Aid Replenishment Strategy during Demand Increment On Humanitarian Logistics Relief

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Abstract - **Replenishment strategy is very important to any aid agency. A situation that an agency may handle is a disaster relief program. A good aid replenishment strategy during this period is critical. The fulfillment of any item needed is important to ensure the survival ability of the victim. The demand of items may have certain patterns, including a trend characteristic. The traditional Economic Order Quantity (EOQ) may not be suitable to be applied during this situation. Therefore, an alternative mathematical model is proposed. The model is developed by considering the increasing demand behavior, the deterioration of inventory item, the urgency of items during the period, and the shortage issue. An analytical calculation approach is performed to demonstrate how the model could be implemented. The result shows that the more often the replenishment is executed, the higher the service level will be, without compromising the cost. At the end of this research we also suggest some future potential work to perform.**

Keywords - aid replenishment strategy; humanitarian logistics; logictics response; disaster relief

I. INTRODUCTION

Humanitarian logistics is a part of the supply chain which requires a high level of agility and service due to its dynamic characteristic and impact on life [1]. This characteristic is gained due to its function of saving the lives of affected people and preventing more people from becoming victims. The humanitarian logistics dynamic characteristic corresponds to the disaster relief phase and type of disaster.

There are 4 phases of disaster relief. These are mitigation, preventive and preparedness, response, and recovery. Mitigation deals with reducing the chance of emergency. Preventive and preparedness relate to activities that enhance a community's ability to respond whenever a disaster occurs. The response phase refers to activities during the disaster which place an emphasis on responsiveness, whilst the recovery phase deals with activities to rebuild the victim's normal life, which place an emphasis on efficiency. Different types of disaster will also have a different dynamic characteristic for each phase. Some examples of these dynamic situations are a sudden change of demand and unpredictable resource availability [2]. During the recovery phase, the dynamic level of humanitarian logistics can be considered to be low; whilst in a predictable catastrophe such as typhoon, the dynamic level can be considered to be in the middle to low. The more unpredictable the catastrophe is, the more dynamic the humanitarian logistics program will be. The structure or the supply network of aid agencies is ideally formed to overcome the dynamic characteristic of humanitarian logistics.

As described by some aid agencies, a general supply network model for the type of aid collection and distribution system is shown in Fig 1. During the disaster relief phase, aid supplies from donors can be donated to aid agencies in the form of funds or products/goods. Meanwhile aid agencies can distribute the aid to victims in the form of products/goods. In Fig. 1, an alternative assumption of the donation procedure is apparent which would let the supplier directly send the aid item to the victim. Therefore, the aid agency would not need third party logistics. Different aid agencies may have different supply structures. Some aid agencies may hire and distribute the aid through logistics services, and then the logistics providers/services will deliver it to the recipients [3]. Some of the aid agencies may independently self-manage their distribution system with their own vehicles. In the second scenario, the aid agencies do not deliver the aid to the logistics provider. Even though the supply networks vary, the aid agencies will still have the same coordination scope. The aid agencies are responsible for coordinating the entire aid distribution and also ensure that the aid is delivered in proper condition.

During the coordination activities in a humanitarian supply network, some bottlenecks may form. The two most common activities in humanitarian logistics where bottlenecks form are procurement and replenishment [2]. Every bottleneck activity increases the dynamic level of a supply network and decrease its responsiveness, therefore lowering the service level of the aid agency. Bottleneck situations in the procurement and replenishment activity can be overcome by introducing safeguards to these activities [2]. This can be accomplished by applying strategic alliances [4]. One strategic alliance that is widely applied in business supply networks is Vendor Managed Inventory (VMI) [5].

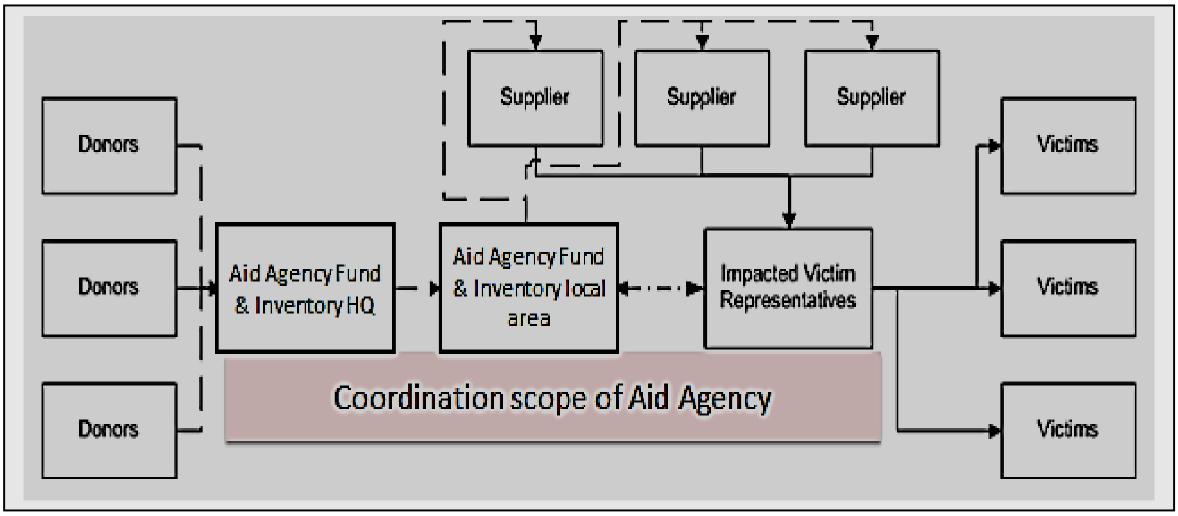

Figure 1. Supply network model of humanitarian logistics

VMI is a strategy where a vendor sets the replenishment strategy for retailers [5]. VMI is able to minimize the dynamic condition across the responsive supply chain by eliminating information delays from customer to vendor [6]. The VMI practices correspond to the situations faced by aid agencies. Aid agencies are analyzed as vendors, while the victims are analyzed as retailers. In the real situation, victims rarely have adequate skills to determine the demand replenishment. VMI practice enables aid agencies to manage their own inventory and replenishment processes effectively, in coordination with their suppliers or donors.

However, sometimes the aid agencies have to face an urgent situation in which they have difficulties in managing the aid. Based on interviews with well-known national aid agencies, an overstock or understock of some critical aid items is common. This means that there is inefficient management of a donor's aid. The understock may be caused by underestimating the demand. The overstock may be caused by overestimating the needs and scarcity of goods. Overestimation is considered as common, because the main purpose of the aid agency is to be as responsive as possible in aid fulfillment.

Nowadays, many aid agencies focus their activities on shortening the lead time of response and neglecting the cost [7]. Even though the main goal of a humanitarian logistics is not to minimize the cost, it is also an important parameter of the logistics performance value. A good aid agent must be able to optimize the funds collected from donors in order to save as many lives as possible, even in situations where the funds donated are less than required. Therefore, even in most dynamic condition, logistics cost is still a vital factor to consider [8].

In order to optimize the cost, some approaches suggest setting the replenishment strategy. In the traditional approach, EOQ is used very often. This method considers order cost, holding cost and demand to assist in determining the optimum quantity of orders [9]. This approach only fits a deterministic demand situation [9]. Therefore, different approaches shall be performed accordingly.

Paper Structure: This paper is divided into four major section. The first section is an introduction to the problem and the objective of the research. The second section contains a set of research steps conducted to answer the research problem. The third section covers the results of the research and provides corresponding analysis, while in section four conclusions are drawn and potential future areas of work are considered.

II. RELATED WORK

Several research programs have been conducted to model the inventory for the humanitarian logistics problem in a disaster relief situation. Minic et al [10] developed a mathematical model for inventory and distribution which is based on deterministic and stochastic data for three echelon humanitarian logistics. Inventory planning of the preparedness phase has been conducted by Lodree [12] and Saputra et al [13].

The model developed by Minic et al [10] is validated to estimate the optimum condition in humanitarian logistics. This research simulated its model with a general stochastic demand, but without including any trend pattern. Das and Okumura [11] attempted to solve this trend issue characteristic. Das and Okumura [11] developed a standard replenishment model where the demand had a decreasing trend. This model is very useful for a disaster recovery phase which is usually characterized by this demand behavior. On the contrary, another disaster management activity may have a very opposite nature. The disaster response phase usually has an increasing demand behavior and it is also critical to have a good replenishment strategy to handle the demand.

There is a research gap in optimizing the inventory during the response phase. Therefore, this research intends to fill the gap in building a model which reflects the behavior of the disaster response phase. To complete this objective, a replenishment model developed by Das and Okumura [11] was modified. The developments include implementing an increasing demand function of victims' aid requirement and its urgency that follows an exponentially increasing characteristic.

III. THE RESEARCH METHOD

This research is divided into two major steps. The first step is building a mathematical model, while the second step is an analytical optimization performed by implementing the model in hypothetical data. The detail of the research method is depicted in Fig 2 which consists of 5 activities. Hypothetical data and parameter values implemented in this research follow the method of [11] with modifications on the demand and urgency function characteristic. Although data from the previous research is used, performing analytical calculations for our iteration approach is preferred to using the algorithm developed in [11]. The algorithm proposed in [11] fails to find an optimal solution, hence it is proposed that a simple analytical approach be used to obtain an optimal solution. As an example, for the model used by an aid agency, the iteration was executed using MS. Excel, Solver.

Literature Study	Mathematical Modelling	Iteration Approach	Analysis And Managerial Implications	Conclusions

Figure 2. Research Method.

IV. RESULTS AND DISCUSSION

A. Mathematical Model

In this research, a mathematical model is built for products that are essential and have a relatively long shelf life, e.g. rice, hygiene kits, blankets or sarongs, or covers. The conditions of those items during the response phase are assumed to have a delivery lead time of 0 (zero) period time unit, be always available for replenishment, and have a warehouse space which is always available for holding. An illustration of aid item inventory fluctuation number in disaster response phase can be depicted in Fig 3. The quantity of inventory is expected to increase along the T replenishment period because of the increasing demand behavior. Each replenishment cycle will start at the j time point and end at the k time point. The p time point is the time when the replenishment order is placed and at the same time when the replenishment arrives. It refers to the zero lead time assumption.

Product availability assumption is taken based on multi-sourcing strategy as suggested by Ikovaou et al [4]. In reality, a bottleneck in replenishment may form because of some supply disruption. If the primary supplier can not supply some items because of dynamic demand changes, Ikovaou et al [4] suggest setting a multi-sourcing strategy for critical items. A secondary supplier or back up supplier can be substituted whenever the primary supplier fails. This strategy allows the assumption that a product will always be available during the replenishment process.

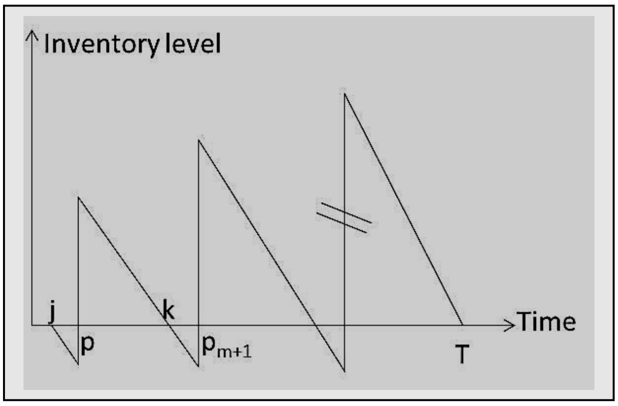

Figure 3. Inventory Position during Increasing Demand

The inventory replenishment model proposed in this research is a modification of the model developed by Das and Okumura [11], especially in the demand and urgency function which are adjusted for the disaster response phase properties. These modifications are shown in (4) and (5). Eq. (4) models a linearly increasing demand phenomenon, while (5) describes an exponentially increasing urgency value. These modifications affect the rest of problem formulation (6)--(18) so that the detail of the model will be quite different from the original one [11].

As stated in Das and Okimura [11], when an aid agency has a T period of time for handling a particular project of a disaster relief phase, and if each T period consists of m replenishment cycles, then the objective function for the replenishment strategy is to minimize the following total cost as Eq. (1) follows.

$$\min(TC_{total}) = \sum_{m=1}^{n} TC_m \tag{1}$$

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with TC_{total} = total cost of all replenishment period
TC_m = total cost for replenishment cycle-m

Where:

$$TC_m(j_m, p_m, k_m) = Ao + RS_m + HC_m + OC_m \quad (2)$$

with
j_m = starting time for replenishment cycle *m*
p_m = ordering and replenishment time
k_m = the end of replenishment cycle m
A_o = fix order cost ($)
RS_m = realized shortage cost in cycle m ($)
HC_m = holding cost of cycle *m* ($)
OC_m = operational cost of cycle *m*($)

Subject to:

$$j_m \leq p_m < k_m \quad ; m = 1, 2, \ldots, n \quad (3)$$

For $m = 1$, $j_m = 0$
For $m \geq 1$, $j_m = k_{(m-1)}$

The demand function will linearly increase during the replenishment period as described in Eq (4). The increment will happen only during a short time period when compared to total length of time of disaster recovery and preparedness. Moreover, linear increment can easily be managed by an aid agency.

$$D(t) = a_0 + a_1 t, \qquad 0 < t < T \quad (4)$$

with :
a_0 = demand constant (unit)
a_1 = parameter of demand (unit)
t = time (day 1, day 2, …, day t)
T = the total time horizon of the replenishment response relief phase

An urgency function is developed to consider the urgency rate of aid items. The higher the time period, the higher the urgency is. The urgency function has an exponential increment to emphasize the impact towards victim's life and salvation. Consider rice as an example. The longer a victim is in a disaster area, the more urgent the need for rice is, because they can't work on the rice by themselves during the response phase. The urgency function f for urgency parameter (μ, ɣ) is

$$f(t) = 1 + \gamma e^{\mu t} \quad ; 0 < t < T \quad (5)$$

Inside the replenishment cycle m, there is a possibility that a shortage occurs. The number of shortages which occur from j to p can be quantified by function of S as follows.

$$S(t) = \int_j^t a_0 + a_1 z \, dz \quad ; j < t < p \quad (6)$$

While the shortage cost due to S is SC

$$SC(t) = \int_j^t P_o(a_0 + a_1 z)dz \; ; \; j < t < p \quad (7)$$

where P_o equals to shortage cost per unit ($/unit).

However, the actual shortage cost will actually be higher because it takes the urgency function into account**.** This actual shortage cost is defined as the Risk Shortage (RS) that happens during j to p period as follows.

$$RS = \int_j^p f(t)SC(t)dt \quad (8)$$

The number of inventory I for p to k period can be calculated by

$$I(t) = e^{-\theta t}\left[\int_t^k e^{\theta z}(a_0 + a_1 z)dz\right] \; ; p < t < k \quad (9)$$

where θ is the deterioration rate of unit stock. Deterioration rate explains the rate of damage that an inventory item might have during the processes of holding or storing.

The holding cost HC for keeping the I amount of inventory can be calculated by:

$$HC = \int_p^k H_o I(t)dt \quad (9)$$

$$H_o \int_p^k e^{-\theta t}\left[\int_t^k e^{\theta z}(a_0 + a_1 z)dz\right]dt \quad (10)$$

Where H_O is the holding cost per unit per period ($/unit/period).

The ordering quantity in time p for cycle m, Q(p) can then be calculated by adding the shortage quantity S(p) and inventory I(p). The I(p) is assumed to be a total number of items needed for a p to k demand fulfillment, while S(p) is the number of items not fulfilled in the previous periods, which become a backorder. It is desired that the quantity ordered can fulfill the shortage and gives enough inventory for cycle m.

$$Q(p) = S(p) + I(p) \quad (11)$$

The operational cost for cycle m can be calculated by multiplying the operational cost per unit per time, C_o unit with the quantity of order.

$$OC = C_o Q(p) \quad (12)$$

The demand and urgency function become the two different functions modified from Das and Okumura model because of the characteristics of response phase observed in this research. Other functions are also adopted from the Das and Okumura model. See [11] for further details.

From all the defined functions, the functions defined below are the functions for every component considered in the total cost calculation. A_o is a fix ordered cost which is a constant for every cycle. Every component of (2) that has been completed according to its integral function can be shown as below.

$$\mathrm{RS} = P_0\begin{bmatrix}\frac{a_0}{2}p^2 - a_0jp + \frac{a_1}{6}p^3 - \frac{a_1}{2}j^2p + \frac{\mu a_0 e^{\mu p}}{\mu}\left(p - \frac{1}{\mu}\right)\\ -\frac{\gamma a_0 j}{\mu}e^{\mu p} + \frac{\gamma a_1 e^{\mu p}}{2\mu}\left(p^2 - \frac{2p}{\mu} + \frac{2}{\mu^2}\right) - \frac{\gamma a_1 j^2}{2\mu}e^{\mu p}\end{bmatrix} \quad (13)$$

$$\mathrm{HC} = H_0\left[-\frac{a_0}{\theta}\left(\frac{1}{\theta} + k\right) - \frac{a_1}{\theta}\left(\frac{k}{\theta} + \frac{1}{2}k^2\right) + \frac{a_1}{\theta^2}\left(\frac{1}{\theta} + k\right)\right]$$

$$\left[\frac{\gamma a_1 e^{\mu j}}{2\mu}\left(j^2 - \frac{2j}{\mu} + \frac{2}{\mu^2}\right) - \frac{\gamma a_1 j^2}{2\mu}e^{\mu j}\right]$$

$$- H_0\begin{bmatrix}-\frac{a_0}{\theta}\left(\frac{e^{\theta(k-p)}}{\theta} + p\right) - \frac{a_1}{\theta}\left(\frac{k}{\theta}e^{\theta(k-p)} + \frac{1}{2}p^2\right)\\ +\frac{a_1}{\theta^2}\left(\frac{1}{\theta}e^{\theta(k-p)} + p\right)\end{bmatrix} \quad (14)$$

$$\mathrm{OC} = C_0\begin{bmatrix}\frac{a_0}{\theta}\left(e^{\theta(k-p)} - 1\right) + \frac{a_1}{\theta}\left(ke^{\theta(k-p)} - p\right)\\ -\frac{a_1}{\theta^2}\left(e^{\theta(k-p)} - 1\right) + a_0(p-j) + \frac{a_1}{2}(p^2 - j^2)\end{bmatrix} \quad (15)$$

All three cost components above are calculated for each replenishment cycle m that will finally be added to a total cost function of replenishment strategy during T time period.

B. Model Implementation

In this section, the proposed model is implemented using a parameter described in Das and Okumura [11], which is listed in Table I.

First, a specific value of n is determined. The value of *n* is defined as a feasible cycle number of replenishments that may be performed in a recovery phase within 50 units of time period (T). The aid agency might perform 1 time, 2 times, 3 times replenishment and so on. The analytical calculation (iteration) result for each cycle is shown in Table II, and the trend of the cost is depicted by Fig. 4. In Table II, the TC max is gained by implementing Eq. (1) – (15) based on the *j**, *p**, and *k**. Values of *j**, *p**, and *k** are gained from the Ms. Excel solver optimum solution.

According to Table II and Fig. 4, we can see that the more often an aid agency makes replenishments, the smaller the total cost for the entire response horizon will be. The cost decrement may continue until the number of cycles can no longer be feasible. Based on the Table II, we may see that the optimum condition occurs when n = 10 with the total cost of $1,302.19. Here, the decreasing of total cost is followed by the increasing of service level for each number of cycles.

TABLE I. PARAMETER AND CONSTANT [11]

Parameter or Constant	Value
Ao	20.00
a_0	10.00
a_1	0.20
P_0	1.00
H_0	0.30
C_0	0.50
γ	2.00
μ	0.08
θ	0.08
T	50.00
Beginning Inventory	0.00

Service level is calculated based on the sum of days of stock out for entire cycle, as suggested by [11].

TABLE II. ANALYTICAL CALCULATION BASED ON THE PARAMETER STATED

Scena-rio	*n*	TC_m	Max holding period (days)	Max stock out period (days)	Max cycle length (days)	Service level
1	1	$ 19,676.32	35	15	40	0.7
2	2	$ 6,299.05	22	6	28	0.86
3	3	$ 3,646.98	16	4	20	0.90
4	4	$ 2,635.46	13	2	15	0.94
5	5	$ 2,103.43	10	2	12	0.94
6	6	$ 1,801.80	9	1	10	0.96
7	7	$ 1,601.20	8	1	9	0.96
8	8	$ 1,466.17	7	1	8	0.96
9	9	$ 1,373.90	7	1	8	0.96
10	10	$ 1,302.19	6	1	7	0.96
11	11	Not feasible				

In Table II, the increment of service level may occur because of a smaller maximum cycle length and smaller maximum days of stock-out. This can happen due to the smaller accumulation effect of γ, μ, and θ. It means that during implementation, the aid agency shall not hesitate to make more frequent replenishments. The more frequent replenishments also give more flexibility to the aid agency to plan their operation while it faces a dynamic characteristic of the disaster response phase. Usually, during the early days of a disaster, only small number of aid is available. By making the cycle shorter, the problem with the small number of supplies could be overcome.

The shorter cycle is also shown by the graph of (k-p) max and (p-j) max which are depicted in Fig. 4. The frequent replenishment is characterized by smaller (k-p) max and smaller (p-j) max. The (k-p) value is showing the maximum

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length of storage period in a replenishment cycle. Shorter storage periods will cause lower storing cost and shorter cycles. Meanwhile (p-j) value shows the maximum allowable stock out period in a replenishment cycle. The shorter cycle means a lower allowable stock out period.

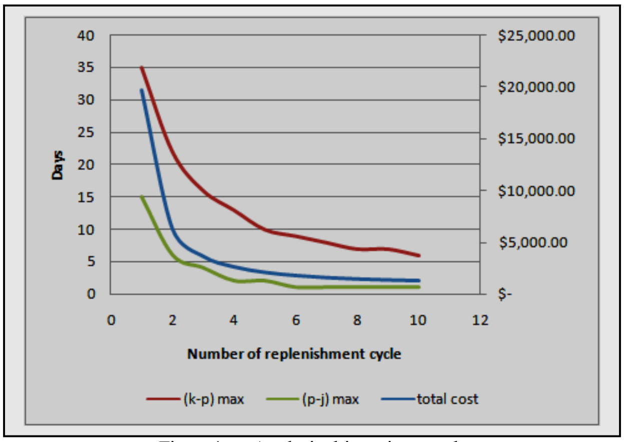

Figure 4. Analytical iteration result

However, a smaller cycle length can also mean a higher coordination effort in monitoring the fund. Here, the role of aid agency as professional distributer and logistician is challenged. An online information system can be developed to ease the challenge. The online information system can speed up the communication and reduce the information delay. Therefore, at the same time, an online information system may reduce the dynamic characteristic of disaster response.

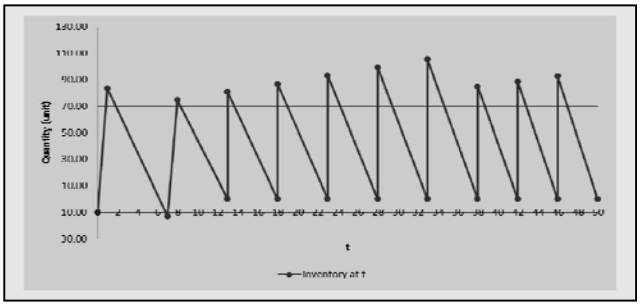

Figure 5. Inventory position in replenishment horizon (n=10)

Fig. 5 illustrates the cheapest replenishment strategy which is a 10 times replenishment within 50 units of time period. It shows the inventory position along the replenishment horizon which follows an increasing trend. This graph is in contrast with the result of Das and Okimura model [11] due to the contrary demand trend and urgency function. The Das and Okimura model [11] has a declining trend while by Fig. 5 we can see the increasing trend.

In Fig. 5, shortage occurs only for the first two replenishment cycles. The shortages of the first two cycles determine the value of service level for the entire replenishment cycle. To increase the service level, it is suggested that an aid agency has a preposition inventory in its warehouse. The preposition inventory can reduce the load of replenishment especially when the fixed order cost is high [12]. Saputra et al [13] gives a simple and basic formulation to determine optimum preposition inventory based on mean-time between disruptions.

However, the simulation in Fig. 5, only shows several number of shortage. In the Das and Okimura simulation algorithm [11], the shortage occurred in each replenishment cycle which shows the tendency of an unoptimized condition. This un-optimized condition can be caused by the use of different algorithm to find the solution. Therefore, a different approach is used in this research which may cause viewer shortages in a replenishment period. Fig 5 shows that the approach used in this research is sufficient to generate a better solution.

The optimum scenario (n = 10) is then used to understand the impact of urgency parameter γ and deterioration rate θ towards the total cost. The result of analytical calculation for sensitivity analysis of parameter γ is shown in Table III. Meanwhile the result of analytical calculation for sensitivity of θ is shown in Table IV.

TABLE III. SENSITIVITY ANAYLISIS OF γ

Scena-rio	γ	TC_m	Max holding period (days)	Max stock out period (days)	Max cycle length (days)	Service level
1	2	$ 1,302.19	6	1	7	0.96
2	3	$ 1,318.09	6	1	7	0.96
3	4	$ 1,314.39	5	1	6	0.98
4	5	$ 1,319.70	5	1	6	0.98
5	6	$ 1,325.01	5	1	6	0.98
6	7	$ 1,330.32	5	1	6	0.98

As seen in Table III, the higher the urgency parameter, the greater the total cost. The max length of cycle decreases when the urgency parameter increases. Here, the Table III shows the same phenomenon as Table II, where the decrement of cycle length would increase the service level.

TABLE IV. SENSITIVITY ANAYLISIS OF θ

Scena-rio	θ	TC_m	Max holding (days)	Max stock out (days)	Max cycle length (days)	Service level
1	0.05	$1,239.10	6	1	7	0.96
2	0.07	$1,280.53	6	1	7	0.96
3	0.08	$1,302.19	6	1	7	0.96
4	0.1	$1,347.51	6	1	7	0.96
5	0.12	$1,395.65	6	1	7	0.96
6	0.15	$1,473.62	6	1	7	0.96

Here in Table IV, we can also see that the smaller the deterioration rate is, the smaller the total cost will be. A shift in deterioration rate most likely does not affect the maximum cycle length and service level. This may result in the conclusion that this model might be relevant for low to middle deterioration rates.

The assumption of lead time delivery and goods availability of course would make the model became less accurate. In the model, lead time delivery is considered as 0 (zero), while goods/items are always assumed available. If the delivery lead time was longer than 0 (zero) the aid agency is advised to perform a demand forecast and to set the replenishment strategy based on the iteration result on the demand forecasted. In the iteration, it will find the p (replenishment time point) for each cycle of replenishment and they should place the order a few days prior to p based on the delivery lead time.

In reality, the assumption of warehouse availability has a risk of violation because of the location of victims. The violation of warehouse availability deducts the number of goods replenished from its optimum number. Thus, it may lead to a shortage risk. In this condition, an aid agency would normally rent or build a temporary warehouse in cooperation with local stakeholders. Şahin et al [14] suggested using a container as a storage facility which is placed in strategic locations to minimize the holding and transportation cost.

V. Conclusions

This research provides a proposal for determining the replenishment strategy for an aid agency during the emergency response phase. This research also gives an illustration of how the model will perform with hypothetical data by using an analytical iteration. The hypothetical data are chosen since disaster data are very difficult to obtain. Based on the analytical calculations, the higher the number of replenishment cycles performed by the aid agency, the lower the replenishment cost and the higher the service level will be. In the near future, it is suggested to set parameters of the model so that they can match every dynamic characteristic of disaster relief phase or furthermore the type of disaster handled.

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