Sustainable Transportation and the Role of Intuitionistic Fuzzy Optimization

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Abstract. Developing environmentally friendly transportation that is affordable, secure, and simple to use is what is meant by sustainable transportation development. One of the best strategies to reduce the usage of private vehicles is to restructure the routes of public transportation. In order to reduce the uncertainty that might be present in the data, the problem of finding the transit route was solved using an intuitionistic fuzzy technique with interval values. The decision maker can develop a transportation route that reduces the number of private automobiles on the road in order to get to sustainable transportation as soon as possible by using intuitionistic fuzzy optimization. A straightforward case study produced a number of ideal routes to the nearby public facilities.

Keywords: public transportation · optimization · interval value · intuitionistic fuzzy · reroute

1 Introduction

Undoubtedly, one of the key infrastructures required for the growth of the economy and industry is transportation. It also contributes significantly to CO2 emissions and greenhouse gas emissions. Due to its low cost, high flexibility, and quick response time, road transportation continues to be heavily relied upon by businesses despite advancements in air, sea, and train transportation. The environmental effects of many businesses as a whole, and specifically transportation pollution, should no longer be disregarded as a threat, and immediate and appropriate studies as well as actions should be considered in order to address this situation [2].

Transformation towards sustainable transport calls for integrated approaches that unite multiple stakeholders around shared objectives. Such approaches should promote holistic, end-to-end analysis of different dimensions, including vulnerability risks and environmental impacts, that can help identify and develop integrated solutions. Sustainable solutions are often multimodal in optimally integrating the relative advantages of different transport modes. Sustainable development depends on sustainable transportation, which has the following goals: universal access, improved safety, less environmental and climate impact, improved resilience, and increased efficiency.

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However, changing habits is not easy. Current community mobility dominate by private vehicles, which still consume gasoline. Bicycle use is still limited and not widely used in urban areas. Electric vehicles need more cost to realize. Sustainable Transport is one way that can do today to achieve green transportation. Bjorklund [3] defines *Green Transportation* as a Transportation service with a lesser or reduced negative impact on human health and the natural environment compared to competing transportation services that serve the same purpose. By implementing sustainable transportation that supports the achievement of green transportation, people's quality of life will be better.

The research of Sbihi and Eglese [4] and Palmer's Ph.D. dissertation [5] appear to be where the public's understanding of the vehicle routing problem's contribution to green transportation began. Sbihi and Eglese examine the literature on vehicle routing in a working paper for the Lancaster University Management School [4] to determine the connection between scheduling and green logistics and vehicle routing. They cannot discover much literature that connects models with Green Logistics difficulties, but they do provide an introduction to green logistics challenges applicable to vehicle routing and scheduling, including a discussion of the environmental objectives. The existing literature, however, contends that cutting back on overall mileage will assist the environment because less fuel will be used, which means fewer pollutants produced [5].

The data used is the main problem in scheduling or determining transportation routes. Many approaches use to maximize the data to fit actual conditions. However, because the data strongly influence by the road network condition that continues to change, the solutions provided are less than optimal.

Intuitionistic fuzzy sets were first suggested by Atanassov [6] in 1986, and they soon rose to the top of many optimization discussions. Many scholars implemented intuitionistic fuzzy in discrete modeling, particularly [7–10], to produce a visible answer. In this study, the road network will be modeled using interval-valued intuitionistic fuzzy to reroute public transit. [9, 10] have applied intervals valued in intuitionistic fuzzy to improve the uncertainty data. According to Broumi [17], because there are several alternatives in the solution, the interval value in intuitionistic fuzzy provides a more relevant and workable solution to the actual problem that is solved.

2 Methods

As an iconic district in Jawa Timur, Jombang was famous for Kota Santri, which means Jombang is a center for learning religious knowledge. More generally, this icon shows that Jombang is a symbol of a learning city where students from all over Indonesia and even the world can come. For Jombang itself, there are differences in the number of schools at each level for each district. This condition requires students who will continue their studies to move to another sub-district which, of course, requires transportation. BPS Jombang data [12] shows that the difference in the number of schools at each level and the existence of schools is quite significant (see Fig. 1).

For elementary and junior high school students, parents will drop and pick them up from school if it is not possible to reach the school by bicycle. While for high school students, the majority use private vehicles in the form of motorbikes for school. With the condition of the school centrally located in the Jombang sub-district, one can imagine the traffic jams caused by the daily routine of going to and returning from school. Furthermore, this becomes a severe problem because of the number of accidents and the number of students' mobility every day.

Public transportation in Jombang is not running optimally. From 22 routes until now, only six routes operate [11], with a long waiting time. This condition certainly needs to be a concern of the district government because with the increasing number of private vehicle users, traffic in Jombang district, the city center especially, will become congested during peak hours [11]. The main contributing factor is people's tendency to use personal or online transportation[12].

Green transportation in Jombang can be realized more quickly with sustainable transportation. So it is necessary to do a study on determining the route again to optimize the role of public transportation in Jombang [11]. If public transportation can run optimally, then private transportation will be reduced, and traffic will be more orderly. As mentioned

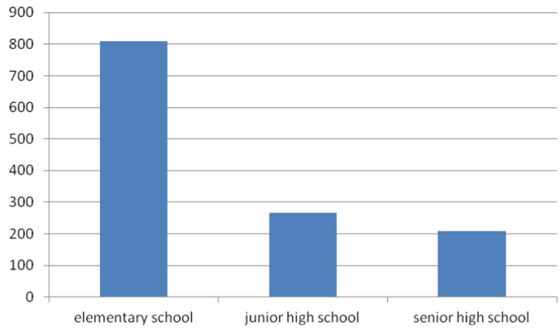

Fig. 1. School amount at every level in Jombang.

Table 1. Subdistrict as Vertices in Transportation Network.

vertex	subdistrict	status	vertex	subdistrict	status
1	Kabuh		12	Sumobito	
2	Plandaan		13	Perak	
3	Ploso	center	14	Diwek	center
4	Kudu		15	Jogoroto	
5	Ngusikan		16	Mojoagung	center
6	Megaluh		17	Gudo	
7	Tembelang	center	18	Ngoro	center
8	Kesamben		19	Mojowarno	
9	Bandar Kedung Mulyo	center	20	Bareng	
10	Jombang	center	21	Wonosalam	center
11	Peterongan		**total center**		**8**

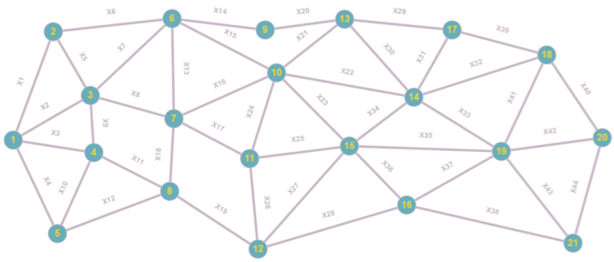

Fig. 2. Transportation Network in Jombang.

in BPS Jombang data [12], Jombang has 21 subdistricts that must be reached by public transportation as in Table 1. Figure 2 shows the transportation network in Jombang that will use in this study. There are seven subdistricts as a center that have better facilities for the public in the surrounding. Those subdistricts not only have a famous and good schools at every level but also have better health centers, markets, and other facilities. Here, those eight subdistricts will use as an end of the public transportation route.

Definition 1. [13] An intuitionistic fuzzy set is a fuzzy set A in space E so that

$$A = \{(x, \mu_A(x), \nu_A(x))|x \in E\}$$

where $\mu_A : E \to [0, 1]$, $\nu_A : E \to [0, 1]$ in which $\mu_A(x)$ is the membership function that show the possibility that x belongs to set A and $\nu_A(x)$ is the nonmembership function that show the possibility that x does not belong to set A

$$0 \leq \mu_A(x) + \nu_A(x) \leq 1$$

Here the pair value $(\mu_A(x), \nu_A(x))$ is called intuitionistic fuzzy number of element x in set A.

Definition 2. [14] Let $\overline{A}$ be an intuitionistic trapezoidal fuzzy number, and its membership function is

$$\mu_{\overline{A}}(x) = \begin{cases} \frac{x-a}{b-a}\mu_{\overline{A}}, \ a \leq x \leq b; \\ \mu_{\overline{A}}, \ b \leq x \leq c; \\ \frac{d-x}{d-c}\mu_{\overline{A}}, \ c \leq x \leq d; \\ 0, \quad \text{others} \end{cases}$$

Its nonmembership function is

$$\nu_{\overline{A}}(x) = \begin{cases} \frac{b - x + \nu_{\overline{A}}(x - a_1)}{b - a_1}, \ a_1 \leq x \leq b; \\ \nu_{\overline{A}}, \quad b \leq x \leq c; \\ \frac{x - c + \nu_{\overline{A}}(d_1 - x)}{d_1 - c}, \ c \leq x \leq d_1 \\ 1, \ \text{others} \end{cases}$$

where $0 \leq \mu_{\overline{A}} \leq 1;\ 0 \leq \nu_{\overline{A}} \leq 1$ and $\mu_{\overline{A}} + \nu_{\overline{A}} \leq 1$ then $\overline{A} = \langle \mu_{\overline{A}}, \nu_{\overline{A}} \rangle$ is called Intuitionistic Trapezoidal Fuzzy Number.

Definition 3. [13] An interval valued intuitionistic fuzzy set A in space E is an object of the form:

$A = \{\langle x, M_A(x), N_A(x)\rangle : x \in E\}$,

Where $M_A(x) \subset [0, 1]$ and $N_A(x) \subset [0, 1]$ are intervals and $0 \leq \sup M_A(x) + \sup N_A(x) \leq 1$, for every $x \in E$.

Definition 4. [13] An interval valued intuitionistic fuzzy sets A (over a basic set E) is defined by the membership function $M_A : E \rightarrow INT([0, 1])$, the nonmembership function $N_A : E \rightarrow INT([0, 1])$ where $INT([0, 1])$ is the set of all subsets of the unit interval.

For an interval valued intuitionistic fuzzy set A, the pair $(M_A(x), N_A(x))$ is called an Interval-valued Intuitionistic Fuzzy Number (IIFN). If $((a, b), (c, d))$ is an IIFN then $a = \inf M_A(x)$, $b = \sup M_A(x)$, $c = \inf N_A(x)$, $d = \sup N_A(x)$, where $(a, b) \subset [0, 1], (c, d) \subset [0, 1]$, and $0 \leq b + d \leq 1$.

For every two interval valued intuitionistic fuzzy number hold the same arithmetic operation as general intuitionistic fuzzy number, that is if $A_1 = ((a_1, b_1), (c_1, d_1))$ and $A_2 = ((a_2, b_2), (c_2, d_2))$ holds

$$A_1 + A_2 = \begin{pmatrix} (a_1 + a_2 - a_1 a_2, b_1 + b_2 - b_1 b_2), \\ (c_1 \cdot c_2, d_1 \cdot d_2) \end{pmatrix}$$

Definition 5. [15] An intuitionistic fuzzy graph is of the form $G = (V, E)$ where

i. $V = \{v_1, v_2, v_3, \ldots, v_n\}$ such that $\mu_1 : V \rightarrow [0, 1]$ and $\nu_1 : V \rightarrow [0, 1]$, denotes the degree of membership and non-membership of the element $v_1 \in V$ respectively and $0 \leq \mu_1(v_i) + \nu_1(v_i) \leq 1$, for every $v_i \in V$, $i = 1, 2, 3, \ldots, n$
ii. $E \subseteq V \times V$ where $\mu_2 : V \times V \rightarrow [0, 1]$ and $\nu_2 : V \times V \rightarrow [0, 1]$, are such that $\mu_2(v_i, v_j) \leq \max(\mu_1(v_i), \mu_1(v_j))$, $\nu_2(v_i, v_j) \leq \max(\nu_1(v_i), \nu_1(v_j))$ denotes the degree of membership and non-membership of an edge $(v_i, v_j) \in E$ respectively.

If a graph consist IIFN as it weights (on verticess or edges), then we call it interval valued intuitionistic fuzzy graph. To compare between any two IIFN we use the distance or the norm of the edges weight. Here we will use Generalized Improved Score (GIS) function by [16]. If $A = \langle (a, b), (c, d) \rangle$ is IIFN, then $GIS(A) = |A|$ defined by

$$|A| = \frac{a + b}{2} + 0,5a(1 - a - c) + 0,5b(1 - b - d),\ \ |A| \in [0, 1]$$

In this study, the algorithm Floyd Warshall will be used to find a minimum path for each subdistrict in Jombang so that we can arrange some routes. That route can use as the new public transportation route. This algorithm chooses because of its capability to find the shortest weight of each vertex in the graph. The most famous idea in this algorithm is the triangle operation. For every two vertexes, if there is another vertex that can reach those two vertexes, the distance between the two vertexes can be obtained not only from

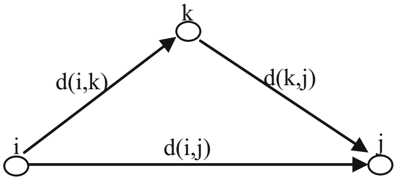

Fig. 3. The Triangle Operation.

the two vertexes directly but also by the reach of that other vertex. If the length from two vertexes is directly longer than the new distance, then we find the triangle operation work in the graph.

Figure 3 shows vertex i directly connect to vertex j. The weigth of edge (i,j) is d(i,j). If there is exist vertex k which is between i and j, so the weight of edge (i,j) can be replace with d(i,k) + d(k,j) if and only if d(i,j) > d(i,k) + d(k,j). With this operation, we will get the nearest distance for all the vertices in the graph. After we find the shortest path for all vertices, we will make some study cases on how to reroute public transportation.

3 Result and Discussion

Using intuitionistic fuzzy in transportation planning makes a proper approach to the mathematics model. With intuitionistic fuzzy, decision-makers have a qualitative solution that can fix reality. The most considerable difficulty was the mapping process based on the expert's judgment. The expert's review uses a trapezoidal approach in this research, where the longest extended and lowest time travel became the basis. Interval-valued was used to maximize the possibility so that the decision maker could apply freely. The basis for interval value using the speed limits that apply to district roads. The speed limit is 40 to 50 km/h, so that time travel for 40 km/h will become an upper value, and time travel for 50 km/h becomes a lower value.

Here we use $\mu_{\overline{A}} = 0.8$ *and* $\nu_{\overline{A}} = 1 - 0.8 = 0.2$ and all the addition of every mapping xi fit the condition $0 \leq \mu_{\overline{A}}(xi) + \nu_{\overline{A}}(xi) \leq 1$. This mapping applied to lower and upper time travel since both cases used the same variable (Fig. 4). With this mapping, all the time travel data will become an Intuitionistic Fuzzy Number (IFN). Since we use estimation with the lower dan upper value, the intuitionistic fuzzy number becomes Interval-valued Intuitionistic Fuzzy Number (IIFN) see Table 2. From this part, the data was mapped into qualitative value and made us easy to solve.

The membership function $\mu_{\overline{A}}(x)$ defined by

$$\mu_{\overline{A}}(x) = \begin{cases} \frac{(0.6)(x-5)+(0.2)15}{15}, & 5 \leq x \leq 20; \\ 0.8, & 20 \leq x \leq 35; \\ \frac{(0.6)(50-x)+(0.2)15}{15}(0.8), & 35 \leq x \leq 50; \\ 0.2, & \text{others} \end{cases}$$

The nonmembership function $\nu_{\overline{A}}(x)$ defined by

$$\nu_{\overline{A}}(x) = \begin{cases} \frac{(0.6)(20-x)+(0.2)20}{20}, & 0 \le x \le 20; \\ 0.2, & 20 \le x \le 35; \\ \frac{(0.6)(x-35)+(0.2)20}{20}(0.8), & 35 \le x \le 55; \\ 0.8, & \text{others} \end{cases}$$

Because we have edge weight in the graph, we call the graph a weighted graph, and since it does not have any direction in every vertex, we call it an undirected graph. An undirected graph means the vertex can go vice versa to any other vertex. As shown in Fig. 2, there are no multiple edges or looping vertex in the graph so we can call the graph a simple graph. Now, we can find the optimal path with an algorithm after we have an interval-valued intuitionistic fuzzy graph. Figure 2 and Table 2 was the main component of building a mathematics model to study rerouting public transportation in Jombang.

Interval values use to maximize the possibility of the solution that will be made from this study, as mentioned in [17]. These studies use sub-district as vertices and travel time from two sub-district connected directly as the edges of the graph. The transportation network arranges into a graph which is given an interval-valued fuzzy intuitionistic weight at each edge. After being compiled into Interval-Valued Intuitionistic Fuzzy Graph, the graph solve by the Floyd Warshall algorithm to get the optimal distance for all vertices. Using trapezoidal intuitionistic fuzzy, as mentioned in Definition 2, we can obtain IIFN for every edge in the graph from Fig. 2. Table 2 shows the interval value of each edge of the transportation network in Jombang.

Floyd Warshall's algorithm uses to find the optimal path in the transportation network. There is an iteration in this algorithm that has to be fit. The first iteration is the initial matrix that shows the edge of the connected vertex. From the first iteration, we will count the weight of every edge by using GIS. Then we will focus on finding the triangle operator held in the transportation network. As shown in Fig. 2, there are many triangle operators in the graph.

In the first iteration, the weight of each edge that counts using GIS will be a basic comparison when we find a triangular operation. We find 39 triangular operations in the second iteration and only four replacements. It means almost all vertices connect in the shortest time. The replacement that made are d(x5) replaced by d(x6 + x7), d(x11) replaced by d(x10 + x11), d(x17) replaced by d(x16 + x24) and d(x27) replaced by d(x25 + x26).

The weight of edges, x41, can be found from the weight of x41 itself, d(x32 + x33) or d(x40 + x42). From the second iteration, we find that d(x41) < d(x32 + x33) so that the weight of edges x41 is not changing. However, in the third iteration, the weight of edges x41 was changed by x40 + x42. There are 18 triangular operations in the third iteration, and we get only one replacement. It means the subdistrict Ngoro to Mojowarno will shorten if we go with Ngoro-Bareng-Mojowarno.

Defuzzifikasi process uses the criteria of solution description, they are:

a. If $0 \le \sup M_{\overline{A}}(xi) + \sup N_{\overline{A}}(xi) \le 0.8$ and $M_{\overline{A}}(xi) > N_{\overline{A}}(xi)$ then the path is leak feasible.
b. If $0 \le \sup M_{\overline{A}}(xi) + \sup N_{\overline{A}}(xi) \le 0.8$ and $M_{\overline{A}}(xi) < N_{\overline{A}}(xi)$ then the path is not feasible.

Table 2. IIFN of Each Edges in Transportation Network.

Variable	μ		ν	
	inf	**Sup**	**Inf**	**sup**
x1	0,373	0,533	0,520	0,400
x2	0,693	0,800	0,280	0,200
x3	0,693	0,800	0,280	0,200
x4	0,800	0,800	0,200	0,200
x5	0,437	0,613	0,472	0,340
x6	0,053	0,133	0,760	0,700
x7	0,309	0,453	0,568	0,460
x8	0,053	0,133	0,760	0,700
x9	0,373	0,533	0,520	0,400
x10	0,245	0,373	0,616	0,520
x11	0,800	0,800	0,200	0,200
x12	0,747	0,267	0,240	0,600
x13	0,309	0,453	0,568	0,460
x14	0,800	0,800	0,200	0,200
x15	0,373	0,533	0,520	0,400
x16	0,181	0,293	0,664	0,580
x17	0,437	0,613	0,472	0,340
x18	0,800	0,800	0,200	0,200
x19	0,309	0,453	0,568	0,460
x20	0,181	0,293	0,664	0,580
x21	0,245	0,373	0,616	0,520
x22	0,181	0,293	0,664	0,580
x23	0,373	0,533	0,520	0,400
x24	0,245	0,373	0,616	0,520
x25	0,181	0,293	0,664	0,580
x26	0,309	0,453	0,568	0,460
x27	0,629	0,800	0,328	0,200
x28	0,309	0,453	0,568	0,460
x29	0,373	0,533	0,520	0,400
x30	0,373	0,533	0,520	0,400
x31	0,373	0,533	0,520	0,400

(*continued*)

Table 2. (*continued*)

Variable	μ		ν	
	inf	**Sup**	**Inf**	**sup**
x32	0,757	0,800	0,232	0,200
x33	0,437	0,613	0,472	0,340
x34	0,181	0,293	0,664	0,580
x35	0,373	0,533	0,520	0,400
x36	0,565	0,773	0,376	0,220
x37	0,437	0,613	0,472	0,340
x38	0,800	0,800	0,200	0,200
x39	0,693	0,800	0,280	0,200
x40	0,373	0,533	0,520	0,400
x41	0,757	0,800	0,232	0,200
x42	0,245	0,373	0,616	0,520
x43	0,565	0,773	0,376	0,220
x44	0,800	0,800	0,200	0,200

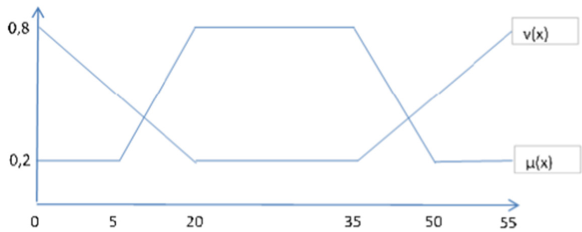

Fig. 4. The Membership and Non Membership Degree of IIFN Transportation Network.

c. If $0.8 \leq \sup M_{\overline{A}}(xi) + \sup N_{\overline{A}}(xi) \leq 1$ and $M_{\overline{A}}(xi) > N_{\overline{A}}(xi)$ then the path is strong feasible.
d. If $0 \leq \sup M_{\overline{A}}(xi) + \sup N_{\overline{A}}(xi) \leq 0.8$ and $M_{\overline{A}}(xi) < N_{\overline{A}}(xi)$ then the path is not feasible.

The result in Table 2 shows a strong, feasible solution. All the subdistricts connect to a minimum of one center sub-district with better public facilities. As shown in Table 2, all the weights fulfill the boundaries below. The time travel need as shown in Eq. 5 below.

$$\text{time travel}(t) = \begin{cases} 0 \leq |xi| \leq 0.5 \text{ then t is less than } 30\,\text{m} \\ 0.5 \leq |xi| \leq 0.8 \text{ then t is between } 30 - 60\,\text{m} \\ 0.8 \leq |xi| \leq 1 \text{ then t is more than } 60\,\text{m} \end{cases}$$

Table 3. The Route of Transportation Network in Jombang

No	From	To	Route	IIFN	Weight
1	Kabuh	Tembelang	x1-x6-x13	{(0.590266,0.778904),(0.224474,0.1288)}	0.775206
2	Kabuh	Ngusikan	x2-x9-x10	{(0.85497,0.941511),(0.08969,0.0416)}	0.929848
3	Ngusikan	Jombang	X12-x18-x16	{(0.958521,0.896356),(0.031872,0.0696)}	0.9473
4	Bandar Kedung Mulyo	Peterongan	X20-x21-x24	{(0.533752, 0.722484),(0,251959,0.156832)}	0.728903
5	Sumobito	Mojowarno	X26-x25-x35	{(0.645667,0.819721),(0.196119,0.10672)}	0.81392
6	Sumobito	Wonosalam	X28-x37-x43	{(0.831082,0.952088),(0.100804,0.034408)}	0.926318
7	Gudo	Jombang	X19-x30-x22	{(0.645667,0.819721),(0.196119,0.10672)}	0.81392
8	Gudo	Wonosalam	X39-x40-x44	{(0.961564,0.981333),(0.02912,0.016)}	0.977236
9	Bareng	Jombang	X40-x32-x22	{(0.875504,0.934044),(0.080105,0.0464)}	0.933339
10	Mojoagung	Jombang	X36-x25-x24	{(0.731454,0.899622),(0.153793,0.066352)}	0.872812
11	Wonosalam	Jombang	X43-x33-x22	{(0.799777,0.938065),(0.117841,0.043384)}	0.910565

If the route should reach a minimum of 3 sub-districts and one center, then we can choose all strongly possible paths with time travel between 30 to 60 min, as shown in Table 3. The algorithm could find about 420 paths, but only 100 are feasible. The path that is possible to use as public transportation is only 11 paths.

All the start point was the outer subdistrict that goes to the center point nearest. Those routes ensure that all the subdistricts connect. If we need to move from Kabuh to Jombang, we can choose route number 1 with a time travel estimated 30–60 min and then change the route to route number 3 from Tembelang. This route goes back and forth. The following studies should discuss what kind of vehicle uses, how many vehicles use, and how the vehicle could gather the public interest.

The main point of reactivating public transportation is how to make the public interest in using a massive vehicles so that private transportation can reduce. With all those criteria, we will have the route of public transportation in Jombang, as shown in Table 3. All the routes are still in studies, so they need some experimental trials or profound continuous studies to ensure the path is effective.

4 Conclusion

Based on these studies, intuitionistic fuzzy made the scenario easier to understand. Intuitionistic fuzzy can maximize data in the form of estimates by actual conditions. The interval value makes the decision-maker can apply the solution freely. After getting the optimal shortest path in the transportation network, we can choose the optimal path that will be fit to be public transportation. Eventhough the model has boundaries like minimizing time travel and the route has to minimum connect with one center, we can obtain the solution.

For the following research, it will be more challenging to solve not only a simple graph of interval value intuitionistic fuzzy graph but also the multiple edges. Most roads traversed between sub-districts have more than one choice, so it should be counted as multiple edges. Many algorithms can use in the intuitionistic fuzzy graph, but the Floyd Warshall algorithm is still rare. This algorithm should use widely in an intuitionistic fuzzy graph in the future since this algorithm can be well applied.

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