Emergency Goods Distribution Model over Finite Time Interval using Genetic Algorithm

Worameth Chinchuthakun
Mahidol Wittayanusorn School, Nakhonpathom, Thailand

ABSTRACT

Whenever disasters take place, it is literally difficult to design a strategy for goods distribution. 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. The constraints of the model, such as (a) demand of victims, which is linearly increasing, (b) quality and quantity of emergency goods, and (c) structure of disaster area, are considered. In this model, transportation routes are defined as a shortest path tree of graph representing disaster area. The model is flexible enough to handle insertion/deletion of edge/node as well as dynamic demand. Genetic Algorithm (GA) is applied to optimize the parameters of this model. In this GA, chromosomes represent distribution strategies. Hence, unlike traditional GA, the length of chromosomes in this work can vary in the considered time interval. To handle this problem, the chromosome encoding system with dynamic chromosome length is introduced, and the detailed description of basic implementation steps for the algorithm is given. The finding shows that GA and dynamic length chromosome encoding system are suitable for solving the emergency goods distribution over finite-time interval problems.

INTRODUCTION

In 2011, Thailand witnessed its worst flooding throughout the year. 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.

Nowadays, there exist many research works [1,2,5,6] related to emergency goods distribution under emergency incident. There has been attempts to explore emergency good distribution model in variety of incidents such as a multi-category emergency goods distribution model [1], a logistics routes optimization model under large scale emergency incident [2], a modeling framework for disaster response [5], and an algorithm to find optimal location for distribution center under traffic network [6].

According to these research studies, many accomplishments have been achieved on emergency goods distribution models under emergency incidents. However, research on the emergency goods distribution models over a finite-time interval is not considered. To improve efficiency of emergency goods distribution over a finite time interval, I established an optimization model for equality emergency goods distribution. Because of its practicality and flexibility, I applied genetic algorithm to optimize the parameters of the model. To deal with finite time interval, I proposed the dynamic length chromosome encoding system with emphasize on how to establish an optimization model to distribute emergency goods equally.

PROBLEM DESCRIPTION

Imagine yourself as the head of a distribution center, where your job is to plan a strategy to distribute emergency goods to victims in your responsible disaster area over finite-time interval. Every day you receive a finite amount of emergency goods. You know nothing about emergency goods which you will receive in future. You have to distribute all received emergency goods by the end of that day. Note that emergency good cannot be divided into multiple pieces to serve victims equally. Emergency goods during transportation stage can be reassigned with appropriate destination. You are given infinite amount of money for distribution. The unit of time, (day 1, 2, 3, …) in the model is discrete.

Your responsible disaster area is represented in a weighted undirected connected simple graph, where nodes and edges represent location of victims and connection between pairs of locations, respectively. There is exactly one special node represented the distribution center called *distributor*. If pairs of locations are not connected to each other, then the edge between them does not exist. Weight of edge represents time required to travel between a pair of nodes.

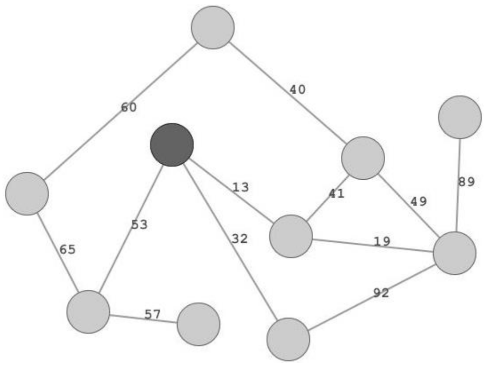

Figure 1. Example of disaster area

Emergency goods, known as *object*, have their own *utility value*, which is a positive real number representing amount of demand it can fulfilled. In addition, object also has its own expire date. When times reach expire date, the object results in *expiration*, the state that utility value of an object becomes zero.

There is only one type of demand: *population-based demand*. As the name suggested, population-based demand for a node is subject to its number of population. Population-based demand is represented by a positive constant which indicates how much utility value a node needs per day. Before the distributor begins the distribution, each node might already have had demand called *initial demand*. When a node receives object, its cumulative received utility value will increase by utility value of that object. Note that it is possible that cumulative received utility value is more than cumulative demand.

When you assign destination to objects already, you have to decide how to pack those objects into transportation vehicles. These are information involve.

- There is infinite number of identical transportation vehicles with infinite maximum load capacity.
- Each transportation vehicle belongs to its specific edge. When you reach another node, you have to switch transportation vehicle.
- The transportation routes are edges in a shortest path tree rooted at the distribution center.

ESTABLISHING THE SIMPLIFIED MODEL

A. Variables Description

T is the ending time of disaster; G is the graph represent disaster area; $V(G)$ is the set of nodes in graph G; $t_G(i,j,u)$ is the arrival time at node u of j^{th} object which received at time i in graph G. Note that weight on edge represents time required to travel on that edge.

z_u is the initial demand of node u; r_u is the population-based demand of node u; $L_u(t)$ is the cumulative population-based demand of node u over time interval $[1,t]$ which can be calculated by $r_u t + z_u$; $X_u(t)$ is the cumulative received utility value of node u over time interval $[1,t]$. Since there is only one type of demand, $D_u(t)$, the cumulative demand of node u over time interval $[1,t]$ is equal to $L_u(t)$ i.e. $D_u(t) = L_u(t)$; $\forall t \in \mathrm{D}_{L_u}$

$R_u(t)$ is the ratio between cumulative fulfilled demand and cumulative demand of node u over time interval $[1,t]$ which can be calculated by $\min\left(1, \frac{X_u(t)}{D_u(t)}\right)$. Note that the ratio is less than 1 if the cumulative received utility value cannot fulfill the cumulative demand at this node. It can be greater than 1 if the cumulative received utility value exceeds the cumulative demand.

N_i is the number of received objects at time i for all $i = 1,2,\dots,T$; $b_{t,i}$ is the utility value of i^{th} object received at time t; $d_{t,i}$ is the expire date of i^{th} object received at time t. When you receive input at time t, you receive only N_t, $b_{t,i}$, and $d_{t,i}$ for all $i = 1,2,\dots,N_t$.

B. Objective Function

The efficiency of distribution strategy is measure by equality of the strategy. In this research, equality means every node has equal ratio between its cumulative fulfilled demand and its cumulative demand:

$$R_1(t) = R_2(t) = \cdots = R_{|V(G)|}(t)$$

If the distributor does not have enough objects to fulfill all demand of every node, then each node should receive objects subject to its demand. Node with more unfulfilled demand should receive more objects; node with less unfulfilled demand should receive less objects. To achieve the desired equality, I need to measure the variation between the ratio of each nodes.

One of the statistics used to quantify the amount of variation of a set of data, standard deviation (S.D.), is applied to formulate the loss function.

$$S.D. = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n}}$$

From the standard deviation formula, minimal value of this function occurs when all data have the same value, arithmetic mean. This is the reason why loss function of the model is formulated from S.D. formula according to definition of equality above. Since $\sum_{i=1}^{n}(x_i - \bar{x})^2$ and $\frac{1}{n}$ are guaranteed to be non-negative real number, square root and $\frac{1}{n}$ can be removed without affecting the S.D. minimal value. Thus, the formula can be simplified as follows:

$$\min\left(\sqrt{\frac{\sum_{i=1}^{n}(x_i-\bar{x})^2}{n}}\right)\Rightarrow\min\left(\sum_{i=1}^{n}(x_i-\bar{x})^2\right)$$

Based on the above simplified S.D. formula, loss function of the model at time t which denoted by $p(t)$ can be calculated by

$$p(t)=\sum_{u\in V(G)}\left(R_u(t)-\frac{1}{|V(G)|}\sum_{u\in V(G)}R_u(t)\right)^2$$

Since the distribution last for T days, the objective function for equality emergency goods distribution is defined by arithmetic mean of loss function of the model over time interval $[1,T]$.

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

SOLVING METHOD BASED ON GENETIC ALGORITHM

A. Graph Pre-Processing

Let G be the graph represent disaster area. A shortest-path tree rooted at distributor of graph G denoted by $T(G)$ was constructed through Dijkstra's algorithm [4] as shown in Fig. 2.

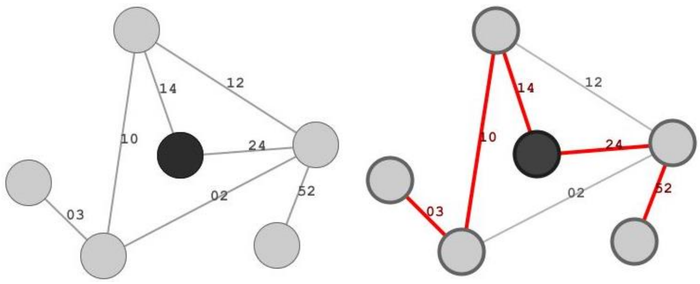

Figure 2. Example of G and $T(G)$

According to the problem description, transportation vehicle belongs to specific edge, thus all nodes except leaves can be treated as virtual distributor since it has authority to distribute and pack objects. Since the algorithm used to distribute objects from node in i^{th} level to $(i+1)^{th}$ level is the same, $T(G)$ can be simplified to the tree that all nodes have direct edge to the distributor. Therefore, I only designed an algorithm considering the tree that all nodes have direct edge to the distributor and apply that same algorithm for all virtual distributors.

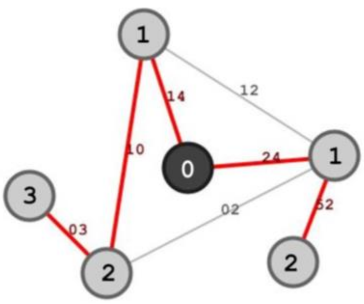

Figure 3. Level of node in $T(G)$

B. Chromosome Encoding System

One dimension integer vector is applied to represent chromosome. The solution of distribution strategy at time t is represented by a chromosome with length $L_{\mathrm{t}} = \sum_{i=1}^{t} N_i$ i.e. $\bar{\chi} = \{\bar{\chi}_{1,1}, \bar{\chi}_{1,2}, \dots, \bar{\chi}_{t,L_t}\}$. Note that $\bar{\chi}_{i,j}$ represents destination of j^{th} object received at time i. For example, $t = 1$ and $N_1 = 4$, the chromosome is $\{3,1,3,0\}$. The encoding of chromosome denotes that the first, second, third, and fourth object at time $t = 1$ is sent to node index 3, 1, 3, and 0, respectively.

In this genetic algorithm, length of chromosome varies over time. Length of chromosomes at time t is the same, $\sum_{i=1}^{t} N_i$. Note that the length of chromosomes at time t is not the same as the length of chromosomes at time $t' \neq t$. Therefore, an additional step is needed in order to generate new chromosomes for time $t + 1$ based on chromosomes that survive at time t.

C. Implementation steps of Genetic Algorithm

The detail implementation of genetic algorithm for the equality distribution emergency goods model is designed as follows.

```
(1) Initial Parameters Determination
FOR t in range [1,T]
     IF t = 1 THEN (2) Population Initialization
     ELSE (8) Population Re-Initialization
     WHILE (7) Not terminate
          (3) Fitness Value Calculation
          (4) Parent Selection
          (5) Crossing over with probability Pc
          (6) Mutation with probability Pm
     Best Candidate Selection
```

Figure 4. Pseudo code of Genetic Algorithm

Step 1: Initial Parameters Determination

- Determine the number of initial population denoted by NP
- Determine the number of duplicated chromosome denoted by DP
- Determine the maximum evolutionary generation denoted by $G_{\max}$
- Determine the maximum non-improved evolutionary generation denoted by $G'_{\max}$
- Determine the crossing over probability denoted by P_c
- Determine the mutation probability denoted by P_m

Step 2: Population Initialization

Note that this step is performed when $t = 1$ only. Based on the chromosome encoding system described above, NP chromosomes with length N_1 are generated by random number generator under constraint $0 \leq \bar{\chi}_{1,i} < |V(G)|$ for $i = 1,2, \dots, N_1$.

Step 3: Fitness value Calculation

The fitness function is negative value of the objective function.

$$\text{Fitness}(\bar{\chi}) = -\frac{1}{T}\sum_{t=1}^{T} p(t)$$

The fitness function can be represented in chromosome-based form as follows. Let set $S_k = \{(i,j) | \bar{\chi}_{i,j} = k \text{ and } t_{T(G)}(i,j,\bar{\chi}_{i,j}) \leq T \text{ and } t_{T(G)}(i,j,\bar{\chi}_{i,j}) \leq d_{i,j}\}$ for $k = 0,1,\ldots,|V(G)|-1$. Note that $t_G(i,j,u)$ is the arrival time at node u of j^{th} object received at time i in graph G.

If $t_{T(G)}(i,j,\bar{\chi}_{i,j}) > T$, then it implies that the arrival time of this object is after the ending time of incident, T. That means this object can be ignored in the calculation of the objective function in time interval $[1,T]$. If $t_{T(G)}(i,j,\bar{\chi}_{i,j}) > d_{i,j}$, it implies that arrival time of this object is after its expire date. Note that expiration is the state that utility value of an object has become zero, occurs when time reach expire date. Since the utility value of this object is guaranteed to be zero when it arrives, I can just simply ignore this object.

Then, all elements in set S_k are sorted in increasing order of 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 objects transportation. Therefore, I only need to update the utility value each time an object arrive at the node. This observation can be used to simplify the calculation of $R_u(t)$ as follows.

Let $S_{k,i,j}$ be j^{th} element of i^{th} pair in set S_k.

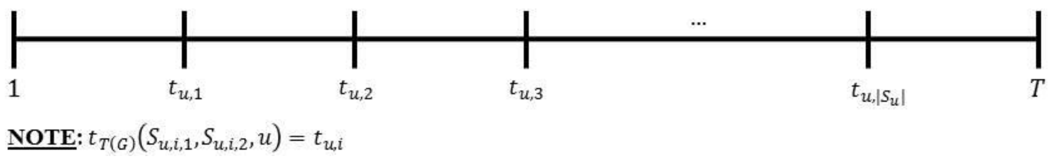

Figure 5. Line number of arrival time of objects in node u

From the figure above, the analysis can be explained as below.

(1) $\forall t \in [1, t_{u,1})$, $X_u(t) = 0$; $R_u(t) = 0$

(2) $\forall t \in [t_{u,1}, t_{u,2})$, $X_u(t) = b_{S_{u,1,1},S_{u,1,2}}$; $R_u(t) = \min\left(1, \frac{b_{S_{u,1,1},S_{u,1,2}}}{D_u(t)}\right)$

(3) $\forall t \in [t_{u,2}, t_{u,3})$, $X_u(t) = b_{S_{u,1,1},S_{u,1,2}} + b_{S_{u,2,1},S_{u,2,2}}$; $R_u(t) = \min\left(1, \frac{b_{S_{u,1,1},S_{u,1,2}} + b_{S_{u,2,1},S_{u,2,2}}}{D_u(t)}\right)$

From (2) and (3), it can be implied that $\forall t \in [t_{u,i-1}, t_{u,i})$; $\exists i \in [2, |S_u|]$, $X_u(t) = \sum_{j=1}^{i-1} b_{S_{u,j,1},S_{u,j,2}}$; $R_u(t) = \min\left(1, \frac{1}{D_u(t)} \sum_{j=1}^{i-1} b_{S_{u,j,1},S_{u,j,2}}\right)$

(4) $\forall t \in [t_{u,|S_u|}, T]$, $X_u(t) = \sum_{j=1}^{|S_u|} b_{S_{u,j,1},S_{u,j,2}}$; $R_u(t) = \min\left(1, \frac{1}{D_u(t)} \sum_{j=1}^{|S_u|} b_{S_{u,j,1},S_{u,j,2}}\right)$

From above analysis, $R_u(t)$ can be calculated by

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

Step 4-6: Genetic Operators Implementation

Tournament selection is applied to select parents. The operator choose k individual from the population uniformly random, and sort them by their fitness value in descending order. i^{th} individual has probability to be chose $p(1-p)^{i-1}$.

According to crossing over probability P_c, uniform crossover strategy with mixing ratio R_m is applied to implement crossover operator. According to crossing over probability P_m, random resetting strategy is applied to regenerate some genes under constraint $0 \leq \bar{\chi}_{i,j} < |V(G)|$.

Step 7: Termination Criteria

Genetic algorithm will stop when one of following criteria is met:

- Current evolutionary generation $g > G_{max}$
- Non-improved evolutionary generation $g' > G'_{max}$
- Chromosome with zero fitness value has been found i.e. $\text{Fitness}(\bar{\chi}) = 0$

Step 8: Population Re-Initialization

The objective of population re-initialization is two-fold. First, I need to encode new distribution strategy for the received objects. This is why the length of the chromosomes at time t is longer than that at time $t-1$. However, 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 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 current population. This decreases probability that good chromosome turns into bad chromosome through the addition of some new genes. Then, each chromosome will be added by N_t new genes which are generated by random number generator under constraint $0 \leq \bar{\chi}_{t,i} < |V(G)|$ for $i = 1,2,\dots,N_t$. Finally, select NP chromosomes from $NP(DP+1)$ chromosomes in population by tournament selection.

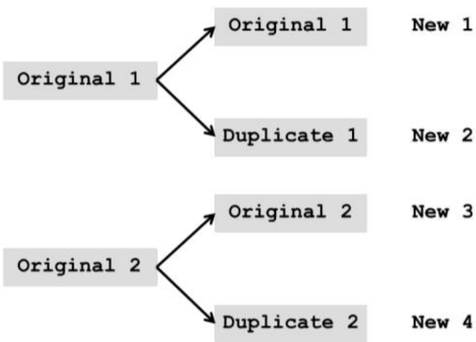

Figure 6. Example when $NP = 2$ and $DP = 1$

MODEL ADJUSTMENTS

In this section, I will discuss some improvements of the model and how to modify the algorithm to handle those improvements.

A. Dynamic Graph

During the incident, there might be some situations which affect structure of disaster areas. The following are examples of possible situations.

- The disaster area expanded, result in *node insertion*.

The proposed algorithm can be modified to handle with node insertion as follows. For all chromosomes $\bar{\chi}$ in population, generate chromosome $\bar{\chi}'$ from $\bar{\chi}$ by modify exactly one gene i.e. $\bar{\chi}'_{i,j} = u'$ where u' is the index of inserted node. If chromosome $\bar{\chi}'$ has fitness value more than chromosome $\bar{\chi}$, replace $\bar{\chi}$ by $\bar{\chi}'$.

- The disaster area shrieked, result in *node deletion*.

The proposed algorithm can be modified to handle with node deletion as follows. Apply random resetting strategy to all genes which $\bar{\chi}_{i,j} = u$ where u is the index of deleted node.

- Government decided to create new transportation route, result in *edge insertion*.

To deal with edge insertion, I can use existing algorithm [3] to maintain shortest path tree rooted at distributor. Then, I change transportation route of all transportation vehicles which will be sent in the future.

- Some transportation route was destroyed during the incident, result in *edge deletion*.

Let $e = (u, v, w)$ represent edge e which connect to node u and v with weight w and $e_d(u, v, l)$ represent edge deletion operator which is performed on point on edge that is connected to node u and v such that weight from that point to node u is l.

Create dummy nodes λ_1 and λ_2 such that $R_{\lambda_1}(t) = R_{\lambda_2}(t) = \frac{1}{|V(G)|}\sum_{u \in V(G)} R_u(t)$; $\forall t \in [1, T]$. Then, maintain shortest path tree rooted at distributor by using algorithm discussed in edge insertion operator. Note that transportation vehicle which is located exactly at weight l from node u will be at dummy node λ_1.

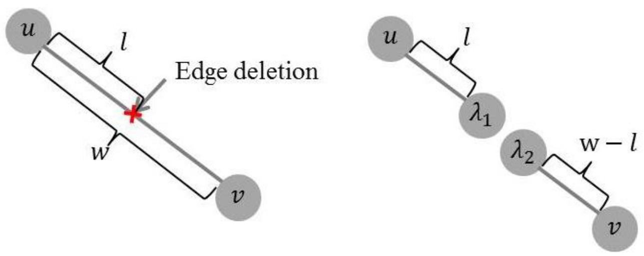

Figure 7. Dummy nodes insertion

- Time used to travel on edge increased/decreased, result in *weight modification*.

To deal with weight modification, I can use existing algorithm discussed in edge insertion operator to maintain shortest path tree rooted at distributor. Then, I change transportation route of all transportation vehicles which will be sent in the future.

- The distribution center was damaged during the incident; result in location change of distribution center called *distributor update*.

In case that the distributor update operator is performed, I just have to re-calculate shortest path tree rooted at the new distributor and change transportation route of all transportation vehicles which will be sent in the future.

B. Dynamic Population-Based Demand

Since the severity of disaster varies over time, constant population-based demand is way too ideal to handle in real situation. Thus, the formula to calculate cumulative population-based demand is re-formulated to handle this kind of update.

Let $L_u^{(k)}(t)$ be cumulative population-based demand of node u at time t such that population-based demand of node u has been updated k times; C_u is the number of demand update that node u has been performed; T_k is time that population-based demand of node u has been updated k^{th} times. Note that $T_0 = 1$ and $T_{C_u+1} = T + 1$.

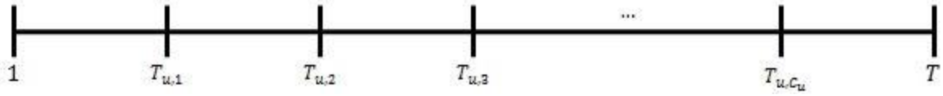

Figure 8. Line number of updated time of population-based demand of node u

From the figure above, the analysis can be explained as below.

(1) $\forall t \in [1, T_{u,1}),\ L_u^{(0)}(t) = r_{u,0}t + z_u$

(2) $\forall t \in [T_{u,1}, T_{u,2}),\quad L_u^{(1)}(t) = r_{u,1}\big(\max(0, t - T_{u,1} + 1)\big) + r_{u,0}\big(\max(0, \min(t, T_{u,1}) - T_{u,0}\big) + z_u$

(3) $\forall t \in [T_{u,2}, T_{u,3}),\quad L_u^{(1)}(t) = r_{u,2}\big(\max(0, t - T_{u,2} + 1)\big) + r_{u,1}\big(\max(0, \min(t, T_{u,2}) - T_{u,1}\big) + r_{u,0}\big(\max(0, \min(t, T_{u,1}) - T_{u,0}\big) + z_u$

From (1), (2) and (3), it can be implied that $\forall t \in [T_{u,k}, T_{u,k+1});\ \exists k \in [0, C_u],\ L_u^{(k)}(t) = r_{u,k}\big(\max(0, t - T_{u,k} + 1)\big) + \sum_{j=1}^{k} r_{u,j-1}\big(\max(0, \min(t, T_{u,j}) - T_{u,j-1})\big) + z_u$

From above analysis, $L_u^{(k)}(t)$ can be calculated by

$$L_u^{(k)}(t) = r_{u,k}\big(\max(0, t - T_{u,k} + 1)\big) + \sum_{j=1}^{k} r_{u,j-1}\big(\max(0, \min(t, T_{u,j}) - T_{u,j-1})\big) + z_u$$

C. Transportation Cost

In reality, you are given a finite amount of money for distribution. Therefore, this topic is introduced to find a distribution strategy under finite transportation cost.

Φ is amount of money you have; $c(t)$ is transportation cost at time t. The objective function is established as follows.

$$\text{minimize } f = \frac{1}{T}\sum_{t=1}^{T} p(t) + C$$

where

$$C = \begin{cases} \lambda \log\left(\dfrac{\Phi}{\Phi - \sum_{t=1}^{T} c(t)}\right) & \text{if} \quad \Phi > \displaystyle\sum_{t=1}^{T} c(t) \\ \infty & \text{if} \quad \Phi \leq \displaystyle\sum_{t=1}^{T} c(t) \end{cases}$$

Note that in order to calculate fitness value, $c(t)$ must be formulated chromosome-based form.

EXPERIMENT

A. Test data Construction

In order to perform an experiment on designed algorithm, I need actual incident information. Unfortunately, I cannot find information I needed, therefore I decided to generate it myself. Detail of algorithm for generate test data can be described as below.

Name	Symbol	Description
DAY_LIMIT	DL	maximum expire date of object
EDGE_LIMIT	EL	maximum weight of edges in graph
NODE_LIMIT	NL	maximum number of nodes in graph
NUM_OBJ_LIMIT	NOL	maximum number of received object per day
RATE_LIMIT	RL	maximum initial/population-based demand of node
TIME_LIMIT	TL	maximum ending time of disaster
UTIL_LIMIT	UL	maximum utility value of object

Table 1. Constants used for construct test data

```
T = random integer in range [1,TL]
|V(G)| = random integer in range [1,NL]
FOR u in range [0,|V(G)|)
     z_u = random real number in range [0,RL]
     r_u = random real number in range [0,RL]
|E(G)| = random integer in range [|V(G)|-1,C(|V(G)|,2)]
FOR i in range [1,|E(G)|]
     u_i = random integer in range [0,|V(G)|)
     v_i = random integer in range [0,|V(G)|)
     w_i = random integer in range [1,EL]
FOR t in range [1,T]
     N_t = random integer in range [0,NOL]
     FOR i in range [1,N_t]
          b_t,i = random real number in range [1,UL]
          d_t,i = random integer in range [1,DL]
```

Figure 9. Pseudo code of algorithm for construct test data

B. Pretesting

Before the genetic algorithm is designed, pretesting is conducted to reassure that genetic algorithm is suitable to optimize parameters of the model. Test data used in pretesting are generated under following constrains: $TL \leq 1$, $NL^{NOL} \leq 10^9$, and generated graph is random graph. Initial parameters used in pretesting are described below.

Variable	**Value**
NP	$10N_1$
G_{max}	500
G'_{max}	100
P_c	0.50
P_m	0.20
R_m	0.50

Table 2. Initial parameters used in pretesting

The result from genetic algorithm compared with brute force algorithm is shown here.

Interval of Error	**Number of test data**	**Percentage of test data**
[0,1)	9875	98.75
[1,2)	78	0.78
[2,3)	25	0.25
[3,4)	12	0.12
[4,5)	4	0.04
[5,6)	4	0.04
[6,7)	1	0.01
[7,8)	0	0.00
[8,9)	0	0.00
[9,10)	1	0.01
[10,INF)	0	0.00
Total	10000	100

Table 3. Result of pretesting

Note that errors shown in result below are percentage error (δ) which are calculated by

$$\delta = \left|\frac{v - v_{\text{approx}}}{v}\right| \times 100\%$$

where v and v_{approx} is minimum value of objective function calculated by brute force algorithm and genetic algorithm, respectively.

RESEARCH CONTRIBUTIONS

- The optimization model can be used in emergency goods distribution over finite-time interval in future disasters.
- The dynamic length chromosome encoding system proposed can be used in the successive optimization problems.
- The population re-initialization step proposed in this research can be used GA to deal with successive optimization problems.

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