A Transport Resource Planning Model for Synchronizing Relief Flows at a Relief Hub for Minimizing Non-Food Relief Inventory

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Generally relief inventory models assume uniform or normally distributed demand pattern and unbounded planning horizon. This study formulates a relief inventory model for a limited relief operation duration. A large stock of relief items in a warehouse is not economical and causes shortage in other affected areas. Therefore inventory replenishment strategy is proposed for trapezoid type of demand distributions by changing parameter values. It is found that the system costs for all parameter values are stable. The order quantity in each replenishment cycle varies and has a certain pattern. A sensitivity analysis for several parameters are also presented.

Key words: *Disaster logistics; Trapezoid relief demand; Inventory; Relief*

1. INTRODUCTION

A product's demand is inversely proportional to its price. In a market economy, if a product's price is higher, its demand is lower. Disaster victims receive relief goods free of cost and, therefore market economics in disaster logistics is absent. However, relief goods are distributed for alleviating the disaster victims' suffering. Disaster logistics manager similar as commercial logistics manager also needs an inventory plan for effective utilization of relief items.

If a large amount of the relief items are stocked in a single location, it will increase the holding cost and cause shortage in other locations. In a single-order policy, the relief items required for an inventory cycle are collected once at the beginning of a relief operations-period. However, relief items may be required at the later part of the relief operation. On the other hand, a multi-order policy may decrease holding cost because the policy encourages the timely use of relief items, resulting in a lower holding cost.

Relief demand characteristics are not well explored in literature. Disaster survivors need several types of relief items. After a disaster occurs, demand for aid supplies will likely change over time (Balcik and Beamon, 2008). Demands for some relief items are high in the aftermath of a disaster and decrease gradually. Two figures are illustrated below to explain the relief demand properties. Fig. **1** and Fig. 2 are depicted based on the relief delivery to all shelters in Aoba ward, Sendai Japan after the 2011 great east Japan earthquake. Sendai ward office, Japan distributed the relief items among different shelters. Aoba ward is one of the wards under the jurisdiction of Sendai. Each dot in the figures represents an event of delivery of relief items, not the delivered quantity of relief items. Data for initial four days were not available. **Fig. 1** illustrates rice delivery to different shelters. As Sendai ward office did not face shortage of rice and water, we assume supply and demand of rice and water in Sendai region was similar. The demand for rice decreases gradually (as shown in **Fig. 1**). On the other hand trapezoidal demand trend is observed for water as shown Fig. 2. As relief demand is time sensitive, a logistics manager requires to prepare the warehouse facility and transport capacity for supporting time dependent demand.

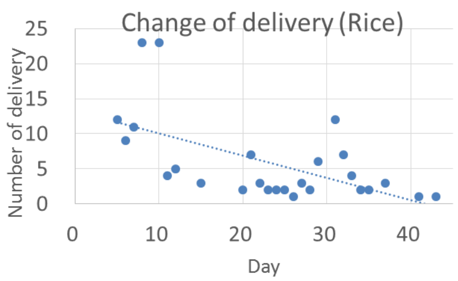

Fig. 1 Linear decreasing of rice demand after the 2011 great east Japan earthquake (based on author's survey in Aoba ward)

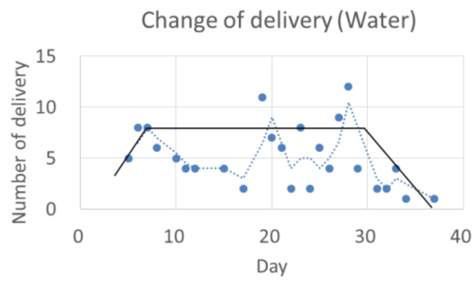

Fig. 2 Trapezoidal trend of water demand after the 2011 great east Japan earthquake (based on author's survey Aoba ward)

Due to time stake nature, a disaster logistics manager confronts difficulties in collecting relief demand information. We aim to propose a mathematical model for inventory management to meet target demand. Our model will be implemented in pre-disaster situation pursuing a push-logistical strategy. This model assumes that a secondary hub (SH) is responsible for collecting relief goods and delivering the collected relief goods to a local distribution center. This model assume that relief demand will become zero after a certain period. The system is designed for no shortage of relief goods. The relief operation period is fixed and the operation will be terminated after the planning horizon.

The contributions of this research are as follows

1. Traditional inventory models consider an unbounded planning horizon. This condition is not applicable to the relief inventory model, as the relief operation takes place over a certain period. Therefore, we propose a model for a finite horizon.
2. The relief operation will end when the relief demand becomes zero. The relief demand may show a continuous decreasing trend or may show a trapezoidal demand trend. This study considers both types of relief demand.

The remainder of the paper is structured as follows. Section 2 presents mathematical notations and the assumptions of the proposed model. Section 3 includes several sub-sections that explain the proposed model, and explains a solution algorithm. Section 5 reports the results of numerical analyses that use the proposed model. Finally, Section 6 presents the conclusions of this study and a summary of the study results.

2. ASSUMPTION AND DEFINITION

The relief operation period is separated into several cycles. The length of the cycle and other operation properties are required to be planned before a disaster. A cycle starts at period j and ends at period k.

1. The system operates for a prescribed H units of time (planning horizon). At time $t = 0$ and $t = H$, the inventory level is zero.
2. The lead time is constant.
3. Shortages are not allowed in any cycle.
4. At every replenishment, a variable lot size q_i is ordered so as to meet demand in the target cycle length.

In this system, we consider two types of costs: holding cost and replenishment costs. Holding costs have a tradeoff relationship with replenishment costs. The replenishment cost G_i for the i-th cycle (i = 1,2,..m) is partly constant and partly dependent on the lot size during that cycle and is of the following form:

$$G_i = A_0 + C_0 q_i \qquad (1)$$

The relief items that arrive at time j will satisfy the demand until time k. Therefore, the i-th cycle starts at period j_i and ends at period k_i.

The following notations have been used:

Input parameter

f(t) : Demand function. Here, a_1,b_1,a_2,b_2, μ_1, and μ_2 are given.

μ_1 : Start point of constant demand rate in trapezoidal demand trend

μ_2 : End point of constant demand rate in trapezoidal demand trend

H : Planning horizon (day)

h_1 : Holding cost ($/unit-day)

A_0 : Fixed cost ($)

C_0 : Operational cost($/unit)

Explanatory items

n_i : Cycles during increasing demand rate in trapezoidal demand trend in multi-order strategy

c1i : Cycle combination with increasing demand rate and constant demand rate in trapezoidal demand trend in multi-order strategy

L_i : Cycles during constant demand rate in trapezoidal demand trend in multi-order strategy

c2i : Cycle combination with constant demand rate and declining demand rate in trapezoidal demand trend in multi-order strategy

d_i : Cycles during decreasing demand rate in trapezoidal demand trend in multi-order strategy

1s : Section during increasing demand rate in trapezoidal demand trend in one-order strategy

2s : Section during constant demand rate in trapezoidal demand trend in one-order strategy

3s : Section during decreasing demand rate in trapezoidal demand trend in one-order strategy

S_m : Starting point of the replenishment cycle number m

E_m : End point of the replenishment cycle number m

γ : Ratio of horizontal section and planning horizon($\frac{\mu_2}{H}$)

β : Ratio of holding cost and lot size dependent part of operational cost ($\frac{h_1}{C_0}$)

Output variable

$I_i(t)$: Inventory level at time t in cycle i

R_i : Holding cost of cycle i

G_i : Replenishment cost in cycle i. It has two components. One is fixed and another is dependent on lot size

D_0 : Constant demand rate of trapezoidal demand trend in between μ_1 and μ_2

j_i : Start time of cycle i

k_i : End time of cycle i

q_i : Order quantity in cycle i

m : Total number of cycle in a planning horizon

W(j,k) : Total cycle cost

TC_k : Total cost at time k

TC_j : Total cost at time j

TC_0 : Total cost at the beginning of relief operations

3. MODEL FOR DIFFERENT INVENTORY PATTERN

At $t = j_i$, the relief items arrive at the secondary hub. The stock level in the secondary hub decreases owing to demand and becomes zero at time $t = k_i$, when the next batch arrives. The cycle length is not fixed and is dependent on lot size. The entire cycle repeats m times during (0,H). Our problem is to determine the optimal values of lot size of each cycle (q_i) and replenishment time (j_i), which minimizes the total cost over the time horizon.

The demand rate f(t) at any instant is a linear function of t such that

$$\mathrm{f(t)} = \begin{cases} a_1 + b_1 t & when \quad t \le \mu_1 \\ D_0 & when \quad \mu_1 \le t \le \mu_2 \\ a_2 - b_2 t & when \quad \mu_2 \le t \le H \le \dfrac{a_2}{b_2} \end{cases} \qquad (2)$$

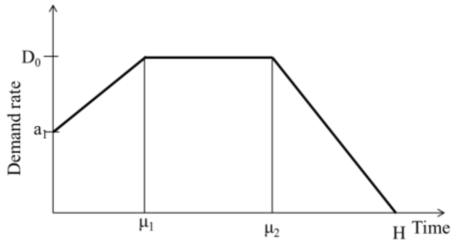

Fig. 3 The trapezoid demand trend

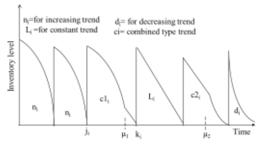

Fig. 4 Inventory trend (multi-order strategy)

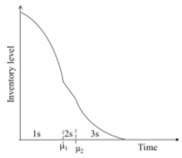

Fig. 5 Inventory trend(single-order strategy)

(1) Inventory model with multi-order strategy

As the demand type has a trapezoidal trend in the planning horizon (Fig. 3), the inventory trend becomes complex, as shown in Fig. 4 for multi-order strategy and in Fig. 5 for single-order strategy. It shows that some cycles start and end before μ_1. These cycles are named n_i. Again, one cycle may start before μ_1 and may end after μ_1. This cycle is named $c1_i$. If a cycle starts after μ_1 and ends before μ_2, it is named L_i. Again, one cycle may start before μ_2 and end after μ_2. This cycle is named C2i. If a cycle starts and ends after μ_2, it is known as d_i.

Now, the change of inventor level

$$\frac{\mathrm{d}I_i(t)}{\mathrm{dt}} = -(a_1 + b_1 t) \quad for\ n_i\ and\ t \le \mu_1 \qquad (3)$$

$$\frac{\mathrm{d}I_i(t)}{\mathrm{dt}} = -(a_1 + b_1 t)\ \ for\ c1_i\ and\ t \le \mu_1 \qquad (4)$$

$$\frac{\mathrm{d}I_i(t)}{\mathrm{dt}} = -D_0 \qquad for\ c1_i\ and\ t \ge \mu_1 \qquad \mathbf{(5)}$$

$$\frac{\mathrm{d}I_i(t)}{\mathrm{dt}} = -D_0 \quad for\ L_i\ and\ \ \mu_1 \le\ t \le \mu_2 \qquad \mathbf{(6)}$$

$$\frac{\mathrm{d}I_i(t)}{\mathrm{dt}} = -D_0 \quad for\ c2_i\ and\ \mu_1 \le t \le \mu_2 \tag{7}$$

$$\frac{\mathrm{d}I_i(t)}{\mathrm{dt}} = -(a_2 - b_2 t)\ for\ c2_i\ and\ \mu_2 \le t \tag{8}$$

$$\frac{\mathrm{d}I_i(t)}{\mathrm{dt}} = -(a_2 - b_2 t) \quad for\ d_i\ and\ \mu_2 \le t \tag{9}$$

Assume that the arrival of a relief item occurs at j and the inventory becomes zero at k.

Solving the differential equations from (3) to (9),

$for\ n_i$, $t \le \mu_1$

$$I_i(t) = \int_t^k (-a_1 - b_1 t) du \tag{10}$$

$$= a_1(k - t) + \frac{b_1}{2}(k^2 - t^2) \tag{11}$$

$for\ c1_i$, $t \le \mu_1$

$$I_i(t) = \int_t^{\mu_1} (-a_1 - b_1 t) du \tag{12}$$

$$= D_0 k - D_0 \mu_1 + a_1 \mu_1 + \frac{b_1}{2}\mu_1^2 - a_1 t - \frac{b_1}{2} t^2 \tag{13}$$

$for\ c1_i$, $t \ge \mu_1$

$$I_i(t) = -\int_t^k D_0 du \tag{14}$$

$$= D_0(k - t) \tag{15}$$

$for\ L_i$, $\mu_1 \le t \le \mu_2$

$$I_i(t) = -\int_t^k D_0 du \tag{16}$$

$$= D_0(k - t) \tag{17}$$

$for\ c2_i$, $\mu_1 \le t \le \mu_2$

$$I_i(t) = -\int_t^{\mu_2} D_0 du \tag{18}$$

$$= a_2(\mathrm{k} - \mu_2) - \frac{b_2}{2}(k^2 - \mu_2^2) + D_0(\mu_2 - t) \tag{19}$$

$for\ c2_i$, $\mu_2 \le t$

$$I_i(t) = -\int_{\mu_2}^t (a_2 - b_2 t)\, dt \tag{20}$$

$$= a_2(k - t) - \frac{b_2}{2}(k^2 - t^2) \tag{21}$$

$for\ d_i$, $\mu_2 \le t$

$$I_i(t) = -\int_t^k (a_2 - b_2 t)\, dt \tag{22}$$

$$= a_2(k - t) - \frac{b_2}{2}(k^2 - t^2) \tag{23}$$

The holding cost is computed for each cycle in the following manner

The holding cost for cycle type n_i

$$R_i = h_1 \int_j^k a_1(k - t) + \frac{b_1}{2}(k^2 - t^2)\, dt \tag{24}$$

$$= h_1\left(a_1\left(\frac{k^2}{2} + \frac{p^2}{2} - kp\right) + \frac{b_1}{2}\left(k^2(k - p) - \frac{k^3}{3} + \frac{p^3}{3}\right)\right) \tag{25}$$

The holding cost for cycle type $c1_i$

$$R_i = h_1 \int_j^{\mu_1}\left(D_0 k - D_0 \mu_1 + a_1 \mu_1 + \frac{b_1}{2}\mu_1^2 - a_1(\mu_1 - t) - \frac{b_1}{2}(\mu_1^2 - t^2)\right) dt + h_1 \int_{\mu_1}^k D_0(t - k) dt \tag{26}$$

$$= h_1\left(D_0 k(\mu_1 - j) - D_0 \mu_1(\mu_1 - j) + a_1 \mu_1(\mu_1 - j) + \frac{b_1}{2}\mu_1^2(\mu_1 - j) - a_1\left(\frac{\mu_1^2 - j^2}{2}\right) - \frac{b_1}{2}\left(\frac{\mu_1^3 - j^3}{3}\right) + D_0\left(\frac{\mu_1^2}{2} + \frac{k^2}{2} - k\mu_1\right)\right) \tag{27}$$

The holding cost for cycle type L_i

$$\mathrm{R}_i = \int_j^k D_0(k - t) dt \tag{28}$$

$$= h_1 D_0\left(\frac{j^2}{2} + \frac{k^2}{2} - kj\right) \tag{29}$$

The holding cost for cycle type $c2_i$

$$\mathrm{R}_i = \int_j^{\mu_2}\left(a_2(\mathrm{k} - \mu_2) + \frac{b_2}{2}(k^2 - \mu_2^2) - D_0(\mu_2 - t)\right) dt + \int_{\mu_2}^k\left(D_0(\mu_2 - j) + a_2(j - \mu_2) - \frac{b_2}{2}(j^2 - \mu_2^2) - a_2(t - \mu_2) + \frac{b_2}{2}(t^2 - \mu_2^2)\right) dt \tag{30}$$

$$= h_1\left(a_2(\mathrm{k} - \mu_2)(\mu_2 - \mathrm{j}) - \frac{b_2}{2}(k^2 - \mu_2^2)(\mu_2 - \mathrm{j}) + D_0\left(\frac{\mu_2^2 + j^2}{2} - \mu_2 j\right) + a_2\left(\frac{\mu_2^2}{2} - \frac{k\mu_2}{2}\right) - \frac{b_2}{2}\left(\frac{\mu_2^3}{3} - \frac{k^2\mu_2}{3}\right)\right) \tag{31}$$

The holding cost for cycle type d_i

$$R_i = \int_j^k\left(a_2(k - t) - \frac{b_2}{2}(k^2 - t^2)\right) dt \tag{32}$$

$$= h_1\left(a_2\left(\frac{k^2 + j^2}{2} - kj\right) - \frac{b_2}{2}\left(\frac{2k^3 + j^3}{3} - k^2 j\right)\right) \tag{33}$$

(1) Model For Single-Order Strategy

The inventory trend for one-order cycle strategy is shown Fig. 5. The inventory curve is divided into three sections named 1s, 2s and 3s on the basis of its gradient. Now, the change of inventor level

$$for\ \ 1s\ and\ t \le \mu_1 \quad \frac{\mathrm{d}I_i(t)}{\mathrm{dt}} = -(a_1 + b_1 t) \tag{34}$$

$$2s; \mu_2 \ge t \ge \mu_1 \quad \frac{\mathrm{d}I_i(t)}{\mathrm{dt}} = -D_0 \tag{35}$$

$$for\ 3s\ ;\ \ \mu_2 \le\ t \quad \frac{\mathrm{d}I_i(t)}{\mathrm{dt}} = -(a_2 - b_2 t) \tag{36}$$

Assume that the relief items arrive at the beginning of the planning horizon and the inventory becomes zero at the end of the planning horizon (H)

for cycle type 1s

$$I_i(t) = \int_t^{\mu_1} (-a_1 - b_1 t) du \tag{37}$$

$$= a_2(\mathrm{H} - \mu_2) - \frac{b_2}{2}(H^2 - \mu_2^2) + D_0(\mu_2 - \mu_1) + a_1(\mu_1 - t) + \frac{b_1}{2}(\mu_1^2 - t^2) \tag{38}$$

for cycle type 2s

$$I_i(t) = -\int_t^{\mu_2} D_0 du \tag{39}$$

$$= a_2(\mathrm{H} - \mu_2) - \frac{b_2}{2}(H^2 - \mu_2^2) + D_0\mu_2 - D_0 t \tag{40}$$

For cycle type 3s

$$\mathrm{I(t)} = \int_t^{H} (a_2 - b_2 t) dt \tag{41}$$

$$= a_2(\mathrm{H} - \mathrm{t}) - \frac{b_2}{2}(H^2 - t^2) \tag{42}$$

The holding cost in the cycle

$$\mathrm{R}_i = \int_0^{\mu_1} \left(a_2(\mathrm{H} - \mu_2) - \frac{b_2}{2}(H^2 - \mu_2^2) + D_0(\mu_2 - \mu_1) + a_1(\mu_1 - t) + \frac{b_1}{2}(\mu_1^2 - t^2)\right) dt + \int_{\mu_1}^{\mu_2} \left(a_2(\mathrm{H} - \mu_2) - \frac{b_2}{2}(H^2 - \mu_2^2) + D_0(\mu_2 - t)\right) dt + \int_{\mu_2}^{H} (a_2(\mathrm{H} - \mathrm{t}) - \frac{b_2}{2}(H^2 - t^2)) dt \tag{43}$$

$$= a_2(\mathrm{H} - \mu_2)\mu_1 - \frac{b_2}{2}(H^2 - \mu_2^2)\mu_1 + D_0(\mu_2 - \mu_1)\mu_1 + \frac{1}{2}(a_1\mu_1^2) + \frac{b_1\mu_1^3}{3} + a_2(\mathrm{H} - \mu_2)(\mu_2 - \mu_1) - \frac{b_2}{2}(H^2 - \mu_2^2)(\mu_2 - \mu_1) + D_0\left(\mu_2(\mu_2 - \mu_1) - \frac{1}{2}(\mu_2^2 - \mu_1^2)\right) + a_2\left(\mathrm{H}(\mathrm{H} - \mu_2) - \frac{1}{2}(H^2 - \mu_2^2)\right) - \frac{b_2}{2}\left(H^2(\mathrm{H} - \mu_2) - \frac{1}{3}(H^3 - \mu_2^3)\right) \tag{44}$$

(2)Total Cycle Cost

The total cycle cost consists of replenishment cost and holding cost. Therefore the total cycle cost is

$$\mathrm{W(j,k)} = A_0 + C_0 q_i + h_1 R_i \tag{45}$$

The cycle cost depends on the replenishment time and cycle length. Therefore, we differentiate eq. (45) with respect to j

$$\frac{\partial \mathrm{W(j,k)}}{\partial \mathrm{j}} = 0 \tag{46}$$

As obtaining a closed-form solution of eq (46) is difficult, the replenishment point j is estimated using a numerical search engine. A bisection algorithm is used to ascertain the location of j*.

(3) Sequence of Replenishment

The objective of the proposed model is to ascertain the optimal sequence of replenishment point *j* along the planning horizon *H* that minimizes total system costs. The optimal sequence of replenishment points may be determined by solving the following dynamic programming equations.

$$TC_k = Min\{TC_j + W(j,k)\} \tag{47}$$

$$TC_0 = 0 \tag{48}$$

Eq. (48) shows that the cost at the starting point is zero. The forward recursive procedure is used to ascertain the minimal total cost over planning horizon *H*. To solve the model, a dynamic programming algorithm is proposed and subsequently explained. The algorithm is a modified version of that of (Das and Okumura, 2016)

Step 0: Input parameters: A_0, C_0, h_1, f(t)

Step 1: Let $TC_0=0$, $j=0$ and $m=1$

For *k=1* to *H* {

$\textit{Solve eq}$ (46)$\textit{to obtain}$ $\mathrm{W(j,k)}$

$\textit{Let}\ TC_k = W(j,k)$, $S_m = 0$, and $E_m = k$

}

Step 2: Let i←1

For k=2 to H {

For j=i to *k-1* {

Solve eq (46) to obtain $\mathrm{W(j,k)}$

IF $TC_k > TC_j + \mathrm{W(j,k)}$ {

$TC_k = TC_j + \mathrm{W(j,k)}$, $m = m + 1$, $S_m = j$ and $E_m = k$

i=k+1

For t= i to H {

$\textit{Solve eq}$ (46) $\textit{to obtain}$ $\mathrm{W(k,t)}$

$\textit{Let}\ TC_t = TC_k + W(k,t)$

}

}

}

}

Step 3: Let $k = H$

While $(m \neq 1)$ {

Replenishment cycle= $[S_m, E_m]$

Cumulated total cost $= TC_k$

$\mathrm{m} \leftarrow \mathrm{m} - 1.$

}

4. NUMERICAL ILLUSTRATION

The model developed in section 3 is applicable to the distribution of different long-term relief items. We present a numerical example to illustrate the solution concepts presented previously. **Table 1** lists the key parameters.

The values used in the numerical example are useful for illustration purposes, but they might not match the values estimated by the ultimate users of the model. A user should gather parameter values before using the model. Cost parameters are local condition values. We have done sensitivity of cost parameters. Historical relief operation data can be helpful for setting parameter values for the demand. In this analysis, we kept total demand value is constant and the value is one thousand two hundred unit (1200 unit). For keeping the analysis tractable, we set $\mu_1 = 0$ and here $\gamma$is the ratio of horizontal section length and planning horizon.

Table 1: Demand parameters

	a	b	D_0
Linear decreasing (γ=0)	48	0.96	0
Uniform distribution(γ=1)	24	0	24
Combination of uniform and linear decreasing (γ=0.5)	64	1.28	32

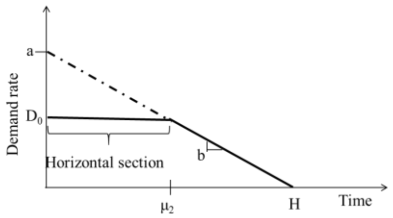

Fig. 6 : Trapezoid demand trend for numerical analysis

$$\gamma = \frac{\textit{Horizontal section length}}{\textit{Planning horizon}} \tag{49}$$

If $\gamma = 0$,becomes linear decreasing demand trend. If $\gamma = 1$, becomes uniformly distributed demand. The parameters of demand function is shown in **Table 1**

Since the relief demand depends on disaster intensity, socio-economic status, population density, frail-population density, and many other unknown factors. Therefore, the demand parameter can be set on the basis of available budget and target demand. Planning horizon (*H*) is assumed to be fixed and set to a value of 50.

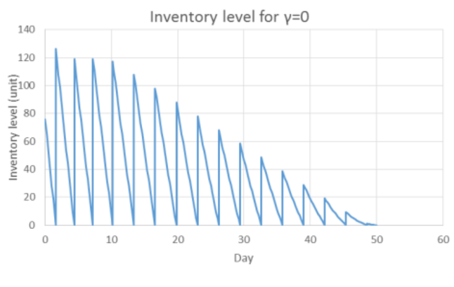

Fig. 7 Inventory level and order cycle for linear decreasing trend demand type (γ=0)

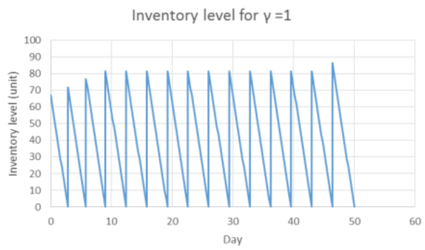

Fig. 8 Inventory and order cycle for uniform demand distribution (γ=1)

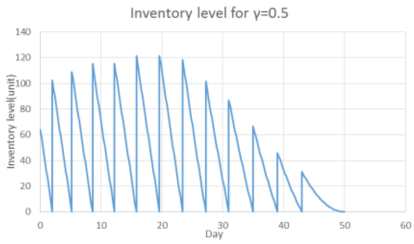

Fig. 9 Inventory level and order cycle for combination of uniform and linear decreasing demand trend (γ=0.5)

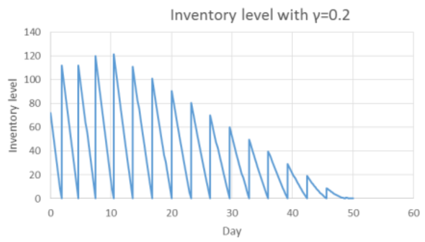

Fig. 10 Inventory level and order cycle for combination of uniform and linear decreasing demand trend (γ=0.2)

Eq (46) is solved by using the proposed algorithm in previous section. Fig. 7 - Fig. 10 illustrated relief ordering policy for different γ values. In the case of $\gamma = 0$, the order quantity decreases gradually. For $\gamma = 1$ the order quantity are kept constant. For other γ values the order quantity has decreasing and increasing trend. The increasing trend of order quantity ends before the μ_2 and decreasing trends of order quantity starts after the μ_2. This finding provides valuable suggestion for a logistics manager to conduct transportation and warehousing contract. So the location of μ_2 (or γ value) is critical for lowering order quantity. The order quantity and replenishment time can be found from the respective figures. This analysis shows that the position of μ2 are important in warehouse and transport cost capacity selection.

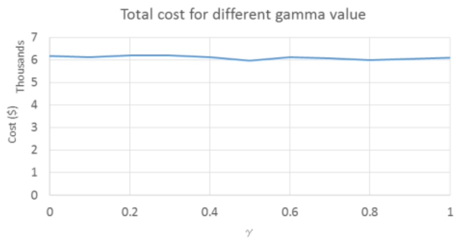

Fig. 11 Cost sensitivity with γ value

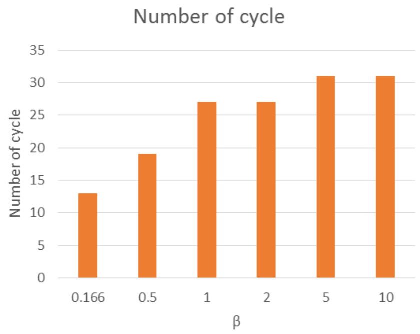

Fig. 12 Total number of cycle sensitivity with β values

We have conducted a sensitivity analysis for different γ values. It is observed that our system adjust the total number of cycles and order quantity for minimizing the total cost. Here total cost are stable (percent deviation less than 1%) with the increment of γ. In our numerical setting, the total cost was minimum at the position of $\gamma = 0.5$. As this system has tradeoff between the holding costs and replenishment costs, we did sensitivity analysis for different βvalues (Note that βrepresents is the ratio of holding cost and lot size dependent part of operational cost). With the increment of β, the number of cycle also increases. For higher βthe holding cost also increases, therefore the system aims for lowering on-hand inventory and the average cycle lengths become shorter.

5. CONCLUDING REMARK

In this paper, we have discussed the inventory problem for a trapezoid demand trend over a finite time horizon. The replenishment cost is taken to be dependent on the lot size of the current replenishment. A logistics manager may bring all relief at the beginning of the relief operations. However, this strategy is not rational, as the stocked relief items could be used in other affected places. Therefore, the multi-order inventory policy is suitable for relief inventory management. The model outcomes show that the cycle lengths are not fixed and the order quantities are dependent on cycle length.

After the 2011 great east Japan earthquake, several types of demand trends depending on product type are observed. Order quantity for a trapezoidal demand trend (with $\mu_1 = 0$) showed increasing and decreasing trend. The kink point (μ_2) is a critical point for identifying transition period of ordering quantity. It proves that the selection of the type of demand distribution has significance influence on the system cost. Of course, the paper provides an interesting topic for the further study of such kind of important inventory models.

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