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A novel holistic approach for solving the multi-criteria transshipment problem for infectious waste management

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A B S T R A C T

Effective transshipment network is currently recognized as an important success determinant for most manufacturing organizations, because the transshipment management has significant impact on cost and environmental impact. Due to the complexity of the multi-criteria transshipment problem for infectious waste management (IWM) for this case, forty hospitals and three candidate disposal municipalities in Northeastern Thailand, a novel holistic approach (combination of fuzzy AHP, transshipment model and DEA) was developed for solving this problem. We first utilized the fuzzy AHP technique to calculate the location weights of each candidate disposal municipalities. Secondly, a new cost-based transshipment model was formulated and solved in order to provide the set of feasible solutions. These solutions can be viewed as decision making units (DMUs), inputs and outputs. Finally, DEA-CCR model was applied to calculate the efficiency scores of candidate DMUs. The study results demonstrated that the proposed holistic approach can help decision makers (DMs) to choose a suitable transshipment network for IWM. The major advantage of the proposed holistic approach is that both costs and environmental impacts under constraints are focused on simultaneously. Future work will apply the developed approach with other real-world complex problems to enhance the validity of the research output further. For large-size transshipment problems in which an exact solution cannot be found, meta-heuristics must be applied.

1. Introduction

Transshipment problem, which form a subgroup of the transportation problem, has become a critical issue in the current logistics and supply chain management. Effective transshipment network management is currently recognized as a key success factor for the competitiveness and success by most sectors. The transshipment problem is similar to the transportation problem which deals with shipping a commodity from an origin to a final destination. In a transshipment problem, the commodities are not sent directly from sources to final destinations, i.e. they pass through at least one intermediate point before reaching the final destination (Gass, 1984). The transshipment problem is a critical area of transportation network management that can enable a transportation network to achieve cost savings by consolidating shipments from several supply points at intermediate points, and then sending them together to demand points. Traditionally, the transshipment problem is one of the single-objective optimization problems. A transshipment network that incurs the lowest total cost is

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considered as the best transshipment network. Although cost-based transshipment theory has a long history, it seems that the viewpoint of cost alone cannot deal with real-world problems such as networks for waste disposal, networks for nuclear power plants and networks for IWM. One of the most essential difficulties in solving the multi-criteria transshipment problem for IWM is to choose suitable methods for evaluating these complicated decision criteria, such as economic impact, ecological impact, governmental, municipal and environmental regulations (Önüt & Soner, 2008). Undoubtedly, in practice, the viewpoints of costs and other relevant decision criteria need to be considered together in designing a suitable transshipment network for IWM. This is very complex and it is very difficult to choose the best transshipment network because there are several criteria and various regulations that must be considered together.

From the literature review, the transshipment model is one of the mathematical models often used for solving optimization problems in various application areas. Certainly, in the transshipment problem for IWM, the viewpoint of cost alone cannot deal with this complex problem. Hence, a traditional transshipment model needs to be adapted for solving this problem. In this research, a novel holistic approach is proposed for handling the multi-criteria transshipment model for IWM. Firstly, the fuzzy Analytical hierarchy Process (AHP) (Saaty, 1980) technique is used to identify the global priority weights for candidate disposal municipalities, which is potentially capable of solving the multi-attribute decision making (MADM) problem with uncertain data and imprecise knowledge. Secondly, a new cost-based transshipment model is formulated and solved to provide the set of feasible solutions, based on the variation of the predetermined number of opened disposal municipalities. According todata envelopment analysis (DEA) (Charnes et al., 1978), these solutions can be viewed as decision making units (DMUs), inputs and outputs. Finally, DEA-CCR model (Charnes et al., 1978) is proposed for calculating the efficiency scores of each DMU in order to rank the candidate alternatives, based on three relevant factors/variables including total cost, number of disposal municipalities and global priority weight of disposal municipalities. Certainly, selecting the proposed holistic approach for solving the multi-criteria transshipment problem for IWM will enhance the confidence of decision making (DMs) in choosing a new transshipment network for IWM. The goals are to obtain the lowest total cost, to obtain the minimum number of opened disposal municipalities and to obtain the maximum total weight processing of opened disposal municipalities under the existing constraints. The combination of the advantages of each technique and ways to overcome their weaknesses are potentially capable of solving real-world complex problems. Therefore, the proposed holistic approach is believed to be more appropriate and applicable than stand-alone methods for a multi-criteria transshipment network design.

2. Literature review

Transshipment theory, first introduced by Orden (Orden, 1956), has been extensively applied to solve various optimization problems for over a hundred years. The transshipment problem is an extension of the original transportation problem, in which the shipment of products/goods between the source and the destination is interrupted at one or more intermediate points. The product (such as raw material) is not sent directly from the supplier point to the demand point; rather, it is first transported to a transshipment point, and from there to the demand point (destination). The purpose of the traditional transshipment model is to find the shortest transport route/transportation cost from supplier point in a network to an intermediate point, and then from the intermediate point to a destination point. Later, the transshipment problem has received much attention from many researchers and it has been proposed in a number of various ways in the literature (Alpan et al., 2011; Javaid & Gupta, 2011; Khurana, 2015). Although numerous transshipment models have been studied for a long history, it seems that since the origin of MCDM theory in management sciences, the MCDM theory has been widely used for solving complex real-world problems instead of the stand-alone optimization models in the literature (He et al., 2012; Rezaei et al., 2017). The complex real-world problems cannot be addressed using a cost-based mathematical model alone because there are several criteria and various regulations that must be considered together. Therefore, selecting transshipment network for IWM is one of complex real-world problems/ MCDM problems, because it requires integrating relevant criteria, and various regulations must be taken into account. Existing techniques for solving complex real-world problems/MCDM problems can be divided into two categories (Mendoza & Martins, 2006; Wallenius et al., 2008): (1) including Multi-Attribute Decision Making (MADM) and (2) Multi-Objective Decision Making (MODM)/Multi-Objective Programming (MOP). MADM implicate the selection of the best alternative based on the known attributes of a limited number of pre-specified alternatives, whereas MODM implicate the selection of the suitable alternative that meets the DM's desires (Scott et al., 2012). In MODM, the feasible solutions are usually very large and the suitable alternative will be the one which meets DM's constraints and priorities. There are various MCDM techniques for solving the real-world complex problems in the different fields. Some of the MADM techniques which are widely applied to solve MADM problems are, AHP, DEMATEL, TOPSIS, ELECTRE, SAW, PROMETHEE, ANP and UTA method (Saaty, 2008). Some of the basic MODM techniques are goal programming (GP), weighting method and e-constraint (Banasik et al., 2018). Both MODM and MADM techniques have been widely used to support decision making in MCDM problems in many fields, depending on the case under study and the scope of the analysis. Additionally, each existing MCDM technique differs in complexity and model characteristics.

Although there are many traditional techniques used to tackle MADM problems, AHP is often used to deal with real-world complex problems in the literature (Abdollahzadeh et al., 2016; Al-Harbi, 2001). AHP is one of most powerful and flexible techniques for handling MADM problems with crisp numbers (Karasakal & Aker, 2017; Mobaraki et al., 2014; Unutmaz Durmuşoğlu, 2018). For this reason, AHP techniques have been applied in a wide variety of application areas in the literature. However, due to insufficiency of information, especially for values of qualitative attribute, generally it cannot be expressed by crisp numbers, and some of them are easier to be manifested by fuzzy numbers (Liu et al., 2017). The fuzzy set theory of Zadeh (1965) has been widely applied to deal with uncertainty and fuzziness in the MADM process, and nowadays the fuzzy MADM techniques, such as fuzzy ANP and fuzzy AHP, have often been used to replace traditional MADM techniques in dealing with uncertain data and imprecise knowledge. The main advantages of fuzzy AHP are that the consistency ratio can be measured, and, it can apply to both tangible and intangible criteria (Durán & Aguilo, 2008). However, the disadvantages of fuzzy AHP are that consistency is difficult to achieve when there are too many criteria and alternatives. Thus the fuzzy AHP is potentially capable of solving complex real-world problems with uncertain data and imprecise knowledge. These are the major reasons why the fuzzy AHP technique is chosen as a suitable technique for predetermining the location weights of candidate disposal municipalities in this research. The frontier approach was described by Farrel in 1957 (Farrell, 1957), but a mathematical model for measuring relative efficiency was first introduced as the DEA-CCR model by Charnes et al. (1978). The DEA technique defines the relative efficiency of a group of homogeneous DMUs on the basis of various input- output variables, using mathematical model (Hosseinzadeh Lotfi et al., 2013). Generally, a DMU will be efficient if it obtains the maximum score of 1; otherwise DMUs are inefficient. In recent years a variety of application areas of DEAs have been applied widely in various forms to evaluate the performance of such entities as hospitals, business firms, universities, regions, etc. (Asandului et al., 2014; Ennen & Batool, 2018; Fazlollahi & Franke, 2018; Hosseinzadeh-Bandbafha et al., 2018; Khushalani & Ozcan, 2017; Leleu et al., 2014). DEA is one of the MADM techniques and the relationship between DEA and MADM has been highlighted by a group of researchers (Doyle & Green, 1993; Hu et al., 2017; Lin et al., 2011, 2017; Sinuany-Stern et al., 2000; Stewart, 1996). It has been recognized that the MADM and DEA techniques coincide if input and output variables can be viewed as decision criteria, and DMUs can be viewed as alternatives (Hu et al., 2017; Stewart, 1996). DEA technique is becoming a popular technique since it has the following practical advantages (Fan et al., 2017; Hosseinzadeh Lotfi et al., 2010; Wang et al., 2016): (1) DEA technique is appropriate for evaluating the effectiveness of multiple criteria (multiple inputs and multiple outputs); (2) DEA technique does not require to carry out non-dimensional treatment on the parameters; (3) DEA technique does not need experts to provide weight-related information, because the weights for each variable (Both inputs and outputs) can be gained through mathematical mode; (4)

The relationship between input variables and output variables does not need to be considered in the DEA technique and (5) DMUs can be production units, universities, schools, bank branches, hospitals, power plants, etc. However, some of the disadvantages of DEAs are as follows (Berg, 2010): (1) Results of DEA technique are sensitive to the selection of both inputs and outputs; (2) The best specification cannot be tested and (3) If the number of variables are increased, the number of efficient DMUs tends to increase. The various DEAs have been applied continuously in many application areas because of the advantages of this method. However, one of the disadvantages of DEA is that it cannot rank efficient DMUs, because the efficiency scores of all efficient DMUs are the same value (efficiency score =1), so other methods (Falagario et al., 2012; Hou et al., 2018) should be used to solve such problems. For this reason, we are motivated to apply DEA to calculate the efficiency scores for ranking all DMUs. These are the major reasons why DEA is chosen as a technique for calculating the efficiency scores of each DMU, in order to rank all DMUs in this paper.

The rest of this research is organized as follows. Literature review, Methodology and Application example are presented in Sections 2, 3 and 4 respectively. Finally, Section 5 is the Conclusion.

3. Methodology

When selecting a suitable new transshipment network for IWM, the selection process should have an approach that is appropriate and flexible, and the approach must be able to solve the problem effectively. Therefore, this section presents a holistic approach for solving a multi-criteria transshipment network for IWM. Details of the study framework are demonstrated in Fig. 1.

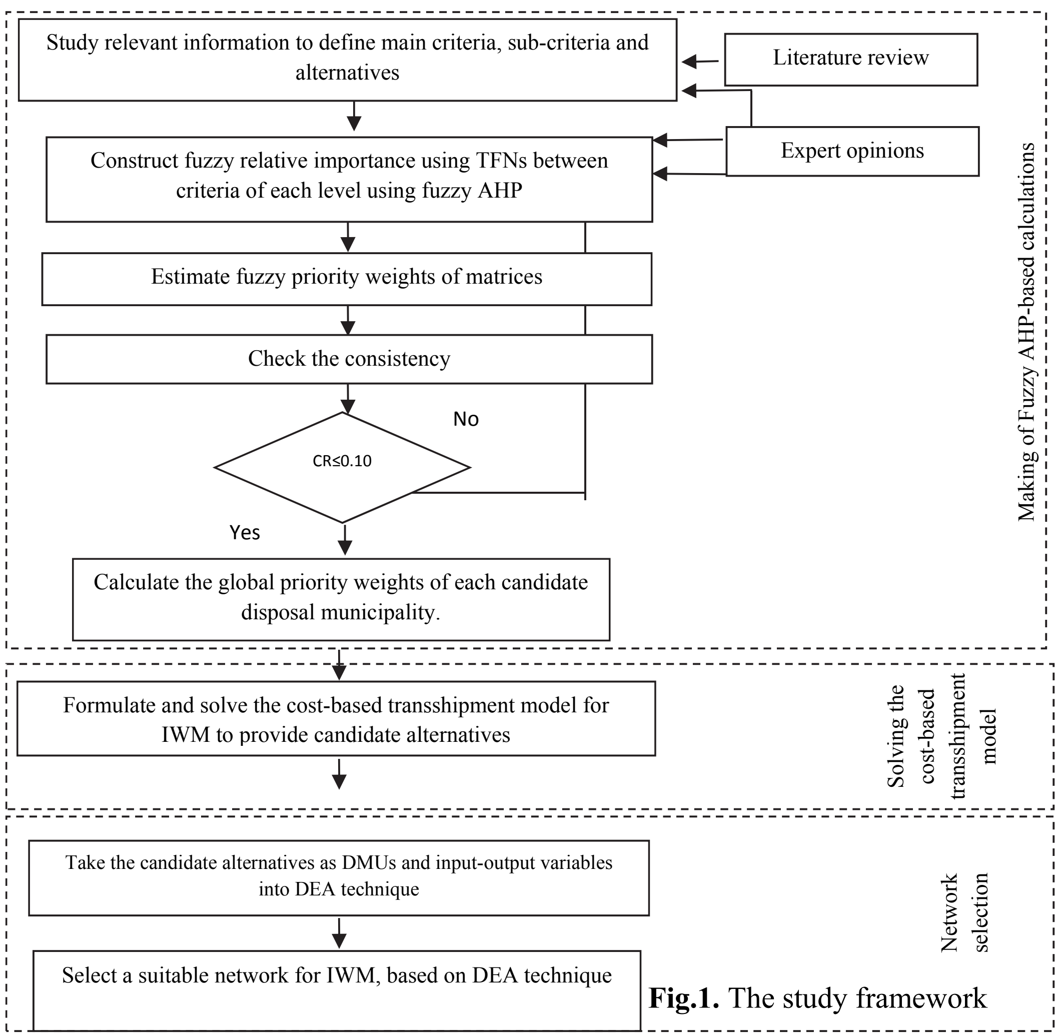

Fig.1. The study framework

3.1 Fuzzy AHP

AHP has been proposed by Saaty (Saaty, 1980; Saaty, 1977). It is one of most powerful and flexible techniques for handling MADM problems. However, the use of AHP's discrete scale cannot handle the ambiguity and uncertainty in deciding on different attributes priorities (Choudhary & Shankar, 2012). Hence, the fuzzy AHP technique has been widely employed for addressing MADM problems instead of original AHP in the literature. In this research, the location weights of candidate disposal municipalities will be evaluated using the same method as Wichapa (Wichapa & Khokhajaikiat, 2017b).

3.2 A cost-based transshipment model for IWM

The transshipment problem is a multi-phase transportation problem, in which the flow of goods or products between the source and the destination is interrupted at one or more points. The goods do not need to send directly from the origin to the destination; rather, they are first transported to a transshipment point, and from there to the destination. Therefore, a transshipment model for IWM that differs from the traditional transshipment models in the literature is formulated to choose various size incinerators, various size stores, multiple candidate transshipment hospitals and multiple candidate disposal municipalities. Details of cost-based transshipment model for IWM are shown below.

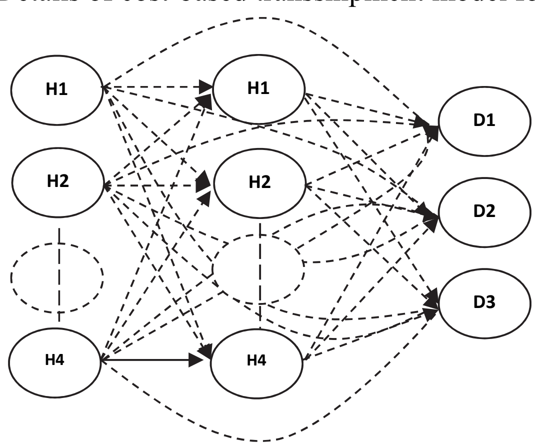

Fig.2. A transshipment network for IWM

Indices:

i is hospitals, $i = 1, 2, \ldots, I$ (I=40).
j is candidate transshipment hospitals, $j = 1, 2, \ldots, J$ (J=40).
k is candidate disposal municipalities, $k = 1, 2, \ldots, K$ (K=3).

Parameters:

u is the value of unit transportation cost (baht/km).
$dt1_{ij}$ is actual distance between hospital i and candidate transshipment hospital j.
$dt2_{ik}$ is actual distance between hospital i and candidate disposal municipality k
$dt3_{jk}$ is actual distance between candidate transshipment hospital j and candidate disposal municipality k.
fs_m is facility and operating costs of storage at stores m, $m = 1, 2, \ldots, M$ ($M = 2$).
fd_n is facility and operating costs of incinerator n, $n = 1, 2, \ldots, N$ ($N = 2$).
d_i is the demand of the hospital i (kg/day).
ds_j is the storage requirement of the opened transshipment hospital j (kg/day).
cs_m is the storage capacity m (kg /day).
cd_n is the incinerator capacity n (kg /day).
p is the number of disposal municipalities to be located.

Decision variables:

$X1_{ij}$ is a binary variable; $X1_{ij}$ = 1 if the waste materials are delivered from hospital i to candidate transshipment hospital j; $X1_{ij}$ = 0 otherwise.
$X2_{ik}$ is a binary variable; $X2_{ik}$ = 1 if the waste materials are delivered from hospital i to candidate disposal municipality k; $X2_{ik}$ = 0 otherwise.
$X3_{jk}$ is a binary variable; $X3_{jk}$ = 1 if the waste materials are delivered from candidate transshipment hospital j to candidate disposal municipality k; $X3_{jk}$ = 0 otherwise.
Y_{jm} is a non-negative variable; Y_{jm} = 1 if candidate transshipment hospital j is selected by using the size of storage m, Y_{jm} = 0 otherwise.
Z_{kn} is a non-negative variable; Z_{kn} = 1 if candidate disposal municipality k is selected by using the size of incinerator n, Z_{kn} = 0 otherwise.

Objective function:

$$\begin{aligned} Min\ G = &\sum_{j=1}^{J}\sum_{m=1}^{M} fs_m \cdot Y_{jm} + \sum_{k=1}^{K}\sum_{n=1}^{N} fd_n \cdot Z_{kn} + \sum_{i=1}^{I}\sum_{j=1}^{J} u \cdot dt1_{ij} \cdot X1_{ij} + \\ &\sum_{i=1}^{I}\sum_{k=1}^{K} u \cdot dt2_{ik} \cdot X2_{ik} + \sum_{j=1}^{J}\sum_{k=1}^{K} u \cdot dt3_{jk} \cdot X3_{jk} \end{aligned} \tag{1}$$

Subject to:

$$\sum_{j=1}^{J} X1_{ij} + \sum_{k=1}^{K} X2_{ik} = 1, \qquad \forall i \tag{2}$$

$$\sum_{i=1}^{I} d_i \cdot X1_{ij} - \sum_{k=1}^{K} ds_j \cdot X3_{jk} = 0, \qquad \forall j \tag{3}$$

$$\sum_{i=1}^{I} d_i \cdot X1_{ij} \le \sum_{m=1}^{M} cs_m \cdot Y_{jm}, \qquad \forall j \tag{4}$$

$$\sum_{m=1}^{M} Y_{jm} \le 1, \qquad \forall j \tag{5}$$

$$\sum_{j=1}^{J} ds_j \cdot X3_{jk} + \sum_{i=1}^{I} d_i \cdot X2_{ik} \le \sum_{n=1}^{N} cd_n \cdot Z_{kn}, \qquad \forall k \tag{6}$$

$$\sum_{n=1}^{N} Z_{kn} \le 1, \qquad \forall k \tag{7}$$

$$\sum_{k=1}^{K}\sum_{n=1}^{N} Z_{kn} \le p \tag{8}$$

$$X1_{ij} \in \{0,1\} \tag{9}$$

$$X2_{ik} \in \{0,1\} \tag{10}$$

$$X3_{jk} \in \{0,1\} \tag{11}$$

$$Y_{jm} \in \{0,1\} \tag{12}$$

$$Z_{kn} \in \{0,1\} \tag{13}$$

The objective function given by Eq. (1) will attempt to minimize the total cost of opened disposal municipalities. Eq. (2) means that the demand of hospital i is delivered from hospital i to either a transshipment hospital j or a disposal municipality k. Eq. (3) means that the amount of waste materials delivered to each transshipment hospital is equal to the amount of waste materials transported from that transshipment hospital to the candidate disposal municipality. Eq. (4) means that the amount of waste materials transported from each hospital to all the transshipment hospitals cannot exceed their storage capacity. Eq. (5) ensures that the sum of storage m at transshipment hospital j cannot exceed one. Eq. (6) means that the amount of waste materials transported from each hospital and transshipment hospital to all the candidate disposal municipalities cannot exceed their incinerator capacity n. Eq. (7) ensures that the sum of opened incinerator n at disposal municipality k cannot exceed one. Eq. (8) requires exactly p disposal municipalities to be located. Eq. (9) to Eq. (13) are binary constraints.

3.3 Using DEA technique for ranking DMUs

In this research, the holistic approach is developed for finding the suitable transshipment network for IWM. Initially, the location weights of the candidate disposal municipalities must be calculated using the fuzzy AHP technique. After that, the cost-based transshipment model, Eq. (1) to Eq. (13), must be calculated, to vary the predetermined number of opened disposal municipalities, to determine the feasible solutions of each p. These feasible solutions will be considered as DMUs with three variables, including total cost, predetermined number of opened disposal municipalities and priority weights of candidate disposal municipalities.

Each candidate alternative from the cost-based transshipment model will be divided as DMUs and input-output variables in the DEA technique. The DEA technique is a non-parametric mathematical model used to calculate the relative efficiency scores of a set of homogeneous DMUs on the basis of various outputs and inputs. In this paper, DEA -CCR model (1978) will be used to address the multi-criteria transshipment model for IWM. Details of DEA -CCR model are as follows.

Indices:
i is the index of each input variable i, i= 1, 2,...,m, (m=2).r is the index of each output variable r, r= 1, 2, ..., R, (R=1).
j is the index of each DMU j, j= 1, 2,...,n, (n=7).

Parameters:
x_{ij} is the value of each input variable i.
y_{rj} is the value of each output variable r.

Variables:
u_r is the weight associated with output variable r
v_i is the weight associated with input variable i

$$\max = \sum_{r=1}^{s} y_{ro} \cdot u_r \tag{14}$$

$$\sum_{i=1}^{m} v_i \cdot x_{io} = 1 \tag{15}$$

$$\sum_{r=1}^{s} y_{rj} \cdot u_r - \sum_{i=1}^{m} v_i \cdot x_{ij} \le 0; \qquad \forall j \tag{16}$$

$$v_i,\ u_r \ge 0; \qquad \forall i,\ \forall r \tag{17}$$

where y_{rj} and x_{ij} are generated using the feasible solutions/candidate alternatives. From each alternative, let the total cost be Input variable *-1*, the number of disposal sites be Input variable *-2* and the priority weight of selected disposal centers be Output variable *-1*. Based on the DEA-CCR model, the efficiency scores of each DMU can be achieved using LINGO13 software. The better DMU are those that have higher efficiency score and therefore should be chosen because they are closer to the efficiency score of 1 (efficient DMUs). If there is more than one efficient DMU, DEA technique will not be able to rank those DMUs. Therefore, choose other methods such as cross efficiency or a hybrid technique instead of original DEA.

4. Application example

Infectious waste is one of the serious hazardous waste problems for management in Thailand. This waste, which is generated at medical facilities can spread pathogens to the environment. Legally, municipalities have been designated as waste disposal agencies. In the past, there were many hospitals that had their own incinerator, but as a result of protests by local communities and environmental anxiety, some incinerators within hospitals were shut down. Hence, these hospitals eventually have to use disposal services from external agencies. External services, however, were not able to dispose of existing IW effectively, because they are far from the locations of hospitals. Hence, the relevant public sectors of Thailand, which are the Ministry of Health, the Ministry of Natural Resources and the Environment, and the Ministry of the Interior, have set up a policy to support IWM by integration of neighborhoods, in order to increase the efficiency of IWM. Thus, the relevant government agencies assigned to municipalities are responsible for building a suitable new transportation network/transshipment network using the existing areas of candidate disposal municipalities and using the existing areas of candidate transshipment hospitals. Although this problem has been studied by researchers (Wichapa & Khokhajaikiat, 2017a, 2017b), the total cost is still high. For this reason, the authors have developed and redesigned a new transshipment network for solving this problem. A new transshipment network should be considered with economic, environmental and social aspects simultaneously. The disposal municipalities must not cause harm to the biophysical environment and the ecology of the neighboring areas. An ideal transshipment network (disposal municipalities, transshipment hospitals, hospitals, arcs) should provide lowest costs, a minimum number of disposal municipalities and a maximum weight of disposal municipalities. Hence, viewpoints of all impacts should be considered in designing a transshipment network, at the same time. The study was done in 40 hospitals (H1, H2,..., H40) and 3 candidate disposal municipalities (D1, D2 and D3). The candidate disposal municipalities were located from legislation and regulations by experts on knowledge and attitude in IWM. Therefore, a suitable municipality for IWD must be chosen from three candidate disposal municipalities to serve the 40 hospitals (see details in Fig.3). Details of each calculation step are shown in sections 4.1, 4.2 and 4.3.

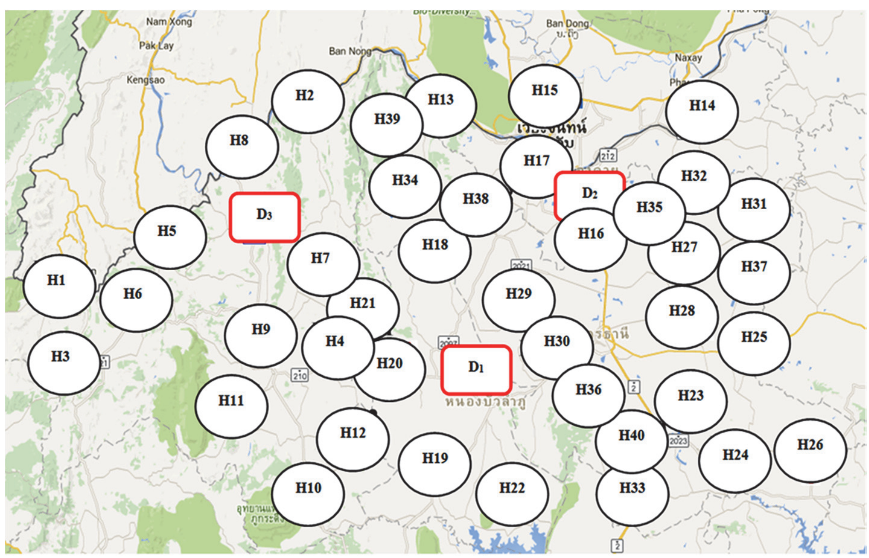

Fig.3. The transshipment network for candidate municipalities and hospitals

4.1. Calculate the global priority weights of each candidate disposal municipality using fuzzy AHP

This section describes the identification of the weights assigned to candidate disposal municipalities, w_k, needed for evaluation using fuzzy AHP in Section 3.1. Firstly, a multi-level hierarchy was constructed by interviewing 6 experts, who have been working in the field for more than 15 years. In the hierarchical structure (see Fig.4), the goal for this case is a suitable disposal municipality for IWM, and level 1 was for the three main criteria: C_1 = infrastructure, C_2 = geological and C_3 = environmental & social. Level 2 was for the ten sub-criteria: C_{11} = public utilities, C_{12} = traffic, C_{21} = area size, C_{22} = features of the area, C_{23} = flooding in the past, C_{24} = density of population, C_{31}= municipal administrators, C_{32} = ability of municipalities, C_{33}= distance from communities and C_{34} = distance from public water resources. The bottom level was the candidate disposal municipalities: D_1= Nong Bua

Lam Phu, D_2= Nong Khai and D_3= Loei. After that, the comparison matrices were constructed by interviewing 6 DMs, using triangular fuzzy numbers. Finally, the location weights of candidate disposal municipalities are shown in Table 1. Details of the priority weights of all elements are shown in Wichapa (Wichapa & Khokhajaikiat, 2017b).

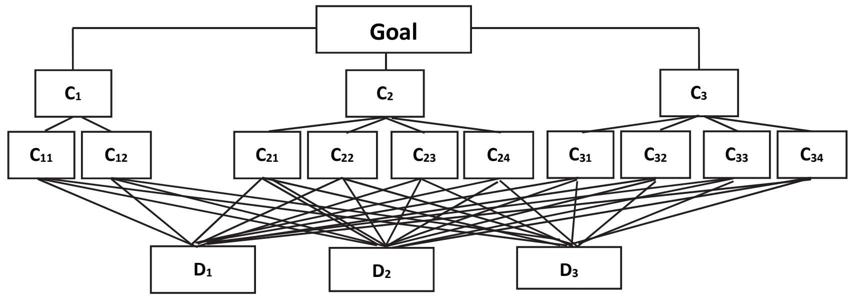

Fig.4. A multi-level hierarchy for evaluating the disposal locations for IWM

Table 1
The final evaluation of weights of candidate disposal municipalities

Candidate disposal municipalities	*Global priority weights*
D_1 (NLTM)	0.550
D_2 (NKTM)	0.210
D_3 (LTM)	0.240

4.2 Compute the feasible solutions of a new cost-based transshipment model

The cost-based transshipment model described in Section 3.2 has been applied to identify the feasible solutions/candidate alternatives. These have been viewed as decision making units (DMUs) and variables (Input and output variables).The necessary data for the analysis was collected as follows. The distance matrices, demands of each candidate municipality and hospitals are shown in Appendix A as $dt1_{ij}$, $dt2_{ij}$, $dt3_{ij}$ *and* d_i. Let u be 4.3 baht/km. The values of fs_m are 986 and 1,972 baht/day respectively. The values of cs_m are 400 and 800 kg/day respectively. The values of fd_n are 11,763 and 22,129 baht/km. The values of cd_n are 400 and 800 kg/day respectively. Finally, the feasible solutions were achieved using LINGO13 software. Based on DEA-CCR model, these solutions were viewed as candidate DMUs, inputs and outputs, details are shown in Table 2.

Table 2
The feasible solutions for each alternative

DMUs	X_1 (Total cost)	X2 (Number of opened disposal municipalities)	Y_1 (Priority weights)
DMU_1 (NLTM)	34,825.21	1	0.550
DMU_2 (NKTM)	35,024.73	1	0.210
DMU_3 (LTM)	36,023.19	1	0.240
DMU_4 (NLTM and NKTM)	35,408.21	2	0.550 and 0.210
DMU_5 (NLTM and LTM)	35,996.89	2	0.550 and 240
DMU_6 (LTM and NKTM)	35,704.06	2	0.240 and 0.210
DMU_7 (NLTM, LTM and NKTM)	46,409.68	3	0.550, 0.240 and 0.210

4.3 Compute the efficiency scores of each DMU using DEA technique

The efficiency scores of each candidate DMU were computed using DEA-CCR model in Section 3.3 For example, the efficiency score of DMU_1 was computed using LINGO13 as follows.

- The DEA model was programmed using LINGO13.

- After that, the second step starts with entering the relevant parameters from Table 2. The output variables were divided into three sets. Details of relevant parameters for DEA are shown in Table 3. Therefore, each DMU's efficiency score has three sets.
- Finally, the efficiency scores of each DMU were computed using LINGO13, as shown in Table 4.

Table 3
Relevant parameters for DEA

Parameters for DEA	X1	X2	Y1_set 1	Y1_set 2	Y1_set 3
DMU1 (NLTM)	34,825.21	1	0.550	0.550	0.550
DMU2 (NKTM)	35,024.73	1	0.210	0.210	0.210
DMU3 (LTM)	36,023.19	1	0.240	0.240	0.240
DMU4 (NLTM and NKTM)	35,408.21	2	0.550	0.210	0.210
DMU5 (NLTM and LTM)	35,996.89	2	0.550	0.240	0.240
DMU6 (LTM and NKTM)	35,704.06	2	0.240	0.210	0.210
DMU7 (NLTM, LTM and NKTM)	46,409.68	3	0.550	0.240	0.210

Table 4
The efficiency scores of each DMU using DEA technique

DMUs	Efficiency score of set 1	Efficiency score of set 2	Efficiency score of set 3	Average	Ranking
DMU1	1.000	1.000	1.000	1.000	1
DMU2	0.382	0.382	0.382	0.382	7
DMU3	0.436	0.436	0.436	0.436	5
DMU4	0.984	0.376	0.376	0.578	3
DMU5	0.967	0.422	0.422	0.604	2
DMU6	0.426	0.372	0.372	0.390	6
DMU7	0.750	0.327	0.287	0.455	4

As seen in Table 4, since he average efficiency score of DMU1 is equal to 1.00 (efficient DMU), DMU1 is the best choice. In addition, the efficiency scores of each DMU is different values. Hence, DEA can rank all DMUs, which does not need to choose other methods. Finally, the comparison of the DEA technique and the cost-based transshipment model is shown in Table 5.

Table 5
Comparison of the cost-based model and proposed DEA

Ranking	Cost-based transshipment model (Total cost)	**DEA**
DMU1: NLTM	1 (134,825.21)	1 (1.000)
DMU2: NKTM	2 (35,024.73)	7 (0.382)
DMU3: LTM	6 (36,023.19)	5 (0.436)
DMU4: NLTM and KTM	3 (35,408.21)	3 (0.578)
DMU5: NLTM and LTM	5 (35,996.89)	2 (0.604)
DMU6: NKTM and LTM	4 (35,704.06)	6 (0.390)
DMU7: NLTM, NKTM and LTM	7 (46,409.68)	4 (0.455)

As seen in Table 5, for DMU_1 the rankings are clearer and more suitable in practice than in other solutions. The selected disposal municipality has the minimum total cost (34,825.21 baht) and minimum number of undesirable locations (p=1). In addition, the selected disposal municipality is an ideal location for IWD (*Priority weight* =0.55). This means that it can reduce the environmental risk and community protests. These are the major reasons why the DMU_1 (NLTM) was selected as a suitable municipality for IWD. Finally, details of the solutions are shown in Fig.5 and Table 6.

Table 6
The solutions of the proposed holistic approach

	Selected	Selected transshipment hospitals		
Name of opened locations	NLTM	H9	H17	H23
Size of opened locations (kg/day)	800	400	400	400
Assigned hospitals	H18, H19, H20, H22, H29,	H1, H2, H3, H4, H5,	H13, H14, H15, H16,	H24, H25, H26, H27,
Demand (kg/day)	(130)+(250.5+185.0+231.0)	250.5	185.0	231.0

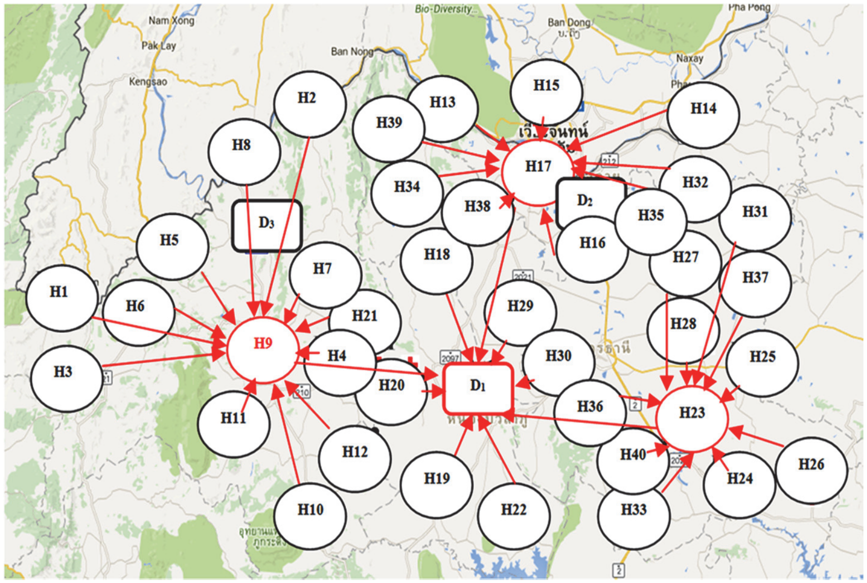

Fig. 5. The suitable transshipment network for IWM

The results of this study provide practical applications and additional insights for research, it can help DMs to establish a novel systematic approach for choosing a suitable transshipment network for IWM. The proposed holistic approach is flexible, valuable and applicable for DMs to limit environmental impact and costs, which differs from other stand-alone optimization models. Therefore, it is believed that the proposed holistic approach should be suitable for solving the multi-criteria transshipment problem for IWM in this case study. Especially important, we believe that the proposed holistic approach can be used to solve other multi-criteria/objective problems in real-world situations.

5. Conclusions

This research has presentes a novel holistic approach to tackle the multi-criteria transshipment problem for IWM with both quantitative and qualitative criteria, under relevant resource limitations, in order to choose a suitable new transshipment network for IWM. The proposed holistic approach was tested with a case study comprising forty hospitals and three candidate disposal municipalities in Northeastern Thailand. We first utilized fuzzy AHP technique to calculate the location weights of candidate disposal municipalities. Secondly, a new cost-based transshipment model was formulated and solved in order to provide the set of feasible solutions /candidate alternatives. Finally, the efficiency scores of each DMU were computed using DEA-CCR model. The results show that NLTM was selected as a suitable disposal municipality for IWM with lowest total cost (134,825.21), minimum number of undesirable locations (p=1) and ideal priority weight (0.550) which were achieved using the proposed holistic approach. This approach is useful and applicable for DMs to limit environmental impact and costs, which differs from other stand-alone optimization models. Especially important, we believe that the proposed holistic approach can be used to solve other multi-criteria/objective problems in real-world situations.

For future research, the limitations of this research lie in that only one case study was studied. Application of proposed methods should be tested with the more cases of multi-criteria transshipment network to enhance the validity of the research output further. Also, for large-size transshipment problems in which an exact solution cannot be found, meta-heuristics must be used.

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Appendix:

Appendix A:

https://sites.google.com/site/appendixnarongwichapa0/appendix-a

Appendix B:

https://sites.google.com/site/appendixnarongwichapa0/appendix-b