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SELECTING MADIUN–DOLOPO TRACE ROUTE WITH THE FUZZY AHP (*ANALYTIC HIERARCHY PROCESS*) METHOD

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Abstract

Introduction: The National Railway Master Plan (RIPNAS), dated 2018, mentions that the railway network size and railway service capacity for using trains as the main means of transportation can be increased by reactivating non-operational routes and improving the condition of the existing routes. **Methods**: In our study, we propose the Fuzzy Analytic Hierarchy Process (Fuzzy AHP) method to determine the best option for the reactivated Madiun–Dopolo trace route in East Java, Indonesia. The data obtained were derived from questionnaires filled in by experts in the field. The model used six main criteria: land use, technical aspects, transportation node integration, social insecurity, disaster factors, and funding. **Result and Discussion**: The analysis reveals that the predominant route selection criterion chosen by the respondents was the Land Use (with a score of 0.25). The least significant Madiun–Dopolo route selection criterion was the Disaster Factors (0.07). Based on the results of weighting the criteria and aggregating the respondent alternatives, the trace route most commonly chosen by the respondents was the Alternative Trace Route (Trace Route 2), with a score of 0.698, while the Existing Trace Route (Trace Route 1) had a score of 0.302. The Alternative Trace Route is longer than the Existing Trace Route, but it will mostly pass through farming regions, which is assumed to create less social conflicts than in the case of Trace Route 1. This also automatically means that Trace Route 2 will need fewer funds in land acquisition.

Keywords

Fuzzy Analytic Hierarchy Process, route, railway.

Introduction

In 2018, the number of passenger and freight train users rose by 7.54 and 12.92% respectively compared with the previous year. Such an increase must be followed by the enhancement of facilities and infrastructure services. The National Railway Master Plan (RIPNAS), dated 2018, mentions that the railway network size and railway service capacity for using trains as the main means of transportation can be increased by reactivating non-operational routes and improving the condition of the existing routes. One example is the Madiun–Ponorogo railway, which is expected to be reactivated and launched between 2025 and 2030.

The Madiun–Ponorogo railway has not been active since 1984, when it was used for distributing goods as well as passengers. This railway route links Madiun City in Madiun Regency and Slahung District, Ponorogo Regency. There are two major sugar factories along the route.

Ministerial Regulation No. 11 of 2012, which concerns the procedure of determining railway routes, defines a trace route as a railway track layout with known coordinates. The arrangement of a railway trace route becomes a guideline for performing technical design activities, analyzing the environmental impact, and actualizing the land before building the railway.

The Analytical Hierarchy Process (AHP) is a popular method for tackling multi-criteria analysis problems involving qualitative data (Saaty, 1980). This method uses unique mathematical procedures to process single or multiple subjective preferences, based on pairs of factors, helping relevantly rate and analyze decisions (Saaty and Vargas, 2012). In most cases, the individuals who take part in the rating process are experts in particular fields. The AHP has already been used for studying the alternative development of the railway trace route to NYIA Indonesia airport. The results showed that the prior trace route had the potential of social conflict and did not comply with the new master plan of the airport (Chasanah and Putro, 2018). Mohajeri and Amin (2010) used the methods of the AHP and data envelopment analysis (DEA) to find the optimum site for a railway station in the city of Mashhad, Northeast Iran. They identified a four-level hierarchy model for the railway station site selection problem. The model used four main criteria: rail-related, passenger services, architecture and urbanism, and economics (Mohajeri and Amin, 2010).

The Fuzzy AHP combines analysis using the AHP method and the fuzzy approach concept. The fuzzy method includes subjective criteria that can compensate for the weaknesses of the AHP method. The fuzzy theory helps to deal with the subjective ratings made by humans who use language or linguistic methods (Chang, 1996). Buckley (1985) extended Saaty's AHP to the case where the evaluators are allowed to employ fuzzy ratios in place of exact ratios, to address difficulties with assigning exact ratios when comparing two criteria and derive the fuzzy weights of criteria through the geometric mean method.

The applications of the Fuzzy AHP have been well-documented in construction management literature, especially literature on project site selection. Yu and Liu (2012) proposed a FAHP model to select the most suitable projects among multiple sites for safety improvement. With the Fuzzy AHP model, they were able to capture the comprehensive impacts of all contributory factors that are usually neglected by most other existing single- or multi-criteria approaches during the safety project selection process (Yu and Liu, 2012).

The Fuzzy AHP was also used by Peetawan and Suthiwartnarueput (2018) to identify factors affecting the success of rail infrastructure development projects contributing to Thailand's logistics platform. The projects addressed in the study included double-tracking the existing railways and constructing new routes. It was found that a rail development master plan has the highest influence on a project's success.

Based on the background above, we are interested in studying the selection of the most suitable Madiun–Dolopo railway trace route with the Fuzzy AHP method. In the future, we expect that this study can contribute to selecting the best trace route when planning the reactivation of the Madiun–Dopolo Railway.

Table 1. Fuzzy numbers used for making qualitative assessments

Fuzzy numbers	Membership function
1	(1,1,3)
x	(x-2,x,x + 2) f or x = 3,5,7
9	(7,9,11)

$$S_i = \frac{\sum_{j=1}^{m} \mu_i^j}{\sum_{i=1}^{n} \sum_{j=1}^{m} \mu_i^j}, i = 1, 2, ..., n \quad (1)$$

FUZZY ANALYTIC HIERARCHY PROCESS

The Fuzzy AHP is designed to solve the problems of making multi-criteria decisions while working with subjective ratings. The Fuzzy AHP is considered to be better in describing uncertain decisions than the AHP (Buckley, 1985). The first Fuzzy AHP method was proposed by Van Laarhoven and Pedrycz (1983), who used the Triangular Fuzzy Numbers (TFNs) in the comparison pairs of a matrix. Within the Fuzzy AHP, the comparison of both the criteria and the alternatives can be done through linguistic variables, represented by triangular numbers (Emrouznejad and Ho, 2018). The scale of linguistic variables within the AHP, as applied by Saaty (1991), ranges from 1 to 9. It is then converted to fuzzy form using the Triangular Fuzzy Numbers. These Triangular Fuzzy Numbers can be denoted by (l, m, u) (Chang, 1996). It is easier to show the fuzzy problem by using the Triangular Fuzzy Numbers rather than the interval number (Zhang and Liu, 2010). Fuzzy numbers used for making qualitative assessments are listed in **Table 1** (Deng, 1999).

Consistency Index (CI)

An important measure of consistency for pairs of expert judgment comparisons is the consistency ratio (CR) (Saaty, 1980). The steps in the Fuzzy AHP Consistency test (Saaty, 2010) are to find the max value of λ, followed by finding the CR, which is determined by Eq. (2).

$$CI = \frac{\lambda_{max} - n}{n - 1}, \quad (2)$$

where *CI* = consistency index, n = size of matrices < λ, max = maximum or principal Eigen value of the judgment matrix.

The CI is modified into the Consistency Ratio (CR), which is CR = CI/RI (RI = Random Index, based on the size of matrices n). Saaty (1980) suggested that the value of the CR should not exceed 0.1 for a confident result.

Methods

We began our study by reviewing literature, such as journals and scientific articles, in order to gain supporting references. Data collection involved primary and secondary data. Primary data included the results of the survey on the condition of the Existing Madiun–Dopolo Trace Route (Trace Route 1) and Alternative Madiun–Dopolo Trace Route (Trace Route 2) and the results from the questionnaires. In turn, secondary data included the neighborhood map and the hamlet document of the Ministry of Madiun City and Regency, as well as the map of the existing Madiun–Dopolo railway. For collecting the data samples, we used the purposive sample method. A purposive sample is a non-probability sample that is based on the segment of the population with the most information on the characteristic of interest and the objective of the study (Guarte and Barrios, 2006).

After gaining these data, we then followed up with data management, which was done by using the Fuzzy AHP method with the help of Microsoft Excel.

Below are the steps of data management (Buckley, 1985; Chang, 1996; Tzeng and Huang, 2011) Figure 1:

a. Create a three-level hierarchical structure model, as shown in Fig. 1.
Level 1 indicates the target;
Level 2 indicates criteria to ease decision-making;
Level 3 indicates the railway trace route options.

b. Construct matrix comparison pairs among all the elements/criteria in the dimensions of the hierarchy system, using the TFN scale.

$$\begin{bmatrix} (1,1,1) & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & (1,1,1) & \cdots & \tilde{a}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & (1,1,1) \end{bmatrix}. \quad (3)$$

c. Define the fuzzy geometric mean and fuzzy weights for each criterion, using the geometric mean technique by Buckley (1985), as follows:

$$\tilde{r}_i = \left(\tilde{a}_{i1} \otimes \tilde{a}_{i2} \otimes \ldots \otimes \tilde{a}_{in}\right)^{1/n}; \quad (4)$$

$$\tilde{w}_i = \tilde{r}_i \otimes \left(\tilde{r}_1 \otimes \ldots \otimes \tilde{r}_n\right)^{-1}, \quad (5)$$

where $\tilde{a}_{in}$ is the value of fuzzy comparison of criterion i to criterion n, thus, $\tilde{r}_i$ is the geometric mean value of fuzzy comparison between criterion i and each criterion, $\tilde{w}_i$ is the fuzzy weight of the i^{th} criterion, $\tilde{w}_i = \left(l_i, m_i, u_i\right)$ are the lower, middle and upper values of the fuzzy weight of the i^{th} criterion.

d. Calculate the fuzzy weight that has been defuzzified by each matrix comparison pair. The fuzzy weight vector of each criteria was calculated by dividing the minimum degree of possibility by the summation of the minimum degree of possibility:

$$w_i = \frac{MinP_i}{\sum_i^n MinP_i}, i = 1, 2, \ldots, n. \quad (6)$$

e. Calculate the defuzzy weight with the Center of Area Method.

$$M_i = \frac{lw_i + mw_i + uw_i}{3}. \quad (7)$$

f. Normalize the fuzzy weight vector.

$$N_i = \frac{M_i}{\sum_{i=1}^n M_i}. \quad (8)$$

g. Calculate the value of the Consistency Index (CI) and Consistency Ratio (CR).

h. Calculate the alternative weight. The steps for calculating the alternative weight are the same as for calculating the criteria weight, but each alternative must be compared with each criterion (6 criteria).

i. Rank the fuzzy number and interpret the calculation results and draw conclusions.

Results and Discussion

The aim of this study was to obtain the right option to meet a specific goal (selection of the Madiun–Dolopo railway trace route). The options were based on the criteria determined. We followed up on our literature overview by spreading questionnaires for data collection. The questionnaires were then analyzed using the Fuzzy AHP method with the help of Microsoft Excel.

a. General Description of Respondents

There were seven respondents involved in the study: functionaries of the Madiun City and District Transportation Office, functionaries of the Madiun Regency Development Planning Agency at Sub-National Level, functionaries of PT.KAI DAOP 7 Madiun, and lecturers in the railways field. These respondents were considered to be involved and competent in determining the policy and technicalities of railway construction. The general description of the respondents includes their position, latest education, and period of working experience in the field. The

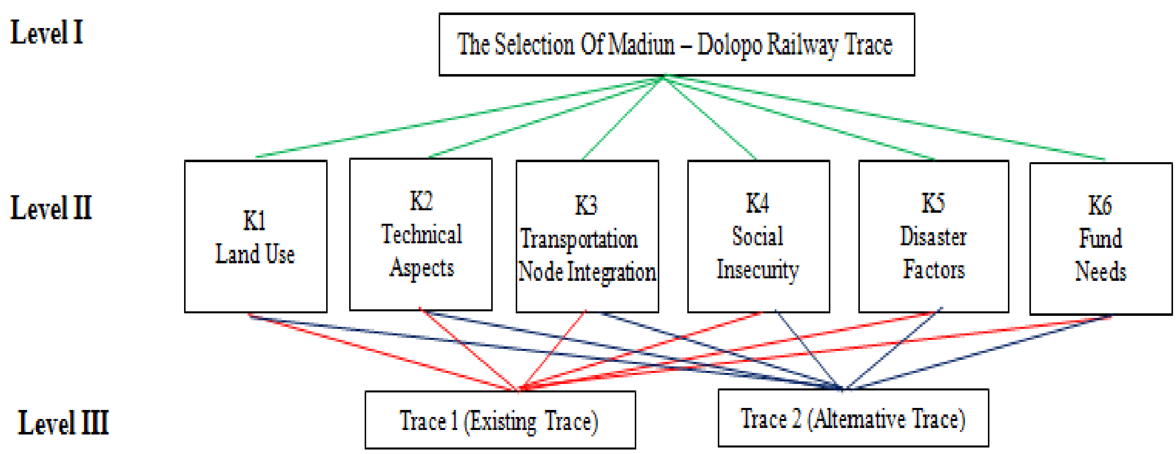

Figure 1. Hierarchical structure of the trace route selection process

respondents' education level represents two stages of education: 42.86% of the respondents hold a Bachelor's degree (S1) and 57.14% hold a Master's degree (S2). In terms of working experience, the respondents can be divided into three groups: 57.14% have 1–10 years of experience, 28.57% have 10–20 years of experience, and 14.29% have over 20 years of experience.

b. Existing Trace Route (Trace Route 1)

The existing trace route, with the total length of 18 km, is divided into three parts: Madiun Station–Kanigoro Station (7 km), Kanigoro Station–Pagotan Station (5 km), and Pagotan Station–Dopolo Station (6 km), with at-grade construction and fairly flat topography. There are 19 curves in total along Trace Route 1. Based on the observation results, the railways between Madiun Station and Dopolo Station have mostly deteriorated, and the location is utilized by citizens as a populous settlement. Some of the rail tracks can still be seen in some small areas, yet they cannot be used due to wear and tear as well as corrosion. The land between Madiun Station and Dopolo Station is predominantly used for settlements, shop complexes, graveyards, and even government buildings. We can classify the land use as follows: 87,331.8 m^2 for rice fields, 368,188 m^2 for settlements, 580.6 m^2 for public graveyards, and 9864.8 m^2 for farming.

c. Alternative Trace Route (Trace Route 2)

The proposed alternative trace route is 23+250 km further and longer compared with the existing trace route, with at-grade construction and fairly flat topography. There are 15 curves in total along Trace Route 2. This trace route passes from Madiun Station to Sukosari, then heads to rice field areas, which end at the border of Kanigoro Station. After that, it mostly passes through more rice fields and ends at Dopolo Station. The land use is allocated as follows: about 439,660.8 m^2 for rice fields and about 368,188 m^2 for citizen settlements.

d. Weighting Criteria

The process of determining the priorities of railway trace route selection was structured by decomposing the relevant problems in order to picture the influence factors along with the alternative decisions, arranged in the form of hierarchy. All elements within the decision structure have different intensities, in order to give impact to the goal. This study includes six criteria that need to be considered when selecting the trace route: land use (K1), technical aspects (K2), transportation node integration (K3), social insecurity (K4), disaster factors (K5), and funding (K6). The Land Use aspect became one of the criteria for selecting the trace route; its indicator is a percentage ratio of the railway trace route that passes through a specific region/land to the total length of the railway trace route (%) (Palayukan and Adisasmita, 2018). In our study, we based the Land Use indicator on the area of rice fields, settlements, public graveyards, farmlands, and rivers that might be affected by the activity of the railway. In turn, the Technical Aspects indicator included the trace route length, the total number of curves, the types of construction used, and topography. The Transportation Node Integration aspect was related to the distance between the planned station and the terminal. Social risk, defined as the severity and uncertainty of an activity with respect to human values, which may influence the whole society and lead to social unrest (Aven and Renn, 2009), was prevalent. The Social Insecurity aspect referred to the possible social conflict that might occur, for instance, if the economic compensation of land acquisition and housing demolition was not handled properly (Yang and Kuang, 2019), as well as to resistance against the reactivation plan. The Disaster Factors aspect pertained to the regions or areas with potential of natural disaster that were traversed by the trace route; such factors included geology, hydrometeorology, or even geotechnical factors. The Disaster Factors that we calculated in this study were the factors of flooding from nearby areas over the last 20 years. The results from observing the area around the existing and alternative trace routes showed that the area is safe from prolonged floods. The last criterion (Funding) is related to the estimated funds needed for route reactivation, from the design phase to the execution phase. These could be the funds for both technical and non-technical activities, especially land acquisition.

e. Calculation of Weighting Criteria

In the Fuzzy AHP, the assessment (preferences) of decision-making under conditions of uncertainty is modeled by using logical fuzzy operations (Chang, 1996). Similar to the conventional AHP, the information within the Fuzzy AHP was obtained in the form of matrix comparison pairs. According to Deng (1999), fuzzy numbers are used for making qualitative assessments.

Table 2. Triangular Fuzzy Numbers for Likert Scale

Definition of linguistic variables	Likert Scale	TFN	Likert Scale	TFN
Similar importance	1	(1,1,3)	1/1	(1/1,1/1,1/3)
	2	(1,2,4)	½	(1/4,1/2,1/1)
Moderate importance	3	(1,3,5)	1/3	(1/5,1/3,1/1)
	4	(2,4,6)	¼	(1/6,1/4,1/2)
Intense importance	5	(3,5,7)	1/5	(1/7,1/5,1/3)
	6	(4,6,8)	1/6	(1/8,1/6,1/4)
Demonstrated importance	7	(5,7,9)	1/7	(1/9,1/7,1/5)
	8	(6,8,10)	1/8	(1/10,1/8,1/6)
Extreme importance	9	(7,9,11)	1/9	(1/11,1/9,1/7)

The stages of weighting criteria were defined by creating a matrix comparison. The weight value of each criterion was determined by using pair comparison questionnaires. We then continued by searching for the geometric mean values, derived from the value of fuzzy comparison (Ri). The process is explained below in **Table 3.**

Table 3. Value of Geometric Means from Criteria

Criteria	R_i		
	1	m	u
K1	1.814	2.67	3.502
K2	1.487	2.263	3.067
K3	1.582	2.515	3.595
K4	0.576	0.92	1.385
K5	0.464	0.696	1.113
K6	0.813	1.407	2.074
Total	6.735	10.471	14.736
Inverse	0.148	0.096	0.068
Increasing Order	0.068	0.096	0.148

After finding the value of R_i, the next stage was to determine the relative fuzzy weight of the criteria (W_i), as explained in **Table 4.**

The next table (**Table 5**) shows the value of M_i and N_i, which is the weight of the criteria after normalization.

After finding the weighting value, the next stage was to calculate the Consistency Ratio (CR), based on the Eigen value (λ), the maximum Eigen value (λmax), and the Consistency Index (CI). The calculation results can be seen in **Table 6**

Table 4. Relative Fuzzy Weight of Criteria

Criteria	Wi		
	l	m	U
K1	0.12	0.26	0.52
K2	0.10	0.22	0.46
K3	0.11	0.24	0.53
K4	0.04	0.09	0.21
K5	0.03	0.07	0.17
K6	0.06	0.13	0.31

Table 5. Relative Fuzzy Weight of Criteria

Criteria	M_i	N_i	(%)
K1	0.30	0.25	24.64
K2	0.26	0.21	21.19
K3	0.29	0.24	24.18
K4	0.11	0.09	9.13
K5	0.09	0.07	7.22
K6	0.17	0.14	13.65
Total	1.21	1.00	100

Table 6. Results of *Eigen* Value Calculation

Criteria	Total	Weight	Eigen Value
K1	1.814	0.246	7.362
K2	1.487	0.212	7.016
K3	1.582	0.242	6.542
K4	0.576	0.091	6.313
K5	0.464	0.072	6.428
K6	0.813	0.136	5.957
		Eigen Max	6.603

Based on the table above, the values of CI and CR were obtained as follows:

$$CI = \frac{\lambda_{max} - n}{n-1} = \frac{6.603-6}{6-1} = 0.121, \quad (9)$$

with R_i for n = 6, which is 1.24, we then obtained $CR = \frac{CI}{RI} = 0.121/1.24 = 0.0973.$ Since the value of CR is smaller, we can conclude that the results from the data used are consistent and do not require decision-making i mprovement.

f. Alternative Weighting

Our alternative weighting calculations used the same stages as criteria calculations, but with one addition: alternative weighting needed to be compared with each criterion. In other words, this analysis was repeated six times for each existing criterion. The alternative weighting was derived from the results of the respondents' assessments in the questionnaires. We conducted a test on normalizing the data after obtaining the weighting value from pair comparison. In order to achieve the best alternative, the weighting totaling was based on the normalized data. We reached the final decision through developing priority weights for the six criteria (K1, K2, K3, K4, K5, K6) with the two alternatives (Trace Route 1, Trace Route 2) to reach the overall objective, as mentioned in **Table 7**.

In line with the goal (obtaining the best criteria for trace route selection), the Land Use criterion achieved the highest value of priority weight compared with the other five criteria: 25%. On the other hand, the Disaster Factors criterion achieved the lowest value of priority weight, 7%. According to the disaster factor survey, which shows the factors of flooding over the last 20 years, the areas close to both the existing railway and the alternative railway are safe from prolonged floods. Therefore, this aspect achieved the lowest value of priority weights among all other aspects.

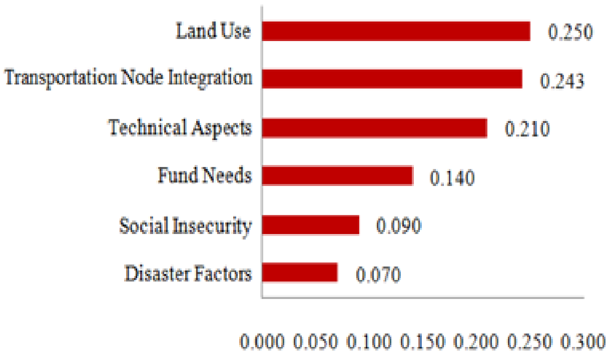

Figure 3. Diagram of Weighting Criteria

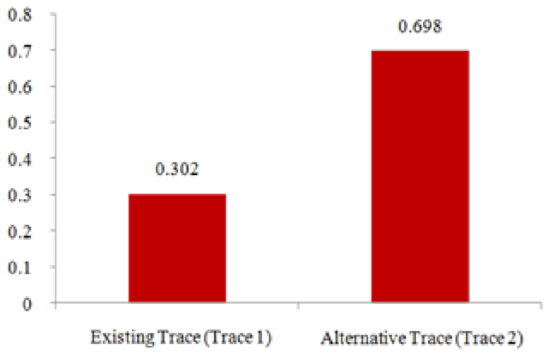

Figure 4. Diagram of Best Altemative

Table 7. Combination of Priority Weights

Criteria	Weights	Trace 1	Trace 2
K1	0.250	0.202	0.798
K2	0.210	0.324	0.676
K3	0.243	0.448	0.552
K4	0.090	0.224	0.776
K5	0.070	0.429	0.571
K6	0.140	0.195	0.805

Table 8. Alternative Weighting

Criteria	Weights	
	Trace Route 1	Trace Route 2
Land Use	0.202	0.798
Technical Aspects	0.324	0.676
Transport Node Integration	0.448	0.552
Social Insecurity	0.224	0.776
Disaster Factors	0.429	0.571
Funding	0.195	0.805
Total	0.302	0.698

As stated in **Table 8** above, the values of the alternative trace route are higher in every criterion. We ordered the criteria from the highest down to the lowest: Funding, Land Use, Social Insecurity, Technical Aspects, Disaster Factors, and Transport Node Integration. Trace Route 1 needs less funding for technical activities because there are still some remaining functional railways, with a shorter trace than Trace Route 2. However, the funding needed for land acquisition is higher because of the greater requirements for demolishing settlements and other buildings as compared with Trace Route 2, which mostly passes through farming fields.

Based on the total responses with relation to weighting criteria and the alternative, the most frequently chosen Madiun–Dopolo railway trace route option was the Alternative Trace Route (Trace 2 Route), with a score of 0.698. The least frequently chosen option was the Existing Trace Route (Trace Route 1), with a score of 0.302.

Conclusion

Based on the analysis done, there are several conclusions to be drawn, as follows:

a) According to the Fuzzy AHP calculations, the most influential criterion for selecting railway trace routes chosen by the respondents is the Land Use criterion (0.25). The least influential criterion is the Disaster Factors criterion (0.07).

b) The railway trace route most favored by the respondents is the Alternative Trace Route (Trace Route 2) (0.0698), while the Existing Trace Route (Trace Route 1) was favored less (0.302). Even though the Alternative Trace Route is longer than the Existing Trace Route, it will mostly pass through farming regions, which is assumed to create less social conflicts than in the case of Trace Route 1. This also automatically means that Trace Route 2 will need fewer funds in land acquisition.

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