Introduction

Thailand's worst flooding was witnessed in 2011. Various disaster areas were found in the entire country, especially north and central ones, leaving severe impairments to the country's agricultural, industrial, and economic sectors, and society in general. During the incident, many distribution centers were established, resulting in plenty amount of emergency goods which were about to be distributed to those unfortunate. However, due to the large number of victims, the distribution cannot be equally distributed.

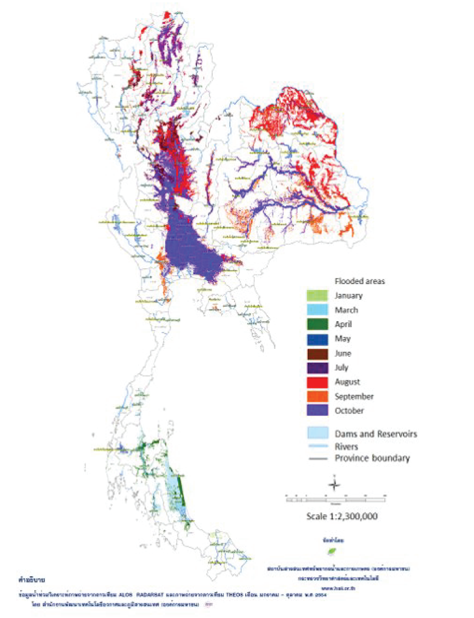

Fig. 1 Diagram of Flooded Areas
Source: National Hydro Informatics and Climate Data Center

Fig. 2 Emergency Goods

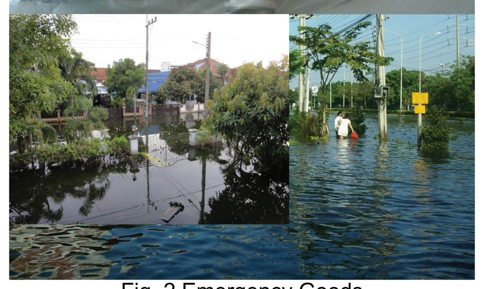

Fig. 3-4 Flooded Area

It is believed that the effective strategy should yields equality, where disaster victims receive the same proportion of cumulative goods according to their cumulative demand. To explore such a strategy, an optimization model for equality emergency goods distribution is established. The objective of this model is to investigate an equality distribution strategy over finite-time interval. Three constraints of the model are considered: (a) linearly increasing demand of victims, (b) quality and quantity of emergency goods, and (c) structure of disaster areas.

Problem Formulation

To solve this problem, an optimization problem is formulated to represent emergency goods distribution problem.

Disaster Area

The disaster area is represented by a weighted undirected graph. In the graph, there are two types of nodes. There is only one black node representing the distribution center. Blue nodes represent locations where the distribution center has to send emergency goods to or cities. Edges represent roads between pairs of cities. Weights of the edges represent traveling time. Transportation routes are edges in a shortest path tree rooted at the distribution center.

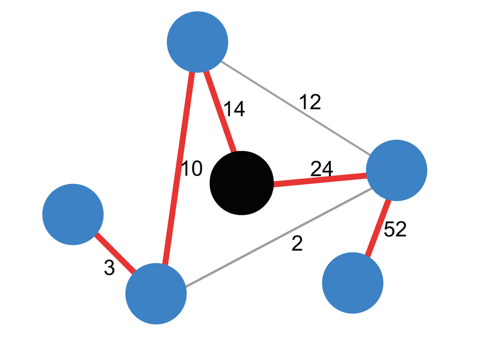

Fig. 5 Example of graph which represented disaster area

Demand

The cumulative demand of a node is defined by two values: initial demand and increasing rate of the demand per day.

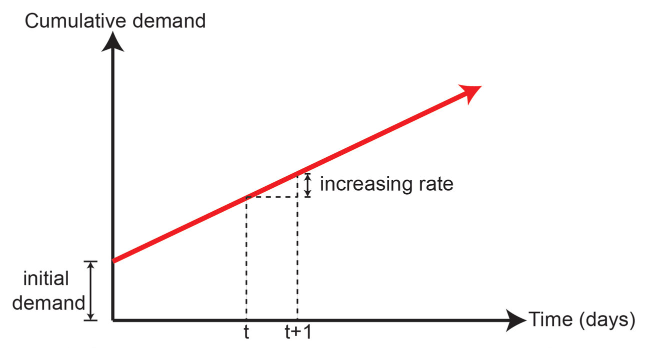

Fig. 6 Graph represents the cumulative demand of a node

Emergency Good

Each emergency goods is defined by two values: utility value and expiration date. Note that emergency goods cannot be divided into multiple pieces to serve victims equally. The demand of a node will be fulfilled if its cumulative utility value is not less than its cumulative demand.

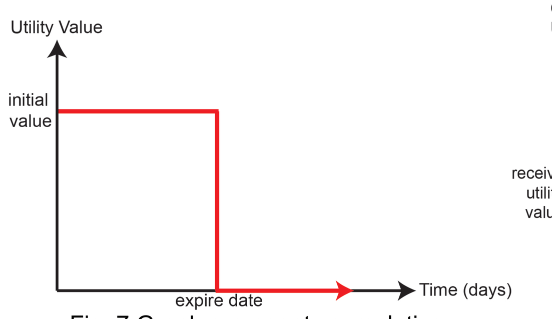

Fig. 7 Graph represents cumulative utility value of a node

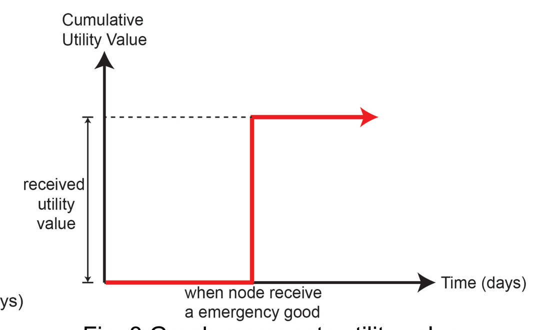

Fig. 8 Graph represents utility value of an emergency goods

Assumption

In this optimization problem, there are 5 additional assumptions on emergency goods distribution problem shown here.

- The distribution center may receive or not receive emergency goods in every day.
- All emergency goods must be distributed at the end of the day.
- The distribution center doesn't know anything about emergency goods received in the future.
- Emergency goods during transportation stage can be reassigned to appropriate destination.
- There are infinite amount of money and infinite identical transportation vehicles with infinite maximum load capacity.

Problem Formulation

Variables

- T is the ending time of disaster
- G is a graph representing a disaster area
- $V(G)$ is a set of nodes in the graph G
- $t_u(i,j)$ is the arrival time at node u of the j^{th} emergency goods which is received at time i
- N_t is the number of received emergency goods at time t
- $b_{t,i}$ is the utility value of the i^{th} emergency goods received at time t
- $d_{t,i}$ is the expiration date of the i^{th} emergency goods received at time t
- z_u is the initial demand of node u
- r_u is the increasing rate of the demand of node u
- $D_u(t) = r_u t + z_u$ is the cumulative demand of node u over the time interval $[1,t]$
- $X_u(t)$ is the cumulative received utility value of node u over the time interval $[1,t]$
- $R_u(t) = \min\left(1, \frac{X_u(t)}{D_u(t)}\right)$ is the ratio between the cumulative fulfilled demand and the cumulative demand of node u over the time interval $[1,t]$

Objective Function

The efficiency of a distribution strategy is measured by the equality of the strategy. In this research, equality implies every node has an equal ratio between its cumulative utility value and its cumulative demand or $R_1(t) = R_2(t) = \cdots = R_{|V(G)|}(t)$. To measure the variation of the ratios, the standard deviation is applied to formulate the loss function.

$$\min_{(x_1,x_2,\ldots,x_n)\in(\mathbb{R}_0^+)^n} \sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n}} \equiv \min_{(x_1,x_2,\ldots,x_n)\in(\mathbb{R}_0^+)^n} \sum_{i=1}^{n}(x_i-\bar{x})^2$$

The loss function at time t is formulated by replacing parameters in the formula with the ratios

$$\min_{(R_1(t),R_2(t),\ldots,R_{|V(G)|}(t))\in[0,1]^n} p(t) = \sum_{u\in V(G)}\left(R_u(t) - \frac{1}{|V(G)|}\sum_{u\in V(G)} R_u(t)\right)^2$$

In this research, the objective function is the arithmetic mean of values of the loss function over a finite-time interval. Thus, the algorithm must minimize

$$f = \frac{1}{T}\sum_{t=1}^{T} p(t)$$

Node	Cumulative Utility Value	Cumulative Demand	Ratio
1	70	100	0.7
2	70,000	100,000	0.7
3	7	10	0.7

Table 1 Variables in the optimization problem

Genetic Algorithm

This section is separated into 2 parts. Part one covers the genetic algorithm which is used to solve the optimization problem in case $T = 1$. Another part covers the genetic algorithm which is used to solve the optimization problem in general case.

Chromosome Encoding System

In this research, a chromosome is represented by an integer vector. The solution of a distribution strategy is represented by the chromosome with length N_1. In this system, $\bar{\chi}_i$ represents the destination of i^{th} emergency goods.

3	1	3	0	…

Fig. 9 Example of chromosome

In the figure above, the encoding of the chromosome denotes that the first, second, third, and fourth emergency goods are sent to node index 3, 1, 3, and 0, respectively.

Initial Parameters

- NP is the number of the initial population
- DP is the number of the replicated chromosome
- $G_{\max}$ is the maximum evolutionary generation
- $G'_{\max}$ is the maximum non-improved evolutionary generation
- P_c is the crossover probability
- P_m is the mutation probability

Population Initialization

NP chromosomes with length N_1 are generated by a random number generator under the constraint $\bar{\chi}_i \in [0, |V(G)|]$

Genetic Operators

In this research, genetic operators are k-tournament selection, uniform crossover, and random resetting mutation

Termination Criteria

The GA will stop when one of these criteria is met:

- The current evolutionary generation $g > G_{\max}$
- The non-improved evolutionary generation $g' > G'_{\max}$
- The chromosome with $\mathrm{Fitness}(\bar{\chi}) = 0$ has been found

Dynamic Length Chromosome Encoding System

The solution of distribution strategy at time t is represented by the chromosome with length $L_t = \sum_{k=1}^{t} N_k$. In this system, $\bar{\chi}_{t,j}$ represents the destination of the j^{th} emergency goods which the distribution center received at time t. Length of chromosome will change if the distribution center receives new emergency goods.

$x_{1,1}$	$x_{1,2}$	$x_{1,3}$	$x_{1,4}$	⋯	x_{t,N_t}

Fig. 13 General chromosome in dynamic length chromosome encoding system

Population Re-Initialization

The objectives of population re-initialization step are twofold. First, I need to encode new distribution strategies for the received emergency goods. However, the simple addition of new genes to the chromosome can eventually turn good chromosomes at time $t-1$ into bad ones. Hence, the second objective is to assure that good chromosomes in previous time $t-1$ have a higher chance of being good now.

Let consider this step at time $t > 1$. Every chromosome is replicated to create other DP identical chromosomes and add them to the current population. This decreases the probability that a good chromosome turns into bad ones through the addition of some new genes. Then, each chromosome will be added by N_t new genes which are generated by a random number generator under constraint $0 \le \bar{\chi}_{t,i} < |V(G)|$ for $i = 1,2,\ldots,N_t$. Finally, select NP chromosomes from $NP(DP+1)$ chromosomes in the population by tournament selection.

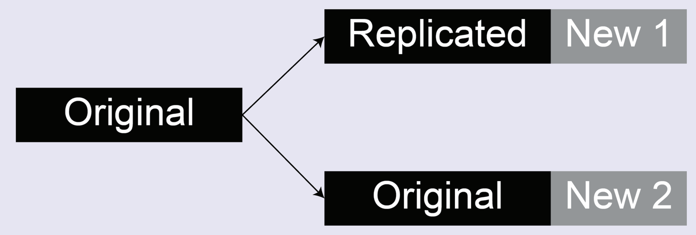

Fig. 14 Mechanism of population re-initialization step

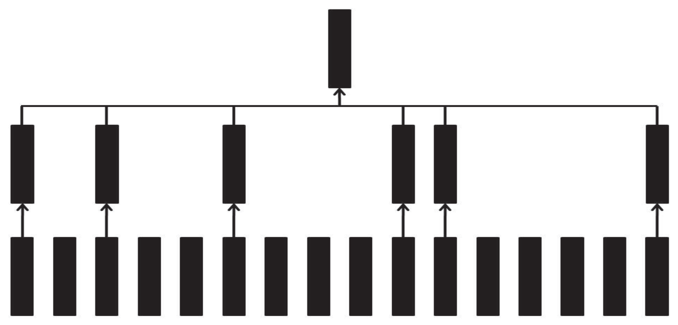

Fig. 10 K-Tournament Selection

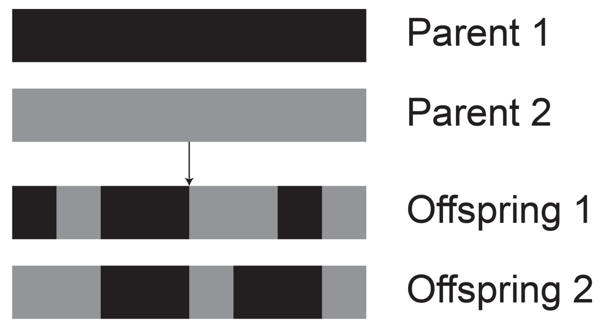

Fig. 11 Uniform crossover

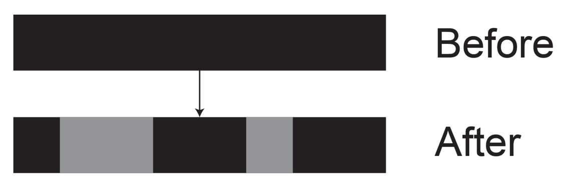

Fig. 12 Random Resetting Mutation

Fitness Function

In this research, the fitness function is the negation of function f defined above. But, f cannot be calculated using only allele from a single chromosome. Thus, $R_u(t)$ is re-formulated. The result of the re-formulation is shown below for chromosome $\bar{\chi}$.

$$R_u(t) = \begin{cases} 0 & \text{if} \quad t \in \left[1, t_u(S_{u,1,1}, S_{u,1,2})\right) \\ \min\left(1, \dfrac{1}{D_u(t)}\displaystyle\sum_{j=1}^{i-1} b_{S_{u,j,1},S_{u,j,2}}\right) & \text{if} \quad t \in \left[t_u(S_{u,i-1,1}, S_{u,i-1,2}), t_u(S_{u,i,1}, S_{u,i,2})\right);\ \exists i \in [2, |S_u|] \\ \min\left(1, \dfrac{1}{D_u(t)}\displaystyle\sum_{j=1}^{|S_u|} b_{S_{u,j,1},S_{u,j,2}}\right) & \text{if} \quad t \in \left[t_u(S_{u,|S_u|,1}, S_{u,|S_u|,2}), T\right] \end{cases}$$

The formula can be derived using the observation on the behavior of the cumulative utility value for nodes as follows. Let set $S_k = \left\{(i,j)\middle|\bar{\chi}_{i,j} = k \text{ and } t_{\bar{\chi}_{i,j}}(i,j) \le T \text{ and } t_{\bar{\chi}_{i,j}}(i,j) \le d_{i,j}\right\}$ for $k = 0,1,\ldots,|V(G)|-1$.

If $t_{\bar{\chi}_{i,j}}(i,j) > T$, then it implies that the arrival time of this emergency goods is after the ending time of the incident, T. That means this emergency goods can be ignored in the calculation of the objective function in the time interval $[1,T]$. If $t_{\bar{\chi}_{i,j}}(i,j) > d_{i,j}$, it implies that the arrival time of this emergency goods is after its expiration date. Since the utility value of this emergency goods is guaranteed to be zero when it arrives, this emergency goods can be ignored in the calculation of the objective function in the time interval $[1,T]$.

Then, all elements in the set S_k are sorted in the increasing order of the arrival time of these objects for $k = 0,1,\ldots,|V(G)|-1$. Note that the cumulative received utility value at each node remains unchanged during emergency goods transportation. Therefore, it only needs to update the utility value each time that an emergency goods arrives at the node. This observation can be used to simplify the calculation of $R_u(t)$. Let $S_{k,i,j}$ be the j^{th} element of the i^{th} pair in set S_k. $R_u(t)$ is re-formulated by the figure below.

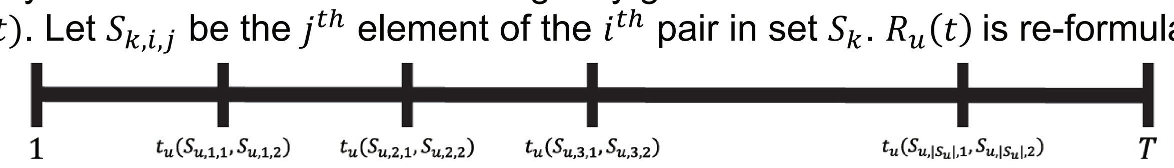

Fig. 9 Line number represents arrival time of emergency goods of node u

Genetic Algorithm

Pseudocode of GA

Initial Parameters Determination
FOR t in range $[1,T]$
  IF $t = 1$ **THEN** Population Initialization
  ELSE Population Re-Initialization
  WHILE Not terminate
    Fitness Value Calculation
    Parent Selection
    Crossing over with probability P_c
    Mutation with probability P_m
    Survival Selection
  Best Candidate Selection

Fig. 15 Pseudocode of GA for general case of the optimization problem

Experiment

Setup

Simulated data (500) were used to study the behavior of the algorithm on specific scenarios. GA is applied to distribute emergency goods, using specific initial parameters.

Discussion

From many simulated data, there are three interesting observations on the behavior of the algorithm.

- If there are not enough emergency goods, nodes with demand more than the average tend to receive more emergency goods than the less ones.
- If there are < 10% nodes that take time to reach, the distribution center tends to send the emergency goods to them first to deal with the transportation duration.
- If there are < 10% nodes with extremely high demands and there are not enough emergency goods, the distribution center tends to ignore them. But, if there are enough emergency goods, the algorithm can distribute emerncy goods normally.

These scenarios can be explained in these formula as follows:

- There are not enough emergency goods at time t iff

$$\sum_{k=1}^{t}\left(\sum_{i=1}^{N_k} b_{k,i}\right) < \sum_{u\in V(G)} D_u(t)$$

- Let s be the distribution center. Node u takes time to reach iff

$$\sum_{(x,y)\in su} w(x,y) \ge \frac{2}{|V(G)|}\sum_{u\in V(G)}\left(\sum_{(x,y)\in su} w(x,y)\right)$$

- Node u has an extremely high demand at time t iff

$$D_u(t) \ge 5\sum_{u\in V(G)} D_u(t)$$

Future Works

There are three designed improvements which can be implied into the model: dynamic graph, dynamic demand, and financial constraint.

- Dynamic graph covers how to modified the algorithm to handle graph operations include node insertion, node deletion, edge insertion, edge deletion, weight modification, and change distribution center.
- Dynamic demand covers how to re-formulate the cumulative demand formula to handle update of the increasing rate of demand per day where the formula can still be used within the current GA.
- Financial constraint covers how to re-formulate the objective function to handle constrained optimization problem by using the barrier function technique.

Research Contributions

- According to simulation result, the proposed optimization model has high potential for emergency goods distribution.
- The proposed dynamic length chromosome encoding system can be used in the successive optimization problems.
- The proposed population re-initialization step in this research can be used GA to deal with the successive optimization problems.

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