

Location Analysis for Emergency Medical Service Vehicle in Sub District Area

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ABSTRACT

This research aims to formulate a mathematical model and develop an algorithm for solving a location problem in emergency medical service vehicle parking. To find an optimal parking location which has the least risk score or risk priority number calculated from severity, occurrence, detection, and distance from parking location for emergency patients, data were collected from Pratoom sub-district Disaster Prevention and Mitigation Center from October 2010 to April 2011. The criteria of risk evaluation were modified from Automotive Industry Action Group's criteria. An adaptive simulated annealing algorithm with multiple cooling schedules called multi-agent simulated quenching (MASQ) is proposed for solving the problem in two schemes of algorithms including dual agent and triple agent quenching. The result showed that the solution obtained from both scheme of MASQ was better than the traditional solution. The best locations obtained from MASQ-dual agent quenching scheme was nodes #5 and #133. The risk score was reduced 61% from 6,022 to 2,371 points.

Keywords: Emergency Medical Service, Location Problem, Multi-Agent Simulated Quenching

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1. INTRODUCTION

Accident and emergency illness is the main cause of death of the world. The World Health Organization (WHO) reported in World Health Statistic 2011 that 29.4% of the world citizens died from heart disease and stroke. And 2.1% of the world population died from traffic accidents (World Health Organization, 2011).

In Thailand, emergency medical service (EMS) plays an important role in the health insurance system. However, the management of EMS nowadays has not been so efficient. The statistics have shown that more than 18% of emergency patients were taken to the hospital too late (Emergency Medical Institute of Thailand, 2011). Thus, many things need to be improved including the EMS vehicles management.

This research aims to find two optimal locations for EMS vehicles parking that have the shortest distance to serve emergency patients. A real case study in Pratoom

sub-district, Ubon Ratchathani was formulated as a p-median problem, and a multi-agent simulated quenching algorithm was introduced to solve the problem.

2. LITERATURE REVIEW

2.1 Facility Location Problem

Facility location is a crucial process of strategic planning in organizations. There were many criteria to consider including cost and distance from depot to customer nodes. The location analysis models were applied to various perspectives such as selecting the best location for an ethanol plant, finding the optimal location of warehouse, and finding the distribution center in the supply chain (Nanthasamroeng and Pitakaso, 2010).

For siting of EMS vehicles, Marianov and ReVelle

(1996) applied a queuing maximal availability location problem (Q-MALP) for solving the 55 nodes test network by using branch and bound heuristic. Gendreau *et al.* (1997) had also success in applying Tabu search algorithm to solve a double coverage ambulance location problem.

In recent research, Schmid and Doerner (2010) have studied the ambulance location and relocation problems with time-dependent travel times. Global positioning system (GPS) was introduced for collecting velocity of ambulance—so called floating car data (FCD). Variable neighborhood search (VNS) was developed to solve the real-world problem in Vienna.

2.2 Simulated Annealing

Simulated annealing (SA) has been successfully applied to many NP-hard combinatorial problems since it was introduced by Kirkpatrick *et al.* (1983) and Cerny (1985). SA is a simulation of the recrystallization of atoms in metal during its annealing. While annealing, atoms migrate naturally to configurations that minimize the total energy of the system, and during this migration the system undergoes high energy configurations. SA is a hill climbing local exploration optimization heuristics, which means it can skip local minima by allowing the exploration of the space in directions that lead to a local increase in the objective function. It consequentially applies random modifications to the evaluation point of the objective function. If a modification yields a point of smaller objective function value, it is automatically kept. Otherwise, the modification can also be kept with probability obtained from the Boltzmann distribution as shown in Eq. (1) below (Ingber, 1993).

$$h(\Delta E) = \exp \frac{-\Delta E}{kT} \quad (1)$$

where

$h(\Delta E)$ represents the probability for acceptance of new cost function given the previous value.

ΔE represents the energy difference between the present and previous values of the energies.

k is the Stefan-Boltzmann constant.

T is the instantaneous temperature of the process.

SA algorithm begins with some initial solution and initial temperature. For each value of temperature, a certain number of iterations is executed where a new solution is randomly chosen from the neighborhood of the current one, that is, the set of neighboring solutions defined by some rule. This solution becomes the current one according to a certain probabilistic law, whereupon the temperature is reduced. The algorithm operates until the temperature reaches the critical value or other stop criteria (Levanova and Loresh, 2004). The standard procedure of SA is shown in Figure 1 (Park and Kim, 1998).

There are four annealing parameters for annealing

schedule scheme: 1) Initial temperature (T_1), 2) Cooling function ($F(T_k)$), 3) Epoch length (L), and 4) Stopping condition. Selections for appropriate annealing parameters contribute to the best performance of SA algorithm (Tavares *et al.*, 2011).

Many applications of SA have been reported in the area of location analysis and also vehicle routing problem including Paik and Soni (2007), Antunes and Peeters (2001), Arostegui Jr. *et al.* (2006), Taheri and Zomaya (2007), and Righini (1995). In a recent paper, Yu *et al.* (2010) used SA heuristics for solving three standards instant of capacitated location routing problem. The computational study showed that SA heuristic was competitive with other well-known algorithms such as ant colony system, clustering based heuristic, greedy randomized adaptive search procedure (GRASP), mimetic algorithm with population management and genetic algorithm.

Procedure Simulated Annealing (SA)

- (1) Generate an *Initial solution*, S
 - (2) Select a value for *Initial temperature*, $T_1 > 0$
 - (3) Set the *epoch count* $k = 1$
 - (4) Repeat the following *epoch length*, L
 - for $i = 1, i < L$ do;
 - generate a *neighborhood solution* S' of S ;
 - let $\Delta = Z(S') - Z(S)$;
 - if $\Delta < 0$, let S be S'
 - if $\Delta \geq 0$, let S be S' with probability, $h(\Delta E)$;
 - end for loop;
 - (5) If a given *Stopping condition* is satisfied, stop. Otherwise, let $T_{k+1} = F(T_k)$ and $k = k+1$ and back to step (4)
- end**

Figure 1. Pseudo-code for standard simulated annealing algorithm.

2.3 Simulated Quenching

Simulated quenching (SQ) is an algorithm improved from the standard procedure of SA as shown in Figure 1. In material science, quenching is a rapid cooling of metal, alloy or plastic to obtain certain material properties. Quenching is most commonly used to harden steel. This is done by heating the material to a certain temperature, dependent on the material, and then rapidly cooling the material. This produces a harder material by either surface hardening or through hardening varying on the rate at which the material is cooled (Callister and Rethwisch, 2010). SQ algorithm and analogy of technique is the same as SA except for the cooling schedule. SA algorithm normally requires a large number of evaluations to find the global optima with high probabilities even for weak conditioned functions with numerous local minima. Therefore, SA technique is quite slow and many researchers tried to speed up the algorithm by rapidly reducing the temperature in the system which is

the basis of SQ. However, the advantage of SA such as convergence to the global optima is defeated and this is the weakness of SQ. The initial temperature, cooling rate, and epoch length are the important parameters for SQ (Vasan and Raju, 2009).

The literature review indicates that SA algorithm is competitive with other well-known algorithms. However, SA normally requires a large number of evaluations to find the global optima with high probabilities even for weak conditioned functions with numerous local minima that made it very slow computational time. Therefore, this paper focuses on using SQ which has the nearly same procedure of SA but rapidly reduces the investigation time.

3. MATHEMATICAL MODELING

A mathematical model was formulated from the basic location allocation model. The objective function was focus on the risk priority number (RPN) which was calculated from multiplication of severity (S), occurrence (O) and detection (D). The RPN concept is adopted from failure modes and effects analysis (FMEAs) which are widely used in automotive industry to assess the risk from deviation of product design and production processes (Xiao *et al.*, 2011). RPN is used on the basis of the real world situation where each citizen has different needs for using emergency medical service. Therefore, the RPN score is suitable for stating the importance of each node in the case study. The following indices, parameters and, decision variables are used in the mathematical model.

3.1 Sets

- I denote for the set of potential EMS vehicle parking location
- J denote for the set of possible emergency illness or accident cases

3.2 Parameters

- RPN_i represent the risk priority number at node i
- RPN_j represent the risk priority number at node j
- d_{ij} represent the distance from EMS parking location i to emergency case j

3.3 Decision Variables

- x_i represent 1 if node i is selected, $i \in I$; 0 otherwise
- y_{ij} represent 1 if an arc from node i to node j is on the route of EMS vehicle, $i \in I, j \in J$; 0 otherwise

3.4 Objective Function

$$MinZ = \sum_{i=1}^I RPN_i x_i + \sum_{i=1}^I \sum_{j=1}^J RPN_j d_{ij} y_{ij} \quad (2)$$

3.5 Constraints

Subject to;

$$\sum_{i=1}^I y_{ij} = 1, \quad \forall j \quad (3)$$

$$y_{ij} \leq x_i, \quad \forall i, \forall j \quad (4)$$

$$\sum_{i=1}^I x_i = p \quad (5)$$

$$y_{ij}, x_i \in \{0, 1\} \quad (6)$$

The objective function (2) aims to minimize the risk priority number for EMS vehicles, which is the summation of risk values from parking node itself plus the summation of accident's risk values multiplied by distance from parking node to accident node. In constraints (3), each emergency or accident instant node must be serviced. Constraints (4) prevent patients from being serviced from parking node with undefined to be a parking node. The total number of parking nodes is set to p by constraints (5). Finally, constraints (6) show two decision variables including y_{ij} and x_i which must be 0 or 1.

4. TEST PROBLEM: A REAL CASE STUDY

The test instance used in this research was formulated from a real case study of EMS vehicles parking in Pratoom sub-district Disaster Prevention and Mitigation Center (Pratoom DPMC). All data were collected from October 2010 until April 2011. During that time, Pratoom DPMC serviced 172 cases of both emergency patients and accident victims. All cases were pointed in electronics map, and then Euclidean distance matrix was calculated. Risk priority number in each case was calculated also. The criteria of severity, occurrence and detection were modified from Automotive Industry Action Group (AIAG)'s criteria (AIAG, 2008) and listed in Tables 1-3, respectively.

Table 1. Severity criteria

Level	Description	Score
Very high	Unconscious without any response, a lot of bleeding, need a cardiopulmonary resuscitation (CPR)	5
High	Unconscious but can waking up, abnormal breathing, bleeding, need a CPR	4
Medium	Slow breathing, wound size bigger than 2 cm	3
Low	Drowsily, normal breathing, wound size smaller than 2 cm	2
Very low	Full consciousness, normal breathing, a little wound	1

Table 2. Occurrence criteria

Level	Description	Score
Very high (persistent)	More than 8 times in the same node	5
High (frequent)	More than 6 times in the same node	4
Medium (occasional)	More than 4 times in the same node	3
Low (relatively few)	More than 3 times in the same node	2
Very low (unlikely)	More than 2 times in the same node	1

Table 3. Detection criteria

Level	Description	Score
Very low	Without detection or prevention system	5
Low	There are some safety sign or health monitoring once a year	4
Medium	There are safety signs and street light or health monitoring twice a year	3
High	There are street light and traffic light or health monitoring every 3 months	2
Very high	There are safety signs, street light and traffic light or health monitoring once a year	1

Normally, EMS vehicle parking locations of Pratoom DPMC were located at node #146 and #160. The objective value obtained from the traditional location was 6,022 points. All nodes and location are shown in Figure 2 below.

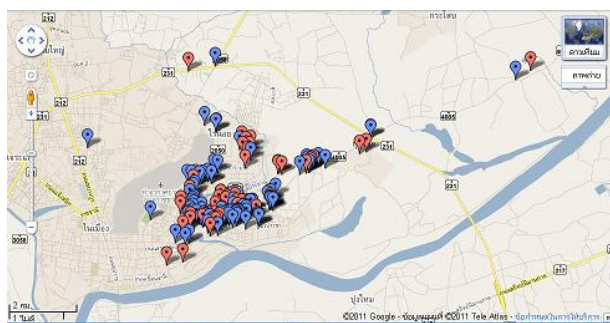


Figure 2. Emergency potential node of Pratoom sub-district Disaster Prevention and Mitigation Center.

5. MULTI-AGENT SIMULATED QUENCHING

In this paper, we introduced multi-agent simulated quenching (MASQ) algorithm to solve the location problem. MASQ was developed from SQ, therefore, the structure of algorithm was nearly the same as SQ and SA except the cooling function. A term “multi-agent” means multiple quenching agents (or media) with various cooling rates. So, we can utilize both advantages of SA and SQ simultaneously. MASQ procedure was simi-

lar to figure that is shown in Figure 1, but some parameters are different. A pseudo-code for MASQ is shown in Figure 3.

Procedure *Simulated Annealing (MASQ)*

- (1) Generate an *Initial solution, S*
- (2) Select a value for *Initial temperature, T₁ > 0*
- (3) Set the *epoch count k = 1*
- (4) Repeat the following *epoch length, L*
 for $i = 1, i < L$ do;
 generate a *neighborhood solution S'* of *S*;
 let $\Delta = Z(S') - Z(S)$;
 if $\Delta < 0$, let *S* be *S'*;
 if $\Delta \geq 0$, let *S* be *S'* with probability, $h(\Delta E)$;
 end for loop;
- (5) If a given *Stopping condition* is satisfied, stop.
 Otherwise,

For Dual Agent Quenching Scheme:

- if *Dual Intervention Temperature, T_d < T_k*;
 Change $T_{k+1} = n_{d1} \alpha T_{k-1}$;
 if $T_d > T_k$;
 Change $T_{k+1} = n_{d2} \alpha T_{k-1}$;
 $k = k+1$ and back to step (4);

For Triple Agent Quenching Scheme:

- if *Triple Intervention Temperature, T_{tl} < T_k*;
 Change $T_{k+1} = n_{t1} \alpha T_{k-1}$;
 if $T_{t1} > T_k > T_{t2}$;
 Change $T_{k+1} = n_{t2} \alpha T_{k-1}$;
 if $T_{t2} > T_k$;
 Change $T_{k+1} = n_{t3} \alpha T_{k-1}$;
 $k = k+1$ and back to step (4);
end

Figure 3. Pseudo-code for multi-agent simulated quenching algorithm.

5.1 Initial Solution (S)

Initial solution in this research was obtained from determining number of EMS vehicles parking ($p = 2$) locations then random two integers from 1 to 173 are set to be parking locations. After that, algorithm assigned half of populations (or nodes) to the first location by the nearest assignment policy. So, the rest of populations were assigned to the second location automatically.

5.2 Initial Temperature (T₁)

Kirkpatrick *et al.* (1983) stated that the value of initial temperature is set large enough to make the initial probability of accepting transitions be close to 1. However, in this research, a set of initial temperature was set between 700°C to 1,500°C. The objective value obtained from each parameter will be discussed later.

5.3 Neighborhood Solution

Neighborhood solution in this study was generated

by using a 2-opt local search algorithm. From the initial solution, while $p = 2$, we start with two sets of nodes. The 2-opt local search algorithm swaps each parking location with one node in its set.

5.4 Cooling Function ($F(T_k)$)

Our cooling function is developed from the one originally suggested by Kirkpatrick *et al.* (1983). We applied the quenching agent parameter in the traditional cooling function by multiplied quenching agent constant (n) to cooling ratio (α) as described in Eq. (7) and Eq. (8).

$$T_k = n\alpha T_k - 1 \quad (7)$$

$$\alpha = \left(\frac{T_M}{T_1} \right) \quad (8)$$

where;

- n is quenching agent constant
- T_k is the temperature at the k^{th} epoch
- T_M is the temperature at the final epoch
- M is total number of epoch

In this research, we designed 2 schemes of MASQ: dual agent quenching and triple agent quenching.

In dual agent quenching, temperature was reduced from T_1 to dual intervention temperature (T_d) 400°C with the cooling function of the first agent. After that, quenching is changed to the second agent with a different cooling function, and temperature was reduced until T_M .

In triple agent quenching, temperature was reduced from initial temperature (T_1) to triple intervention temperature (T_{i1}) 600°C with the first quenching agent. Then change quenching agent and reduce the temperature from 600°C to 300°C (T_{i2}). After that, we change agents again and cooling down the temperature from T_{i2} 300°C to T_M .

The temperature-time-transformation diagram of dual and triple agent quenching are shown in Figures 4 and 5.

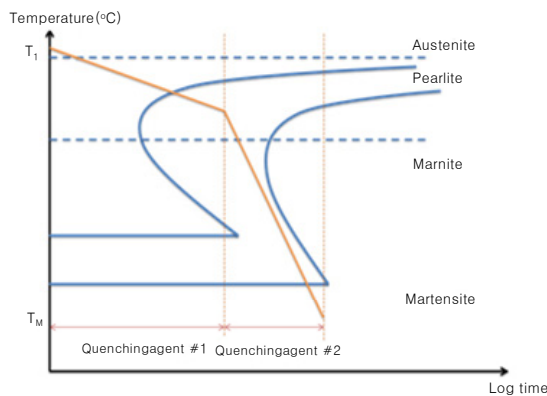


Figure 4. Temperature-time-transformation diagram of dual agent quenching.

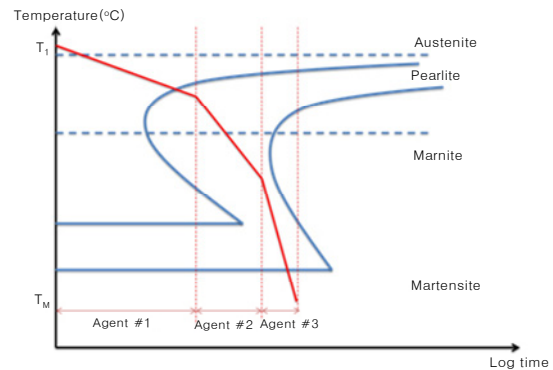


Figure 5. Temperature-time-transformation diagram of triple agent quenching.

5.5 Epoch Length (L)

Park and Kim (1998) suggested that the value of L can be set to be proportional to the size of the problem instance. Therefore, we fixed L to be 50% of nodes or 86.

6. RESULT AND DISCUSSION

6.1 Algorithm Evaluation Result

The MASQ algorithm was coded in C++ and run on CPU Intel® Core™ 2 DUO T7250 @ 2.0 GHz, 1.18 GHz, 2 GB of RAM. The result of testing in changing initial temperature with $T_M = 25$ and $k = 1$ on dual agent quenching scheme is listed in Table 4.

Table 4. Result of changing T_1 on dual agent scheme

T_1 (°C)	Dual agent quenching		
	Z_{average}	Z_{best}	Avg. CPU time (sec)
700	2,535.80	2,418	161.6
800	2,528.80	2,409	215.8
900	2,479.40*	2,408	242.8
1000	2,530.00	2,494	270.0
1100	2,509.40	2,371**	332.8
1200	2,505.00	2,425	298.4
1300	2,546.40	2,517	322.0
1500	2,543.00	2,524	377.2

* The best average run, ** The best single run.

Table 4 lists the result of variations in initial temperature with dual agent quenching schemes. Objective values were obtained from the best single run and average values of 5 replications. The best objective value from MASQ-dual agent quenching scheme is 2,371 at the initial temperature of 1,100°C, and the minimum average objective value is 2,479.40 at initial temperature 900°C.

A triple agent quenching scheme was also tested in the same condition. The result of testing is listed in Ta-

ble 5. Objective values were also obtained from the best single run and average values of 5 replications.

Table 5. Result of changing T_1 on triple agent scheme

T_1 (°C)	Triple agent quenching		
	$Z_{average}$	Z_{best}	Avg. CPU time (sec)
700	2,569.20	2,549	150.0
800	2,558.60	2,435	180.6
900	2,539.40	2,452	206.2
1000	2,522.00	2,445	233.0
1100	2,501.40*	2,431	261.6
1200	2,522.20	2,459	290.4
1300	2,527.80	2,412**	317.4
1500	2,513.40	2,444	345.0

* The best average run, ** The best single run.

The best objective value from MASQ-triple agent quenching scheme is 2,412 at the initial temperature of 1,300°C, and the minimum average objective value is 2,501.40 at initial temperature 900°C.

A comparison of the results and computational time consumed from each scheme is shown in Figures 6 and 7.

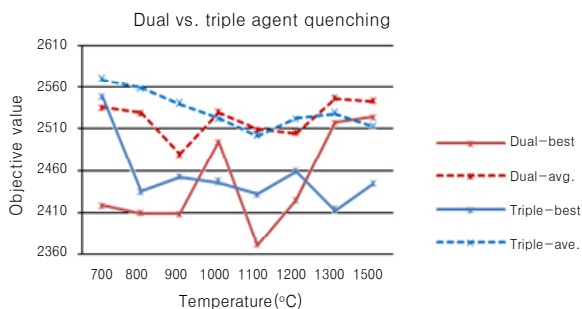


Figure 6. Comparison of dual vs. triple agent quenching scheme.

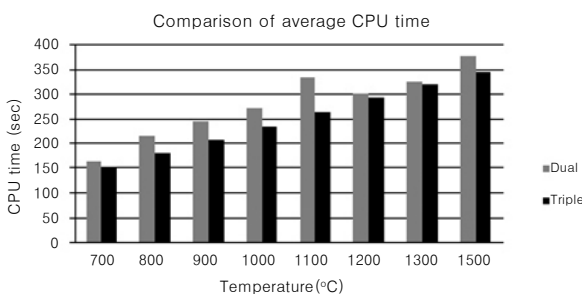


Figure 7. Comparison of dual and triple agent quenching scheme.

Figures 6 and 7 show the comparison of result revealed that the objective values from both schemes are decreased while initial temperature is increased. This phenomenon conforms to the result reported by Kirkpatrick *et al.* (1983) and Park and Kim (1998) which suggested that too high initial temperature may cause a long computational time or a bad performance.

6.2 Real-World Application Result

The best locations obtained from MASQ-dual agent quenching scheme are nodes #5 and #133. The risk score was reduced 61% from 6,022 to 2,371 points as shown in Figure 8. However, the optimal solution is still unknown and has to be solved in the future research.

6.3 Future Research Area

In this research, MASQ was introduced to solve a location problem focusing on EMS vehicle parking location of Pratoom DPMC. There are also a number of opportunities for improvements for both the solution of problem and the performance of algorithm itself.

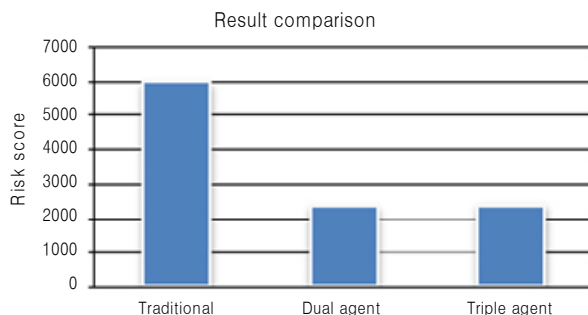


Figure 8. Comparison result from dual and triple agent quenching scheme with traditional risk score.

For the EMS vehicles location problem issue, the optimal solution should be obtained by commercial mathematical or optimization software to compare the result with MASQ. Moreover, a time-dependent travel time is a very interesting model which can be applied to the problem because time is very important for the rescue missions of EMS vehicle.

For the MASQ algorithm, there are specific parameter of MASQ which needs to be verified, e.g., intervention temperature of each agent or number of agents. A verification of algorithm's performance should be done by using the algorithm to solve various types of standard instances and compare with other algorithms.

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