Emergency Goods Distribution Model over Finite Time Interval using Genetic Algorithm

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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.
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

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.

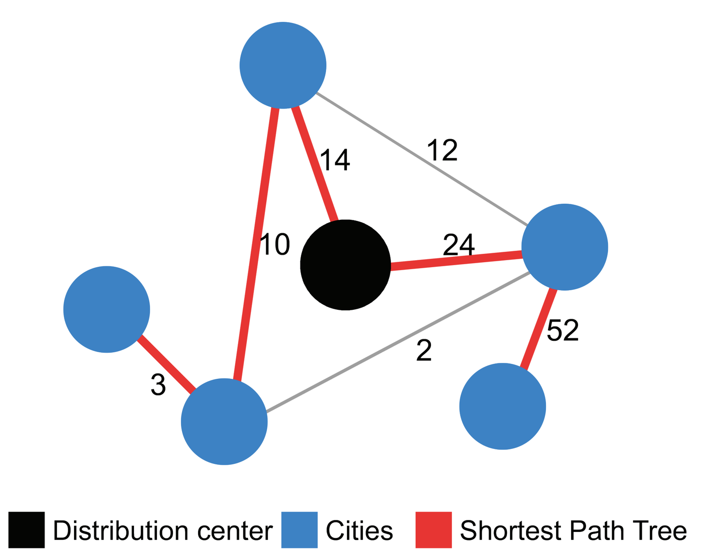

Fig. 1 Example of graph which represented disaster area

Demand

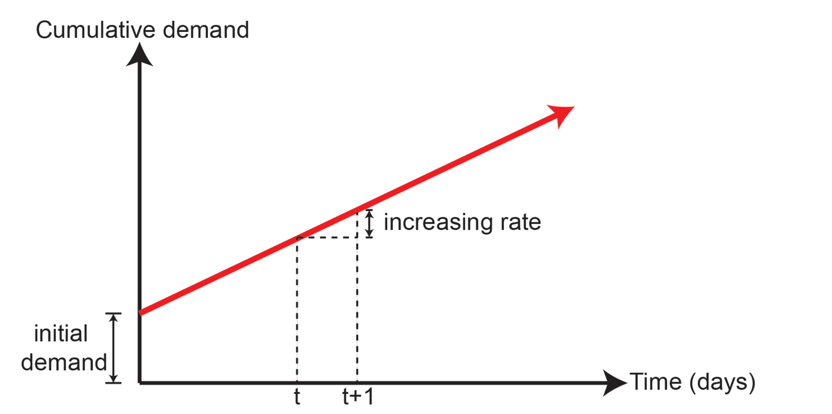

Fig. 2 Graph represents the cumulative demand of a node

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.

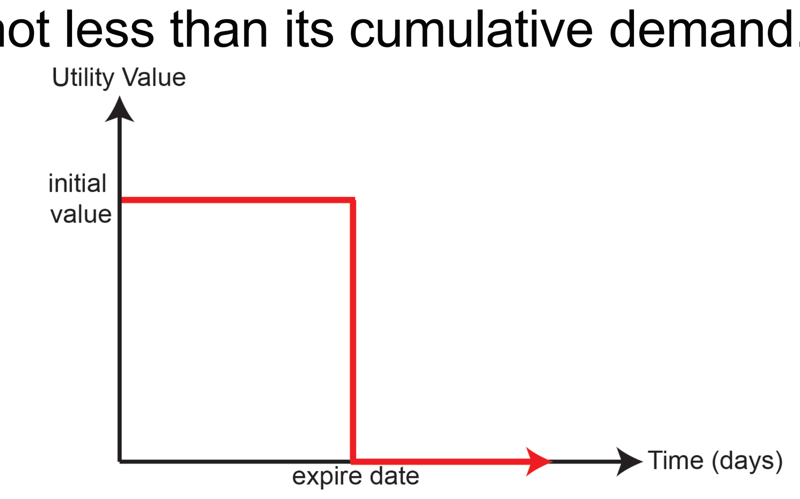

Fig. 3 Graph represents utility value of an emergency goods

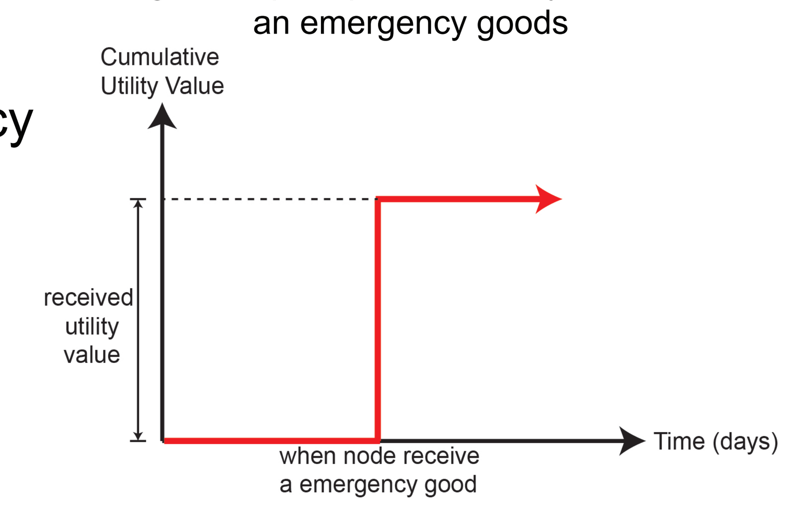

Fig. 4 Graph represents utility value of an emergency goods

Assumption

There are 5 further 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 in the future.
- Transported emergency goods can be reassigned to appropriate destination.
- There are infinite amount of money and infinite identical transportation vehicles with infinite maximum load capacity.

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
- $b_{t,i}$ 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 demand of node u
- $t_u(i,j)$ 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
- $D_u(t) = r_u t + z_u$ 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 $[1,t]$

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.

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

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

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

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

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

Genetic Algorithm

Dynamic Length Chromosome Encoding System

The objective of population re-initialization are twofold. First, I need to encode new distribution strategy for the received objects. 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 higher chance of being good now.

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

Fig. 5 General chromosome in dynamic length chromosome encoding system

Population Re-Initialization

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 $0 \le \bar{x}_{t,i} < |V(G)|$ for $i = 1,2,\dots,N_t$. Finally, select NP chromosomes from $NP(DP+1)$ chromosomes in population by tournament selection.

Fitness Function

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

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

Experiment

There are 500 simulated data used to study behavior of algorithm on specific scenarios. GA is applied to distribute emergency goods by using specific initial parameters.

Discussion

- If $\sum_{k=1}^{t}\left(\sum_{i=1}^{N_k} b_{k,i}\right) < \sum_{u\in V(G)} D_u(t)$, nodes with demand more than average tend to receive more emergency goods than less ones.
- If there are < 10% nodes s.t. $\sum_{(x,y)\in \overline{su}} w(x,y) \ge \frac{2}{|V(G)|}\sum_{u\in V(G)}\left(\sum_{(x,y)\in\overline{su}} w(x,y)\right)$, the distribution center tends to send emergency goods to them first to deal with transportation duration.
- If there are < 10% nodes s.t. $D_u(t) \ge 5\sum_{u\in V(G)} D_u(t)$ and $\sum_{k=1}^{t}\left(\sum_{i=1}^{N_k} b_{k,i}\right) < \sum_{u\in V(G)} D_u(t)$, the distribution center tends to ignore them.

Reference

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