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# A Feedback Model of Control Chart for Supplier Risk Management

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## 1. Introduction

This chapter proposes a control chart model for supplier risk management. In these days, to improve the customer satisfaction of supplier, there has been an increased interest in IT (information technology) control charts which are used to monitor online production processes.

In the supply chain system shown in Figure 1, prompt response of the supplier to the feedback trouble information from the maker is important, not only has become a key point of the supplier competitive edge, but also useful for the improvement of the bottleneck of the whole supply network. In the setting of the due time of the treatment to the various assignable cause, because idle and delay risks are the trade-off relation, setting the optimal due date becomes a problem of great interest to the supplier. The trade-off problem of this research is shown in Figure 2, which will be explained in detail in §2.1.

Since Duncan's pioneering work [1], many studies have been developed to serve different purposes for the economic model of control charts. From the viewpoint of the production run, Gibra [2], Ladany and Bedi [3], Jones and Chase [4], Saniga [5] have considered the economic statistical model of the  $\bar{x}$  control chart for the infinite-length horizon; Crowder [6], Del Castillo and Montgomery [7] have considered models of the control chart for short run cases. However, the feedback model starting from out-of-control state was not considered explicitly.

Sun, Tsubaki and Matsui [8] [9] have defined and considered the CAPD models of the  $\bar{x}$  control chart based on a feedback case. Sun, Tsubaki and Matsui [10] developed the CAPD model of control chart in which tardiness penalty was considered. However, the penalty of idle cost was not considered in those works.

In this paper, a feedback model of control chart considered not only the delay penalty but also the idle penalty is proposed for supplier. First the cost elements of the feedback case are analyzed and the mathematical formulations which correspond to the case are shown. Then, to give clearer understanding about the trade-off relation in this feedback model, the behaviors of idle cost and delay cost are studied by numerical experiments. Finally, to find

out the optimal due time, the relations between the due time and the total expectation cost by the change of action time are discussed.

## 2. The feedback model

### 2.1 Explanation of the feedback model

Figure 2 shows some of the time variables used in the feedback model with the idle and delay penalties. In this paper, the feedback model starts from the out-of-control state (at point  $E$ ) by an assignable cause. But the cause is not understood until the process is searched for when the plotted point is beyond the control limits. At point  $F$ , let the assignable cause be detected for the first time by the  $\bar{x}$  control chart. During  $F$  to  $J$ , the action is done. Therefore, from point  $J$ , the process comes back to in-control state. The random variables  $D$  and  $A$  represent the interval from  $E$  to  $F$  and the interval from  $F$  to  $J$ , respectively.  $T$  is the due time.

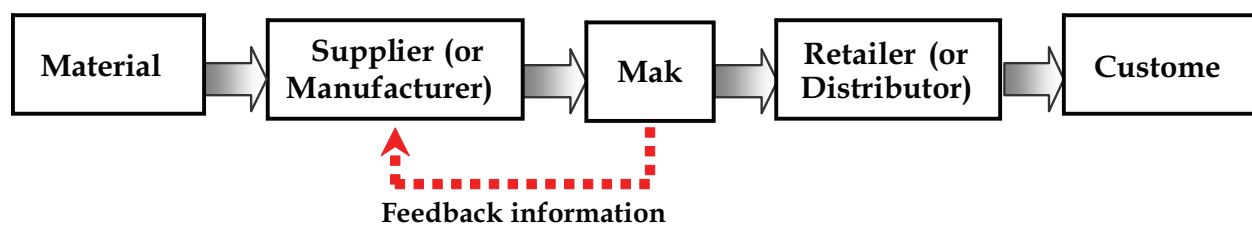


Fig. 1. The supply chain system with feedback information

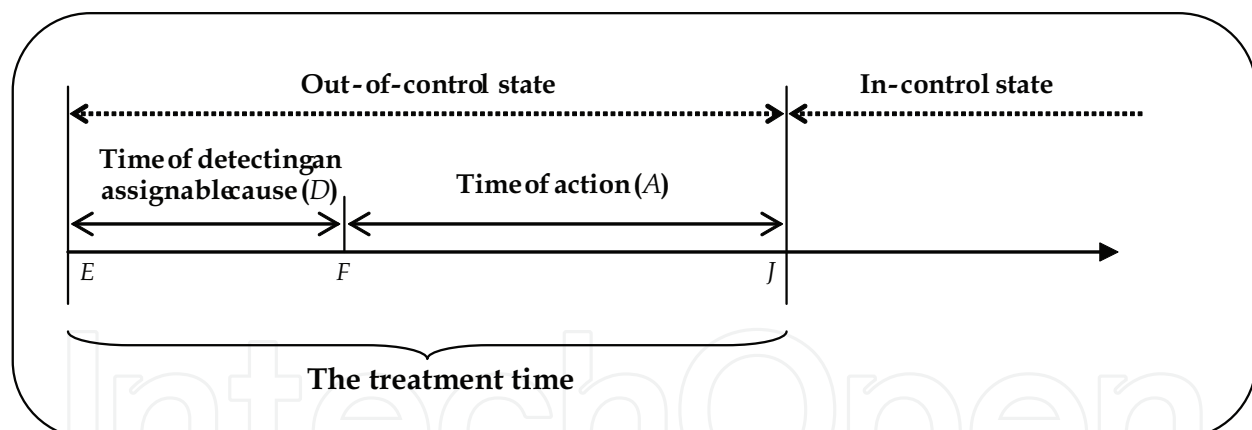


Fig. 2. Some of the time variables used in the feedback model

From Figure 2, it can be noted that when  $T < (D+A)$ , the delay penalty occurs, and when  $T > (D+A)$ , the idle penalty occurs.

In this chapter, the assumptions of the design in this research are as follows:

- i. The due time  $T$  is short, and the process is repetitive.
- ii. The quality shift occurs in the middle of an interval between samples [11]

### 2.2 Explanation of the costs and mathematical formulations

In this paper, the evaluation function is the expected total cost as follows:

$$C_t = E[\text{cost per cycle}] = C_C + C_A + C_I + C_D. \quad (1)$$

In the feedback model, the check cost, action cost, idle cost and delay cost are considered, respectively, as follows:

**(i) The check cost ( $C_C$ )**

It is the cost for sampling and plotting on the  $\bar{x}$  control chart every interval  $v$  for monitoring the process. Therefore the expected check cost is calculated as follows:

$$C_C = \{(c_0 + c_1 n) / v\} E[\text{cycle}] \quad (2)$$

**(ii) The action cost ( $C_A$ )**

It is the cost for acting the assignable cause and preventive measure. Therefore the expected action cost is calculated as follows:

$$C_A = c_a E[(T - D)^+ - (T - D - A)^+] \quad (3)$$

**(iii) The idle cost ( $C_I$ )**

It is the cost for the idle penalty. Therefore the expected idle cost is calculated as follows:

$$C_I = c_i E[\max(T - D - A, 0)] \quad (4)$$

**(iv) The delay cost ( $C_D$ )**

It is the cost for the delay penalty. Therefore the expected delay cost is calculated as follows:

$$C_D = c_d E[\max(D + A - T, 0)] \quad (5)$$

Where

$$E[\text{cycle}] = E[\min(D + A, T)] \quad (6)$$

In this paper, we use assumption of [11] that the shift occurs in the middle of an interval between samples, therefore,  $\mu_2^{-1}$  is set as follows:

$$\mu_2^{-1} = v(1/P_a - 1) + v/2 = v(1/P_a - 1/2) \quad (7)$$

$\alpha$  (the type I error probability) and  $P_a$  (power) of the  $\bar{x}$  control chart are given by [7],

$$P_a = \int_{-\infty}^{-k-\delta\sqrt{n}} \Phi(Z) dZ + \int_{k-\delta\sqrt{n}}^{\infty} \Phi(Z) dZ \quad (8)$$

$$\alpha = 2 \int_k^{\infty} \Phi(Z) dZ. \quad (9)$$

If it is assumed that both the random variable  $D$  and  $A$  are independent and exponentially distributed with mean  $\mu_1^{-1}$  and  $\mu_2^{-1}$ , then combining equations (1)-(5), the expected costs of check, action, idle and delay are shown as follows:

$$C_C = [(c_0 + c_1 n) / v] \frac{1}{\mu_1 - \mu_2} \left\{ \frac{\mu_2}{\mu_1} (e^{-\mu_1 T} - 1) - \frac{\mu_1}{\mu_2} (e^{-\mu_2 T} - 1) \right\} \quad (10)$$

$$C_A = c_a \left\{ \frac{1}{\mu_2} + \frac{1}{\mu_1 - \mu_2} \left( -\frac{\mu_1}{\mu_2} e^{-\mu_2 T} + e^{-\mu_1 T} \right) \right\} \quad (11)$$

$$C_I = c_i \left\{ T + \frac{1}{\mu_1 - \mu_2} \left( \frac{\mu_1}{\mu_2} (e^{-\mu_2 T} - 1) - \frac{\mu_2}{\mu_1} (e^{-\mu_1 T} - 1) \right) \right\} \quad (12)$$

$$C_D = c_d \left\{ -\frac{1}{\mu_1 - \mu_2} \left( \frac{\mu_2}{\mu_1} e^{-\mu_1 T} - \frac{\mu_1}{\mu_2} e^{-\mu_2 T} \right) \right\} \quad (13)$$

From (12) and (13), it can be obtained  $\partial C_I / \partial T > 0$  and  $\partial C_D / \partial T < 0$ . Therefore, it can be understood that the expected idle cost (CI) increases with the increase of the due time (T), the expected delay cost (CD) decreases with the increase of the due time (T). Therefore, it also can be understood that the two risks (CI and CD) have a trade-off problem.

### 3. Numerical experiments

In this section, first we study the behaviors of idle cost and delay cost to give a clearer understanding about the trade-off relation in the feedback model by numerical experiments. Then, to find out the optimal due time of this feedback case for supplier, the relations between the due time and the total expectation cost by the change of action time are studied. The parameters used in this paper are from a company, which are based on a real situation. Where  $c_0 = 0.05$ ,  $c_1 = 0.04$ ,  $c_a = 96$ ,  $c_i = 96$ ,  $c_d = 1000$ ,  $v = 1$ ,  $\delta = 2$ ,  $k = 3.0$ .

#### 3.1 The trade-off relation of idle cost and delay cost

From Figure 3, it can be noted that the expected idle cost (CI) increases with the increase of due time (T). This is because that the idle penalty increases by the increase of due time. Also it can be noted that the expected idle cost (CI) increases with the decrease of action time (a). This is because that the idle penalty of worker or machine increases by the decrease of action time, when T is set.

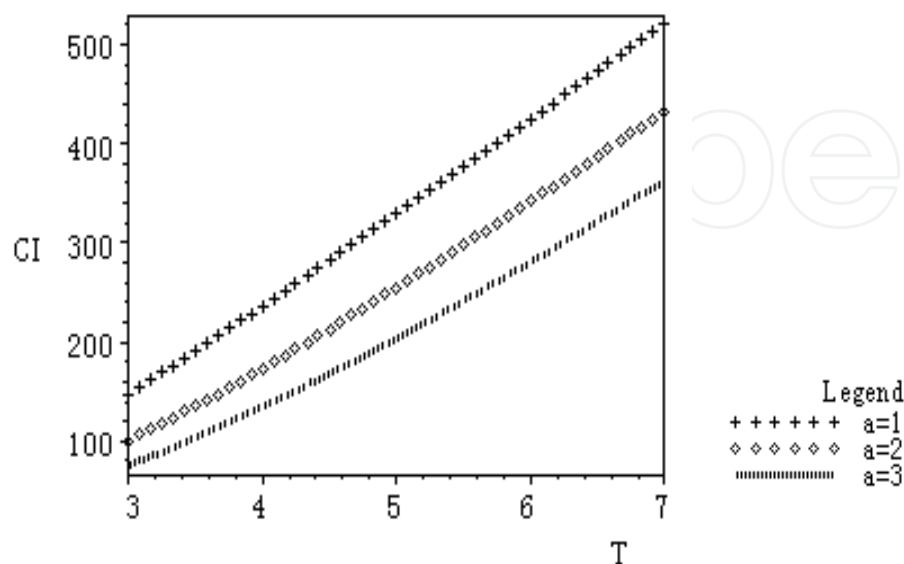


Fig. 3. The behaviors of idle cost ( $a=1$ ,  $a=2$  and  $a=3$ )

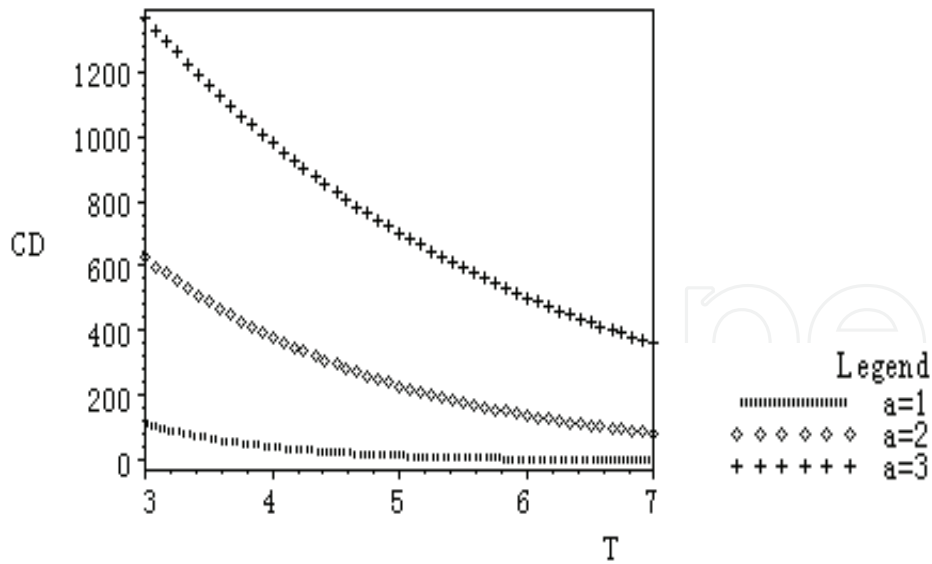


Fig. 4. The behaviors of delay cost ( $a=1, a=2$  and  $a=3$ )

From Figure 4, it can be noted that the expected delay cost ( $CD$ ) decreases with the increase of due time ( $T$ ). This is because that the penalties for delaying the due time decreases by the increase of due time.

Also it can be noted that the expected delay cost ( $CD$ ) decreases with the decrease of action time ( $a$ ). This is because that the delay penalty decreases by the decrease of action time, when  $T$  is set.

**3.2 The relation between the due time, action time and total expected cost**

To understand the relation between the due time and the total expectation cost, Figure 5 shows you the behaviors of all of the cost elements (check, action, idle and delay costs) by the change of due time.

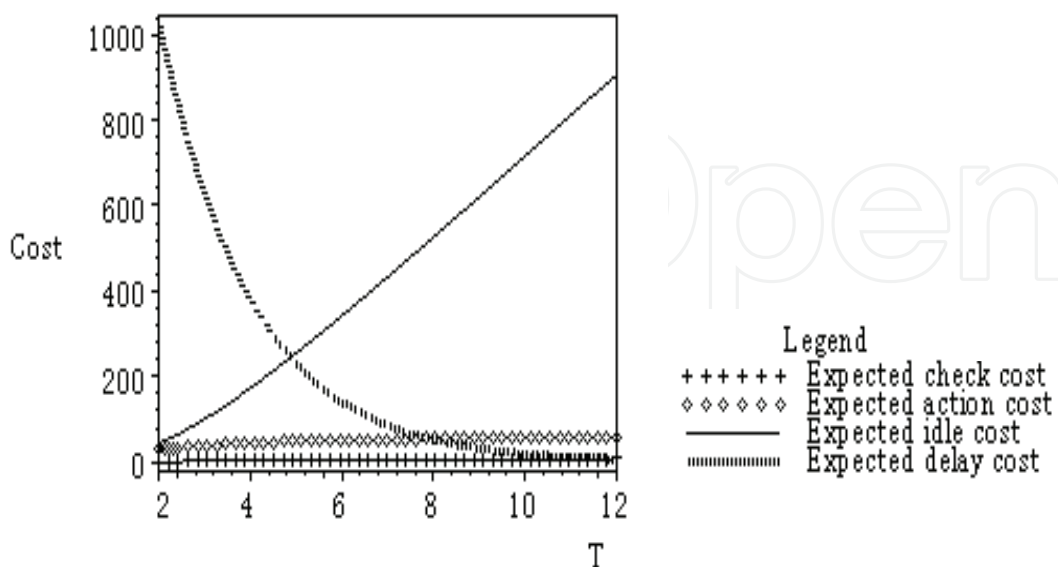


Fig. 5. The behaviors of check, act, idle and delay costs

To clarify it, the behaviors of check and act costs of Figure 5 case is shown by Figure 6.

From Figure 6, it can be noted that the expected check cost ( $C_c$ ) and action cost ( $CA$ ) increase with the increase of due time.

From Figures 5 and 6, it has been understood that determining the optimum value of due time that minimizes the expected total cost is based on the balance of the size of the inclination of  $C_c$ ,  $CA$ ,  $CI$  and  $CD$ . As the result, the relation between the expected total cost and due time of the feedback model is shown by Figure 7.

From Figure 7, it can be note that the optimal value of due time to minimize the expected total cost exists. Also, from Figure 7, it can be note that the optimal value of due time increases with the increase of action time. Therefore, it can be understand that a longer due time should be set when the action time is longer from an economic aspect.

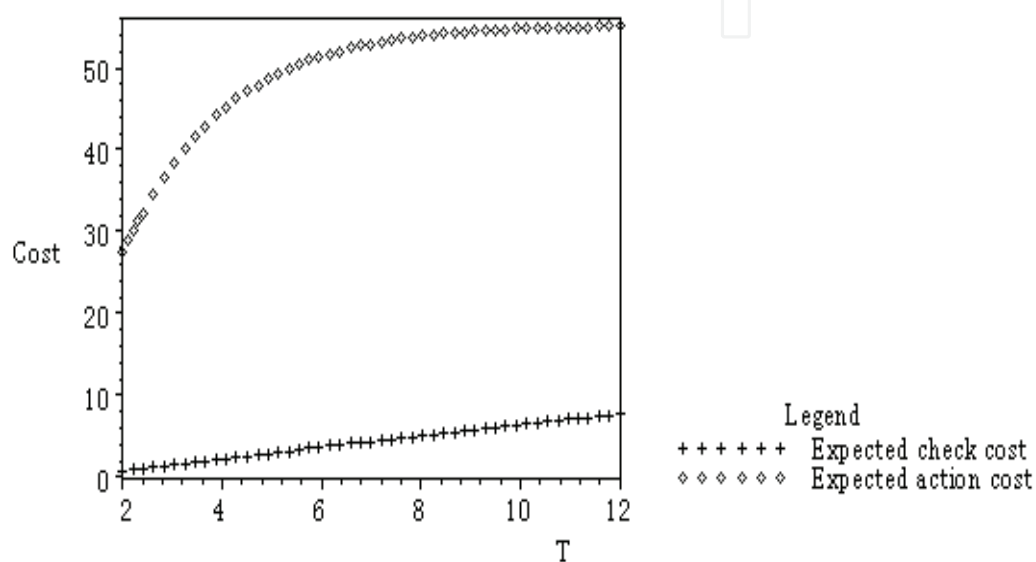


Fig. 6. The behaviors of check and act costs

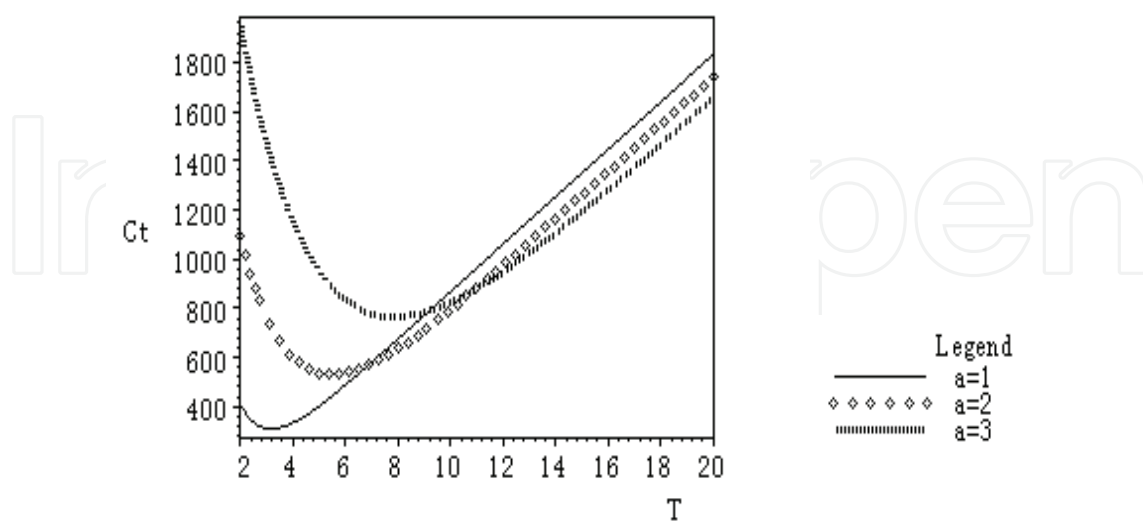


Fig. 7. The relation between  $T$ ,  $a$  and  $C_t$

Tables 1 show the relation between the due time, action time and total expectation cost of the above case. From Table 1, supplier could find out the optimal due time corresponding to

the various action time. For instance, in Table 1, we can note that when action time is 2, the minimum  $Ct$  is 537.0, and the optimal due time would be set at 6.

a	T														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.50	378.6	220.6	256.6	340.2	433.9	529.7	625.9	722.2	818.4	914.7	1011.0	1107.2	1203.5	1299.8	1396.0
0.75	559.2	290.9	267.0	327.4	413.5	507.0	602.6	698.7	795.0	891.3	987.6	1084.0	1180.3	1276.6	1373.0
1.00	765.2	404.4	311.0	333.7	402.3	488.4	581.0	676.0	771.8	868.1	964.4	1060.7	1157.1	1253.5	1349.9
1.25	984.9	549.6	387.7	364.6	406.8	478.8	564.2	655.7	749.9	845.4	941.4	1037.6	1134.0	1230.4	1326.9
1.50	1212.9	717.3	492.3	420.7	430.4	482.3	555.8	640.6	731.0	824.5	919.4	1015.1	1111.2	1207.5	1303.9
1.75	1446.3	901.4	619.8	500.1	474.1	501.4	558.8	633.3	717.4	807.0	899.6	993.9	1089.2	1185.1	1281.2
2.00	1683.2	1097.4	765.7	600.1	537.2	537.0	575.0	636.0	711.1	794.6	883.3	975.1	1068.9	1163.7	1259.3
2.25	1922.7	1302.6	926.5	717.7	618.2	589.0	605.1	650.0	713.6	789.0	872.1	960.1	1051.2	1144.3	1238.7
2.50	2164.1	1514.8	1099.2	850.5	715.3	656.6	649.2	676.1	726.0	791.4	867.2	949.9	1037.2	1127.6	1220.2
2.75	2406.8	1732.5	1281.9	996.2	826.9	738.7	706.9	714.3	749.0	802.7	869.5	945.5	1027.8	1114.6	1204.4
3.00	2650.7	1954.6	1472.7	1153.0	951.2	834.0	777.6	764.6	782.8	823.3	879.8	947.8	1024.0	1106.0	1192.3
3.25	2895.4	2180.2	1670.2	1319.3	1086.8	941.5	860.4	826.5	827.3	853.6	898.6	957.4	1026.3	1102.6	1184.4
3.50	3140.9	2408.8	1873.5	1493.8	1232.3	1059.9	954.6	899.5	882.3	893.5	926.0	974.6	1035.2	1104.9	1181.4
3.75	3386.9	2639.8	2081.6	1675.3	1386.6	1188.3	1059.1	983.0	947.4	942.9	962.2	999.7	1051.2	1113.3	1183.7
4.00	3633.3	2872.9	2293.9	1863.0	1548.8	1325.6	1173.3	1076.2	1022.2	1001.6	1007.0	1032.8	1074.4	1128.2	1191.7

Table 1. The relation between due time ( $T$ ), action time ( $a$ ) and expected total cost ( $Ct$ )

Also, from Table 1, it can be noted that a longer due time should be set when the action time is longer.

#### 4. Conclusions

In this chapter, we proposed a feedback model of the  $\bar{x}$  control chart in which idle and delay risks are considered in order to improve customer satisfaction of supplier. Because of competition in supplier markets, prompt responding to the feedback trouble from the maker is more important.

In the setting of the due time of the treatment to the various assignable cause, because idle cost and delay cost are the trade-off relation, setting the optimal due date becomes a problem of great interest to the supplier.

To resolve this problem, we proposed a feedback model of control chart for supplier and showed their mathematical formulations. Then, to give clearer understanding about the trade-off relation in this feedback case, the behaviors of idle and delay costs are studied by numerical experiments. Moreover, to find out the optimal due time, the relations between the due time and the total expectation cost by the change of action time are discussed. The results obtained in this paper are useful for the setting the optimal due time of the feedback case to supplier.

#### 5. Nomenclature

The notation used is as follows:

$n$  the sample size per each sampling

$v$  the sampling interval

$T$  due time



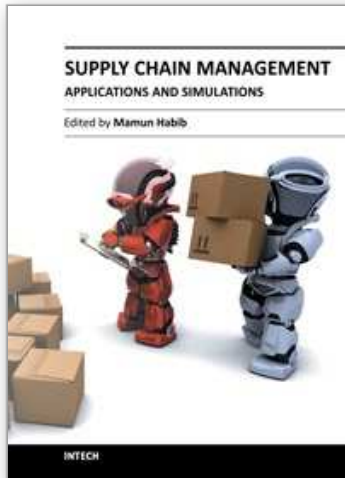
- $c_0$  fixed sampling cost  
 $c_1$  variable sampling cost  
 $c_a$  action cost of per unit time  
 $c_i$  idle cost of per unit time  
 $c_d$  delay cost of per unit time  
 $\delta$  size of the quality shift in the mean  
 $A$  time of action  
 $D$  time of detecting the assignable cause  
 $\mu^{-1}_1$  mean of the  $D$   
 $\mu^{-1}_2$  mean of the  $A$   
 $k$  control limits width

## 6. Acknowledgment

This research was partially supported by Japan Society for the Promotion of Science, a Grant-in-Aid for Research Activity Start-up, 22810011 in 2010.

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## **Supply Chain Management - Applications and Simulations**

Edited by Prof. Dr. Md. Mamun Habib

ISBN 978-953-307-250-0

Hard cover, 252 pages

**Publisher** InTech

**Published online** 12, September, 2011

**Published in print edition** September, 2011

Supply Chain Management (SCM) has been widely researched in numerous application domains during the last decade. Despite the popularity of SCM research and applications, considerable confusion remains as to its meaning. There are several attempts made by researchers and practitioners to appropriately define SCM. Amidst fierce competition in all industries, SCM has gradually been embraced as a proven managerial approach to achieving sustainable profits and growth. This book "Supply Chain Management - Applications and Simulations" is comprised of twelve chapters and has been divided into four sections. Section I contains the introductory chapter that represents theory and evolution of Supply Chain Management. This chapter highlights chronological prospective of SCM in terms of time frame in different areas of manufacturing and service industries. Section II comprised five chapters those are related to strategic and tactical issues in SCM. Section III encompasses four chapters that are relevant to project and technology issues in Supply Chain. Section IV consists of two chapters which are pertinent to risk managements in supply chain.

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