Research Article

A Multi-attribute Urban Metro Construction Excavated Soil Transportation Decision Making Model Based on Integrated Fuzzy AHP and Integer Linear Programming

Warapoj Meethom*
Research Centre for Productivity Improvement in Industrial, Department of Industrial Engineering, Faculty of Engineering, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand

Titiwat Triwong
Department of Industrial Engineering, Faculty of Engineering, King Mongkut's University of Technology North Bangkok, Bangkok, Thailand

* Corresponding author. E-mail: warapoj.m@eng.kmutnb.ac.th DOI: 10.14416/j.ijast.2016.05.004
Received: 17 March 2016; Accepted: 18 May 2016; Published online: 31 May 2016

Abstract
There has been a lack of proper decision making referring to the excavated soil transportation industry from urban metro construction areas and around metropolis Bangkok due to the implemented heavy truck ban on certain streets. Therefore, this research aims to develop a decision making model to support the metro tunnel excavation project engineer with a decision system. This will aid the excavated soil transportation solving the problem of insufficient sail reserves at the construction site, and save transportation costs within the time constraints. This will be achieved by applying qualitative decision criteria affecting the operation in Bangkok by developing an Integer Linear Programming (ILP) model. This model also applies the Fuzzy Analytic Hierarchy Process (FAHP) to calculate the optimal transportation costs and the related qualitative criteria to help increase the decision makers' flexibility in various cases.

Keywords: Urban metro construction, FAHP, Integer linear programming, Excavated soil transport, Decision making

1 Introduction

There has been a lack of proper decision making referring to the excavated soil transportation industry from urban metro construction areas and around metropolis Bangkok due to the implemented heavy truck ban on certain streets. In the future, people from Bangkok will be confronted with the problem of insufficient excavated soil disposal sites around the urban area. There is still a lot of urban metro construction with an excavated soil quantity of 6,838,893 cubic meters [1]. Since 2011 until the present day, it has been found that for many years, metro construction work cannot be continuously operated and contractors regularly encounter problems with high transportation costs which all stems from poor planning.

In general, the construction and demolition waste (C&D Waste) planning is designed to provide enough places for recycling facilities of construction waste and to reduce transportation costs [2]. The planning is mostly carried out at a regional level for residential work [3], [4] but the civil works are carried out at project level. No one has discussed about selecting the excavated soil transportation to solve the problem of insufficient area at the construction site with the lowest transportation costs and least time. Moreover,

Please cite this article as: W. Meethom and T. Triwong, "A multi-attribute urban metro construction excavated soil transportation decision making model based on integrated fuzzy AHP and integer linear programming," *KMUTNB Int J Appl Sci Technol*, vol. 9, no. 3, pp. 153–165, July–Sept. 2016.

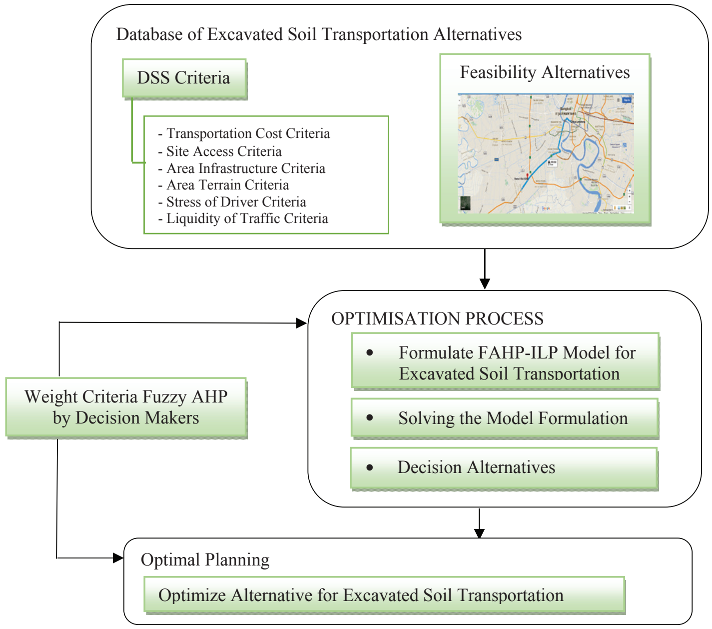

Figure 1: The overall decision support system of the excavated soil transportation model.

the qualitative decision criteria affecting the wasted transportation from the civil works at project level should also be investigated.

Therefore, this research aims to develop a decision making model to assist the metro tunnel excavation project manager with a decision system formulation. This will aid the excavated soil transportation solving the problem of insufficient sail reserves at the construction site, and save transportation costs within the time constraints. This will be achieved by applying qualitative decision criteria affecting the operation in Bangkok by developing an Integer Linear Programming (ILP) model. This model also applies the Fuzzy Analytic Hierarchy Process (FAHP) to calculate the optimal transportation costs and the related qualitative criteria to help increase the decision makers' flexibility in various cases.

2 A Multi-attribute Decision Making Excavated Soil Transportation Model

According to previous research, this type of decision making model would be an alternative to help govern organizations and implement large-scale construction operation sites such as for the metro. A developed system could be applied to improve decision making when excavating soil for transportation selection within a limited area, time and cost. The quantitative and qualitative criteria under fuzzy environmental conditions should also be included in the decision making system to discover the most appropriate transportation routes, in turn saving costs. The new fuzzy AHP-based ILP model is shown in Figure 1.

2.1 *Decision support system criteria*

This research focuses on two selection models, the excavated soil disposal site selection, and transportation route selection. It can be said that the excavated soil transportation selection criteria must be formulated and screened to be appropriate for the specific work. The excavated soil disposal sites and transportation selection criteria were studied and formulated as follows [5], [6]: have created the criteria derived from the criteria screening process from the experts specialized in the related soil transportation with 5–10 years of experience, including managers and engineers of Metropolitan Rapid Transit Project, and the transportation contractor company.

- Transportation Cost Criteria
- Site Access Criteria
- Area Infrastructure Criteria

- Area Terrain Criteria
- Stress of Driver Criteria
- Liquidity of Traffic Criteria

2.2 *Feasibility alternatives*

In this research, two possible alternatives of excavated soil transportation routes are proposed. The first one is the transportation route without a disposal site distribution centre (W/O DC), and the second is the transportation route with a disposal site distribution centre (DC) as shown in Figure 2. The transportation route without a disposal site distribution centre is where that the excavated soil is transported from the soil excavation site directly to the disposal sites with the idea that the loaded trucks will not stop on the way, or the excavated soil is not taken out of the truck. On the contrary, the other way proposes the transportation route alternatives within a disposal site distribution centre. This would mean that the loaded truck would be driven from the soil excavation site directly to the disposal site distribution centre. The excavated soil would be then taken out of the truck and laid aside at the distribution centre. After that the excavated soil would be loaded onto other trucks and transported to the destination of disposal sites with the belief that the rental will be charged by the disposal site distribution centre.

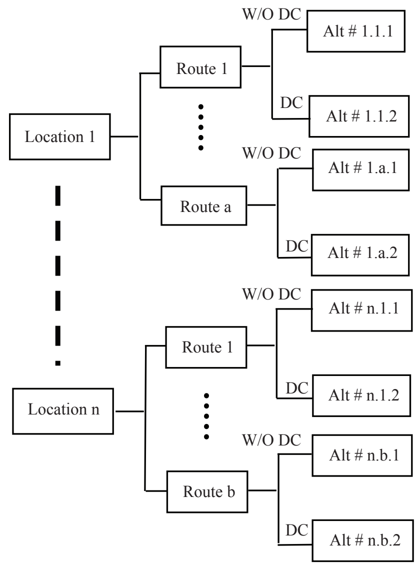

Figure 2: Feasibility alternatives format.

2.3 *Weight criteria by Fuzzy Analytical Hierarchy Process (FAHP)*

FAHP uses the hierarchical structure to show the alternative structure and hierarchical evaluation criteria. The top level of the structure is called the objective or sometimes the goal. The subsequent level is the evaluation criteria used to consider the appropriate alternative to achieve the best results of the objective. Each criterion may consist of a sub-criterion in the subsequent level [7]. In each evaluation criterion, there is no need to have an equal sub-criterion. The criteria in the same level should have equal importance, and the less important criteria should be in the subsequent level. The lowest level is the attribute of each criterion.

Regarding the criteria prioritization such as the quality, the importance can be carried out by the pairwise comparison in each level of the hierarchy. The criteria comparison by FAHP can be done by setting the importance level of each criterion as a fuzzy number. The scale is generally divided into 9 levels [8]. The value may be from $\tilde{1}$ to $\tilde{9}$. The pairwise comparison is applied to the quantitative ratio to make the comparison more explicit. This study proposes the subjective comparison and the fuzzy scale involving the importance which is measured in the form of the relative weight as shown in the Table 1 [9].

Table 1: Triangular fuzzy conversion scale

Linguistic Scale	Triangular Fuzzy Scale	Triangular Fuzzy Reciprocal Scale
Just equal	(1,1,1)	(1,1,1)
Equally important	(1/2,1,3/2)	(2/3,1,2)
Weakly important	(1,3/2,2)	(1/2,2/3,1)
Strongly more important	(3/2,2,5/2)	(2/5,1/2,2/3)
Very strongly more important	(2,5/2,3)	(1/3,2/5,1/2)
Absolutely more important	(5/2,3,7/2)	(2/7,1/3,2/5)

Fuzzy AHP is the combination of the fuzzy set and AHP to fix errors with regards to human opinions. The calculation to gain fuzzy AHP is carried out according to the method of Chang [10]. Finally, when the weighting was obtained, it is multiplied by the decision criteria to get the final scores which can then be ranked. The alternative with the highest scores will be selected.

2.4 *Integer Linear Programming (ILP) model with WFAHP for optimal alternative*

In each alternative, there will be transportation costs and qualitative costs derived from the quality evaluation of each criterion. Both of them will be adjusted to be the same base, and then processed by the integer linear programming model in which the decision maker can weight it in each decision. Six decision criteria used in this research include the quantitative decision criteria comprising of 1) transportation cost criteria; and the qualitative decision criteria 2) site access criteria 3) area infrastructure criteria 4) area terrain criteria 5) stress of driver criteria and, 6) liquidity of traffic criteria. According to when the integer linear programming is employed to achieve the understanding and easy-to-use tool, this study sets the alternative features through the structured network of excavated soil transportation from the urban metro construction.

For mutual understanding, the researchers would like to give examples of the excavated soil transportation steps of the alternatives in this study, including the first transportation alternative starting from the soil excavation station to the disposal site distribution centre and finally to the disposal site (S→DC→D), or the second transportation alternative starting from the soil excavation station directly to the disposal site (S→D).

In the other aspect of the transportation format mentioned above, the integer linear programming weighted as the fuzzy model can be implemented according to the transportation format also. That is, in case of direct transportation, the quantitative and qualitative cost will be calculated for the transportation from the soil excavation station directly to the disposal site without any rental charge at the disposal site distribution centre like the case of transportation from the soil excavation station to the disposal site distribution centre before terminating at the disposal site. Thus the weighted integer linear programming will determine the alternative feature first, then the integer linear programming will help select the alternative the decision makers can then take part in weighting the fuzzy-based importance of each criterion. WFAHP-ILP is proposed as in the equation (1): WFAHP-ILP model for multi-criteria excavated soil transportation problem.

$$\text{Min } z = \sum_{k=1}^{m} \boldsymbol{w_k} \cdot v_k \tag{1}$$

Subject to:

$$\sum_{i=1}^{n} \left[\frac{\boldsymbol{u}_{ik} - Min_{\boldsymbol{u}_{ik}}}{Max_{\boldsymbol{u}_{ik}} - Min_{\boldsymbol{u}_{ik}}} \right] \cdot x_i - v_k = 0\,;\mathrm{k} = 1,...,\mathrm{m} \tag{2}$$

$$\sum_{i=1}^{n} x_i = 1 \tag{3}$$

$$\boldsymbol{u}_{ik} \le \boldsymbol{ub}_{ik}\,;\mathrm{i} = 1,\dots,\mathrm{n}, \mathrm{k} = 1,\dots,\mathrm{m} \tag{4}$$

$$v_{ik} \ge 0\,;\mathrm{k} = 1,\dots,\mathrm{m} \tag{5}$$

$$x_i = \{0,1\}\,;\mathrm{i} = 1,\dots,\mathrm{n} \tag{6}$$

Equation (1) is the application of the urban metro construction excavated soil transportation cost calculation format that includes FAHP in the weight of ILP to conform to the current uncertain condition of selecting the alternative excavated soil transportation from the urban metro construction. The objective is to reduce the excavated soil transportation cost to its minimum and take into consideration the relative weight of all criteria under unclear condition of current environment and society. The abbreviations and symbols used in this programming are shown in Table 2.

Table 2: Abbreviations and symbols in FAHP-ILP model

Indices:	
i, all excavated soil transportation alternatives (n)	
k, all excavated soil transportation alternative criteria (m)	
When k = 1 means transportation cost criterion	
	k = 2 means site access criterion
	k = 3 means area infrastructure criterion
	k = 4 means area terrain criterion
	k = 5 means stress of driver criterion
	k = 6 means liquidity of traffic criterion
Data:	
$\boldsymbol{u}_{ik}$,	coefficient of the transportation alternative i at theconsidered criteria k
$\boldsymbol{w}_k$,	relative weight of 6 criteria
$\text{Max}_{\boldsymbol{u}_{ik}}$,	maximum value of the transportation alternative i at the criteria k
$\text{Min}_{\boldsymbol{u}_{ik}}$,	minimum value of the transportation alternative i at the criteria k
$\boldsymbol{ub}_{ik}$,	upper bound of decision making of each alternative
Decision variables:	
v_k,	results of alternatives through the normalization at the criteria k
x_{ik}	$\begin{cases} 1, & \text{alternative selection i at criteria k} \\ 0, & \text{no alternative selection i at criteria k} \end{cases}$

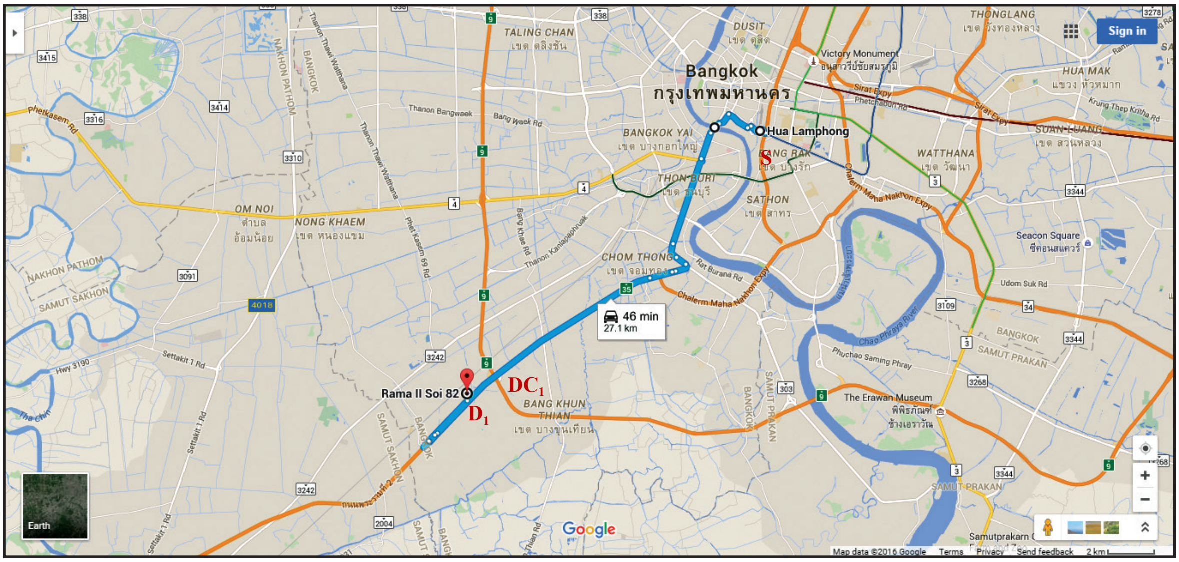

Figure 3: Disposal site, D_1 (Rama II Road, Soi 82).

3 Case Study

In the metro construction industry in Thailand, it is found that the excavated soil needs to be set aside temporarily at an area before the truck transports it to the prepared disposal site. This is because the metro is constructed in the city where the area is limited and a temporary large soil pit cannot be placed at the construction site. The soil excavation and disposal sites are determined to formulate the excavated soil transportation selection model for the urban metro construction so as to optimize the transportation cost and the risk of transportation. The contractor company will be the contractor of both tunnel excavation and excavated soil transportation. In this research, the metro construction of Hua Lamphong Station will be used as the prototype for soil excavation site.

3.1 *Problem definition and requirements*

The Hua Lamphong MRT Station (S) is used in this research as the prototype for the soil excavation site because Hua Lamphong MRT Station junction is an important economic point and Business Centre Distribution (BCD) in the area of China Town, Bangkok, Thailand. In addition, it is in the legal zone of truck driving prohibition in the inner part of Bangkok. The excavation capacity is approximately 630 cubic meters/day. After that the daily excavated soil must be transported to the disposal site (D_k) by the contractor company. However, it is found that the excavated soil disposal sites near the city have limited space and are very rare to find due to the expansion of Bangkok. So it is necessary to find an appropriate disposal site together with the transportation route or the excavated soil is transported to the disposal site distribution centre first before further transported to the prepared disposal site. In this study, the disposal site distribution centre (DC_j) is taken into consideration to formulate the excavated soil transportation alternative before further transportation to the final disposal site.

The excavated soil disposal site and the disposal site distribution centre in each alternative are derived from the interview with decision makers. It is found that 3 appropriate disposal sites are possible, comprising Rama II Road, Soi 82; Yothathikan Road, Nonthaburi 2023; and 90/1 Soi Pracha Uthit 72. A disposal site distribution centre is also available on the way to each disposal site including Rama II interchange, Bot Don Phrom Temple junction, and Suk Sawat Expressway Office interchange respectively.

The disposal site of Rama II Road, Soi 82, has an entire area of 120,000 m^2 with the depth of approximately 2.5 meters as shown in Figure 3. The disposal site of Yothathikan Road, Nonthaburi 2023, has the entire area of 128,000 m^2 with the depth of approximately 1.5 meters

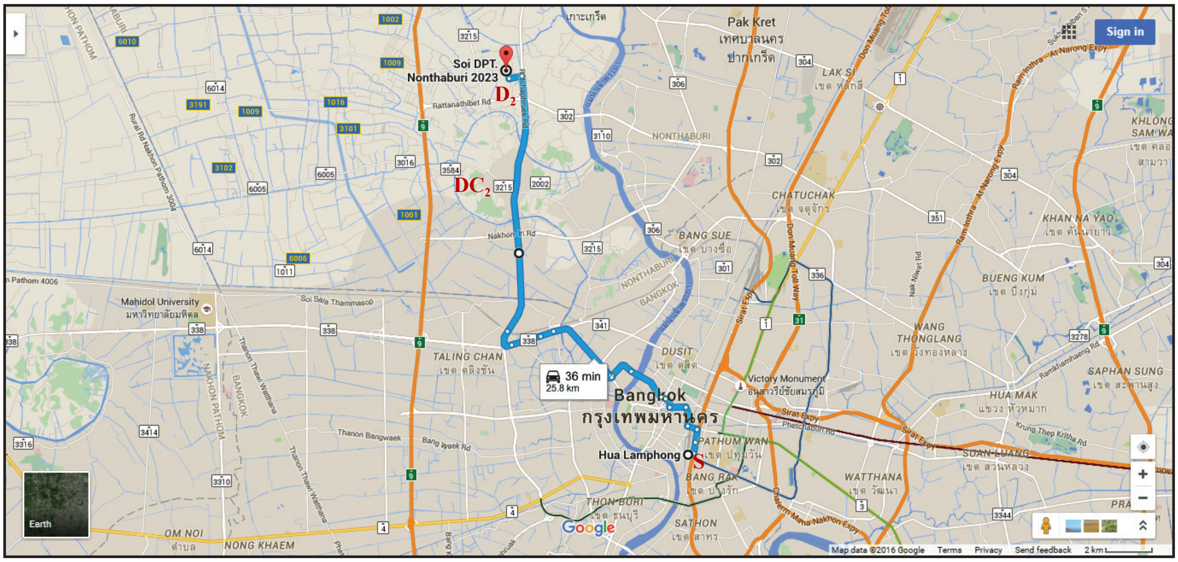

Figure 4: Disposal site, D_2 (Yothathikan Road, Nonthaburi 2023).

Figure 5: Disposal site, D_3 (90/1 Soi Pracha Uthit 72).

as shown in Figure 4. The disposal site of 90/1 Soi Pracha Uthit 72 has an entire area of 96,000 m^2 with the depth of approximately 3 meters as shown in Figure 5. The disposal site distribution centre can bear unlimited excavated soil.

In this research, two feasible alternatives of excavated soil transportation routes are proposed comprising of transportation route without a disposal site distribution centre and the transportation route with a disposal site distribution centre as shown in Figure 6.

The transportation route without a disposal site distribution centre has excavated soil loaded on a truck then driven from the soil excavation site directly to the disposal site. There are three different types of truck, 4-wheeled truck, 6-wheeled truck, and 10-wheeled truck. The different truck types also affect the driving time, 19 hours, 13 hours, and 12 hours respectively. This is a result from the truck ban of different truck types in the inner part of the city.

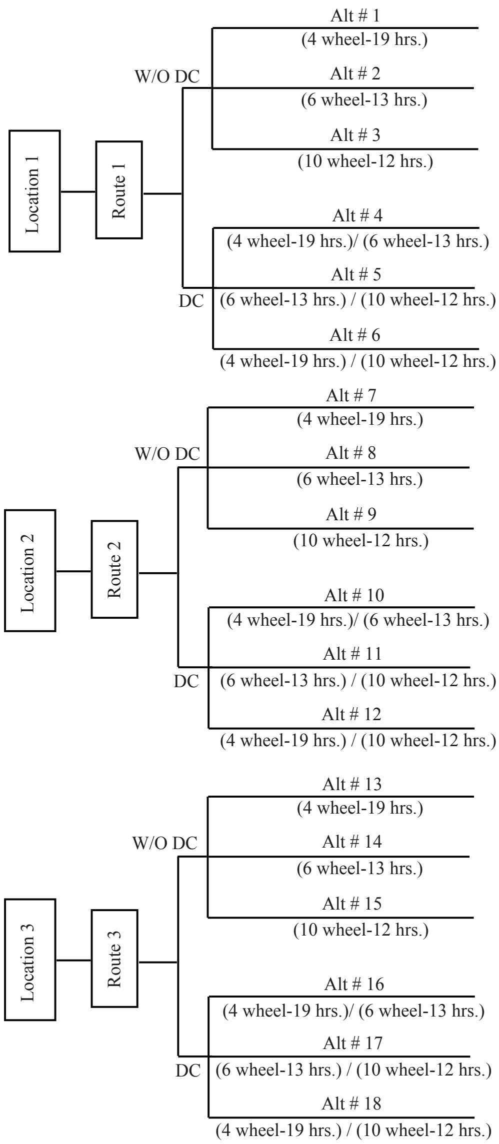

Figure 6: Feasibility alternatives.

The transportation route with disposal site distribution centre in the second alternative is that the excavated soil loaded truck is driven from the soil excavation site to the disposal site distribution centre first before further transportation to the destination disposal site. Similarly, this alternative has 3 sub-features. The 3 different types of truck include 4-wheeled truck, 6-wheeled truck, and 10-wheeled truck. The different truck types also affect the driving time, 19 hours, 13 hours, and 12 hours respectively as shown in Figure 6.

3.2 *Cost estimation and quality criteria assessment*

This study is designed to formulate the decision system to select the excavated soil transportation alternative from the urban metro construction. The decision criteria to be selected must be the criteria solely for this work. Also the economics, environment and society are taken into account and the mentioned experts considered that they should involve the decision making to select the excavated soil transportation route and disposal site. Quality criteria has been assessed by 4 stakeholders of Hua Lamphong MRT Station and results are expressed in mathematic means. The details and evaluation results are as follows:

3.2.1 Cost Estimation

Based on the excavated soil transportation problem in combination with the interview with the experts specialized in the excavated soil transportation from the metro construction, it is found that there are 18 feasibility alternatives to the excavated soil transportation from the urban metro construction. The transportation cost and the time spent in the transportation of each alternative are applied as the decision database as shown in the equation (7).

$$CT = (DIST \times WT \times AT) + SR \tag{7}$$

- Charge of Transportation (CT, baht/day) is the charge for excavated soil transportation from the soil excavation site to the disposal site per day.
- Distance of Transportation (DIST, km/round number) is the distance of transportation by truck per trip in each criterion.
- Wage of Transportation (WT, baht/km) is the charge for the trucks transporting the excavated soil per kilometre in each alternative.
- Amount of Trips (AT, round number/day) is the driving trip number of each truck per day.
- Space Rental (SR, baht/day) is charged by the disposal site distribution centre. The space rental of the disposal site distribution centre No. 1 and No. 3, comprising Rama II interchange and Suk Sawat Expressway Office interchange, is 4,000 baht/month, and that of the disposal site distribution centre No. 2, Bot Don Phrom Temple junction, is 11,000 baht/month.

In this research, the evaluation is carried out from the prototype Hua Lamphong MRT Station to all 3 targeted disposal sites for each transportation route and cost of all 18 feasibility alternatives as shown in Table 3.

Table 3: Cost of excavated soil transportation

No. Alternatives	Type of Truck (Wheel)	Charge of Transportation (Baht)
1	4	63,156
2	6	61,060
3	10	85,287
4	4 and 6	61,425
5	4 and 10	75,641
6	6 and 10	77,161
7	4	55,176
8	6	53,345
9	10	74,511
10	4 and 6	54,756
11	4 and 10	73,482
12	6 and 10	74,526
13	4	45,144
14	6	43,644
15	10	60,963
16	4 and 6	44,747
17	4 and 10	57,086
18	6 and 10	58,054

3.2.2 Quality criteria assessment

1. Site access criteria

These are the qualitative criteria of the excavated soil disposal site that are applied to consider the number and size of traffic lanes by taking the possible traffic island into account. The government organizations or the agencies involved must arrange for the access of that route to be suitable for the trucks driving in and out. The criteria will be evaluated by the scores created by the experts. The scores are divided into 5 levels as shown in Table 4.

Table 4: Site access criteria

Score Level	Qualitative Characteristics
1	4 large traffic lanes with traffic island (two-way street)
2	4 small traffic lanes without traffic island (two-way street)
3	2 large traffic lanes without traffic island (two-way road)
4	2 small traffic lanes without traffic island (two-way road)
5	1 small traffic lanes (two-way road)

Regarding the score evaluation of site access criteria in each alternative, the weight of each route to the excavated soil disposal site is not equal, resulting in the difference of each route. For example, the first alternative of Rama II Road, Soi 28, has the total distance of 27.7 kilometres. If the 4-wheeled truck is driven from the soil excavation site along the road of 4 large traffic lanes with a traffic island, the distance is 20.1 kilometres. In the case of the road with 4 small traffic lanes without a traffic island, the distance is changed to 5.7, 1, and 0.9 kilometres respectively. The evaluator gives all alternatives a score of 1 which can be evaluated by weighting the different distance.

The score of the first alternative is as the equation (8).

$$\frac{(1\times 20.1)+(5\times 5.7)+(4\times 1)+(5\times 0.9)}{27.7}=2.06 \qquad (8)$$

2. Area infrastructure criteria

The infrastructure in the areas to be the excavated soil disposal sites is substantially important. This is because if there is no water, the excavated soil transportation contractor cannot have the truck tires cleaned before leaving the soil disposal site that is certainly illegal and causes the transportation to stop. If no electricity is supplied in the area, the operation at night-time is not possible, and it is rather clear that the excavated soil transportation is mostly carried out at night-time. The criteria are derived from the on-site survey with the score from the experts as shown in Table 5.

Table 5: Area infrastructure criteria

Score Level	Qualitative Characteristics
1	Both the water and electricity are supplied.
2	The water is supplied.
3	The electricity is supplied.
4	Both the water and electricity are not supplied, but the additional installation is possible.
5	Neither the water nor the electricity is supplied.

3. Area terrain criteria

These criteria are applied to evaluate the height condition of excavated soil disposal site to see how it can affect the soil disposal to the place. The terrain environment of limited area is taken into account that if the excavated soil is disposed of, how it will affect the surrounding area environment and the excavated soil transportation.

That means, if the area is so deep from the ground level, in view of the investment, it is worthwhile because the area can hold a great amount of excavated soil. But in view of the operation, it may be very risky and the equipment must be made available to facilitate the excavated soil disposal. On the operational basis, the extremely deep area is not the most appropriate for the excavated soil disposal. The criteria are derived from the on-site survey with the score from the experts as shown in Table 6.

Table 6: Area terrain criteria

Score Level	Qualitative Characteristics
1	2.0 - 3.0 metres lower than the ground level
2	1.0 - 2.0 metres lower than the ground level
3	Less than 1.0 metre or more than 3.0 metres lower than the ground level
4	The ground level
5	Higher than the original ground level

4. Stress of driver criteria

These qualitative criteria reflect the truck driver having the experiences with that transportation route. Taken into consideration is the result of stress of the truck driver in each transportation route and excavated soil disposal site as shown in Table 7.

Table 7: Stress of driver criteria

Score Level	Qualitative Characteristics
1	The least stress
2	Less stress
3	Medium stress
4	Much stress
5	The most stress

5. Liquidity of traffic criteria

These criteria are derived from the expert interview for each transportation route. The liquidity of traffic is also an important factor for the transportation route selection. The expert expressed his opinion on the traffic conditions of each transportation route in each alternative as shown in Table 8.

Table 8: Liquidity of traffic criteria

Score Level	Qualitative Characteristics
1	The most liquidity of traffic
2	Much liquidity of traffic
3	Medium liquidity of traffic
4	Less liquidity of traffic
5	The least liquidity of traffic

The transportation route quality evaluation results of 18 alternatives are shown in Table 9.

Table 9: Qualitative assessment of each alternative

Alt No.	Site Access			Area Infrastructure			Area Terrain			Stress of Driver			Liquidity of Traffic		
	i-k	i-j	j-k	i-k	i-j	j-k	i-k	i-j	j-k	i-k	i-j	j-k	i-k	i-j	j-k
1	2.06	0	0	2.00	0	0	1.00	0	0	3.25	0	0	1.25	0	0
2	2.06	0	0	1.75	0	0	1.00	0	0	3.75	0	0	1.75	0	0
3	2.06	0	0	1.50	0	0	1.00	0	0	3.75	0	0	3.50	0	0
4	0	1.0	4.87	0	1.75	2.25	0	1.0	1.00	0	1.75	2.00	0	1.25	1.25
5	0	1.0	4.87	0	1.50	2.50	0	1.0	1.00	0	2.00	1.50	0	1.75	1.75
6	0	1.0	4.87	0	1.50	3.00	0	1.0	1.00	0	1.25	2.00	0	3.00	3.00
7	2.70	0	0	2.00	0	0	2.00	0	0	2.50	0	0	1.25	0	0
8	2.70	0	0	2.00	0	0	2.00	0	0	2.75	0	0	2.00	0	0
9	2.70	0	0	2.25	0	0	2.00	0	0	2.25	0	0	4.00	0	0
10	0	1.0	4.95	0	1.50	2.75	0	1.0	2.00	0	1.25	1.00	0	1.00	1.00
11	0	1.0	4.95	0	1.25	2.25	0	1.0	2.00	0	1.00	1.75	0	1.75	1.25
12	0	1.0	4.95	0	1.25	2.50	0	1.0	2.00	0	1.75	1.50	0	2.25	1.75
13	1.98	0	0	2.00	0	0	2.00	0	0	2.50	0	0	1.75	0	0
14	1.98	0	0	2.00	0	0	2.00	0	0	2.75	0	0	2.00	0	0
15	1.98	0	0	2.25	0	0	2.00	0	0	2.25	0	0	4.00	0	0
16	0	1	3.02	0	1.50	2.75	0	1.0	2.00	0	1.25	1.00	0	1.00	1.00
17	0	1	3.02	0	1.25	2.25	0	1.0	2.00	0	1.00	1.75	0	1.75	1.25
18	0	1	3.02	0	1.25	2.50	0	1.0	2.00	0	1.75	1.50	0	2.25	1.75

3.3 *FAHP*

After the excavated soil transportation cost calculation is formulated and the qualitative evaluation of the alternative excavated soil transportation is carried out, FAHP is applied to formulate the hierarchical structure of the alternative excavated soil transportation for the decision maker or planner to take part in weighting the importance of each selection criterion as shown in Figure 7. The transportation decision maker or planner has to weight all criteria.

When the criteria structure hierarchy is formulated, the decision makers can weigh the importance of all 6 criteria. The relative weight is carried out by a pairwise comparison with the target by applying the linguistic variable and the triangle fuzzy number scale (see Table 1 above). The fuzzy comparison judgements with respect to the goal are shown in Table 10.

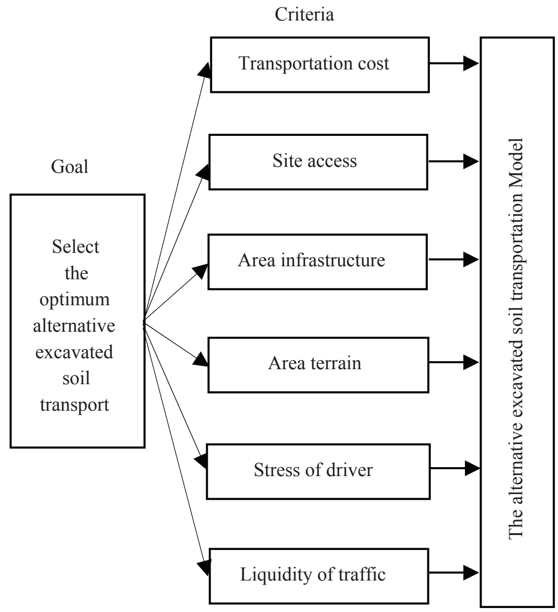

Figure 7: A hierarchy of the alternative excavated soil transportation.

3.4 *Result*

After the data of 3.2.1 and 3.2.2 are obtained, they will be normalized together with the excavated soil transportation cost and the qualitative evaluation data of all 18 alternatives so that the data obtained are on the same basis. Then the data will substitute for the coefficient in the integer linear programming by weighting as FAHP-ILP model. After that the importance of 6 criteria is fuzzily weighted by the decision maker. Decision maker is the project engineer from contractor company who contribute to the decision making process. Thus, he recognizes real environment. It is found that the crisp weightings of these criteria are derived as follows: as shown in Table 10, the transportation cost criteria (wc1=0.325), the site access criteria (wq2=0.232), the area infrastructure criteria (wq3=0.192), the area terrain criteria (wq4=0.13), the stress of driver criteria (wq5=0.05), the liquidity of traffic criteria (wq6=0.071), and C.R.=0.021. All of these weightings will be substituted in the weight FAHP-ILP model, as indicated in the equation (1).

The weight FAHP-ILP model will be applied to select the alternative excavated soil transportation route from the urban metro construction site. The equation mentioned above can process the transportation cost and qualitative cost simultaneously, the data processed by MS Office Excel 2016.

Table 10: Fuzzy pairwise comparison of criteria and relative weights of criteria with respect to goal

Goal	C1	C2	C3	C4	C5	C6	Relative Weights
C1	(1,1,1)	(1,2,2.5)	(1,1.5,2)	(1,1.5,2)	(2,2.5,3)	(2,2.5,3)	0.325
C2	(0.4,0.5,0.667)	(1,1,1)	(1,1,1)	(0.5,1,1.5)	(2,2.5,3)	(2,2.5,3)	0.232
C3	(0.5,0.667,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1.5,2,2.5)	(1.5,2,2.5)	0.192
C4	(0.5,0.667,1)	(0.667,1,2)	(1,1,1)	(1,1,1)	(0.5,1,1.5)	(0.5,1,1.5)	0.130
C5	(0.333,0.4,0.5)	(0.333,0.4,0.5)	(0.4,0.5,0.667)	(0.667,1,2)	(1,1,1)	(0.5,1,1.5)	0.050
C6	(0.333,0.4,0.5)	(0.333,0.4,0.5)	(0.4,0.5,0.667)	(0.667,1,2)	(0.667,1,2)	(1,1,1)	0.071
C.R.							0.021

Notes: C1= transportation cost; C2= site access; C3= area infrastructure; C4= area terrain; C5= stress of driver; C6= liquidity of traffic

Table 11: Optimal solution for WFAHP-ILP model

	wc1 (0.325)	wq2 (0.232)	wq3 (0.192)	wq4 (0.130)	wq5 (0.05)	wq6 (0.071)	Optimum Route	DM Optimum
Project Manager	0.645	0.106	0.100	0.045	0.050	0.054	14	14
Project Engineer	0.256	0.185	0.210	0.109	0.162	0.078	13	13
Transportation Contractor	0.245	0.150	0.178	0.130	0.212	0.085	13	13

The major advantages of this approach, is that the decision maker can consider concurrently both qualitative and quantitative criteria and also viewpoints of the planner and contractor are focused. The decision maker will select the alternative No.13 that the 4-wheeled truck is solely used to transport the excavated soil to the disposal site with the total cost of 45,144 baht.

In the contemporary model, the fuzzy AHP scores of these criteria will be transformed into the weighting criteria and included in the model. The Table 11 illustrates the optimal solution of WFAHP-ILP model. The criteria weighting of each DM depends on his/her expertise, experiences, and responsibilities which are not equal in value. Therefore, the sensitivity analysis is used to evaluate the influence on the optimum route. To achieve this goal, the optimal solution of the excavated soil transportation model should be weighted by all decision makers. The project manager weighted substantially the importance of cost criteria as it is the administrator's viewpoint. It means that the lessened weight is the decrease of human importance. If DMs provides less important weights to the transportation cost criteria, it is to increase the awareness of qualitative criteria. This means that both qualitative and quantitative weighting criteria should be taken into consideration. In other words, the project engineer and transportation contractor give more precedence to the human aspect. According to the results, if DMs give unequal relative weights to the cost and quality criteria, it will finally result in different optimum route of the model. Although this model is to guarantee the lower cost, the acceptance level of decision makers may not always be like that. Finally, DMs should take the real environment into consideration. Therefore, all three DMs reach a consensus that the alternative 13 is the optimum one.

Furthermore, the decision makers can consider only the matter of cost, on the contrary, the decision makers are interested in considering only the matter of quality. From the results above in Table 12, it is found from the optimal solution of WFAHP-ILP that in the case of decision makers choosing to consider solely the relative weighting criteria of excavated soil transportation cost, they will select the alternative No.14, the 6-wheeled truck to transport the excavated soil directly to the disposal site with the total cost of 43,644 baht, or in the case of decision makers choosing to consider solely the qualitative relative weighting criteria, they will select the alternative No. 2, the 6-wheeled truck to transport the excavated soil directly to the disposal site with the total cost of 61,060 baht.

Table 12: Utilizable of WFAHP-ILP model

Only criterion	Alt no.	Total Cost (baht)	Type of Truck
Cost	14	43,644	6 wheels
Quality	2	61,060	6 wheels

For the first analysis, in case the quantitative relative weighting criteria are solely considered, the distance of the transportation route is the shortest and using a 6-wheeled truck which reflects well on the transportation costs. This is because the 6-wheeled truck takes 13 hours to transport the excavated soil, less than the 4-wheeled truck taking 19 hours. So, the short distance of transportation route and short driving time results in the lowest transportation cost. But such results do not reflect well on the qualitative effect on the transportation route or the disposal site. In the other case that the qualitative importance weighting criteria is solely considered, it is found that the alternating use of trucks in each interval, especially the 6-wheeled trucks is rather obvious that this decision model is aimed at lessening the risk of excavated soil transportation in the urban area but it will affect higher cost.

Ultimately, regarding the case, both qualitative and quantitative weighting criteria are considered, although the cost is higher than only the cost criteria case, it is less than only the quality case above. The distance of transportation route is the shortest, the 4-wheeled truck is used for the transportation which can reflect well on the quality of transportation route and disposal site in other dimensions. That is, the transportation route is of the optimum or near optimum, it reflects more convenient, the site access is better, the infrastructure is adequately supplied, and the stress of driver is less. Thus, this is the reason why the quantitative and qualitative characteristics are included in the decision making process to select the alternative excavated soil transportation from the metro construction sites in the urban area where there are limitations on the excavated soil disposal site, construction site area, truck ban ordinance, and congested traffic.

4 Conclusions

The decision making to select, especially the alternative excavated soil transportation from the urban metro construction sites in Bangkok, is an interesting matter nowadays because of the limitations on excavated soil disposal sites, construction site area, and congested traffic. In addition, the urban area is under a Truck Ban Ordinance which restricts operations. As a result, the entrepreneur or the contractor company of the metro construction site require an effective systemized planning system. So, good planning must be derived from good decision making which needs to be hierarchical. It may be said that the hierarchical decision should have the systemized alternatives [11]–[13].

As mentioned above, the problem of excavated soil transportation, especially from urban metro construction, has not yet been solved [13]. In this research, the importance of appropriate alternative formulation is foreseen, also the systemized selection in which the decision makers can take part in weighting the importance of selection criteria in the equation comfortably formulated which is called the "Weight FAHP-ILP Model". This is specially designed to calculate the optimal alternative excavated soil transportation from the urban metro construction. Moreover, this mentioned model which is formed in relative weights on fuzzy qualitative criteria are not clear in decision. The appropriate alternative of excavated soil transportation has the integer relationship of both quantitative and qualitative criteria. It means that if the importance is given solely to the quantitative criteria for any alternative, the quality of that alternative is bad. For example, the transportation distance is short but the entrance to the disposal site is extremely narrow, and the planners try to save only the transportation cost but they forget to consider that the narrow entrance adjacent to the community may result in the problem of petition followed by the order to stop the operation. It is not certain worthwhile investment. Thus, the selection of alternative excavated soil transportation should give equal importance to both quantitative and qualitative criteria, but it is not real because the two criteria are not equal.

Therefore, what must be done in the future is the formulation of the alternatives of database which will be used for data processing. So, it is necessary for the decision makers to formulate the database or adjust it accordingly so as to keep these criteria always up to date, and also the database should be formulated more and bigger than the database in this research.

Moreover, due to the environmental legislation and increased environmental protection awareness of local people around their residences and the soil excavated transportation routes, soil excavation or transportation contractors cannot be ignored for environmental reasons. For example, firstly, the excavated soil loading process may affect the environment around the soil excavation site, for instance, it causes very loud noice and dust during the excavation, etc. Secondly, the excavated soil transportation process may affect tire track-out of dirt and sediment onto public roads. For the last case, the excavated soil unloading process may affect the sensitive environment areas around the disposal sites, for example, common habitats, plants and animals, etc. The future researches should propose WFAHP-ILP integrated environmental criteria in which the DMs' opinions are also taken for the decision making. The possible green evaluation criteria will be defined and the model will be further formulated. Therefore, the environmental subject will be developed so that it could be really used for the selection of urban metro construction excavated soil transportation.

Acknowledgements

The authors would like to thank all experts for their dedicated time and invaluable opinions in the interview.

The authors are also indebted to the reviewers for their constructive comments and suggestions which enabled the improvement of the quality of the present study.

References

[1] The Office of Transport and Traffic Policy and Planning (OTP), "Summary Report of Project Master Plan Rail Transit System in The Metropolitan," Department of Transportation, Thailand, 2010.

[2] E. Dosal, J. R. Viguri, and A. Andres, *Multi- criteria Decision Making Methods For the Optimal Location of Construction And Demolition Waste (C&DW) Recycling Facilities*. Cambridge: Woodhead Publishing Limited, 2013, pp. 76–107.

[3] G. Banias, C. Achillas, C. Vlachokostas, N. Moussiopoulos, and I. Papaioannou, "A web-based Decision Support System for the optimal management of construction and demolition waste," *Waste Management*, vol. 31, pp. 2497–2502, Jul. 2011.

[4] D. J. Epino, E. C. Lopez, J. R. Hernandez, and J. C. C. Jordan, "A review of application of multi-criteria decision making methods in construction," *Automation in Construction*, vol. 45, pp. 151–162, May, 2014.

[5] T. Triwong and W. Meethom, "The criteria establishment for the dumping site selection of urban metro construction by the application of the analytical hierarchy process," *International Journal of Computer Science and Electronics Engineering*, vol. 3, no. 1, pp. 17–21, 2015.

[6] T. Triwong and W. Meethom, "The criteria establishment for dumping site route selection of urban metro construction," *International Journal of Scientific Engineering and Applied Science*, vol. 1, no. 7, pp. 17–21, 2015.

[7] O. S. Vaidya and S. Kumar, "Analytic hierarchy process: An overview of applications," *European Journal of Operational Research*, vol. 169, pp. 1–29, Jan. 2006.

[8] T. L. Saaty, "How to make a decision: the analytic hierarchy process," *European Journal of Operational Research*, vol. 48, pp. 9–26, 1990.

[9] G. Zheng, Y. Jing, H. Huang, G. Shi, and X. Zhang, "Developing a fuzzy analytic hierarchical process model for building energy conservation assessment," *Renewable Energy*, vol. 35, pp. 34–39, Jul. 2010.

[10] D. Y. Chang, "Theory and methodology: applications of the extent analysis method on fuzzy AHP," *European Journal of Operational Research*, vol. 95, pp. 649–655, 1996.

[11] C. Macharis and A. Bernardini, "Reviewing the use of multi-criteria decision analysis for the evaluation of transport projects: Time for a multi-actor approach," *Transport Policy*, vol. 37, pp. 177–186, Nov. 2004.

[12] H. Yuan and L. Shen, "Review: Trend of the research on construction and demolition waste management," *Waste Management*, vol. 31, pp. 670–679, Oct. 2010.

[13] Z. Wua, A. T. W. Yu, L. Shen, and G. Liu, "Quantifying construction and demolition waste: An analytical review," *Waste Management*, vol. 34, pp. 1683–1692, May, 2014.

[14] T. He, W. Ho, C. L. K. Man, and X. Xu, "A fuzzy AHP based integer linear programming model for the multi-criteria transhipment problem," *The International Journal of Logistics Management*, vol. 23, no. 1, pp. 159–179, 2012.