ISSN 1881-5456

International Journal of LOGISTICS and SCM Systems

Volume3 Number1 May, 2009

Official Journal :
The International Federation of LOGISTICS and SCM Systems
The Asia Pacific Federation of LOGISTICS and SCM Systems

Volume5 Number1 May, 2009

International Journal of Logistics and SCM Systems

Official Journal:
The International Federation of LOGISTICS and SCM System:
The Asia Pacific Federation of LOGISTICS and SCM System:

International Journal of **Logistics and SCM Systems**

Volume3 Number1 May, 2009

CONTENTS

A Heuristic Method for SFI Policy with Increasing Power-Form Demand Pattern

Ririn Diar Astanti*A and Huynh Trung Luong*B
***A Universitas Atma Jaya Yogyakarta, Indonesia, e-mail:ririn@mail.uajy.ac.id**
***B Asian Institute of Technology, Thailand, e-mail:luong@ait.ac.th**

Abstract

Sometimes the presence of shortage is economically preferable i.e., when holding cost is significant as compared with shortage cost. In this paper, a heuristic method based on the concept of reduction cost is proposed to determine replenishment times $\{t_i\}$ and shortage points $\{s_i\}$ for shortage followed by inventory (SFI) policy with increasing power form demand pattern. It is noted that SFI policy allows shortage to occur before replenishment is received. The concept of reduction cost that is introduced in this paper is easy in concept, and it is hoped that it can help practitioners to understand the trade-off between holding the inventory and allowing the demand to be shortage. In addition, in order to avoid penalty cost, the proposed heuristic method is developed in such a way that demands over pre-established time horizon can always be met. Numerical experiments are also carried out to illustrate the performance and the applicability of the proposed method and to compare with other published result.

Keywords: Inventory, SFI policy, heuristic, reduction cost, increasing power-form demand

1. Introduction

In practical situation, it might happen the period when customer's order arrives, finished goods are not available. This situation is called shortage period. During the shortage periods, if all customers prefer to wait until finished goods are available in the next replenishment, then it is called completely backlog case. But, especially if there are many suppliers, some customers have a tendency to find another supplier to meet their demands while others are not; or it is called partial backlog case.

In reality, demand can have increasing form, especially during the growth stage of its product life cycle. The research on inventory policy for complete backlog case with linear increasing demand has been done by Teng *et al.* [1] who developed the exact method and divided inventory model into four by taking into consideration whether shortages are allowed or not allowed at the beginning and last cycle of the planning horizon. Other research was done by Zhou *et al.* [2] who classified inventory policy as (1) Inventory Followed by Shortage (IFS) policy and (2) Shortage Followed by Inventory (SFI) policy.

To the best of our knowledge, initial research on IFS policy for complete backlog case with increasing demand was done by Deb and Chaudhuri [3] who extended Silver's heuristic to permit shortage, followed by Goyal *et al.* [4] who developed heuristic method for both IFS policy and SFI policy. They, then, concluded through empirical experiments that SFI policy often perform better than IFS policy.

Unlike Deb and Chauduri [3] who developed a heuristic method, Murdheswar [5], Dave [6], Hariga [7] and Teng [8] developed the optimal solution procedure for IFS policy. It is noted that Deb and Chauduri [3], Murdheswar [5], and Dave [6] developed IFS policies for the case where shortages are not allowed at the last cycle, while Hariga [7] and Teng [8] developed IFS policy for the case where shortages are allowed at the last cycle of planning horizon. Another research was conducted by Hariga and Goyal [9] who considered SFI policy by allowing shortage to be happening at the beginning but not at the end planning horizon.

As some products might have a seasonal form during the growth stage, then, a nonlinear form will be a better form of demand pattern. For complete backlog cases, initial research on developing exact method for IFS policy with nonlinear increasing demand has been done by Hariga [7]. Beside exact solution, the heuristic method also has been developed. Recently, Astanti and Luong [10] developed a heuristic method based on the concept of reduction cost for IFS policy by not allowing shortage to occur at the last cycle of planning horizon. The work of Astanti and Luong [10] can be considered as the extension of the work of Wang [11]. It is noted that Wang [11] originally introduced the concept of reduction cost for nonlinear increasing demand pattern without shortage.

The heuristic method for SFI policy for the case of nonlinear increasing demand was initially done by Hariga [12], who developed two heuristic methods, which were based on Silver-Meal and least cost method respectively, followed by Yang *et al.* [13] proposed a forward recursive algorithm for power-form demand.

Current research has been done by Yang [14] who developed exact solution procedure based on backward recursive algorithm, by taken into

Received Date: November 26, 2008
Accepted Date: February 25, 2009

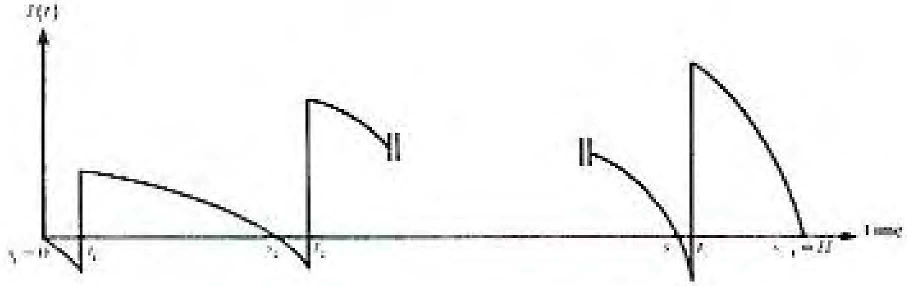

Figure 1: Inventory level under SFI policy

consideration of both IFS and SFI policies. From numerical results, Yang [14] also concluded that the fourth model of Teng *et al.* [1] in which shortages are allowed to be happening both at the beginning and at the end of planning horizon, seems to give the best result among four models. It is noted that even though shortage is assumed to be completely backlogged but both Yang *et al.* [13] and Yang [14] have not mentioned yet on how to handle the shortage demand at the end of planning horizon.

The focus of this research is to develop an algorithm for SFI policy with increasing power-form demand and completely backlogged in such a way that demands during pre-established planning horizon can be met. To illustrate the applicability and the performance of the proposed method, the results from it are then compared with those from Yang *et al.* [13].

The proposed heuristic technique comprises of two stages, in which different concept of reduction cost is incorporated in each stage. The first stage is purposed to find shortage point $\{s_i\}$ in a pre-established planning horizon, in which the reduction cost is defined as the difference between the reduction in shortage cost when a replenishment is added and the ordering cost. Then, the second stage is applied to find replenishment time $\{t_i\}$ in each cycle, in which the reduction cost is the difference between reductions of shortage cost by allowing holding inventory to occur with the holding inventory cost that is incurred. It is noted that the concept of reduction in this paper are developed in a different ways as that of from Wang [11] and Astanti and Luong [10].

The remaining parts of this paper are organized as follows. Mathematical development, in which the expression of total inventory cost is developed, is presented in Section 2 followed by the detail explanation of the proposed heuristic technique in Section 3. Numerical experiment to illustrate the applicability of the proposed technique is conducted in Section 4, followed by some concluding remarks in Section 5.

2. Mathematical Model

The following notations are used throughout the paper:

- H : length of planning horizon under consideration
- $f(t)$: demand rate at time t, which is assumed to have power form: $f(t) = (a + bt)^u$ with $a, b, u > 0$ and $0 \le t \le H$
- c_1 : ordering cost per order
- c_2 : holding cost per unit per unit time
- c_3 : shortage cost per unit per unit time
- n : number of replenishment cycles in the planning horizon
- t_i : the i^{th} replenishment time $(i = 1, 2, ..., n)$
- s_i : the i^{th} shortage starting point $(i = 1, 2, ..., n+1)$, which is also the starting point of the i^{th} cycle $[s_i, s_{i+1}]$, except that $s_{n+1} = H$
- $I(t)$: inventory level at time t, that is evaluated after replenishment arrives at time $t = t_i$ in the i^{th} cycle $[s_i, s_{i+1}]$

The behavior of the inventory level function under SFI policy is illustrated in Figure 1. For mathematical model development, the following assumptions are used:

i) Replenishments are made only at times t_i $(i = 1, 2, ..., n)$
ii) Lead time is negligible, i.e., replenishment is instantaneous
iii) The quantity replenishment that is received at time t is used to meet the accumulated shortage from time s_i to t_i $(s_i < t_i)$; $(i = 1, ..., n)$
iv) Shortages are permitted at the beginning of each cycle but no shortages are permitted at the end of planning horizon (i.e., $s_{n+1} = H$)

By using the assumptions above, the expression of the total inventory cost; which comprises of ordering cost, holding cost and shortage cost; of SFI policy during planning horizon H when n orders are placed is expressed below:

$$C(n, \{s_i\}, \{t_i\}) = nc_1 + c_2 \sum_{i=1}^{n} I_i + c_3 \sum_{i=1}^{n} S_i \qquad (1)$$

in which

I_i cumulative holding inventory during cycle i
S_i cumulative shortage during cycle i

The expressions of cumulative holding inventory I_i and cumulative shortage S_i for each cycle i from s_i to s_{i+1} will be derived in section 2.1 and 2.2 below.

2.1 Cumulative Holding Inventory I_i

If we denote $F(t)$ to be the cumulative demand from time 0 to time t then

$$F(t) = \int_0^t f(\tau)d\tau$$

The cumulative holding inventory I_i in cycle i can be determined as

$$I_i = \int_{t_i}^{s_{i+1}} \int_{t}^{s_{i+1}} f(\tau)d\tau dt$$

$$I_i = (s_{i+1} - t_i)F(s_{i+1}) - \int_{t_i}^{s_{i+1}} F(t)dt \qquad (2)$$

2.2 Cumulative Shortage S_i

The cumulative shortage S_i in cycle i $(i = 1, 2, ..., n+1)$ can be determined as:

$$S_i = \int_{s_i}^{t_i} \int_{s_i}^{t} f(\tau)d\tau dt$$

$$S_i = (s_i - t_i)F(s_i) + \int_{s_i}^{t_i} F(t)dt \qquad (3)$$

From (2) and (3) the expression of the total inventory cost can be defined as Equation (4).

3. Proposed Heuristic Technique

The proposed heuristic technique that is explained in this section is purposed for SFI policy only. The main idea is similar with the techniques of Wang [11] and Astanti and Luong [10], which is to check whether there are any reductions in total inventory cost. The proposed heuristic technique has two main stages, in which the first stage is done in order to find shortage point $\{s_i\}$ and the second stage is applied to find replenishment time $\{t_i\}$.

3.1 Procedure to Find Shortage Point $\{s_i\}$

The approach starts with zero inventory level at the beginning of the planning horizon $(s_1 = 0)$ and only one replenishment occurs at the end of the planning horizon to help fulfill the cumulative shortage in the time interval $[0, H]$ (see Figure 2a for illustration).

Next, a replenishment at time $s \in [0, H]$ is introduced and investigated to see if it can help to reduce the total inventory cost. When the additional replenishment is introduced, the cumulative shortage will be reduced but at the price of an additional order (see Figure 2b). Hence, the additional replenishment is accepted only if the reduction in shortage cost exceeds the ordering cost. The additional replenishment at time s (if acceptable) divides the planning horizon into two cycles, i.e., $[0, s]$ and $[s, H]$, as shown in Figure 2b. These two cycles are then examined by use of the same approach to see if other additional replenishments can be introduced. This procedure is continued until no improvement in total inventory cost can be found. At this time, the number of replenishment cycles in the planning horizon as well as all shortage starting points s_i's have been determined (see Figure 3 for illustration).

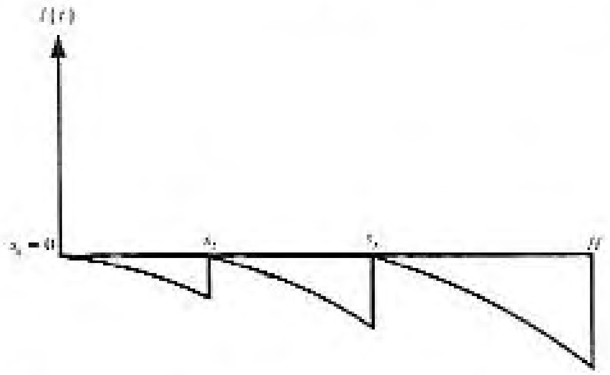

Figure 3: Final Pattern by Allowing Additional Replenishments

$$C\left(n, \{s_i\}, \{t_i\}\right) = nc_1 + c_2 \sum_{i=1}^{n}\left[(s_{i+1} - t_i)F(s_{i+1}) - \int_{t_i}^{s_{i+1}} F(t)dt\right] + c_3 \sum_{i=1}^{n}\left[(s_i - t_i)F(s_i) + \int_{s_i}^{t_i} F(t)dt\right] \qquad (4)$$

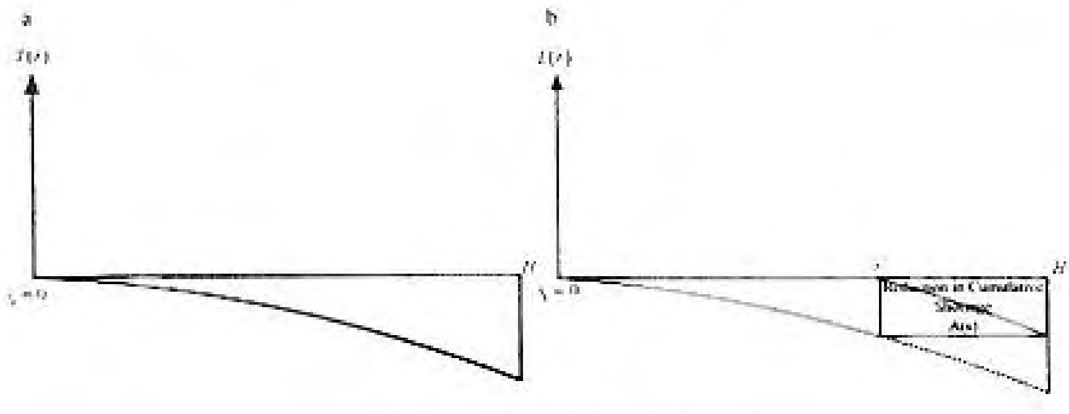

Figure 2: (a) Inventory level in the beginning of period is equal to zero

(b) Reduction in shortage cost by allocating an additional replenishment at time s_2^*

Proposition 1. For a cycle $[s_i, s_{i+1}]$, the optimal time s^* at which an additional replenishment should be placed so as to maximize the reduction in cumulative shortage is the solution of the following equation:

$$\int_{s_i}^{s^*} f(t)dt = (s_{i+1} - s^*) f(s^*) \tag{5}$$

Proof. The reduction in cumulative shortage when an additional replenishment is introduced at time $s \in [s_i, s_{i+1}]$ is determined as

$$A(s)\Big|_{[s_i, s_{i+1}]} = (s_{i+1} - s) \cdot \int_{s_i}^{s} f(t)dt \tag{6}$$

We have,

$$\frac{dA(s)}{ds} = -\int_{s_i}^{s} f(t)dt + (s_{i+1} - s) f(s) = 0 \tag{7}$$

So,

$$\frac{dA(s)}{ds} = 0 \Leftrightarrow \int_{s_i}^{s} f(t)dt = (s_{i+1} - s) f(s) = 0 \quad (*)$$

It is noted that $\lim_{s \to s_i} \frac{dA(s)}{ds} = (s_{i+1} - s_i) f(s_i) > 0$, and $\lim_{s \to s_{i+1}} \frac{dA(s)}{ds} = -\int_{s_i}^{s_{i+1}} f(t)dt < 0.$

Hence, $A(s)$ is an increasing function when s starts to increase from s_i, and $A(s)$ is a decreasing function when s approaches s_{i+1}. In addition, $A(s)$ is also upper bounded. Therefore, there should exist a value $s^* \in (s_i, s_{i+1})$ at which $A(s)$ is maximized. This value s^* must be the solution of equation (*) due to the fact that $A(s)$ is a differentiable function.

In general, the optimal value s^* can be determined by use of numerical techniques to help find the solution of an equation. However, for some particular functional forms of demand rate such as the power-forms used by Yang *et al.* [13] and Yang [14], s^* can be easily determined by analytical technique. It should be noted again that the additional replenishment at time s^* discussed above is accepted only if the resulted reduction in shortage cost; i.e., $c_3 A(s^*)$, exceeds the ordering cost c_1.

3.2 Procedure to find replenishment time $\{t_i\}$

It is noted that s_i's determined in the previous section play the roles of both replenishment times and shortage starting points in the planning horizon. In this section, we examine if moving the replenishment time backward from the shortage point in each cycle can help to reduce the total inventory cost further or not. Consider cycle i, i.e., $[s_i, s_{i+1}]$ with a replenishment time at t_i instead of s_{i+1} as it is shown in Figure 4. The introduction of t_i can help to reduce the cumulative shortage in the cycle i but at the expense of arising holding inventory.

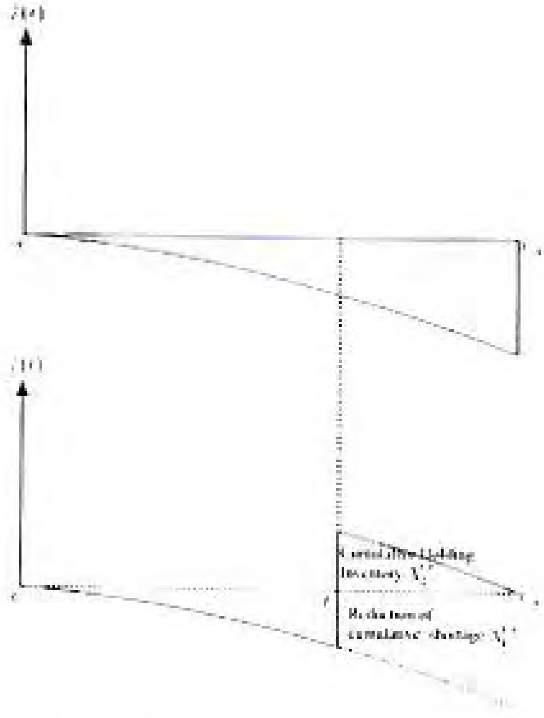

Figure 4 : Concept of reduction cost

The maximization problem discussed above can be formulated as follows:

$$\text{Maximize } RC^{(i)} = c_3\left(A_1^{(i)}\right) - c_2\left(A_2^{(i)}\right) \tag{8}$$

Subject to

$$s_i \le t_i < s_{i+1}$$

in which:

$RC^{(i)}$	Reduction cost in cycle i
$A_1^{(i)}, A_2^{(i)}$	The areas showed in Figure 4, which represent for the reduction of shortage and holding inventory in cycle i

The expression for $RC^{(i)}$ can be derived as follows:

$$RC^{(i)} = c_3\left(A_1^{(i)}\right) - c_2\left(A_2^{(i)}\right)$$

$$RC^{(i)} = c_3\left\{(s_{i+1} - t_i) \cdot \int_{s_i}^{t_i} f(t)dt + \int_{t_i}^{s_{i+1}} \int_{t_i}^{t} f(\tau)d\tau dt\right\} - c_2\left\{\int_{t_i}^{s_{i+1}} \int_{t}^{s_{i+1}} f(\tau)d\tau dt\right\}$$

$$RC^{(i)} = (c_2 + c_3)\int_{t_i}^{s_{i+1}} F(t)dt - (s_{i+1} - t_i) \cdot \left[c_2 F(s_{i+1}) + c_3 F(s_i)\right] \tag{9}$$

Proposition 2. For a cycle $[s_i, s_{i+1}]$, there exists an optimal time t_i^* at which if a replenishment is placed, the reduction cost is maximized and positive. The optimal time t_i^* is uniquely determined from the following equation.

$$F(t_i^*) = \frac{c_2 F(s_{i+1}) + c_3 F(s_i)}{c_2 + c_3} \qquad (10)$$

Proof. We have,

$$\frac{dRC^{(i)}}{dt_i} = -(c_2 + c_3)F(t_i) + c_2 F(s_{i+1}) + c_3 F(s_i),$$

then $\frac{d^2 RC^{(i)}}{dt_i^2} = -(c_2 + c_3) f(t_i) < 0$

Hence, $RC^{(i)}$ is a concave function and has a global maximum that satisfies $\frac{dRC^{(i)}}{dt_i} = 0$, or equivalently $F(t_i^*) = \frac{c_2 F(s_{i+1}) + c_3 F(s_i)}{c_2 + c_3}$.

Due to the fact that $F(s_i) < \frac{c_2 F(s_{i+1}) + c_3 F(s_i)}{c_2 + c_3} < F(s_{i+1})$ and $F(.)$ is an increasing function, the value of t_i that satisfies (10) is uniquely determined in the interval (s_i, s_{i+1}).

In addition, at $t_i = t_i^*$:

$$RC^{(i)} = (c_2 + c_3)\int_{t_i}^{s_{i+1}} F(t)dt - (s_{i+1} - t_i)\cdot \left[c_2 F(s_{i+1}) + c_3 F(s_i)\right]$$

$$RC^{(i)} = (c_2 + c_3)\int_{t_i}^{s_{i+1}} F(t)dt - (s_{i+1} - t_i)(c_2 + c_3)F(t_i)$$

$$RC^{(i)} = (c_2 + c_3)\left[\int_{t_i}^{s_{i+1}} F(t)dt - (s_{i+1} - t_i)F(t_i)\right] > 0$$

(Q.E.D)

4. Numerical Experiments

In this section, numerical experiments are conducted to illustrate the performance of the proposed method. The problem of Yang *et al.* [13] is considered. Demand function has form: $f(t) = (a + bt)^u$ with $u = 2, a = 10, b = 30$. Other parameters are set as follows: $H = 1, c_1 = 4.5, c_2 = 1, c_3 = 3.5$. Optimal replenishment schedule from our proposed method is presented in Table 1 with the corresponding total inventory cost (C) for $n = 8$ is 67.6909.

Table 1: Optimal Replenishment Schedule

Cycle i	Proposed method	
	s_i	t_i
1	0.0000	0.0938
2	0.2713	0.3164
3	0.4390	0.4708
4	0.5659	0.5926
5	0.6757	0.6973
6	0.7665	0.7862
7	0.8500	0.8681
8	0.9273	0.9440
Ending time	1.0000	
C		67.6909

Due to the fact that in the inventory model considered in this paper, shortages are not allowed to occur at the end of planning horizon, then, the results from the proposed heuristic technique can not be directly compared with those of from Yang *et al.*'s [13], in which shortages are allowed to be happening at the end of planning horizon. (see Figure 5 for illustration). Therefore, the results from the proposed heuristic technique are then compared with those from the adjustments of Yang *et al.*'s. [13].

There are two adjustments are made in which the first adjustment is done by adding replenishment at the end of the planning horizon with the replenishment quantity exactly equals to the shortage amount. The second adjustment is done by increasing the time coverage of the last replenishment cycle. The comparison is presented in Table 2.

From Table 2, it can be seen that total inventory cost from the proposed heuristic technique is lower than that of the first adjustment of Yang *et al.*'s. But if it is compared with the second adjustment of Yang *et al.*'s, then the results from the proposed heuristic technique is only 0.16 % higher than that of Yang *et al.*'s. However, the proposed technique is easier in concept.

To further illustrate the performance of this heuristic technique, the results from the proposed heuristic technique are then compared with those from Chen *et al.* [15]. For comparison purpose, the second sample problem taken from Yang *et al.* [16] is solved by using both techniques, and the results are presented below in Table 3.

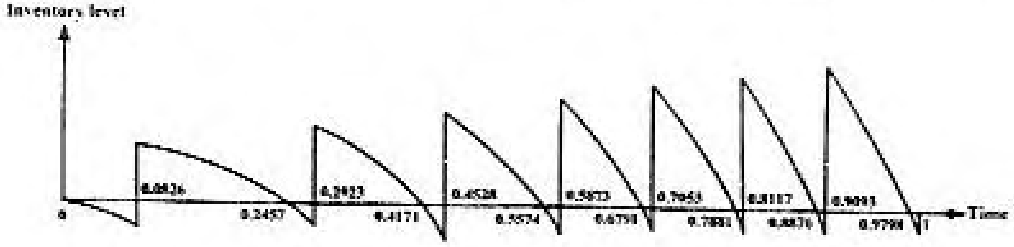

Figure 5: Optimal replenishment schedule from Yang *et al.* [13]

Table 2: Comparison of the result between the proposed method and adjusted Yang *et al.*'s. [13]

Cycle i	Proposed method		Adjusted Yang's (1)		Adjusted Yang's (2)	
	s_i	t_i	s_i	t_i	s_i	t_i
1	0.0000	0.0938	0.0000	0.0826	0.0000	0.0826
2	0.2713	0.3164	0.2457	0.2923	0.2457	0.2923
3	0.4390	0.4708	0.4171	0.4528	0.4171	0.4528
4	0.5659	0.5926	0.5574	0.5873	0.5574	0.5873
5	0.6757	0.6973	0.6791	0.7053	0.6791	0.7053
6	0.7665	0.7862	0.7881	0.8117	0.7881	0.8117
7	0.8500	0.8681	0.8876	0.9093	0.8876	0.9093
8	0.9273	0.9440	0.9798			
Ending time	1.0000		1.0000		1.0000	
C	$n = 8$	67.6909	$n = 8$	70.6336	$n = 7$	67.5814

Table 3: Comparison of the Results from the Proposed Technique with those from Chen *et al.*'s [15]

Case	Proposed Technique			Nelder-Mead Algorithm		
	n	Total Cost	Comp. Time*) (second)	n	Total Cost	Comp. Time*) (second)
$c_2 = 2.5c_3$	17	308.86	0.06	17	320.59	2539.70
$c_2 = 5c_3$	17	336.51	0.04	17	346.85	4348.90
$c_2 = 7.5c_3$	17	348.17	0.04	17	358.53	5842.09
$c_2 = 75c_3$	17	374.38	0.05	20	379.71	3319.80

(*: recorded on a PC with Intel P4 3.4GHz & 1 GB RAM)

From the results in Table 3, it can be seen that the new proposed heuristic technique is better than the technique of Chen *et al.* [15] in term of solution quality. Moreover, the computational times required in the proposed heuristic technique are much smaller.

5. Conclusion

In this paper, a heuristic method based on the concept of reduction cost is developed to solve SFI replenishment problem for increasing power-form demand considering shortage. Basically the method has two main steps, in which in each step, the different concept of reduction cost is used. The concept of reduction cost developed in this paper is wished to help the practitioner understand i.e., trade-off between holding cost and shortage cost more clear. Moreover, the proposed method provide better result in term of producing lower total inventory cost as compare with the first adjustment of Yang *et al.*'s. [13] and provide only 0.16 % higher than the second adjustment of Yang's. In addition, by using this method the demand over pre-established planning horizon can always be met without any adjustment to be made. In addition the result from the proposed technique is better than the technique of Chen *et al.* [15] in term of solution quality and computational time.

It is noted that the shortage situation in the research of this paper is assumed to be completely backlogged. However, in the real situation, some customer who arrives during shortage period might prefer to find another supply sources and it will result in lost sales. The future research then will be carried to deal with partial backlogged case.

References

[1] Teng, J.T., Chern, M. S. and Yang, H. L., "An optimal recursive method for various inventory replenishment models with increasing demand and shortages", *Naval Research Logistics*, **44**, 791-806, 1997.

[2] Zhou, Y. W., Lau, H. S. and Yang, S. L., "A finite horizon lot-sizing problem with time-varying deterministic demand and waiting-time-dependent partial backlogging", *International Journal of Production Economics*, 91, 109-119, 2004.

[3] Deb, M. and Chaudhuri, K., "A note on the heuristic for replenishment of trended inventories considering shortages", *Journal of the Operational Research Society*, **38**, 459-463, 1987.

[4] Goyal, S. K., Hariga, M. A. and Alyan, A., "The trended inventory lot sizing problem with shortages under a new replenishment policy", *Journal of the Operational Research Society*, **47**, 1286-1295, 1996.

[5] Murdeshwar, T. M., "Inventory replenishment policy for linearly increasing demand considering shortages An optimal solution", *Journal of the Operational Research Society*, **39**, 687-692, 1988.

[6] Dave, U., "On a heuristic inventory -replenishment rule for items with a linearly increasing demand incorporating shortages", *Journal of the Operational Research Society*, **40**, 827-830, 1989.

[7] Hariga, M., "The inventory lot sizing problem with continuous time-varying demand and shortages", *Journal of the Operational Research Society*, **45**, 827-837, 1994.

[8] Teng, J.-T., "A deterministic inventory replenishment model with a linear trend in demand", *Operations Research Letters*, **19**, 33-41, 1996.

[9] Hariga, M. and Goyal, S. K., "An alternative procedure for determining the optimal policy for an inventory item having linear trend in demand", *Journal of the Operational Research Society*, **46**, 521-527, 1995.

[10] Astanti, R. D. and Luong, H.T., "A heuristic technique for inventory policy with increasing demand pattern and shortage allowance", *The International Journal of Advanced Manufacturing Technology*, DOI 10.1007/s00170-008-1566-6, 2008.

[11] Wang, S. P., "On inventory replenishment with non-linear increasing demand", *Computers and Operations Research* , **29**, 1819-1825, 2002.

[12] Hariga, M., "Lot-sizing heuristics for continuous time-varying demand and shortage", *Computers and Operations Research*, **23**, 1211-1217, 1996.

[13] Yang, H. L., Teng, J. T. and Chern, M. S. , "A forward recursive algorithm for inventory lot-size models with power-form demand and shortages", *European Journal of Operational Research*, **137**, 394-400, 2002.

[14] Yang, H. L., "A backward recursive algorithm for inventory lot-size models with power-form demand and shortages", *International Journal of Systems Science*, **37**, 235-242, 2006.

[15] Chen, C.K., Hung, T.W. and Weng, T.C., "Optimal replenishment policies with allowable shortages for a product life cycle", *Computers and Mathematics with Applications*, **53**, 1582-1594, 2007.

[16] Yang, J., Zhao, G. Q. and Rand, G. K., "Comparison of several heuristics using an analytic procedure for replenishment with non-linear increasing demand", *International Journal of Production Economics*, **58**, 49-55, 1999.

Author Biographies

Ririn Diar Astanti is a Lecturer in Industrial Engineering, Faculty of Industrial Technology, Universitas Atma Jaya Yogyakarta, Indonesia. She received a D.Eng. from the School of Engineering and Technology at Asian Institute of Technology, Thailand in 2008. Currently, she is conducting the research on the development of heuristic methods for solving inventory policy with nonlinear increasing demand pattern. Her email address is ririn@mail.uajy.ac.id

Huynh Trung Luong is an Assosiate Professor in Industrial & Manufacturing Engineering, School of Engineering and Technology, Asian Institute of Technology, Thailand. He received Doctor of Engineering (D.Eng) from Industrial Systems Engineering, Asian Institute of Technology, Thailand, in 2000. His teaching and research interests include establishment of emergency inventory policies, inventory policies for perishable products, supply chain design, measures of bullwhip effect in supply chains, availability-based and reliability-based maintenance. He has published articles in various peer reviewed international journals. His email address is luong@ait.ac.th.