Multi-Objective Location Selection Model for Thai Red Cross's Relief Warehouses

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Abstract: In recent years, natural disasters occur more frequently and often more violently. The Thai Red Cross needs to evaluate its current relief warehouse capacity and to plan for the future in order to ensure that it can cope with future demands. To find an appropriate warehouse location we normally analyze by qualitative method or quantitative method separately. In the case of the Thai Red Cross, unlike in a more commercial setting, cost is not the major determining factor that we have to consider. There are other relevant factors such as accessibility of volunteers at the time of disasters, for example. This research will analyze the warehouse location problem by using multi-objective optimization model with Pareto theory to come up with the Pareto optimal set that considers both qualitative and quantitative factors.

Keywords: Multi-Objective Optimization, Pareto Optimal Set, Analytic Hierarchy Process, Relief Warehouse

1. INTRODUCTION

Due to the changing conditions of global environment, natural disasters are becoming more violent and more frequent (Oguta, 2010). The most common disasters for Thailand is floods and the organization that handles the disaster in Thailand is the Thai Red Cross, which is responsible for distributing disaster relief to affected areas. Table 1 shows that the maximum demand of relief bags, which contain consumer goods, are more than Thai Red Cross's services. Therefore, they want to evaluate its relief capability in term of its warehouse capacity in particular and to select appropriate network option to be able to support future activities.

Table 1. The demand of relief bag

Disaster	Maximum Demand (Bags/Day)	Maximum Handling Capacity (Bags/Day)
Flood 9 Jul – 31 Oct 2007	2,000	7,000
Flood 8 Oct – 17 Sep 2008	1,400	7,000
Flood 27 Jun – 23 Dec 2011	13,000	7,000

In this paper, we focus on the facility location problem of this project. The facility location problem is a logistics problem that concerns with the optimal location of facility in order to optimize cost or other objectives that we want to consider. Unlike in a more commercial setting, in the case of the Thai Red Cross, cost is not the major determining factor that we have to consider. Analytical approach to the facility location problem include qualitative analysis and quantitative analysis.

While qualitative method analyzes qualitative factors of the problem, quantitative method analyzes mathematical, statistical or numerical data. This paper propose mathematical approach for analyzing the facility location that combines the qualitative and quantitative methods in order to strike a balance that will be practical for implementation. We use data from the Thai Red Cross to analyze possible options for its warehouses.

2. FACILITY LOCATION PROBLEMS FOR DISASTER RELIEF

2.1 Qualitative Method

Qualitative method analyzes something that cannot be measured in number but influences the issues such as flexibility or accessibility. Qualitative method that is commonly used to analyze facility location problem is Analytic Hierarchy Process (AHP). AHP is an analytical technique for analyzing complex decision. AHP helps the decision maker find an efficient answer and meet the targets.

Korpela *et al.* (2007) used AHP to analyze 5 warehouse location problems that deliver commodities from factory to consumers. They consider this problem in 2 criteria, the first criterion is reliability and the second criterion is flexibility. The reliability criterion covers 3 factors, which are delivery time, quality and quantity. The flexibility criterion covers 4 factors which are urgent delivery, frequency, special request and capacity.

Orencio and Fujii (2012) also used AHP to help them choose disaster recovery center in the coast of the Philippines with 7 criteria: (i) environmental and natural resource management, (ii) human health and well-being, (iii) sustainable livelihoods, (iv) social protection, (v) financial instruments, (vi) physical protection and structural and technical measures and (vii) planning regimes. Those 7 criteria are determined by 2 factors: disaster-resilient communities and risk reduction-enabling environment. The selected criteria are environmental and natural resource management, sustainable livelihoods, social protection and planning regimes.

2.2 Quantitative Method

The quantitative analysis for warehouse locations can be divided into 2 forms by problems in the analysis. The first form is the continuous location problem, which analyzes the warehouses in a given area; therefore, the answer will be in the form of coordinates (X, Y). The second form is the discrete location problem, which analyzes warehouses located in candidate positions; so, the answer is a set of selected candidates.

Rawls and Turnquist (2009) considered a distribution center (pre-positioning of emergency suppliers for disaster response) on disaster relief in Gulf-Coast, England. The objective is to develop a tool for planning the emergency of disaster events with the uncertainly of time and place of the hurricane. They use Stochastic Mixed-Integer Program (SMIP) to solve this problem. Rawls and Turnquist employ Lagrangian L-shaped Method (LLSM) to solve this problem faster.

2.3 Combination of Qualitative Method and Quantitative Method

Because in our problem cost is not the major determining factor, we consider other relevant factors such as accessibility of volunteers at the time of disasters. We therefore propose a combined qualitative and quantitative analysis using multi-objective optimization to find the optimal solution. In this section we review literature related to this problem.

Samanlioglu (2012) used a new multi-objective location-routing problem to select locations for a recycling project in Turkey. The aim of his study was to decide on locations of centers: Recycling center, Treatment center, and Disposal center. This paper considers 3 criteria: minimizing total cost, minimizing total transportation risk related to population along transportation routes, and minimizing total risk of the population around treatment centers and disposal centers. He applied Pareto dominance to solve this problem.

Abounacer *et al.* (2013) used multi-objective optimization to find the healing center location with 3 objective functions. The first objective function is to minimize transportation time. The second objective function is to minimize the number of agents to take care of the products. The last objective function is to find location that covers most of the demand area.

For this paper, we use multi-objective optimization with Pareto dominance theory to find non-dominated or Pareto optimal set.

3. METHODOLOGY

In our case study, there are three potential sites that we want to select as our relief warehouses (Red Cross Stations 2, 5 and 11). The selected relief warehouse(s) will have to supply Red Cross Stations 1, 3, 4, 6, 7, 8, 12 and 13 as presented in Fig. 1.

The outline of the methodology is presented in Fig. 2. The qualitative method employs Analytic Hierarchy Process (AHP), while Mixed-Integer Program (MIP) is used for the quantitative method. To combine these 2 methods, we use the Multi-Objective Optimization.

3.1 Analytic Hierarchy Process (AHP)

The structure of AHP has 2 components: alternatives and criteria. In this research there are 7 alternatives and 5 criteria. The 7 alternatives are:

1. Henry Dunant relief warehouse (Station 2),
2. Swang-Nivas relief warehouse (Station 5),
3. Bangkae relief warehouse (Station 11),
4. Henry Dunant and Swang-Nivas relief warehouses,
5. Henry Dunant and Bangkae relief warehouses,
6. Swang-Nivas and Bangkae relief warehouses, or
7. Henry Dunant, Swang-Nivas and Bangkae relief warehouses.

We have 7 alternatives because we the AHP score in each alternative is independent, for example, the AHP score for Alternative 5 (select both Henry Dunant and Bangkae relief warehouses) will not equal the summation of AHP scores for Alternative 1 (Henry Dunant) and Alternative 3 (Bangkae). Therefore, we have to consider all possible alternatives (7) in our AHP analysis.

Figure 1. Red Cross station map in Thailand

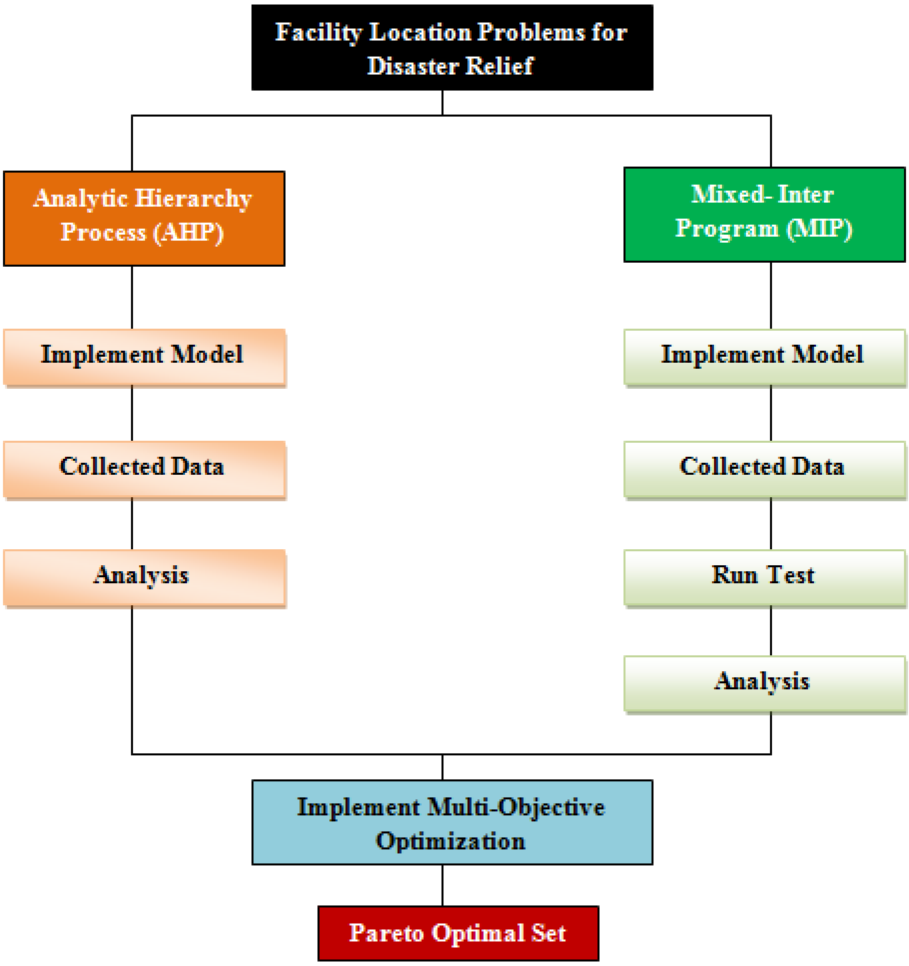

Figure 2. Research methodology procedure

The 5 criteria are:

1. Truck accessibility,
2. Supplier accessibility,
3. Volunteer accessibility,
4. Risk of disaster in the specific area, and
5. Impact on the community.

Criteria 1, 2 and 3 are the problems that Thai Red Cross's met and want to solve. Criteria 4 and 5 are from Orencio and Fujii (2012). Truck accessibility considers factors such as warehouse road width, number of warehouse entrance, and warehouse entrance width. Supplier accessibility considers the distance between all suppliers and Thai Red Cross's warehouse.

The AHP model can be defined as follows:

$$Max \sum_{t \in T} u_t \, p_t \tag{1}$$

Subject to

$$\sum_{t \in T} u_t = 1 \tag{2}$$

, where

Set

T : Set of alternative which has t as the index, T = {1, 2, 3… 7}

- Index 1 in T means the Henry Dunant relief warehouse is selected.
- Index 2 in T means the Swang-Nivas relief warehouse is selected.
- Index 3 in T means the Bangkae relief warehouse is selected.
- Index 4 in T means the Henry Dunant and Swang-Nivas relief warehouses are selected.
- Index 5 in T means the Henry Dunant and Bangkae relief warehouses are selected.
- Index 6 in T means the Swang-Nivas and Bangkae relief warehouses are selected.
- Index 7 in T means the Henry Dunant, Swang-Nivas and Bangkae relief warehouses are selected.

Parameter

p_t : An AHP score on index alternative (t)

Variable

u_t : Binary variable that takes on value 1 when the alternative t is chosen and 0 otherwise

The objective function (1) calculates the maximized AHP score. Constraints (2) guarantee that the model chooses only one case.

3.2 Mixed-Integer Program (MIP)

The quantitative method used in this research is an idea from discrete location problems that will analyze relief warehouses in a given position with minimum cost. The cost structure is divided into 2 categories, fixed cost and variable cost. The fixed cost consists of taxes, overhead cost, warehouse construction cost and asset. The variable cost is transportation cost. The mathematical model for MIP can be formulated in the following way:

$$Min \quad \sum_{i \in S} f_i y_i + \sum_{i \in S} \sum_{j \in D} br_{ij} x_{ij} \tag{3}$$

Subject to

$$\sum_{i \in S} q_i y_i \geq z \quad (4)$$

$$\sum_{i \in S} x_{ij} = 1 \quad \forall_j \in D \quad (5)$$

$$\sum_{j \in D} x_{ij} \leq M y_i \quad \forall_i \in S \quad (6)$$

$$y_i,\ x_{ij} \in \{0,1\} \quad \forall (i,j) \in S, D \quad (7)$$

, where

Set

S : Set of origin nodes, indexed by i
D : Set of destination nodes, indexed by j

Parameter

f_i : Fixed cost of warehouse (i) (Baht)
r_{ij} : A distance of transport in arc (i, j) (km.), computed by $r_{ij} = \frac{2\, s_{ij} d_j}{c}$
s_{ij} : Distance of arc (i, j) (km.)
d_j : Demand at (j) (units)
c : Capacity of truck (2000 units)
b : Cost per Kilometers (33.6 Baht/km)
M : Big number equal 12
z : The required size of the warehouse (m^2)
q_i : Warehouse size capacity (m^2)

Variable

y_i : Binary variable that takes value 1 when the warehouse alternative is used and 0 otherwise
x_{ij} : Binary variable that takes value 1 when the arc is used and 0 otherwise

The objective function (3) calculates the total cost, computed as the sum of fixed cost and variable cost and r_{ij} parameter is computed by destination's demand divided by capacity of truck times distance between origin and destination (in two directions). Constraint (4) is the required size of the warehouse, see the calculation in Section 3.2.1. Constraints (5) ensure that the demand must be served by one origin. Constraints (6) guarantee that if x_{ij} takes on value 1 only when the originating warehouse is selected (i.e., y_i = 1).

3.2.1 Warehouse Capacity Constraint

The required size of the warehouse will be computed by using inventory equation presented by Lovejoy and Desmond (2011).

$$I = R \; x \; T \tag{8}$$

, where

I : Average amount of inventory in the warehouse (units)
R : Inventory through put (units/month)
T : Average holding time (month)

We have to find throughput and average holding time to get average amount of inventory in the warehouse. The maximum amount of inventory in the warehouse is applied to find the required size of the warehouse. Finally the required size is 190.8 m^2. The Henry Dunant and Bangkae relief warehouse size capacity are 150 m^2 and The Swang-Nivas relief warehouse size capacity is 179 m^2.

3.3 Multi-objective Optimization

Multi-objective optimization is used when an optimization problem has more than 1 objective function. In this problem, there are 2 objective functions because we want to analyze qualitative and quantitative method simultaneously as shown in Model (9) to (20). The first objective is to minimize cost and the second is to maximize AHP score.

$$Minimize \quad f_1(x,y) = \sum_{i \in S} f_i y_i + \sum_{i \in S} \sum_{j \in D} br_{ij} x_{ij} \tag{9}$$

$$Maximize \quad f_2(u) = \sum_{t \in T} u_t \, p_t \tag{10}$$

Subject to

$$\sum_{t \in T} u_t = 1 \tag{11}$$

$$y_1 - u_1 - u_4 - u_5 - u_7 = 0 \tag{12}$$

$$y_2 - u_2 - u_4 - u_6 - u_7 = 0 \tag{13}$$

$$y_3 - u_3 - u_5 - u_6 - u_7 = 0 \tag{14}$$

$$\sum_{i \in S} q_i y_i \geq z \tag{15}$$

$$\sum_{i \in S} x_{ij} = 1 \quad \forall_j \in D \tag{16}$$

$$\sum_{j \in D} x_{ij} \leq M y_i \quad \forall_i \in S \tag{17}$$

$$x_{ij} \in \{0,1\} \quad \forall (i,j) \in S, D \tag{18}$$

$$u_t \in \{0,1\} \quad \forall t \in T \tag{19}$$

$$y_i \in \{0,1\} \quad \forall i \in S \tag{20}$$

Constraint (11) is the original AHP constraint. Constraints (12)-(14) link the two models, i.e., AHP and MIP models, together; they ensure which warehouses are open under different AHP Alternatives chosen. Constraints (15)-(17) are the original MIP constraints.

3.4 Pareto Dominance

We apply Pareto dominance (Aurora, 2012) with multi-objective optimization to find the optimal solutions or Pareto optimal set that consider both qualitative method and quantitative factors. The Pareto dominance is presented in Equations (21) and (22).

$$\forall i \in \{1, \dots, N\}, f_i(\overrightarrow{u}) \leq f_i(\vec{v}), \quad (21)$$
$$\exists j \in \{1, \dots, N\}, f_j(\overrightarrow{u}) < f_j(\vec{v}) \quad (22)$$

, where

Set

N : Set of feasible solution indexed by i and j

Parameter

$f_{i,j}(\overrightarrow{u})$: The solution which we determine
$f_{i,j}(\vec{v})$: The other solution which we determine

Equations (21) and (22) mean that there are no answers of *u* that are worse than the answers of *v* and has at least one answer of *u* that is better than the answers of *v*. The answers that are non-dominated by other answers are called Pareto optimal set.

4. DATA

For AHP information, we gave questionnaire to six people who are directors and managers in Relief and Community Health Bureau. Relief and Community Health Bureau is a department of Thai Red Cross that is responsible for distributing disaster relief supplies to other Thai Red Cross stations. In the questionnaire, each question asks the respondent to give scores from 1 (least important) to 9 (most important). The questionnaire was divided into two parts (i) criteria part (ii) alternatives. The results will be in important score percentage of criteria and alternatives.

There were 3 origins and 9 destinations in our transportation network. The disaster relief supplies were sent from the origin to the destination. In this paper, we consider only the highest disaster relief supplies demand that happened within 2011-2013. The average of that demand was 41,269 units/year, the maximum of that demand was 309,185 units/year and the minimum of that demand was 3,988 units/year.

In term of commodity, between 2011 and 2013, there are 15 commodity groups going through the relief warehouse as presented in Fig. 3 and Fig. 4. Instant noodle had the highest throughput of 988,903 packs/month (average 507,550 packs/month and minimum 165,304 packs/month). Flashlight with batteries had the lowest throughput—from 3,850 units/year to 11,231 units/year and average value of 8,624 units/year.

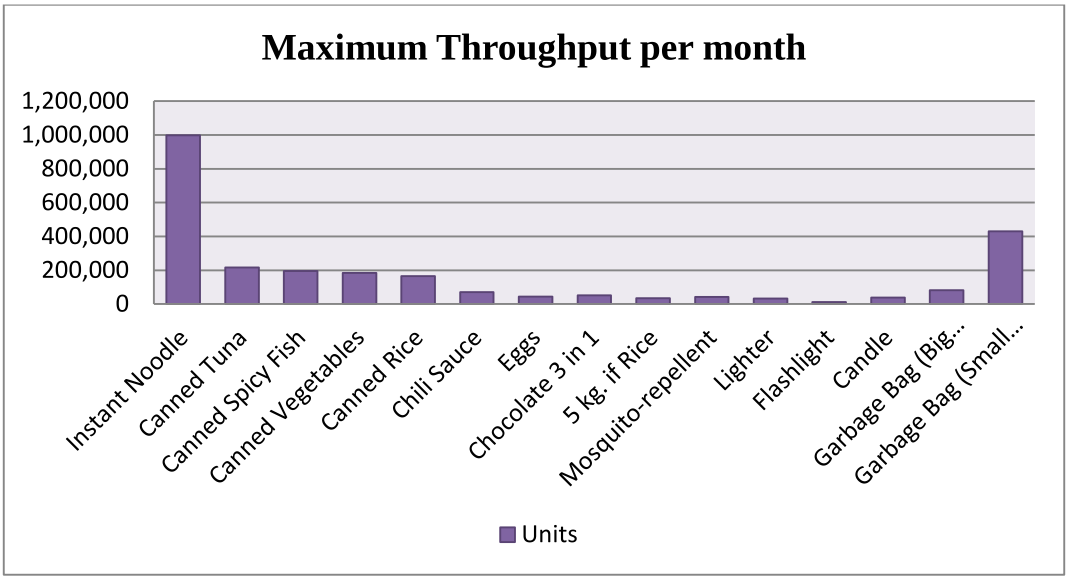

Figure 3. Maximum throughput of 15 commodities per month (2011-2013)

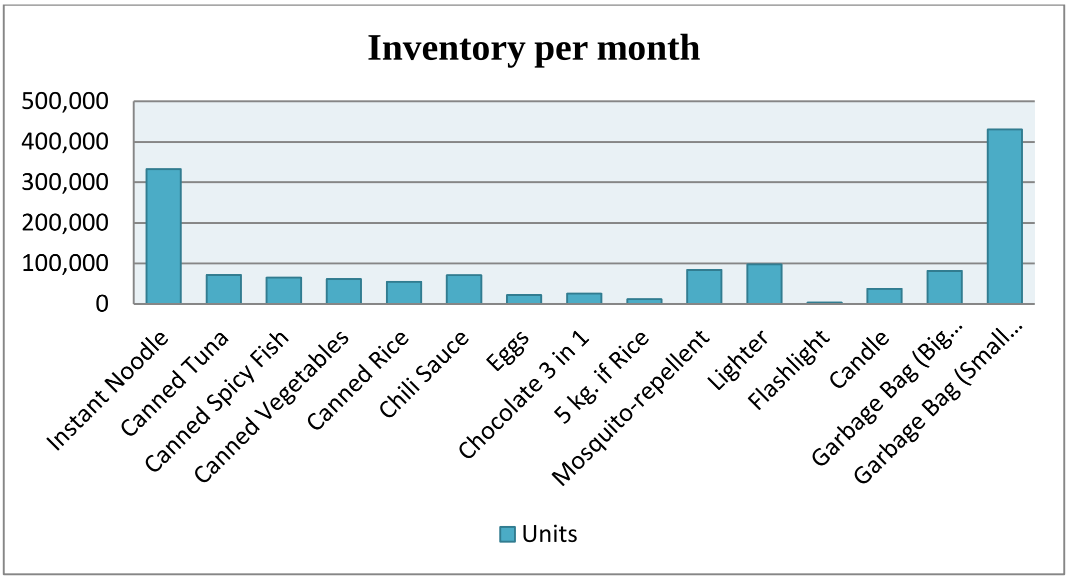

Figure 4. Inventory level that computed from maximum throughput per month (2011-2013)

5. COMPUTATIONAL RESULTS

5.1 Analytic Hierarchy Process (AHP) Results

From the collection of qualitative data and the analysis with AHP, the results are presented in Table 2 and Table 4.

Table 2. AHP Criteria score

Criteria	Score
Truck accessibility	23.2%
Supplier accessibility	19.1%
Volunteer accessibility	9.1%
Risk of disaster in the specific area	31.7%
The impact on the community	16.9%

The most important criteria is risk of disaster in the specific area (31.7%). The criteria score from Table 2 will be computed with alternative score data and the results are shown in Table 3. From Table 3 the AHP result shows that the best solution for qualitative method is Henry Dunant relief warehouse with 19.8% score. This result was consistent with criteria score because in reality the Henry Dunant relief warehouse was not affected by catastrophic flooding in Thailand in 2011 and the warehouse has a good accessibility.

Table 3. AHP alternative score which consider all of criteria

Alternatives	Score
Henry Dunant relief warehouse	19.8%
Swang-Nivas relief warehouse	12.0%
Bangkae relief warehouse	10.2%
Henry Dunant and Swang-Nivas relief warehouse	12.4%
Henry Dunant and Bangkae relief warehouse	16.3%
Swang-Nivas and Bangkae relief warehouse	11.2%
Henry Dunant, Swang-Nivas and Bangkae relief warehouse	18.1%

5.2 Mixed-Integer Program (MIP) Results

Fixed cost and variable cost are considered in MIP analysis to find the optimal solution wherein the answer does not violate the constraints. Fixed cost of all relief warehouses is 29,813.6 Baht/m^2. Variable cost is determined by sending commodity from 7 alternatives to 9 stations of Thai Red Cross. Truck capacity is 2000 units of commodity and transportation cost is 33.6 Baht/km. The fixed cost and variable cost are presented in Table 4.

The Alternatives of having each of the three relief warehouses site alone are not chosen because each warehouse alone cannot meet the total size capacity requirement.

Table 4. The costs of all feasible alternatives

Alternatives	Fixed Cost (Baht)	Variable Cost (Baht)	Sum Cost (Baht)
Henry Dunant and Swang-Nivas relief warehouse	9,808,672	2,371,286	12,179,958
Henry Dunant and Bangkae relief warehouse	8,944,078	2,357,779	11,301,857
Swang-Nivas and Bangkae relief warehouse	9,808,672	2,600,640	12,409,312
Henry Dunant, Swang-Nivas and Bangkae relief warehouse	14,280,711	2,345,952	16,626,663

5.3 Multi-objective Optimization Results

Multi-objective optimization in this paper is concerned with 2 objective functions, AHP score and cost. The data are presented in Table 5 and are plotted on a graph (A is Henry Dunant relief warehouse, B is Swang-Nivas relief warehouse and C is Bangkae relief warehouse) as presented in Fig. 5.

The Pareto dominance is applied to find non-dominated solution. The answers are Henry Dunant and Bangkae relief warehouse which has AHP score 16.3% and cost 11,301,857 Baht and Henry Dunant, Swang-Nivas and Bangkae relief warehouse with 18.1% AHP score and cost 15,762,069 Baht.

Table 5. AHP score and cost in each alternative

Alternatives	AHP	Cost (Baht)
Henry Dunant and Swang-Nivas relief warehouse	12.4%	11,315,364
Henry Dunant and Bangkae relief warehouse	16.3%	11,301,857
Swang-Nivas and Bangkae relief warehouse	11.2%	11,544,718
Henry Dunant, Swang-Nivas and Bangkae relief warehouse	18.1%	15,762,069

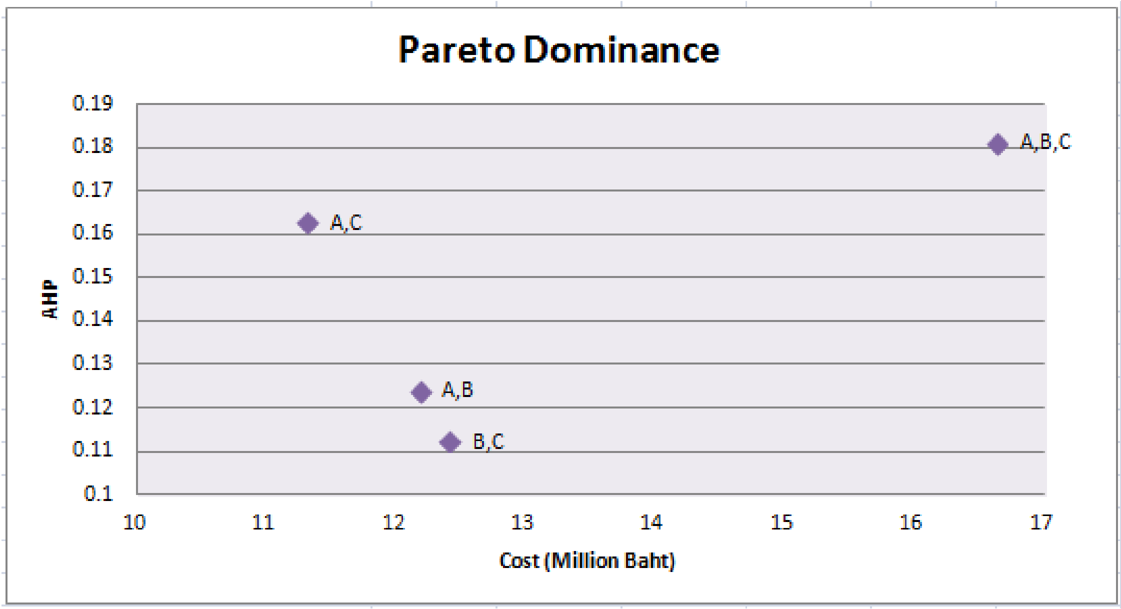

Figure 5. AHP score and cost in each alternative

5.4 Discussion

The Pareto optimal set for our model are Henry Dunant and Bangkae relief warehouses, and Henry Dunant, Swang-Nivas and Bangkae relief warehouses. Respondents to our AHP questionnaire focus on risk of disaster in the specific area criteria (31.7%) as presented in table 1. They believed that if disasters occurred in the relief warehouse area, it will affect the relief supplies distribution system. They saw that in the catastrophic flooding in Thailand in 2011, the Thai Red Cross Station 2 (Henry Dunant) and Station 11 (Bangkae) were not affected by flood, while Station 5 (Swang-Nivas) was affected. Therefore, the alternative

Henry Dunant and Bangkae relief warehouse have higher AHP score than other alternative in case of considering open two warehouses together. In term of cost, operating Henry Dunant and Bangkae relief warehouses together has the lowest cost compared with other alternatives in case of considering open two warehouses together. The case of operating all three relief warehouses is also an answer of our model. This answer has higher score than operating Henry Dunant and Bangkae relief warehouses because there are three relief warehouses available; it can respond the demand better, can spread the risk of getting disaster in the operation area, and has better accessibility. But it comes with a drawback, that is the higher cost. These two answers are in Pareto optimal set and it depends on decision makers which factor they focus more. If they focus more on performance, they have to choose Henry Dunant, Swang-Nivas and Bangkae relief warehouse alternative or if they focus more on cost, they have to choose Henry Dunant and Bangkae relief warehouse alternative.

6. CONCLUSION

The analysis of Thai Red Cross relief warehouse was done by qualitative (AHP) approach which gives the answer Henry Dunant relief warehouse with the highest score 19.8%, with cost 6,850,717 Baht, but it does not consider the capacity of warehouse. On the other hand, quantitative (MIP) approach gives the answer Henry Dunant and Bangkae relief warehouse with the lowest cost 11,301,857 Baht but it does not consider the AHP score. The relief warehouse location which is analyzed by qualitative and quantitative method separately will neglect another important factor; therefore this paper applied multi-objective optimization to consider both qualitative and quantitative factors. The multi-objective optimal answers are Henry Dunant and Bangkae relief warehouse with 16.8% AHP score and cost 11,301,857 Baht and Henry Dunant, Swang-Nivas and Bangkae relief warehouse with 18.1% AHP score and cost 15,762,069. The optimal solutions from applying Pareto dominance with multi-objective optimization are called Pareto optimal set that consider both qualitative method and quantitative method. The two answers represent a tradeoff between AHP score and cost. If decision makers want to focus more on potential of the warehouse they should choose Henry Dunant, Swang-Nivas and Bangkae relief warehouses but if they want to focus more on cost they should choose Henry Dunant and Bangkae relief warehouse.

REFERENCES

Abounacer, R., Rekik, M., Renaud, J. (2013) An exact solution approach for multi-objective location–transportation problem for disaster response. *Computers & Operations Research* 41, pp.83–93

Arora, S. (2012) Introduction to optimum design. University of Iowa College of Engineer Iowa City, Iowa

G. Rawls, C.,A. Turnquist, M. (2009) Pre-positioning of emergency supplies for disaster response. *Transportation Research* Part B 44, pp.521–534

Ghiani, G., Laporte, G. and Musmanno, R. Introduction to Logistics System Management, John Wiley & Sons Ltd, (2013)

Korpela, J., Lehmusvaara, A., Nisonen, J. (2007) Warehouse operator selection by combining AHP and DEA methodologies. *Int. J. Production Economics* 108, pp.135–142

Oguta, J.W. (2010) Global warming or global warning. [cited 2014 Feb. 27] http://judewatchman.blogspot.com/2010/09/global-warming-or-global-warning-by.html

Onur, M., H.,B.Zabinsky , Z. (2008) Stochastic optimization of medical supply location and distribution in disaster management. *Int. J. Production Economics* 126, pp.76–84

Orencio, P., Fujii, M. (2012) A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). *International Journal of Disaster Risk Reduction* 3, pp.62–75

Samanlioglu, F. (2012) A multi-objective mathematical model for the industrial hazardous waste location-routing problem. *European Journal of Operational Research* 226, pp.332–340

Sevkli, M., Koh, L., Zaim, S., Demirbag, M., Tataglu, E. (2007) Hybrid analytical hierarchy process model for supplier selection. *Industrial Management & Data Systems* 108, pp. 122-142