A Hybrid BWM-MCLP Method for Selecting Emergency Medical Service Locations: A Case Study in Maha Sarakham Province, Thailand

Amin Lawong[1*], Nuchsara Kriengkorakot[2] and Preecha Kriengkorakot[3]

[1,*] Department of Industrial Engineering, University of Ubon Ratchathani, Ubon Ratchathani, Thailand
[2,3] Department of Industrial Engineering, University of Ubon Ratchathani, Ubon Ratchathani, Thailand

amin.la.63@ubu.ac.th*, nuchsara.k@ubu.ac.th and preecha.k@ubu.ac.th

Abstract. *The selection of the location of an emergency medical service (ambulance base) is one of the problems involved in designing a suitable emergency medical service, providing life support for emergency patients, under the timing requirements of the Emergency Medical System (EMS). The objective of this research is to select locations to provide coverage and clustering of service areas (minimum number of bases and maximum coverage). In this research, we use a hybrid method based on the Best-Worst Method (BWM) and Maximal Covering Location Problem (MCLP) for locating emergency medical services, based on a case study of thirty-two candidate locations in Muang Maha Sarakham District, Thailand. The area population, local emergency patients, being close to the communities and main roads, wireless local networks, public utilities and social environment were considered by decision makers. Firstly, BWM was used to calculate the criteria weights and final score. After that, the MCLP model was used to select the suitable emergency medical service locations. As a result, seven emergency medical service locations were selected based on the opinions of decision makers.*

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1. Introduction

Emergency Medical Services (EMS) is a governmental organization dedicated to providing crucial medical assistance to individuals facing acute illnesses or injuries that prevent them from seeking help on their own. The primary objective of EMS is to save the lives of emergency patients [1], ensuring their chances of survival under time and distance constraints from the incident location. It is essential to minimize delays in reaching the scene of an incident. This can be achieved by selecting suitable locations for emergency medical services that effectively cover the incident sites. The selection of appropriate emergency medical service locations is a critical issue in decision-making as it directly impacts the survival of patients. If the locations are inappropriate or do not provide coverage in certain areas, it can have serious consequences for patient.

In recent years, the emergency medical system in Thailand has undergone continuous development [2]. However, due to the country's growing population, the assistance of emergency operations teams has become necessary. When an incident is reported through the emergency hotline number 1669 [3], the command center dispatches an emergency operations team from the designated ambulance parking point to reach the accident scene within 10 minutes (covering a distance of 10 km). The severity of the patient's condition determines the response level, which is categorized into three codes: red for critical emergencies, yellow for patients requiring immediate medical attention, and green for non-severe cases. However, this study focuses solely on critically ill patients. If the arrival of the emergency operations team at the accident scene is delayed or fails to meet the standard criteria, it may be due to the inappropriate location of the ambulance emergency base and the insufficient number of bases. Such circumstances can have a significant impact on the survival rates of critically ill patients.

A Case study in Muang Maha Sarakham District, Maha Sarakham Province, Thailand. It is a province located in the central part of the northeastern region of Thailand. It shares boundaries with Kalasin Province, Roi Et Province, Surin Province, Buri Ram Province, and Khon Kaen Province. It is a province located in the central part of the northeastern region of Thailand. Due to social, economic, and the impact of emerging diseases, the provision of emergency medical services cannot fully cover the incident locations according to the established standards. This is because the response time of emergency medical service vehicles to reach the incident sites is delayed, and it may result in patients experiencing more severe conditions, even leading to fatalities [4].

Over the years, numerous researchers have developed alternative decision-making tools that involve evaluating multiple criteria to solve problems effectively. Multi-criteria decision-making (MCDM) is a technique that assists decision makers (DMs) in making informed choices based on the criteria they consider important. One MCDM study focused on determining the optimal locations for emergency medical services base points. Facility location selection has been extensively studied using MCDM, employing various approaches such as fuzzy-technique for Order of Preference by Similarity to Ideal Solution (fuzzy-TOPSIS) [5]-[8], Analytic Hierarchy Process-fuzzy-technique for Order of Preference by Similarity to Ideal Solution (AHP-fuzzy TOPSIS) [9], fuzzy-Elimination and Choice Translating algorithm (fuzzy-ELECTRE) [10], Analytic Network Process-technique for Order of Preference by Similarity to Ideal Solution (ANP-TOPSIS) [11],[12], Analytic Hierarchy Process-Preference Ranking Organization Method for Enrichment Evaluations (AHP-PROMETHEE) [13], fuzzy Analytic Network Process-Data Envelopment Analysis-technique for Order of Preference by Similarity to Ideal Solution (FANP-DEA-TOPSIS) [14], Analytic Network Process (ANP) [15], Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE II) [16], Elimination and Choice Translating Reality method (ELECTRE) [17], Best-Worst method (BWM) [18]-[21], and numerous other related research studies [22]-[30]. The Best-Worst method (BWM) represents a novel MCDM approach [31],[32]. This research is a new technique in MCDM that reduces the number of comparisons for each criterion to less than for the AHP method, and provides a simpler model for calculating the weights of each criterion. In addition, the Maximal Covering Location Problem (MCLP) [33], presents a mathematical model for optimum location selection. and many researchers have studied this [34]-[36]. The MCLP method employs the weight of a single decision criterion for each option, multiplied by the population of that option in the objective function. However, this approach becomes unsuitable for real-world events. In reality, there are often multiple criteria that need to be taken into account. The use of MCDM, on the other hand, allows for the consideration of numerous criteria.

Therefore, this research introduces a new model, known as the BWM-MCLP method, for identifying the optimal emergency medical service locations: a case study on A Case study in Muang Maha Sarakham District, Maha Sarakham Province, Thailand. The main objective of this research is to guide decision-maker for choosing suitable emergency medical service locations.

In this research, we use BWM method to find the criteria weights locations for emergency medical services, and then MCLP method is used for select locations to provide coverage and clustering of service areas. The rest of this paper is arranged as follows: Section 2 describes the method used in the study; Section 3 describes results and discussion; Finally, the conclusion of this research work in Section 4.

2. Method used in the study

From the literature review, it was found that no researchers have yet applied MCDM to cooperate with MCLP to select locations of emergency medical service. Therefore, the researcher presented the BWM-MCLP method to make decisions and select the appropriate alternative by assessing a case study to select the location of emergency medical service locations in Muang Maha Sarakham District. The research process is shown in Fig. 1 and the thirty-two candidate location selections are shown in Table 1.

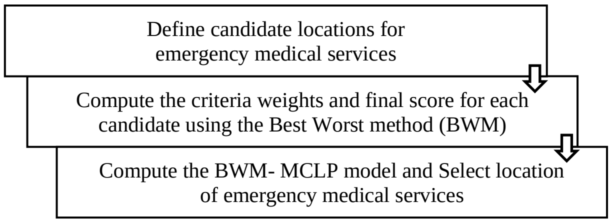

Fig. 1 The roadmap of research steps

ID.	EMS name	ID.	EMS name
L1	Maha Sarakham Municipality	L17	Ban Khwao Health Promoting Hospital
L2	Waeng Nang Municipality	L18	Ban Tha Tum Health Promoting Hospital
L3	Khwae Subdistrict Administrative Organization	L19	Ban Nong Waeng Health Promoting Hospital
L4	Tha Tum Subdistrict Administrative Organization	L20	Ban Khok Ko Health Promoting Hospital
L5	Waeng Nang Subdistrict Administrative Organization	L21	Bandon Wan Subdistrict Health Promoting Hospital
L6	Khok Ko Subdistrict Administrative Organization	L22	Ban Keng Health Promoting Hospital
L7	Don Wan Subdistrict Administrative Organization	L23	Ban Nong Chik Health Promoting Hospital
L8	Geng Subdistrict Administrative Organization	L24	Ban Upparat Health Promoting Hospital
L9	Kaeng Loeng Chan Subdistrict Administrative Organization	L25	Ban Non Tae Subdistrict Health Promoting Hospital
L10	Tha Song Khon Subdistrict Administrative Organization	L26	Ban Lat Health Promoting Hospital
L11	Lat Phatthana Subdistrict Administrative Organization	L27	Ban Tha Ngam Health Promoting Hospital
L12	Nong Pling Subdistrict Administrative Organization	L28	Ban Hua Na Kham Health Promoting Hospital
L13	Huai Ang Subdistrict Administrative Organization	L29	Ban Huai Ang Health Promoting Hospital
L14	Nong No Subdistrict Administrative Organization	L30	Ban Nong No Health Promoting Hospital
L15	Buakho Subdistrict Administrative Organization	L31	Ban Khok Bua Kho Health Promoting Hospital
L16	Ban Chiang Hian Health Promoting Hospital	L32	Ban Non Phek Health Promoting Hospital

Table 1 Candidate locations

2.1 Best – Worst Method (BWM)

The Best-Worst method is a tool used to solve the decision problem [31]. It is a new technique in multi-criteria decision to calculate each of weights of the criteria [32]. The calculation steps are:

1. Define decision making criteria as $(c_1, c_2, ..., c_n)$.
2. Define the best and worst criteria.
3. Calculation of scores for the best criterion over each of the criteria, compared using a scale of relative importance from 1 to 9 rating (Likert) scale by experts.
   $a_{Bj} = (a_{B1}, a_{B2}, ..., a_{Bn})$.
   a_{Bj} comparison scores of best criterion B with each j th criterion.
4. Calculation of scores for the worst criterion for each of the criteria, compared using a scale of relative importance from 1 to 9 rating (Likert) scale by expert.
   $a_{jw} = (a_{1w}, a_{2w}, ..., a_{nw})^{\mathrm{T}}$.
   a_{jw} comparison scores of the worst criterion B with each j th criterion.
5. Calculate optimum weights $(w_1^*, w_2^*, ..., w_n^*)$ and index for consistency ratio (ξ^{L*})
6. Evaluate performance matrix as follows of score 1-9 (positive and negative), then normalize the score.

$$x_k^{norm} = \begin{cases} \dfrac{x_k}{\max\{x_i\}}, \text{(criteria is positive)} \\ 1 - \dfrac{x_k}{\max\{x_i\}}, \text{(criteria is negative)} \end{cases}$$

7. Calculate final score $V_i = \sum_{j=1}^{n} w_j p_{ij}$

The model developed is as follows Equations. (1) – (5):

Objective function:

$$\text{Min}\, z = \xi^L \tag{1}$$

Constraints:

$$\left| w_B - a_{Bj} w_j \right| \le \xi^L, \text{ for all j} \tag{2}$$

$$\left| w_j - a_{jw} w_w \right| \le \xi^L, \text{ for all j} \tag{3}$$

$$\sum_j w_j = 1 \tag{4}$$

$$w_j \ge 0 \text{ , for all j} \tag{5}$$

These give the consistency index values, and Eq. (6) gives the formula for the consistency ratio as shown in Table 2.

$$\text{Consistency ratio} = \frac{\xi^{L*}}{\text{Consistency index}} \tag{6}$$

a_{BW}	1	2	3	4	5	6	7	8	9
CI	0.00	0.44	1.00	1.63	2.30	3.00	3.73	4.47	5.23

Table 2 Table of consistency index (CI)

In this article, the objective function of the Linear BWM Model is to minimize the good indicator of the consistency of the comparison. Eq. (2) ensures that the absolute difference between the weight values of the best criterion and each criterion j are less than or equal to this consistency index. Eq. (3) ensures that the absolute difference between the weight values of the worst criterion and each criterion j are less than or equal to this consistency index. Eq. (4) ensures that the sum of obtained criteria weights is equal to one. Eq. (5) ensure that the criterion weight (w_j) is greater or equal than zero. and Eq. (6) the consistency ratio can be obtained from the good indicator of the consistency divided by consistency index.

2.2 BWM-MCLP Method

2.2.1 Indices:

i is the index of each location for an emergency medical service, $i = 1, 2, ..., n, (n = 32)$

j is the index of each population for an emergency medical service, $j = 1, 2, ..., m, (m = 32)$

D is the distance covered by candidate location i, (D = 10,20,30)

2.2.2 Parameters:

w_i is the final score by the BWM method.

d_{ij} is the actual distance between location i and emergency medical service location j (km).

p is the number of emergency medical service locations (number of ambulance).

D is the distance covered by candidate location i (distance).

2.2.3 Decision variables:

x_{ij} is a binary decision variable; $x_{ij} = 1$ if the population area j is served by candidate for emergency medical service location i; $x_{ij} = 0$ otherwise.

y_i is a non-negative integer decision variable; $y_i = 1$ if the candidate location for emergency medical service i is opened for consideration (cover distance less than or equal to D), $y_i = 0$ otherwise

Objective function:

$$\text{Max } z = \sum_i \sum_j w_i y_i \quad (7)$$

Constraints:

$$\sum_i x_{ij} = 1 \quad , \forall j \quad (j = 1, 2, ..., m) \quad (8)$$

$$d_{ij} x_{ij} \le D \quad , \forall i, j \quad (i = 1, 2, ..., n) \; (j = 1, 2, ..., m) \quad (9)$$

$$y_i \ge x_{ij} \quad , \forall i, j \quad (i = 1, 2, ..., n) \; (j = 1, 2, ..., m) \quad (10)$$

$$\sum_i y_i = p \quad (11)$$

$$x_{ij}, y_i = \{0, 1\} \quad (12)$$

In this article, the objective function of the BWM-MCLP method is to maximize the population area coverage. Eq. (8) ensures that the covering of each population area j is served. Eq. (9) ensures that the emergency medical service location is less than or equal to the distance. Eq. (10) ensures that emergency medical service location is greater than or equal to the coverage of each population area. Eq. (11) ensures that the selected emergency medical service locations are equal to the number of emergency medical service locations (number of ambulance) and Eq. (12) that x and y are binary. LINGO19 can solve this model to find the optimal solution.

3. Results and Discussion

This was a case study of emergency medical service locations in Muang Maha Sarakham District. The number of candidate locations is thirty-two, Fig. 2 shows the candidate locations selected for emergency medical services. The BWM-MCLP method is a new model that is a hybrid of the MCDA and a mathematical model for evaluating the suitability of a selected location for emergency medical services.

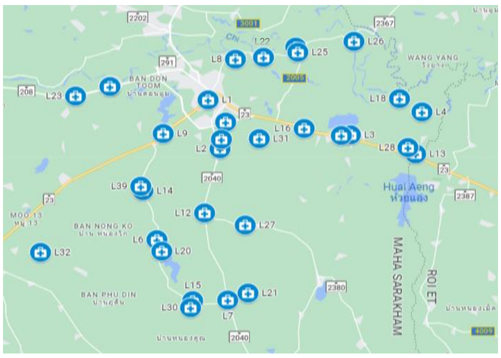

Fig. 2 The candidate locations for emergency medical services

3.1 Define Candidate Location Selection for Emergency Medical Services

In this stage, experts and decision makers from the public health sector identified the necessary criteria for selecting an emergency medical service location in the case study. As a result, six relevant criteria were established, namely population (C1), local emergency patients (C2), proximity to the community and main road (C3), wireless local area network (C4), public utilities (C5), and social environment (C6). Details of the six criteria are shown in Table 3.

Criteria	Definition	Criteria type
C1	Population of the responsible area	Positive
C2	Emergency patients receiving services in the area	Positive
C3	Ease of service and support	Positive
C4	Local communications signal network	Positive
C5	Public services such as electricity, water supply, bus operation, telephone	Positive
C6	Environmental impacts such as weather, noise pollution, smoke and livelihoods in the area	Negative

Table 3 Definition of main criteria

3.2 Computing the Criteria Weights and Final Score for Each Candidate using the Best Worst Method

Through a questionnaire administered to five experts representing various job positions, including Professional Academic, Public Health Academician, Computer Academician, Professional Pharmacist, and Pharmacist, we defined the best and worst of the six criteria considered. The closeness to the community and the main road (C3) is chosen as the best criterion and the worst criterion is chosen as the wireless local area network (C4) as shown in Table 4. In Table 5, the calculation of the optimal weights of each criterion and its final score can be solved by MS Excel OpenSolver (COIN-OR CBC (Linear solver)) were calculated using Eq. (1) - (6). The objective function value and consistency ratio are less than 0.1, CI is stated as 4.47 (a_{BW} = 8). As shown in Table 6, the results show that the weighted candidate final scores by the BWM method merged six criteria into one criterion to compute with the MCLP method and find the number of emergency medical services and constrain the distances to the covered areas. The model can be solved by LINGO19.

Criteria	C1	C2	C3	C4	C5	C6
Best (C3)	9	8	1	8	5	6
Worst (C4)	4	2	7	1	6	7

Table 4 Pairwise comparisons of case study

Criteria	Weights	Parameters	Values
C1	0.08002	Objective function	0.20006
C2	0.09003	Consistency ratio	0.04475
C3	0.52015		
C4	0.04573		
C5	0.14404		
C6	0.12003		

Table 5 Weights of criteria and parameters

ID.	Final Score (w_i)	ID.	Final Score (w_i)
L1	0.78832	L17	0.58195
L2	0.68061	L18	0.57216
L3	0.74674	L19	0.64125
L4	0.55067	L20	0.59924
L5	0.67971	L21	0.73450
L6	0.52289	L22	0.75385
L7	0.68745	L23	0.80456
L8	0.70407	L24	0.75829
L9	0.61357	L25	0.79479
L10	0.77365	L26	0.77690
L11	0.59871	L27	0.63141
L12	0.67057	L28	0.60434
L13	0.48188	L29	0.51242
L14	0.50277	L30	0.47892
L15	0.55908	L31	0.51793
L16	0.61040	L32	0.50948

Table 6 Final score of candidate locations

3.3 Compute BWM- MCLP Model and Select Locations of Emergency Medical Service

This step computes locations suitable for P =7 cover a distance of 10 km. for Clusters of Emergency Medical Service locations. is shown in Table 7. And locations suitable for P =3 cover a distance of 20 km. for Clusters of Emergency Medical Service locations. is shown in Table 8. And locations suitable for P =1 cover a distance of 30 km. for Clusters of Emergency Medical Service locations. is shown in Table 9.

Number of emergency medical services P=7	**Clusters of emergency medical service locations.**
Maha Sarukhan Municipality (L1)	L1,L2,L5,L9,L19,L32
Khwae Subdistrict Administrative Organization (L3)	L3,L4,L13,L17,L18,L29
Ban Khok Ko Health Promoting Hospital (L20)	L6,L12,L14,L20,L28,L30,L31
Bandon Wan Subdistrict Health Promoting Hospital (L21)	L7,L15,L21
Ban Nong Chik Health Promoting Hospital (L23)	L23
Ban Non Tae Subdistrict Health Promoting Hospital (L25)	L10,L24,L25
Ban Lat Health Promoting Hospital (L26)	L8,L11,L16,L22,L26,L27

Table 7 Locations suitable for P =7 cover a distance of 10 km.

As shown in Tables 7 – 9, the results show which locations are suitable, using Eq. (7) - (12). and in Table 10 we compare the methods with the results of the total scores (criteria C3 to C6) by Factors rating method. The BWM - MCLP method was consistent with the experts, with a higher total score, this is a new model that is appropriate for decision-making in this case study.

Number of emergency medical services P=3	**Clusters of emergency medical service locations**
Waeng Nang Municipality (L2)	L1,L3,L6,L7,L8,L11,L12,L14, L16,L17,L20,L21,L24,L25,L28 ,L32
Ban Nong Chik Health Promoting Hospital (L23)	L15,L23,L30,L31
Ban Lat Health Promoting Hospital (L26)	L2,L4,L5,L9,L10,L13,L18,L22 ,L26,L27,L29

Table 8 Locations suitable for P =3 cover a distance of 20 km.

Number of emergency medical services P=1	**Clusters of emergency medical service locations**
Maha Sarakham Municipality (L1)	L1-L32

Table 9 Locations suitable for P =1 cover a distance of 30 km.

Number of emergency medical services		**Method**	
		BWM-MCLP	**MCLP**
Location	Distance (km.)		
P =7	10	44.87225	42.39611
P = 3	20	19.86510	15.47985
P =1	30	5.82909	5.04944

Table 10 Factors rating method test results of sum score criteria

As shown in Figures 3 – 5, the emergency medical service locations that determines the number of locations and distances. That emergency medical service locations for P = 7 cover a distance of 10 km. and that emergency medical service locations for P = 3 cover a distance of 20 km. and that emergency medical service locations for P = 1 cover a distance of 30 km. As a result, P = 7 cover a distance of 10 km were selected based on the opinions of decision makers.

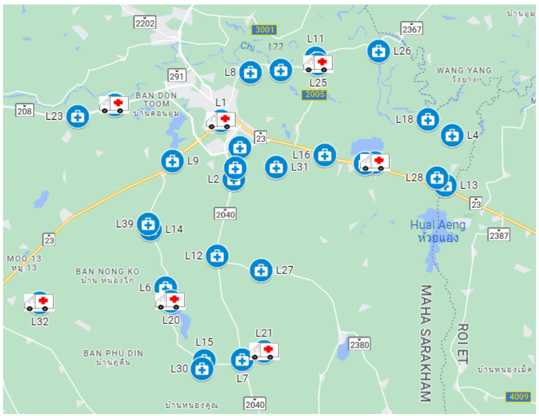

Fig. 3 The emergency medical service locations for P =7 cover a distance of 10 km.

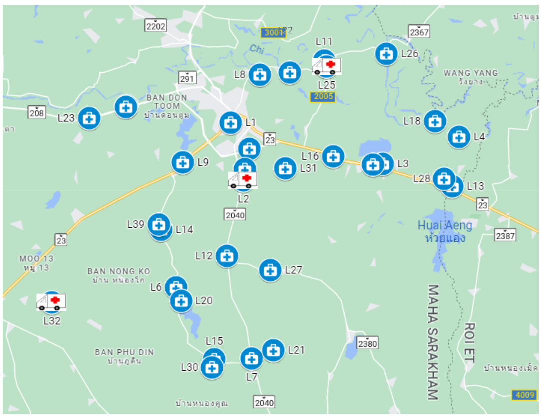

Fig.4 The emergency medical service locations for P =3 cover a distance of 20 km.

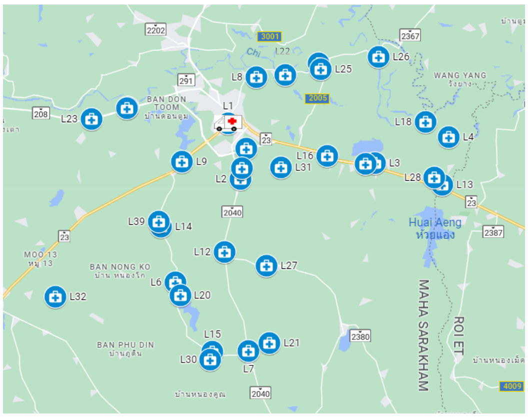

Fig. 5 The emergency medical service locations for P =1 cover a distance of 30 km.

4. Conclusions

This study presents the BWM-MCLP method for selecting emergency medical service locations in Muang Maha Sarakham District, with the objective of achieving the optimal coverage of service areas within distances. The method aims to minimize the number of required locations while ensuring adequate coverage. The research introduces a novel approach for addressing multi-criteria decision-making problems related to emergency ambulance service locations, utilizing quantitative data obtained from a questionnaire survey conducted with experts and members of the public health group. Firstly, The BWM method is applied to determine the weight of six factors as area population (C1), local emergency patients (C2), closeness to the community and a main road (C3), wireless local area network (C4), public utilities (C5) and social environment (C6). the BWM method was used to define the weight of each of the criteria for candidate location selection of an emergency medical service location, the best criterion is being close to the community and the main road (C3), the worst criterion is having a wireless local area network (C4) and the final score was used to solve the optimal solution by MS Excel OpenSolver (COIN-OR CBC (linear solver)). Second, the BWM-MCLP model was modified to determine the number of emergency medical services and total distance covered. To solve the optimal solution by LINGO19. The results show that the emergency medical service locations were P =7 cover a distance of 10 km., P =3 cover a distance of 20 km., and Locations suitable for P =1 cover a distance of 30 km. Based on the opinions of decision makers, seven potential locations for emergency medical services were identified as suitable. These locations have ambulance parking points appropriately placed to effectively cover the accident scenes within a 10 km distance.

This research offers a new hybrid method based on the BWM and MCLP methods to select suitable locations for this case study of emergency medical services. In future research work the proposed method could be used to solve MCLP with fuzzy data and should be considered such as cost, time and hospital capacity for providing those services. We believe that the proposed method can be used to apply to other real-world cases.

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Biographies

Amin Lawong is a PhD student in the Industrial Engineering Depart-ment, Faculty of Engineering, Ubon Ratchatani University, Thailand.

Nuchsara Kriengkorakot is an Associate Professor in the Industrial Engineering Department, Faculty of Engineering, Ubon Ratchatani University, Thailand.

Preecha Kriengkorakot is an Associate Professor in the Industrial Engineering Department, Faculty of Engineering, Ubon Ratchatani University, Thailand.