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Selection of locations and incinerators for infectious waste of hospitals in Northeastern Thailand

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Abstract

In the Northeast of Thailand, there are approximately 1.58 tons of infectious waste a day. Each hospital has very little ability to eliminate the waste by themselves. As a result, most hospitals use agencies to handle it. There is a high cost of carrying the infectious waste from the hospital to the disposal site, since most hospitals are located far away from the infectious waste disposal facility. Therefore, if the infectious waste disposal facility is established at a proper location in the Northeast of Thailand, the hospitals can reduce the transportation cost of delivering the infectious waste to the facility. This research presents the data on the selection of location and the size of infectious waste incinerators for hospitals in the Northeast of Thailand with the objective of minimizing the total costs. The mathematical model of the problem is formulated based on the facility location problem and it is solved by using the AMPL program. The result shows that there are 2 appropriate areas for establishing an infectious waste incinerator in the Northeast of Thailand. The first one is in Kuchinarai District, Kalasin Province, serving 248 hospitals and the other one is in Tha Li District, Loei Province, providing service for 77 hospitals. Both locations use infectious waste incinerators with a waste burning capacity of 600 kilograms per hour and the lowest overall cost is 5,024,726.40 baht per month.

Keywords

infectious waste; incinerator; hospital; northeastern thailand; nonlinear mixed integer programming

1. Introduction

Infectious waste is classified as dangerous waste that must be given priority for the process of storage, collection, transportation and disposal sanitarily. It is considered an important issue in every country, especially the infectious waste disposal, since it directly affects the environment or people [6]. The infectious waste is caused by various methods and procedures of medical treatment, such as needles, gauzes, cottons, excretion or body fluid coming out of the patients' body, etc. In 2018, Thailand has a total of 55,497.22 tons of infectious waste generated from more than 38,235 sources including public hospitals, private hospitals, private clinics, animal hospitals and dangerous infection laboratories. About 50% of the infectious waste derives from hospitals under the Ministry of Public Health and about 24 % comes from private hospitals and clinics. The amount of infectious waste is expected to increase by approximately 5.5 % per year [6]. The Northeast of Thailand has the estimated amount of infectious waste approximately 15,798 kilograms per day, it is one of the regions with the second highest rank of infectious waste inferior to the central region. Each hospital has a policy to eliminate the infectious waste by incineration. Most hospitals have their own incinerators but they are damaged and cannot be used [16]. Therefore, most hospitals deliver the infectious waste to agencies to process instead of self-disposal, which takes a very high expense. For small public health facilities or hospitals, some of the infectious waste will be sent together with the government hospitals in their network. According to the Thailand State of Pollution Report 2018, the Pollution Control Department reported that only 89.91 % of all incurred infectious waste is handled correctly and the rest amount cannot be inspected. Initially, improper disposal of infectious waste is usually done by smuggling to dispose with general waste or the hospitals proceed to dispose of the waste in the open area, which is not a sanitary method. Later, the government establishes a policy to encourage the disposal of infectious waste sanitarily by providing the local governments of Thailand to have the authority in supervising and arranging for public health facilities to dispose the infectious waste properly. However, only 2.3 % of the local governments of Thailand have policies and readiness to handle infectious waste [13]. Therefore, the public health facilities are assigned to manage with the infectious waste issue by themselves. Regarding to the above problems, it is necessary to establish the infectious waste disposal facilities in the Northeast of Thailand with the purpose of reducing the cost of disposal of infectious waste by choosing appropriate locations for the infectious waste disposal facilities that can provide service equally for all hospitals in the region at a low overall cost with the least impact on the environment and the society [1,5,14].

The area established for storage, collection, disposal and transportation of materials which are dangerous to the environment and sanitation is classified as an undesirable facility. It should not be located adjacent to the community as well as contain the least effect to the environment and economy [10,15]. Krarup et al. [12] has studied and collected the solutions of location problems for the undesirable facility in push-pull models. Later, in 2013 Barbati [2] applied push-pull models and explained that the purposes of establishing the obnoxious facility and the different limitations of each organization make the Mathematical models varied with the pull objective, the facilities such as schools, department stores, train stations or hospitals, etc. are needed by the community or the general public. Customers will be induced to come to the nearest facility. In case of the obnoxious facility such as waste disposal points or waste treatment points, the objective of choosing the obnoxious facilities is the push objective, and they should be located at the farthest distance from the customers. However, other purposes of establishing obnoxious facilities maybe also considered, namely decision making situations (Certainty or uncertainty of data or risk), the duration for considering the suitability, number of facilities to serve, method of determining the location to use, customer service styles, or a variety of product types that the obnoxious facility can serve, etc. Tamir [18] has provided methods for selecting many obnoxious facilities in order to have the shortest travel distance between the customers and the obnoxious facility and between each obnoxious facility. Bhattacharya [4] has designed methods for selecting the obnoxious facility with the objective of reducing the number of existing obnoxious facilities and transport distances between the obnoxious facility and other locations and maximizing the use of the obnoxious facility. FernándezJ et al. [11] has presented the methods for selecting location of the public Semi- obnoxious facility in the concept of a tri-objective model. The first objective is to increase customer service and reduce the sum of travelling distance between customers and the obnoxious facility as short as possible. Secondly, the cost of social impact caused by the location of obnoxious facility is to be reduced. The last objective is to distribute the repulsions fairly (as equal as possible) among the affected people. Dimitrijevi. B. et al. [7] has developed the multi-objective model in choosing a location for waste landfill with the objective of reducing the total cost of investment and management as well as reducing the number of people affected by waste landfill as many as possible. In addition, the location of the incinerator is also important because it may affect the environment and economy. Almeida et al. [1] has implemented the concept of the multi-objectives model for determining the location of the incinerator and the amount of hazardous waste supported by such a location in Portugal, containing 5 objectives, namely 1) To reduce the cost of investment in opening a waste incinerator 2) To reduce the cost of operating the incinerator 3) To reduce the effects that may occur (measured in average per person) 4) To reduce the average impact that occurs the most in every district and 5) To reduce the effects of the constraint equation. There is a limitation that the amount of waste must not exceed the burning capacity of the incinerator, along with using the geographic information system (GIS) to support the decision to choose the right location. In 2017, Wichapa and Khokhajaikiat [19] has proposed that since the infectious waste disposal affects the environment, society and health, therefore the location of the waste disposal facility should be considered and selected carefully to have the least impact on various aspects and not against the law. However, it must provide service equally among all customers at a low overall cost. Regarding to the literature review, This research considered to the location of the industrial area determined from the proportion of land use according to the Ministerial Regulations enforcing the comprehensive city plan of each province in the Northeast of Thailand as an option to establish an infectious waste disposal facility, as well as selecting the suitable size of the incinerator so that all the infectious waste can be burned within one month with the objective of having a lowest total cost, including the cost of burning infectious waste, transportation cost and penalty cost.

2. Location and incinerator selection model for infectious waste disposal

2.1 Assumption and Constraints

Based on the above problem, the assumptions and constraints of the location and Incinerator selection model are as below:

1) Potential locations for establishing the infectious waste disposal facilities are considered from the locations in the industrial areas according to the comprehensive city plan of each province in the Northeast of Thailand enforced by the Ministerial Regulations. As a result, there are 21 potential locations as shown in Table 1. There are 325 hospitals in the Northeast of Thailand that need service of infectious waste burning as shown in Figure 1.

Table 1 The potential locations for establishing the infectious waste disposal facilities in the Northeast of Thailand.

Code	Area	The number of people within a 5 kilometer radius (person)
P01	Sung Noen	7,053
P02	Puk Thong Chai	5,333
P03	Mueang Nakornratchasrima	21,935
P04	Kang Sam Nang	27,297
P05	Mueang Bueng Kan	6,538
P06	Se ka	5,806
P07	Kuchinarai	6,599
P08	Benjaruk	8,779
P09	Junghan	18,684
P10	Phon Thong	10,553
P11	Sa Krai	9,884
P12	Sri Bunrueang1	8,664
P13	Sri Bunrueang2	8,664
P14	Na Klang	9,108
P15	Mueang Udonthani	12,915
P16	Mueang Amnat Charoen	12,566
P17	Pathum Ratchawongsa	6,752
P18	Mueang Surin	18,987
P19	Tha li	3,034
P20	Nam Phong	7,950
P21	Lam Plai Mat	11,270

2) The amount of infectious waste deriving from all hospitals in the Northeast of Thailand is approximately 719,800.40 kg / month.

3) There are 3 types of infectious waste incinerators, classified by the maximum incineration rate, namely 100 kg./hr., 300 kg./hr. and 600 kg./hr. [17]

4) To operate the infectious waste incinerator, it needs to be warmed up for 6 hours before starting the burning process and then it can continuously burn all the infectious waste collected.

Figure 1 The potential locations and hospitals in in the Northeast of Thailand.

5) The transportation of infectious waste is a direct transportation from the hospital to the place of burning infectious waste.

6) In each month, the frequency of infectious waste collection of each hospital must conform to its policy of infectious waste disposal. On average, in each month the community hospitals and the provincial hospitals have a policy to eliminate infectious waste 4 times and 8 times respectively.

7) The total costs consist of transportation cost, fixed costs (staff salary and depreciation of the incinerators), variable costs (fuel cost, utility cost, maintenance fee) [17] and the penalty fee considered from the average medical expense in health insurance privileges per person in the amount of 259.60 baht per person per month of population in a radius of 5 kilometers (Office of the Energy Regulatory Commission,2017) [9] based on the location of the infectious waste incinerator as shown in Table 1. The details of the fixed and variable costs are shown in Table 2.

Table 2 Fixed cost and variable cost of infectious waste incinerators [16]

Types of Incinerator	Fixed cost		Variable cost		
	staff salary (baht/person/ month)	Depreciation (baht/month)	Fuel cost (baht/hour)	Utilities cost (baht/ hour)	Maintenance costs (baht/hour)
type 1	31,500	16,397	53	210	107
type 2	31,500	30,781	90	329	135
type 3	31,500	83,548	128	607	183

2.2 Mathematical model

The mathematical model is developed from the facility location problem with the objective of minimizing the total costs of the system. Parameters and decision variables used in formulating the model are defined and presented below with a brief explanation of each constraint.

Indices

i Hospital: $i = 1, 2, ..., m\,(m = 325)$

j Potential Location; $j = 1, 2, ..., n(n = 21)$

k Incinerator type ; $k = 1, 2, 3$

denote : 1 refer to the type of the incinerator with the burning capacity of 100 kilograms/hour

2 refer to the type of the incinerator with the burning capacity of 300 kilograms/hour

3 refer to the type of the incinerator with the burning capacity of 600 kilograms/hour

Parameters

d_{ij} Travelling distance from hospital i to potential location j (kilometer)

c_k Fixed cost of the incinerator k (bath/month)

R_i Average amount of infectious waste of hospital i (kilogram/month)

a Transportation cost (baht/kilometer)

f_i Frequency of travelling to receive infectious waste of hospital i (times/month)

b_k Burning capacity of incinerator k (kilogram/hour)

o_k Variable cost of the incinerator k (bath/hour)

S Average medical expenses per person (bath/person/month)

l_j Population in potential location j that is expected to be affected (person)

H A number of hours in a month (hours)

Decision Variables

$$X_{ij} = \begin{cases} 1 & \text{; If hospital } i \text{ is assigned to eliminate infectious waste at location } j \\ 0 & \text{; Otherwise} \end{cases}$$

$$Y_j = \begin{cases} 1 & \text{; If location } j \text{ is selected as the infectious waste disposal facility} \\ 0 & \text{; Otherwise} \end{cases}$$

$$N_{kj} = \begin{cases} 1 & \text{; If incinerator } k \text{ is used at location } j \\ 0 & \text{; Otherwise} \end{cases}$$

h_{kj} = Continuous operating time of incinerator k at location j (hours per month)

Objective Function

$$\text{Minimize} \quad Z = \sum_{i=1}^{m}\sum_{j=1}^{n} a f_i d_{ij} X_{ij} + \sum_{j=1}^{n}\sum_{k=1}^{k} c_k N_{kj} + \sum_{j=1}^{n}\sum_{k=1}^{k} h_{kj} o_k N_{kj} + \sum_{j=1}^{n} S l_j Y_j \quad (1)$$

Constraints

$$\sum_{j=1}^{n} X_{ij} = 1 \qquad \forall i\ (i = 1...m) \quad (2)$$

$$\sum_{k=1}^{k} N_{kj} = Y_j \qquad \forall j\,(j = 1...n) \quad (3)$$

$$X_{ij} \le Y_j \qquad \forall ij\,(i = 1...m),(j = 1...n) \quad (4)$$

$$\sum_{k=1}^{k} b_k (h_{kj} - 6) N_{kj} \ge \sum_{i=1}^{m} R_i X_{ij} \qquad \forall j\,(j = 1...n) \quad (5)$$

$$0 \le h_{kj} \le HN_{kj} \qquad \forall kj\,(k = 1...k),(j = 1...n) \quad (6)$$

$$\sum_{i=1}^{m} X_{ij} \ge Y_j \qquad \forall j\,(j = 1...n) \quad (7)$$

$$X_{ij} \in \{0,1\} \quad (8)$$

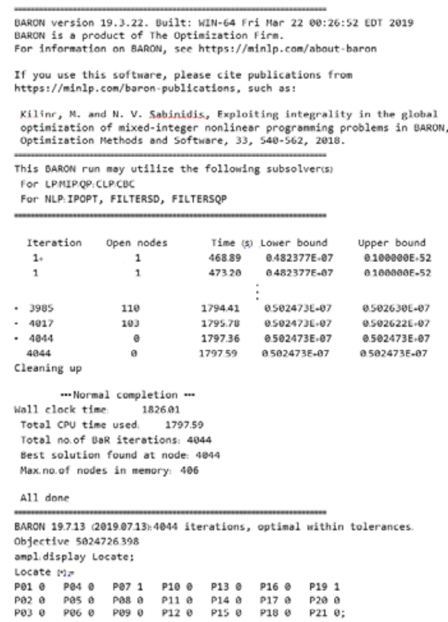
$$Y_{ij} = \{0,1\} \quad (9)$$

$$N_{kj} = \{0,1\} \quad (10)$$

Objective function (1) is to minimize the total cost that consists of the total transportation cost, the fixed and variable costs of operating the incinerators and the penalty cost. Constraint (2) indicates that each hospital can be assigned to only on infectious waste disposal facility. Constraint (3) ensures that the location chosen to operate the infectious waste incinerator must use only one type of incinerators. Constraint (4) makes certain that all hospitals are able to obtain service of infectious waste disposal only from operating locations. Constraint (5) determines that in each month the infectious waste incinerator of the service location will be warmed up for 6 hours before operating continuously burning process and then it shall burn all the infectious waste collected from hospitals in the month. Constraint (6) defines that operating the infectious waste incinerator at any location must continue to operate for no more than 1 month. Constraint (7) determines that the service location of the infectious waste incinerator must have at least one hospital to use the service of the infectious waste incineration disposal. Constraint (8), (9) and (10) define the binary decision variables.

3. Result

The solution of the problem is to find the locations of the infectious waste disposal facilities, assign the hospitals to the selected locations for service and choose the type of the incinerators for each facility as well as determine the monthly burning time of each incinerator in order to minimize the total cost of the system. In this research, the problem is solved using A Mathematical Programming Language (AMPL) with Baron Solver running on a Intel® Core™ i5-8300H-CPU@2.30GHz RAM 16 GB. The Baron solver can solve nonlinear mixed integer programming problems to global optimality [3]. The solution obtained from AMPL is shown in Figure 2, with processing time of 1,797.59 seconds and the total cost of 5,024,726.40 baht per month. The computational result is displayed in Table 3.



```
===========================================================================
BARON version 19.3.22. Built: WIN-64 Fri Mar 22 00:26:52 EDT 2019
BARON is a product of The Optimization Firm.
For information on BARON, see https://minlp.com/about-baron

If you use this software, please cite publications from
https://minlp.com/baron-publications, such as:

 Kilinc, M. and N. V. Sabinidis, Exploiting integrality in the global
 optimization of mixed-integer nonlinear programming problems in BARON,
 Optimization Methods and Software, 33, 540-562, 2018.
===========================================================================
This BARON run may utilize the following subsolver(s)
 For LP/MIP/QP: CLP/CBC
 For NLP: IPOPT, FILTERSD, FILTERSQP
===========================================================================

  Iteration    Open nodes       Time (s)  Lower bound      Upper bound
   1+              1            468.89     0.482377E+07     0.100000E+52
   1               1            473.20     0.482377E+07     0.100000E+52
                                        :
*  3985          110           1794.41     0.502473E+07     0.502630E+07
*  4017          103           1795.78     0.502473E+07     0.502622E+07
*  4044            0           1797.36     0.502473E+07     0.502473E+07
   4044            0           1797.59     0.502473E+07     0.502473E+07
Cleaning up

         *** Normal completion ***
Wall clock time:       1826.01
 Total CPU time used:     1797.59
 Total no. of BaR iterations:  4044
 Best solution found at node:  4044
 Max. no. of nodes in memory:  406

 All done
===========================================================================
BARON 19.7.13 (2019.07.13): 4044 iterations, optimal within tolerances.
Objective 5024726.398
ampl: display Locate;
Locate [*] :=
P01 0   P04 0   P07 1   P10 0   P13 0   P16 0   P19 1
P02 0   P05 0   P08 0   P11 0   P14 0   P17 0   P20 0
P03 0   P06 0   P09 0   P12 0   P15 0   P18 0   P21 0;
```

Figure 2 The solution obtained from AMPL

From Table 3, it is shown that there are 2 appropriate locations for establishing infectious waste disposal facilities in the Northeast of Thailand. The first one is Kuchinarai District, Kalasin Province (P07) using the incinerator with burning capacity of 600 kilograms/hour to serve 248 hospitals. The other location is Tha Li District, Loei Province (P19) operating the same type of the incinerator and providing service to 77 hospitals. The monthly burning time of the incinerators of each location is 719.986 hours and 491.681 hours respectively. According to the report of the Pollution Control Department [6], the amount of infectious waste tends to increase by approximately 5.5 % per year.

Table 3 The result of selection the suitable infectious waste disposal location and incinerator

Suitable disposal facilities	Hospitals	Type of Incinerator	Burning time (hour/month)	Total Cost (baht/month)
P07	H1-H49, H58,H59,H61,H62, ,H63,H64,H65,H66,H68,H69, H71- H89,H90,H91,H92.H93, H94,H95, H98,H99,H100-105, H112,H113,H119, H128,H129, H130-H139, H140-H149, H150-H159, H161-H169, H170-H179,H180-H189, H190-H199, H200,H201, H202,H205,H207,H208,H209, H210,H211,H212,H213,H215, H216,H217,H219,H220,H222, H223,H225,H226,H227,H228, H229, H230-H239,H240,H241, H268,H270-H279, H280-H289, H290,H291,H300,H301,H302, ,H305,H306,H309,H310,H315, H318,H319,H320,H321,H322, H324,H325 (248 hospitals)	600 Kg/hr.	719.99	5,024,726.40
P19	H50,H51,H54,H55,H60,H67,H70,H72,H73,H84,H96, H97, H106,H107,H108,H109,H110, H111,H114,H115,H116,H117, H118,H120,H121,H122,H123, H124,H125,H126,H127,H203, H204,H206,H214,H218,H221, H224,H232,H242,H243,H244, H245,H246,H247,H248,H249, H250,H251,H252,H253,H254, H255,H256,H257,H258,H259, H260,H261,H262,H263,H264, H265,H266,H267,H269,H303, H304,H307,H308,H311,H312, H313,H314,H316,H317,H323 (77 hospitals)	600 Kg/hr.	491.68	

Moreover, Thailand has participated in ASEAN Economic Community – AEC and the Northeast of Thailand has borders with neighbor countries including Cambodia and People's Democratic Republic of Laos. As a result, there are many people from those countries travelling to undergo the medical and public health services in many provinces in the Northeast of Thailand, resulting in an increasing the amount of infectious waste continuously. To analyze the effect of an increase in infectious waste on the solution, the sensitivity analysis [8] is conducted by increasing the amount of infectious wastes from all 325 hospitals by 5%, 10%, 20%, 30%, 40% and 50%. The results are shown in Table 4.

Table 4 The sensitivity analysis of the amount of infectious waste.

The ratio of increase of infectious waste	Area	Type of Incinerator	The number of hospitals	Total cost (bath/month)
5%	P07	3	250	5,079,419.97 (+1.09%)
	P19	3	75	
10%	P07	3	171	5,134,071.15 (+2.18%)
	P19	3	79	
20%	P02	2	77	6,416,683.42 (+27.70%)
	P07	3	190	
	P19	3	58	
30%	P02	3	91	6,442,254.80 (+28.21%)
	P07	3	193	
	P19	2	41	
40%	P02	3	90	6,544,199.69 (+30.24%)
	P07	3	180	
	P19	3	55	
50%	P02	3	95	6,670,997.27 (+32.76%)
	P07	3	174	
	P19	3	56	

Regarding Table 4, when considering the increasing amount of infectious waste by 5% and 10%, it is found that locations P07 and P19 are still suitable for establishing an infectious waste disposal facilities and also use the infectious waste incinerators with the burning capacity of 600 kilograms per hour. There is a change in the service user hospitals having a total cost of 5,079,419.97 baht per month and 5,134,071.15 baht per month, accounting for an increase by 1.09% and 2.18% respectively.

It can be seen that when the infectious waste increase by 20% or more, one more infectious waste disposal facility is needed and additional suitable location is Puk Thong Chai District, Nakhonratchasima province(P02). For the case of 20% and 30% increase two type of the incinerators are used, one of type 2 and two of type 3. For the case of 40% increase, all there facilities operate type 3 incinerators when considering the total system cost, it increase grantly when the infectious waste increase changes from 10% to 20%. This is because one additional infectious waste disposal facility that is required when the infectious waste goes up 20% increase the high fixed cost.

4. Conclusion

This research presents the selection of suitable locations for establishing the infectious waste disposal facilities that provide services of incineration to 325 hospitals in the Northeast of Thailand. According to the Ministerial Regulations enforcing the comprehensive city plan of each province in the Northeast of Thailand, there are 21 locations that can be selected as the infectious waste disposal sites. There are three types of the incinerators with different burning capacities : 100 kilograms/hour, 300 kilograms/hour and 600 kilograms/hour. Each facility can operate only one incinerator. Transportation of infectious waste from the hospitals to the facilities is direct shipping. A mathematical model of the problem is formulated with the objective of minimizing the sum of transportation cost, fixed and variable costs of operating the incinerators and the penalty cost. The problem is then solved using AMPL program with Baron solver. The result shows that there are 2 appropriate locations for establishing infectious waste disposal facilities in the Northeast of Thailand, including Kuchinarai District, Kalasin Province and Tha Li District, Loei Province. Both locations use infectious waste incinerators supporting a burning rate of up to 600 kilograms per hour with the lowest overall cost of 5,024,726.40 baht per month, which is considered to be 6.98 baht per kilogram on the average in disposal of infectious waste. The sensitivity analysis indicates that if the infectious waste increases continuously in the future, both locations will still be in the solution and one additional infectious waste disposal facility is required when the infectious waste jumps up 20% or more. For the future research, instead of direct shipping, a vehicle routing can be incorperated in the problem. This can lower the transportation cost. More or less, this research can be used as a guideline for decision-making in the policy level on the disposal of infectious waste from relevant agencies.

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