchers. Chen (2016) and Bakır et al (2019) evaluated the service quality performance for the airlines industries. Chen (2016) developed a case study in the Taiwanese airline industry using DEMATEL and ANP, while Bakır et al (2019) demonstrated for European LCCs (low cost carriers) using Entropy and WASPAS. Although there was a difference in defining criteria, several criteria were relevant for both studies such as service, management, and convenience. Another study undertaken by Kiani Mavi et al (2018) developed an integrated simulation and MCDM approach to improve BRT performance in Tehran with four improvement scenarios. The research considered grey step-wise weight assessment ration analysis (SWARA-G) to determine the criteria weight and grey complex proportional assessment of alternatives (COPRAS-G) to rank scenarios. Further study demonstrated in a rail mode conducted by Li et al (2020) evaluated passenger satisfaction level when taking the rail transit network in Shanghai using phytagorean fuzzy sets and multi-objective optimization by a ratio analysis plus full multiplicative form method (MULTIMOORA). Hence, many studies have considered that MCDM is both relevant and effective method for evaluating public transportation performance as well as assessing

passenger satisfaction because involving multiple criteria and alternatives for decision-making improvements.

To determine the criteria weight of passengers' decision factors, the AHP method extended to fuzzy sets is proposed in this study. Mardani et al (2016) in the systematic review involving 89 papers indicated that AHP and Fuzzy AHP are the most preferred method pertaining to transportation system problems. Further, Mardani et al (2016) described that the preference of these two methods is due to the simplicity of computation and theoritical understanding, while the fuzzy environment defines the ambiguity that cannot be explained in the traditional AHP. Subsequently, the DEMATEL method is also selected to describe the influential relationship among the significant criteria that are previously obtained using Fuzzy AHP. A case study on the bus rapid transit (BRT) system served for the region of Yogyakarta Indonesia, Transjogja, is demonstrated. The region has become one of the national tourist development priorities which serves a huge number of domestic and foreign tourists daily. Therefore, the region's public access has an essential part to provide a good urban mobility.

Previously, the evaluation of Transjogja performance have been conducted by several studies. Sutari and Herlina (2020) and Wibowo (2014) examined the service level of Transjogja using statistical approaches. Further, the servqual analysis has also been added by Sutari and Herlina (2020) which indicated a gap between passengers' expectations and reality. Besides, Transistari (2017) and Octaviantari (2016) evaluated the performance of BRT Transjogja using an importance-performance analysis (IPA) approach and classified the variables into four quadrants. Sutari and Herlina (2020) and Transistari (2017) identified five variables, which are: tangibles, reliability, responsiveness, assurance, and emphaty, while Octaviantari (2016) categorized 14 indicators into four variables, namely safety, comfort, affordability, and equality. To sum up, it can be concluded that the evaluation of the Yogyakarta's BRT system requires multi factors which are considered as an MCDM problem, while no previous studies has measured the performance of the transport system using the method. Therefore, this study will fill the gap by applying MCDM approaches to investigate the significant factors influencing passengers'

decision on using the city transportation system exhaustively.

2. METHOD

This research consists of two main scopes: first, to determine the criteria weights which represent the significant criteria of passenger decision-making when using the BRT system, and second, to examine the causal relations among the significant criteria. Then, there are four steps to achieve these two scopes: (1) identifying a hierarchical structure of the decision-making, (2) calculating the weight of criteria, (3) screening the criteria, and (4) developing causal relations through a digraph.

2.1. Calculating the weight of criteria using Fuzzy AHP

The Fuzzy AHP method is a technique developed from traditional AHP to solve complex decision-making problems since the method is able to cover AHP' crisp scales limitation through natural linguistic terms (Chou et al, 2019). The Fuzzy AHP calculation begins with converting crisp sets to fuzzy sets, and then calculating the weights using the geometrical mean as described in the following steps.

a. Defining the fuzzy traingular scales
The fuzzy numbers consist of three parameters, namely the lower (l), the mean (m), and the upper bonds (u). Accordingly, the corresponding AHP's fuzzy numbers is provided in Table 1 describing Saaty – fuzzy scales conversion according to the linguistic definition.

Table 1. Linguistic terms and the corresponding TFNs (Chou et al., 2019)

Saaty Scale	Definition	Fuzzy Triangular Scale
1	Equally important	(1,1,1)
3	Weakly important	(2,3,4)
5	Fairly important	(4,5,6)
7	Strongly important	(6,7,8)
9	Absolutely important	(9,9,9)
2	Intermittent values	(1,2,3)
4	between two adjacent	(3,4,5)
6	scales	(5,6,7)
8		(7,8,9)

b. Developing the fuzzy pairwise comparison matrices

The pairwise comparison matrice (1) indicates the elements of $\widetilde{d}$ in AHP fuzzy scales which represents k^{th} decision makers' preference of the ith criterion over the jth criterion.

$$\tilde{A}^k = \begin{bmatrix} \widetilde{d_{11}^k} & \widetilde{d_{12}^k} \cdots \widetilde{d_{1n}^k} \\ \widetilde{d_{21}^k} & \cdots \cdots \widetilde{d_{2n}^k} \\ \cdots & \cdots \cdots \\ \widetilde{d_{n1}^k} & \widetilde{d_{n2}^k} \cdots \widetilde{d_{nn}^k} \end{bmatrix} \qquad (1)$$

c. Calculating the fuzzy weight of criteria
The fuzzy weights is obtained using the geometrical technique (2) so that the fuzzy weights can be calculated using equation (3).

$$\bar{r}_i = \left(\prod_{j=1}^n \bar{d}_{ij}\right)^{1/n}, i = 1,2,\dots,n \qquad (2)$$
$$\bar{w}_i = \bar{r}_i \otimes (\bar{r}_1 \oplus \bar{r}_2 \oplus \dots \oplus \bar{r}_n)^{-1} \qquad (3)$$

d. Calculating the average and the normalized weight criteria
The normalized weight represents the criteria weight is calculated using equation (4).

$$M_i = \frac{\bar{w}_1 \oplus \bar{w}_2 \oplus \dots \oplus \bar{w}_n}{n} \qquad (4)$$
$$N_i = \frac{M_i}{M_1 \oplus M_2 \oplus \dots \oplus M_n} \qquad (5)$$

2.2. Screening the criteria

The next step is screening the criteria via the critera weight value obtained by the Fuzzy AHP and the threshold value, α-cut, calculated using equation (6) for n criteria. The criteria with weight value greater than the α-cut are then selected and represent the relatively important, while the unselected criteria are relatively unimportant (Yang et al 2020).

$$\alpha - cut = \frac{1}{n} \qquad (6)$$

2.3. Developing causal relations through a digraph

The DEMATEL method is proposed since the method is able to visualize a causal diagram describing the influential relations of the criteria. In this study, the DEMATEL is operated based on Shieh et al (2010) and Yazdani et al (2020) procedure.

a. Developing the initial direct relation matrix (A)
The initial stage of the DEMATEL method is generating an $n{\times}n$ direct-relation matrix (A). Both the DEMATEL and the AHP have the same first step which initially develop the

decision-making matrices representing the preference level between two criteria, while in the AHP, it is called the pairwise comparison. In this case, a total number of criteria, n, is the important criteria group selected from the screening step. Then, the DMs, for a second time, will give the influence score from 0 (no influence) to 4 (very high influence) between any two significant criteria.

$$A = \begin{bmatrix} 0 & a_{12} & \cdots & a_{1j} & \cdots & a_{1n} \\ a_{21} & 0 & \cdots & a_{2j} & \cdots & a_{2n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ a_{n1} & a_{n2} & \cdots & a_{nj} & \cdots & 0 \end{bmatrix} \quad (7)$$

b. Calculating the normalized direct-relation matrix (D)

The normalized direct-relation matrix (D) including elements ranged from 0 to 1 is calculated using equation (8).

$$D = A \times S \quad (8)$$

where

$$S = \frac{1}{\max\limits_{1 \le i \le n} \sum_{j=1}^{n} a_{ij}} \quad (9)$$

c. Calculating the total-relation matrix (T) and the sum of rows and columns of the matrix

The total-relation matrix (T) is obtained using equation (10) where I denotes the identity matrix.

$$T = D(I - D)^{-1} \quad (10)$$

Then, the sum of rows (R_i) and the sum of columns (C_j) are calculated using equation (11) and (12), respectively. The R_i and C_j values are the essential element to develop a causal diagram and to indicate whether the criteria belongs to either cause or effect group.

$$R_i = \left[\sum_{j=1}^{n} t_{ij} \right]_{n \times 1} = [t_i]_{n \times 1} \quad (11)$$

$$C_j = \left[\sum_{i=1}^{n} t_{ij} \right]_{1 \times n} = [t_j]_{1 \times n} \quad (12)$$

where

$$i = 1,2,\ldots,n \text{ and } j = 1,2,\ldots,n$$

d. Setting up a threshold value (α)

As described in the screening step, the threshold value in the DEMATEL method will

also determine the influence relations between two criteria. A threshold value, (α), is represented by the average of the elements in matrix T, while the selected influential relations are indicated by the element value that is greater than α value.

e. Visualizing causal relations

The causal relations among criteria are visualized through the digraph. The digraph is developed by mapping the horizontal or prominence, ($Ri+Cj$), and the vertical or relation, ($Ri-Cj$), values of all the significant criteria. In addition, the relation values will also classify the criteria into two groups, which are "cause" group with positive relation values and "effect" group indicated by negative relation values.

3. RESULT AND DISCUSSION

3.1. The passengers' decision-making criteria

Initially, the passengers' decision-making criteria are developed based on in-depth interview and several criteria identified by Kurniawan (2017). There are 21 criteria categorized into four dimensions: time (C_1), service level (C_2), accessibility (C_3), and reliability (C_4) as can be seen in Table 2.

3.2. The Fuzzy AHP decision-matrix for four dimensions

Secondly, all criteria weights for four dimensions are obtained using the geometrical mean technique as in equation (2). Fuzzy aggregated decision-matrices as described in the following tables are the result of linguistic scale conversion previously defined by the DMs. After the matrices are developed, the fuzzy weight for all criteria can be calculated as shown in Table 3 to Table 6 for time (C_1), service level (C_2), accessibility (C_3), and reliability (C_4), respectively.

Table 2. Criteria and the description of passengers' decision for Transjogja

Dimension	Criteria	Code
Time (C_1)	Travel time	C_{11}
	Time to the nearest bus stop	C_{12}
	Waiting time for the bus	C_{13}
	Time duration of arrival	C_{14}
	Total time for a trip (transit and travel)	C_{15}
Service level (C_2)	Convenience at the station	C_{21}
	Security at the station	C_{22}
	Availability of information at the station	C_{23}

Accessibility (C_3)		
	Convenience on the bus	C_{24}
	Safety on the bus	C_{25}
	Availability of information on the bus	C_{26}
Accessibility (C_3)	The number of bus stations	C_{31}
	The distance to the station from the origin	C_{32}
	Route coverage	C_{33}
	The distance from the station to the destination	C_{34}
	The stations' coverage to strategic points	C_{35}
	Cross-route accessibility	C_{36}
Reliability (C_4)	On time departure	C_{41}
	Reliable payment system	C_{42}
	On time arrival	C_{43}
	Certainty of service	C_{44}

Table 3. The fuzzy aggregated decision-matrix of Criteria (C_1)

	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	**Fuzzy Weight**
C_{11}	(1,1,1)	(3.80,4.34,4.89)	...	...	(1.66,1.94,2.22)	(0.19,0.23,0.28)
C_{12}	(0.94,1.12,1.33)	(1,1,1)	...	...	(1.11,1.26,1.41)	(0.11,0.13,0.17)
C_{13}	...	...	...	...	...	(0.15,0.18,0.22)
C_{14}	...	...	...	...	...	(0.17,0.21,0.25)
C_{15}	(2.02,2.30,2.60)	(3.60,4.00,4.42)	...	...	(1,1,1)	(0.21,0.24,0.29)

Table 4. The fuzzy aggregated decision-matrix of Criteria (C_2)

	C_{21}	C_{22}	C_{23}	C_{24}	C_{25}	C_{26}	**Fuzzy Weight**
C_{21}	(1,1,1)	(1.41,1.58,1.78)	...	...	...	(1.83,2.21,2.60)	(0.13,0.16,0.19)
C_{22}	(2.06,2.26,2.47)	(1,1,1)	...	...	...	(3.01,3.45,3.90)	(0.16,0.19,0.23)
C_{23}	...	...	...	...	...	...	(0.08,0.10,0.12)
C_{24}	...	...	...	...	...	...	(0.14,0.17,0.21)
C_{25}	...	...	...	...	...	...	(0.19,0.23,0.27)
C_{26}	(2.18,2.57,2.98)	(1.67,1.92,2.17)	...	...	...	(1,1,1)	(0.13,0.15,0.19)

Table 5. The fuzzy aggregated decision-matrix of Criteria (C_3)

	C_{31}	C_{32}	C_{33}	C_{34}	C_{35}	C_{36}	**Fuzzy Weight**
C_{31}	(1,1,1)	(2.99,3.50,4.02)	...	...	...	(1.61,1.82,2.03)	(0.16,0.20,0.26)
C_{32}	(0.80,0.95,1.12)	(1,1,1)	...	...	...	(1.49,1.70,1.91)	(0.12,0.15,0.19)
C_{33}	...	...	...	...	...	...	(0.11,0.14,0.17)
C_{34}	...	...	...	...	...	...	(0.14,0.17,0.22)
C_{35}	...	...	...	...	...	...	(0.13,0.17,0.21)
C_{36}	(1.96,2.23,2.51)	(2.27,2.62,2.97)	...	...	...	(1,1,1)	(0.14,0.17,0.21)

Table 6. The fuzzy aggregated decision-matrix of Criteria (C_4)

	C_{41}	C_{42}	C_{43}	C_{44}	**Fuzzy Weight**
C_{41}	(1,1,1)	(2.05,2.39,2.74)	(1.21,1.39,1.56)	(2.25,2.67,3.09)	(0.20,0.24,0.29)
C_{42}	(2.56,2.71,2.87)	(1,1,1)	(0.95,1.20,1.46)	(1.09,1.24,1.40)	(0.16,0.20,0.24)
C_{43}	(2.46,2.74,3.01)	(2.89,3.30,3.74)	(1,1,1)	(3.46,3.86,4.26)	(0.28,0.34,0.40)
C_{44}	(1.99,2.27,2.55)	(1.93,2.17,2.41)	(1.42,1.54,1.67)	(1,1,1)	(0.19,0.23,0.27)

3.3. Global rank and criteria screening

Global weights for 21 criteria are calculated using equation (5) reported by Table 7. After the weights are obtained, the screening step is achieved by comparing the weight and α-cut values for each dimension. The α-cut values are calculated using equation (6) where α-cut for C_1, C_2, C_3, and C_4 are respectively 0.200, 0.167, 0.167 dan 0.250. The significant criteria are indicated when the weight of corresponding criteria is greater than the threshold so that the critical factors for time dimension are C_{11} dan C_{15}, service level are C_{22}, C_{24}, and C_{25}, accessibility are C_{31}, C_{34}, C_{35}, and C_{36}, and reliability are C_{43}. The total number of the significant criteria achieved by screening step is 11 criteria which indicate that passengers conern

on these criteria when deciding to use the BRT system.

3.4. Matrices for the DEMATEL

Table 8 shows the initial direct-relation matrix of 11 significant criteria. The elements in matrix A indicate the level of influence between the two criteria. For instance, the C_{11} criterion has a very high influence on C_{43}. Further, the matrix A includes significant criteria of four distinct dimensions so that a higher influence will be indicated by the criteria that have the different dimension. For instance, the criterion of travel time, C_{11}, has a low influence on the criteria of C_{14} and C_{15} since these comparisons are from the same dimension, C_1. Meanwhile, higher influences will be experienced when C_{11} is compared to the criteria in different dimensions such as C_{24}, C_{34}, C_{35}, C_{36}, and C_{43} which indicate very high influences, although it is still possible to obtain low influences even no influence depends on the DMs' assessment.

Subsequently, the normalized direct-relation matrix (D) is developed using equation (8) as reported in Table 9, while Table 10 shows the total-relation matrix (T) calculated using equation (10). The elements in matrix T are obtained by multiplying elements in matrix D, Table 9, with the identity matrix (I) for the 11×11 matrix.

Tabel 7. Criteria weights and screening result based on the α-cut

Dimension	Criteria	Weight	Dimension	Criteria	Weight
Time (C_1)	C_{11}	0.230*	Accessibility (C_3)	C_{31}	0.203*
	C_{12}	0.134		C_{32}	0.149
	C_{13}	0.183		C_{33}	0.138
	C_{14}	0.209*		C_{34}	0.173*
	C_{15}	0.244*		C_{35}	0.167*
				C_{36}	0.169*
	α-cut	0.200		α-cut	0.167
Service level (C_2)	C_{21}	0.156	Reliability (C_4)	C_{41}	0.239
	C_{22}	0.190*		C_{42}	0.196
	C_{23}	0.098		C_{43}	0.336*
	C_{24}	0.174*		C_{44}	0.229
	C_{25}	0.228*			
	C_{26}	0.154			
	α-cut	0.167		α-cut	0.250

*weight value is greater than the α-cut

Tabel 8. The initial direct-relation matrix (A) for the significant criteria

	C_{11}	C_{14}	C_{15}	C_{22}	C_{24}	C_{25}	C_{31}	C_{34}	C_{35}	C_{36}	C_{43}
C_{11}	0	1	1	3	4	0	2	4	4	4	4
C_{14}	1	0	1	2	3	1	1	3	4	4	4
C_{15}	1	2	0	3	4	1	2	4	4	4	4
C_{22}	1	1	2	0	3	1	0	3	4	4	4
C_{24}	1	1	2	0	0	1	1	1	4	3	4
C_{25}	0	1	1	3	4	0	2	4	4	4	4
C_{31}	1	0	1	1	3	1	0	3	4	4	4
C_{34}	1	1	2	0	0	1	1	0	4	3	4
C_{35}	2	1	2	1	0	1	1	0	0	0	4
C_{36}	2	1	2	1	0	1	1	0	4	0	4
C_{43}	3	3	2	4	4	3	3	4	4	4	0

Tabel 9. The normalized direct-relation matrix (D) for the significant criteria

	C_{11}	C_{14}	C_{15}	C_{22}	C_{24}	C_{25}	C_{31}	C_{34}	C_{35}	C_{36}	C_{43}
C_{11}	0.000	0.029	0.029	0.088	0.118	0.000	0.059	0.118	0.118	0.118	0.118
C_{14}	0.029	0.000	0.029	0.059	0.088	0.029	0.029	0.088	0.118	0.118	0.118
C_{15}	0.029	0.059	0.000	0.088	0.118	0.029	0.059	0.118	0.118	0.118	0.118
C_{22}	0.029	0.029	0.059	0.000	0.088	0.029	0.000	0.088	0.118	0.118	0.118
C_{24}	0.029	0.029	0.059	0.000	0.000	0.029	0.029	0.029	0.118	0.088	0.118
C_{25}	0.000	0.029	0.029	0.088	0.118	0.000	0.059	0.118	0.118	0.118	0.118
C_{31}	0.029	0.000	0.029	0.029	0.088	0.029	0.000	0.088	0.118	0.118	0.118

C_{34}	0.029	0.029	0.059	0.000	0.000	0.029	0.029	0.000	0.118	0.088	0.118
C_{35}	0.059	0.029	0.059	0.029	0.000	0.029	0.029	0.000	0.000	0.000	0.118
C_{36}	0.059	0.029	0.059	0.029	0.000	0.029	0.029	0.000	0.118	0.000	0.118
C_{43}	0.088	0.088	0.059	0.118	0.118	0.088	0.088	0.118	0.118	0.118	0.000

Tabel 10. The total-relation matrix (T) for the significant criteria

	C_{11}	C_{14}	C_{15}	C_{22}	C_{24}	C_{25}	C_{31}	C_{34}	C_{35}	C_{36}	C_{43}
C_{11}	0.097	0.110	0.137	0.184	0.232	0.078	0.142	0.239	0.334	0.286	0.334
C_{14}	0.116	0.074	0.125	0.150	0.194	0.099	0.108	0.200	0.311	0.268	0.311
C_{15}	0.131	0.143	0.116	0.193	0.244	0.112	0.149	0.251	0.352	0.302	0.352
C_{22}	0.113	0.102	0.150	0.093	0.191	0.097	0.079	0.196	0.304	0.262	0.304
C_{24}	0.099	0.089	0.131	0.081	0.092	0.085	0.094	0.124	0.267	0.207	0.267
C_{25}	0.097	0.110	0.137	0.184	0.232	0.078	0.142	0.239	0.334	0.286	0.334
C_{31}	0.109	0.069	0.118	0.115	0.183	0.093	0.074	0.189	0.294	0.253	0.294
C_{34}	0.096	0.086	0.127	0.079	0.089	0.082	0.092	0.092	0.259	0.201	0.259
C_{35}	0.108	0.076	0.111	0.096	0.083	0.072	0.081	0.086	0.123	0.106	0.228
C_{36}	0.121	0.085	0.124	0.107	0.093	0.080	0.090	0.096	0.255	0.118	0.255
C_{43}	0.196	0.180	0.187	0.238	0.271	0.175	0.189	0.279	0.393	0.337	0.288

3.5. The causal relations described by influential matrix and digraph

Table 11 provided components of digraph, namely the horizontal axis, ($Ri+Cj$), and the vertical axis, ($Ri-Cj$). The value of R_i and C_j is the sum of the rows and the columns of the matrix T as described in equation (11) and (12). Furthermore, the significant criteria are categorized into two groups, namely cause group and effect group. The determination of the criteria group is based on the value of the vertical axis which represents the "relation" value provided that the positive relation value is included to the cause group while the negative relation value belongs to the effect group.

As can be seen in Table 11, there are six criteria that are classified into cause group, which are: C_{11}, C_{14}, C_{15}, C_{22}, C_{25}, and C_{31}, and five criteria included in effect group, namely C_{24}, C_{34}, C_{35}, C_{36}, and C_{43}. All time dimension (C_1) criteria are causal criteria as the time is deemed an essential reason when passengers using Transjogja service; meanwhile, although most of the criteria on the accessibility (C_3) are the effect group, the number of bus stations (C_{31}) is also a contributing factor when the bus service may be improved including the ability to reach destination more efficiently as well as service

reliability. Then, the criteria relationship mapping can be determined based on threshold value, α, and the elements in matrix T. The threshold value obtained is 0.171 and the elements in the matrix T will represent an influential relationship when the value is greater than the threshold. For instance, the C_{11} has influences on six other criteria, which are: C_{22}, C_{24}, C_{34}, C_{35}, C_{36}, and C_{43}, since the values of C_{11} to C_{22}, C_{11} to C_{24}, C_{11} to C_{34}, C_{11} to C_{35}, C_{11} to C_{36}, and C_{11} to C_{43} are respectively 0.184, 0.232, 0.239, 0.334, 0.286, 0.334. The influential relations mapping for the 11 criteria is shown in Table 12.

As seen in Table 12, the criteria of C_{35} and C_{43} are both criteria with an asterisk indicating that these two criteria are the key factors which have the maximum effect value over the other criteria. Moreover, both criteria are the key effect criteria as the criteria will be highly considered from the other criteria levels. In a decision-making practice, the DMs are advised to consider these two criteria, namely coverage to strategic locations and on time arrival, when improving the quality of the Transjogja service, especially on time arrival which may not only effect receiver but also bring significant effect to all criteria as illustrated in Figure 1.

Tabel 11. The group for the significant criteria

Code	Criteria	$Ri+Cj$	$Ri-Cj$	Group
C_{11}	Travel time	3.455	0.889	Cause
C_{14}	Time duration of arrival	3.081	0.834	Cause
C_{15}	Total time for a trip (transit and travel)	3.808	0.886	Cause
C_{22}	Security at the station	3.409	0.372	Cause
C_{24}	Convenience on the bus	3.437	-0.371	Effect
C_{25}	Safety on the bus	3.224	1.120	Cause
C_{31}	The number of bus stations	3.030	0.551	Cause

C_{34}	The distance from the station to the destination	3.450	-0.529	Effect
C_{35}	The stations' coverage to strategic points	4.396	-2.056	Effect
C_{36}	Cross-route accessibility	4.052	-1.201	Effect
C_{43}	On time arrival	5.958	-0.494	Effect

Coverage to strategic locations and on time arrival criteria are critical reasons for passengers choosing Transjogja since initially passengers may review whether their destinations are within coverage, even due to the tourist region, tourists will consider some tourist attractions' access. Thus, to increase the number of coverages, the DMs are required to evaluate the other significant factors such as the factor for time, comfort and safety, the number of fleets, and cross-lane integration. In addition, the on time arrival criterion experiences the most extreme prominence value of 5.958; moreover, this criterion has also the highest weight of 0.336 as reported in Fuzzy AHP. This indicates that on time arrival is a fundamental parameter which represents all dimensions of passengers' decision. Although C_{43} belongs to the effect group, the degree of relation is not as extreme as C_{35} which hit a low of -2.056 so that in the digraph the C_{43} has significant influences on all

criteria. Hence, the DMs can improve the Transjogja's performance to be the most preferred public transportation in the region by evaluating 11 significant criteria out of the 21 identified criteria, especially the two criteria, namely coverage to strategic destinations and on time arrival, put as top priority.

Tabel 12. Influential relationship for 11 criteria

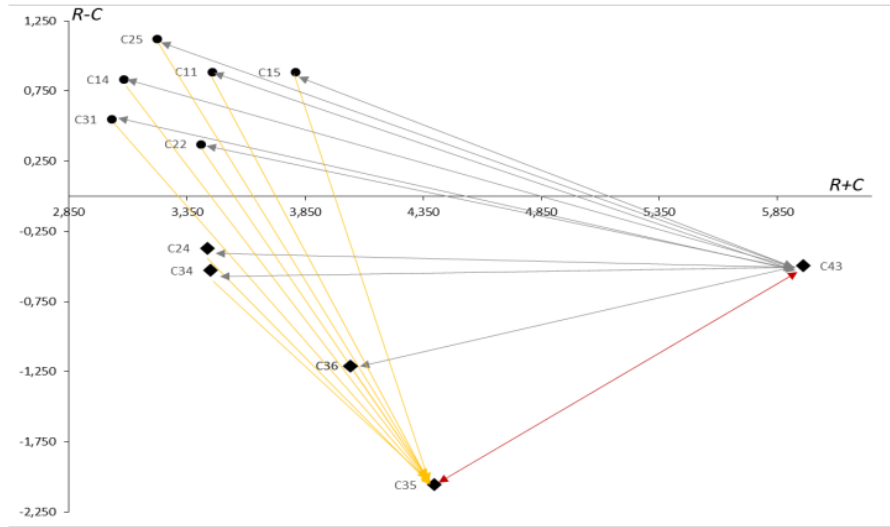| Causal relations		
C_{11}	→	$C_{22},C_{24},C_{34},C_{35}^{*},C_{36},C_{43}^{*}$
C_{14}	→	$C_{24},C_{34},C_{35}^{*},C_{36},C_{43}^{*}$
C_{15}	→	$C_{22},C_{24},C_{34},C_{35}^{*},C_{36},C_{43}^{*}$
C_{22}	→	$C_{24},C_{34},C_{35}^{*},C_{36},C_{43}^{*}$
C_{24}	→	$C_{35}^{*},C_{36},C_{43}^{*}$
C_{25}	→	$C_{22},C_{24},C_{34},C_{35}^{*},C_{36},C_{43}^{*}$
C_{31}	→	$C_{24},C_{34},C_{35}^{*},C_{36},C_{43}^{*}$
C_{34}	→	$C_{35}^{*},C_{36},C_{43}^{*}$
C_{35}	→	C_{43}^{*}
C_{36}	→	C_{35},C_{43}^{*}
C_{43}	→	$C_{11},C_{14},C_{15},C_{22},C_{24},C_{25},C_{31},C_{34},C_{35}^{*},C_{36},C_{43}$

*significant influences

Figure 1. The digraph for the two-priority criteria, C_{35} dan C_{43}

4. CONCLUSION

In conclusion, this study provides a comprehensive result for evaluating the performance of the BRT system demonstrated in a case study of Transjogja with the decision-making approaches. First, this study succeeded in selecting significant criteria from many identified criteria, and second, this study also elaborates the relationship among these key criteria so that it is able to provide an advice to decision-makers if improvements to Transjogja service are needed. The result indicates that there are 11 out of 21 criteria that have a significant value, while from these significant criteria, the DMs can prioritize coverage to strategic points and on time arrival to improve

the BRT performance. The improvement in these key indicators supports the government to encourage passengers, especially in the region of Yogyakarta, to take Transjogja with many benefits.

Although this research can investigate decision-making factors in terms of service aspect, other parameters such as economic and environmental aspect should be added to future research. Additional discussion from other factors is believed to strengthen the DMs' policies to improve public transportation services and to increase the number of passengers; further, a decision-making standard that can be implemented in other regions may be achieved.

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