Continuous review model of mutual support supply system for disaster responses

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Abstract: Mutual support of supply is needed to leverage number of stock between shelters during disaster response time. The goal of this research is to develop reactive lateral stock transshipment between shelters based on traditional continuous review inventory model in which demand and delivery lead time information are greatly biased. This paper presents self-repair framework that provide an emergency relief strategy after natural disaster events. In addition, supply system buffer analysis also presented to enrich model development. A case study focused on volcanic eruption disaster at Merapi Mountain Indonesia, illustrate application of the model.

Keywords: Mutual support supply network, continuous order review model, lateral transshipment, disaster relief supply, self-repair network, buffer analysis.

1 INTRODUCTION

Due to increasing number of natural disaster occurrence recently, disaster relief is extremely important activity today (EMDAT, 2010) [1]. The need to respond to human need in the event of disaster is not diminishing and may even be increasing. Government, NGO, and other related parties should provide life support items such as food, clothes, and medicine; in timely manner.

Planning and management of logistic and inventory activities is needed for better relief supplies. Inventory or supply system play critical role in this emergency situation, in which they system has to manage all the needed items, store it, and provide it to the victim whenever they need.

The role of logistic and inventory for famine relief is explicitly mentioned by (Long & Wood, 1995) [2] that describe complex environment in which disaster relief logistic and inventory system must operate.

The traditional design of an inventory system is hierarchical where transportation flows from one echelon to the next, i.e. from suppliers to manufacturers, from manufacturers to retailers, and from retailers to customers. This inventory system tends to have less flexibility since each supply point cannot communicate or help each other to get a better performance. The more flexible inventory system allows lateral transshipment within same or adjacent echelon, i.e. between wholesalers or retailers (Paterson, et al, 2010) [3].

At disaster recovery situation, lateral transshipments between inventories at each shelter points are allowed to minimize number of run out stock or stock out in each shelter point. Lateral transshipment is one of the alternative ways to leverage number of stock between shelter points and reduce stock out.

Simple lateral transshipment inventory system for a disaster situation is graphically illustrated in Figure 1 with single central warehouse supplies three inventory shelter points. Lateral transshipment in an inventory system is stock movements between locations of the same echelon (Paterson, et al, 2010) [3]. These transshipments can be conducted periodically at predetermined points in time to proactively redistribute stock, or they can be used reactively as a method of meeting demand, which cannot be satisfied from stock on hand.

In proactive transshipment models, lateral transshipments are used to redistribute stock amongst all stocking points in an echelon at predetermined moments in time. Reactive transshipments respond to situations where one of the stocking points faces a stock out or risk of a stock out.

Lateral transshipment is suitable to use in disaster situation since cost consideration is less important than saving life. By stock transfer from one surplus location into needed location, average stock out of all location will significantly reduce.

After occurrence of disaster, needed item's demand is usually fluctuate drastically and arrive at extremely irregular time. In most disaster-relief practices, demand information for emergency resources is mainly collected at the operational level and then flow upward to the higher level (Turoff, 2004) [4]. In addition, transportation time for the item to each shelter point becomes extremely vary due to infrastructure damages.

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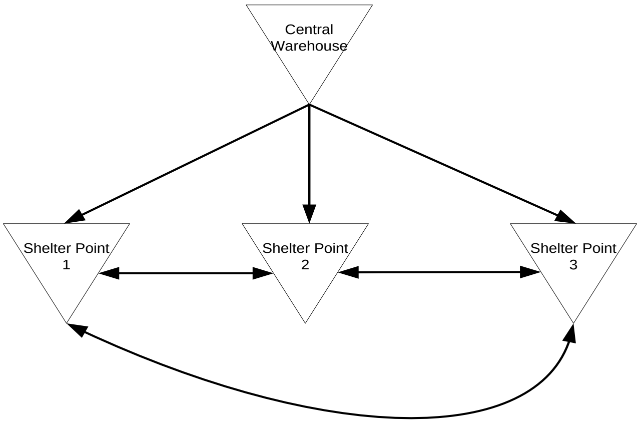

Fig. 1: Lateral transshipments between stock points

Self-repair network model in computer network application is one collaboration model of computer network where each computer tries to repair each other by mutual copying. Repairing process of self-repair network doesn't require resources while repairing process of lateral transshipment sacrifices resources.

This paper propose framework of lateral transshipment of supply system after occurrence of natural disaster with continuous review inventory model and self-repair network as reference model.

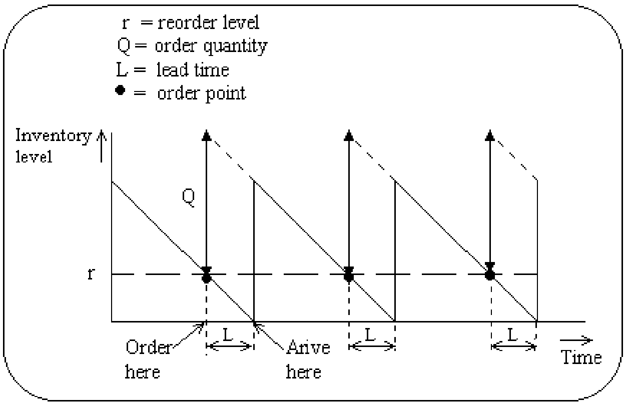

Fig. 2: Continuous review model of inventory

3 MUTUAL SUPPORT MODEL

There are differences between the enterprise and disaster-relief inventory models. These differences are found in the environment and characteristics of disaster-relief inventories in all area from acquisition through storage and distribution (Whybark,2007) [5]. Even though different, fundamental enterprise inventory model can be adopt for modeling inventory at disaster situation.

Continuous order review inventory model or known as economic order quantity (EOQ) model, state that there is optimum order quantity (Q) based on tradeoff between predetermined setup cost (SC) and holding cost (HC) (Heizer & Render, 2008) [6]. Figure 2 illustrate basic model of continuous order review inventory. Another variable necessary for calculating order quantity is overall demand along planning horizon (D). Equation 1 show the calculation of optimum order quantity based on this model.

$$Q = \sqrt{\frac{2.D.SC}{HC}} \qquad (1)$$

This model used reorder point (R) formula which is derived from interaction of demand rate (d), delivery lead time (L), and safety stock (SS). Equation 2 shows calculation of reorder point while safety stock calculation of continuous order review is shown at equation 3.

$$R = d.L + SS \qquad (2)$$

$$SS = z\sigma_{RP+L} \qquad (3)$$

We formulate the lateral transshipment problem into simple mathematical formulation. The model consists of three elements (U, T, R) where U is a set of shelter points, T is a topology connecting the units, and R is a set of rules of interaction among shelter points. A set of shelter point U is a finite set number of shelter points. The topology for the lateral transshipment inventory system is scale free network. We restrict the case where each shelter point has a state: normal (0), abnormal (1) and need help (-1). Each shelter point tries to help the other shelter points in a synchronous fashion with probability **Pr**. The helping will be successful with probability **Ps** and the shelter point states will increase if the current inventory level plus the proportion shared by another shelter point is greater than the standard normal threshold (N). Proportion shared by normal shelter point is Pn while the proportion shared by abnormal shelter point is Pa in which Pa<Pn. In this model, it is assume that *need help* shelter point cannot behave as helping unit. N and A is the proportion threshold of the normal and abnormal unit state, while I represent a proportion of current inventory level. There are several assumption used in this model

1. Only one shelter point can help another shelter point for one period of time.
2. Number of shelter point remains same during periodical review.
3. Each shelter point has dedicated transportation vehicle and common use transportation vehicle.

4. Logistic decision parameter such as vehicle capacity and route is neglected.

Our model has several similar characteristics with the self-repairing network model (SRN) where the network of computer repairs each other by mutual copying (Ishida, 2005) [7]. The following lists are characteristic of our model, which also exists in SRN model:

1. Set of units
2. Topology connecting the units
3. Set of rules of the interaction among units
4. Probability of repairing other units
5. There is possibility of disturbance occurs during interaction of the units

The definition of unit in both models is the smallest entity having an ability to interact, repair, and being repaired by other units. In SRN model, unit is a computer while in our model, unit is shelter points. Even though both models having a great number of similarity, there are also several differences between them as shown at Table 1

Table 1. Differences of SRN and our model

	SRN	Our Model
Repairing action	Mutual copying	Transfer stock
Sacrifices resource	No	Yes
Success rate	Probability (Prn, Pra)	Probability of success Ps and Proportion shared (Pn, Pa) and proportion of current inventory level (I)

Success rate of repairing is depending on the two factor ssuch as probability of success (Ps) and proportion shared (Pn and Pa). Probability Ps represents delivery success of items transported from one place to another during after occurrence of disaster event. Due to infrastructure damage, there is possibility transportation vehicle not able to reach destination or able to reach destination but the item carried has been damaged or deteriorated.

Transition rules for the state changes by helper unit are as followed:

$$0 \rightarrow 0 : (I\text{-}Pn) \geq N \tag{4}$$

$$0 \rightarrow 1 : A \leq (I\text{-}Pn) < N \tag{5}$$

$$0 \rightarrow \text{-}1 : (I\text{-}Pn) < A \tag{6}$$

$$1 \rightarrow 1 : A \leq (I\text{-}Pa) < N \tag{7}$$

$$1 \rightarrow \text{-}1 : (I\text{-}Pa) < A \tag{8}$$

Transition rules for the state changes by helped unit if help by normal unit are as followed:

$$0 \rightarrow 0 : (I+Pn) \geq N \tag{9}$$

$$1 \rightarrow 0 : (I+Pn) \geq N \tag{10}$$

$$1 \rightarrow 1 : A \leq (I+Pn) < N \tag{11}$$

$$\text{-}1 \rightarrow 1 : A \leq (I+Pn) < N \tag{12}$$

$$\text{-}1 \rightarrow 0 : (I+Pn) \geq N \tag{13}$$

Transition rules for the state changes by helped unit if help by abnormal unit are as followed:

$$0 \rightarrow 0 : (I+Pa) \geq N \tag{14}$$

$$1 \rightarrow 0 : (I+Pa) \geq N \tag{15}$$

$$1 \rightarrow 1 : A \leq (I+Pa) < N \tag{16}$$

$$\text{-}1 \rightarrow 1 : A \leq (I+Pa) < N \tag{17}$$

$$\text{-}1 \rightarrow 0 : (I+Pa) \geq N \tag{18}$$

4 NUMERICAL SIMULATION

Numerical simulation conducted using real disaster data of volcanic eruption in Indonesia. In November 2010, one of the active volcanoes in Indonesia, Merapi Mountain, located at Yogyakarta province erupted. During one month, government and other NGO trying to support their life at each shelter point, which spread all over the city. Data of evacuees and shelter points gathered from Indonesia National Disaster Management Agency for two provinces during one-month evaluation is shown at Table 2 (Indonesia National Disaster Management Agency, 2010) [8].

In numerical simulation, two options will be evaluated such as:

1. No transshipment
2. Transshipment

Table 2. Disaster evacuees and shelter point

Sub area	Areas (km2)	Evacuees	Shelter points	Evacuees/shelter	Shelter density
Sleman	574.82	109193	74	1476	7.77
Kulon Progo	586.28	4753	16	297	36.64
Yogyakarta city	32.5	5118	14	366	2.32
Bantul	506.85	20516	17	1207	29.81
Gunung Kidul	1485.35	12162	13	936	114.26
Total	*3185.8*	*151742*	*134*	*4282*	*190.8*

Table 3. Simulation setting

Simulation setting	
Evacuees/shelter	4282
Total demand	385380
Total period (hours)	720
demand rate (/hour)	535
Lead time (hours)	1
Safety stock	318
Order quantity (Q)	6207
Number of pool truck	268
Number of shelter truck/shelter	2
Pn	0.2
Pa	0.1
Pr	0.9
Ps	0.5
Normal threshold (N)	0.7
Abnormal threshold (A)	0.3

First option is the basic inventory model which not allowed any transfer items from any shelter points. This option made for performance reference of a transshipment system proposed. Second option allows transfer items between shelter points.

Number of truck for delivering item is assumed static throughout the time which is 268 trucks at pool or central warehouse and 2 trucks for each shelter. The other simulation setting can be seen at Table 3.

The result of numerical simulation as shown at Figure 3 that number of need help unit decreasing when success delivery rate is increasing and with transshipment option, number of need help unit decrease even bigger. Based on that fact, performance of transshipment system can be measured up to 60% as shown at Figure 4. In transshipment option, number of need help unit also sensitive to probability of helping where number of need help unit decrease significantly as probability of helping increase as shown at Figure 5.

5 BUFFER ANALYSIS

The purpose of buffer or safety stock is to reduce an effect of demand and lead time fluctuation. The prediction of the buffer is relied on the known distribution of the demand and lead time during a planning period.

We propose an analysis of buffer inventory for lateral transshipment system with the goal of getting percentage of expected reduce of stock out and also addition of expected over stock. The benefit of that action is reduction of stock out for certain amount but there is a side effect of increasing possibility of excessive stock.

Consider M as a percentage of additional buffers for current inventory level. Stock out occurs if a current level below abnormal threshold.

$$I \leq A \quad (19)$$

$$TI - d - Pr \cdot Pa \cdot TI \leq A \cdot TI \quad (20)$$

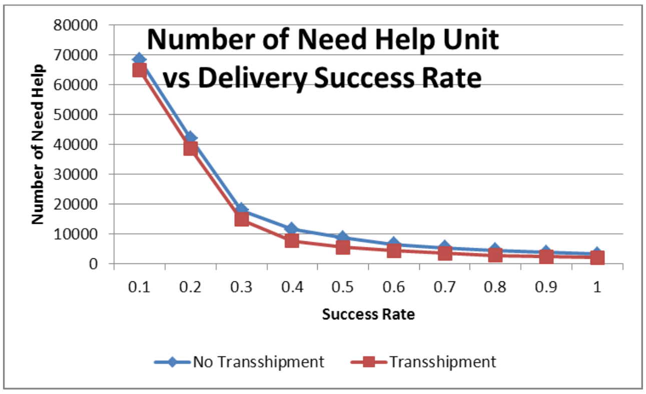

Fig 3. Number of need help unit vs delivery success rate

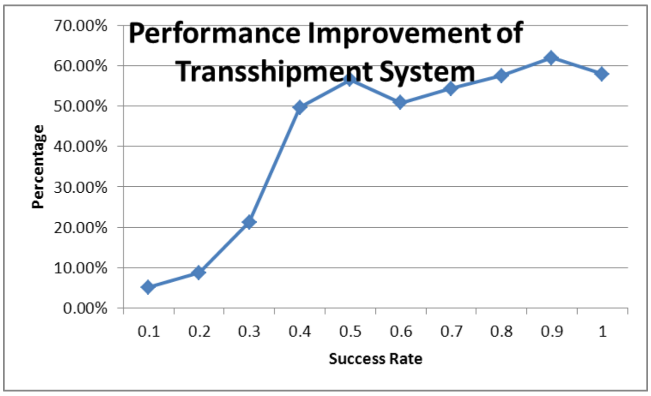

Fig 4. Performance improvement of transshipment

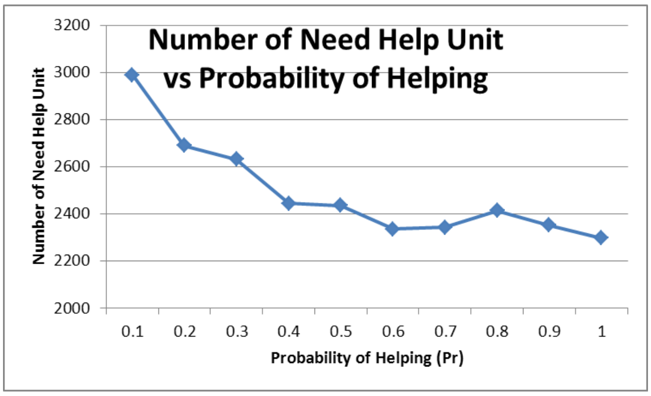

Fig 5. Number of need help unit vs probability of helping

If a proportion amount of M added to the current inventory stock the equation becomes as follows:

$$TI(1+M) \quad - d - Pr \cdot Pa \cdot TI(1+M) \leq A \cdot TI \tag{21}$$

$$TI - d - Pr \cdot Pa \cdot TI + M(1-Pr \cdot Pa) \leq A \cdot TI \tag{22}$$

From equation (22), we can conclude that buffer addition of M, cause the possibility of stock out reduced at maximum M(1 – Pr · Pa). On the other hand, if a proportion amount of M added to the current inventory stock, excess stock will add maximum as much as M(1 + Pr · Pn). The equation (25) shows the calculation of that excess stock.

$$I \quad \geq TI \tag{23}$$

$$TI - d + Pr \cdot Pn \cdot TI \geq TI \tag{24}$$

If a proportion amount of M added to the current inventory stock the equation become as follows:

$$TI(1+M) \quad - d + Pr \cdot Pn \cdot TI(1+M) \geq TI \tag{25}$$

$$TI - d + Pr \cdot Pn \cdot TI + M(1+Pr \cdot Pn) \geq TI \tag{26}$$

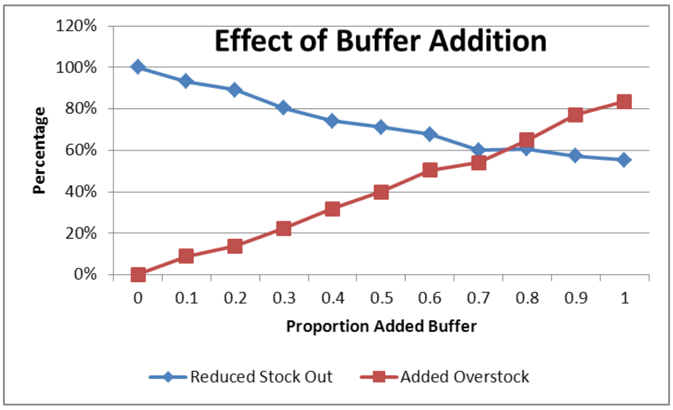

Fig 6. Effect of buffer addition

Based on numerical simulation data, if 10%, buffer is added to the current stock, then maximum stock out will be reduced as much as 9.1 % and maximum excess inventory will be added as much as 11.8 %. Figure 6 show the numerical simulation of proportion of need help unit after buffer M is added. Amount of stock out is reduced about 6.8% comparing the situation without buffer addition but expected maximum over stock increase as much as 8.7%. The result of numerical simulation is consistent with mathematical formulation where buffer addition will have greater effect to the expected over stock rather than expected stock out.

6 CONCLUSION

Lateral transshipment has demonstrated a positive impact to the performance improvement of the inventory system during a disaster where demand and lead time information are greatly biased. It can reduce number of stock out level for all shelter points. The performance of the system is greatly affected by success rate and probability of helping. Even with low delivery success rate and probability of helping, lateral transshipment supply system show significant improvement in inventory performance. It can be noted that the greater success rate and probability of helping the greater also inventory performance as measured by number of need help units.

Future research can be directed to the study on the dynamic of number of shelter points during planning horizon and also characteristic interaction between shelter points. Integration with logistic decision planning can also be one of the major concerns for future development such as truck capacity and routing problems.

7 ACKNOWLEDGEMENT

This works was supported by Global COE "Frontiers of Intelligent Sensing" from Ministry of Education, Culture, Sports, Science and Technology Japan. In addition, this works was supported by Scholarship from Nishijima corp. Not to mention, this works was also partly supported by Grants-in-Aid for Scientific Research (B): "Foundation on Immunity Based Complex Systems and Sensor Agents" (23300057) 2011.

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