Study on RFID-Enabled CONWIP Control Strategy for Multi-Echelon and Multi-Product Inventory of Supply Chain

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Abstract**—***Radio Frequency Identification (RFID) provides an efficient way to the innovation of inventory control strategies. In this paper, we design a RFID-Enable electronic Card system. And a RFID-Enable CONWIP control strategy is designed based on the system. Five criteria to evaluate the performance of control strategies are presented, which include the total inventory cost, the total shortage loss, the total operating cost, the satisfaction rate and the inventory turnover rate. To verify the performance of the RFID-Enable CONWIP control strategy, the strategy is compared with RFID-Enable (s,S) and Push control strategies. Three typical inventory systems of two kinds of products are simulated in the experiments. The simulation results demonstrate the CONWIP strategy is the best one among the three kinds of strategies. It can reduce the total operating cost and enhance the service level for multi-echelon distribution networks in supply chains.*

Keywords—CONWIP, Electronic Card, RFID, Simulation, Supply chain.

I. INTRODUCTION

The production systems can generally be divided into push and pull systems[1]. Both systems have different advantages[2,3]. Therefore, many researchers try to combine the two types of control systems to achieve more superior performance[4-6].

CONWIP (Constant Work in Process) proposed by Spearman et al. is just such a hybrid system. Similar to a typical Kanban system, production in a CONWIP system is also triggered by actual demand of product[7]. In the system, cards instead of Kanbans that are used between each workstation are assigned to the whole production line.

The invisibility of the wide area cards makes the CONWIP control strategy difficult to apply in the distribution system of the wide-area supply chain. After 2000, some scholars attempt to apply the CONWIP control strategy to supply chain management. The CONWIP SC (CONWIP supply chain) was developed by Oscar Rubiano Ovalle., as an extension of the closed production control system, each firm has a similarity to a "work center" being a part of a "global line" of supply chain. The card in the CONWIP system, extends to a virtual center that governs the supply chain and manages the products flow and the inventories along the chain[8].

However, the card system can't be really used in supply chain, the CONWIP control strategy is the "order pull" or "contract pull" virtually[9-11], it is difficult to give full play to the function of decreasing inventory and improving the service level [12].

The emergence of new automatic identification technologies, such as Radio Frequency Identification (RFID), is expected to revolutionize many of the supply chain operations by reducing costs, improving service levels and offering new possibilities for identifying unique product instances[13].

As the ability of RFID that can count and locate products precisely, it provides a technical way to realize RFID-Enable electronic Kanban system. In paper[14] Push strategy and RFID-Enable Pull strategy are combined to design the RFID-Enable Hybrid Push/Pull control strategy for multi-echelon inventory system in supply chain distribution network. Good results have been achieved in the use of the method. But the strategy does not apply to the multi-product and small batch production. Because the CONWIP strategy is to overcome the limitations of Kanban strategy, so it can be applied to an extensive environment.

In this paper, RFID-Enable CONWIP strategy is realized based on the RFID-Enable electronic card system. To test the availability and superiority of the strategy for the multi-echelon inventory system, it is compared with RFID-Enable push and (s,S) strategies.

II. DESIGN OF RFID-ENABLE CONWIP CONTROL STRATEGY AND THE PERFORMANCE EVALUATION OF CONTROL STRATEGIES

The order, shipment and production of each enterprise in the distribution network can be controlled according to the structure of the supply chain, the supply chain inventory status and the function of the enterprises. To obtain the optimization effect of the supply chain, the inventory status of each enterprise is adjusted according to a certain strategy; different strategies have different control mechanism or algorithm[14].

2.1 Design of RFID-Enable CONWIP control strategy

The RFID-Enable CONWIP strategy can decrease the inventory cost and improve the service level by adjusting the total number of electronic card. The manufacture as the core company in the supply chain is the logistics source of the distribution network, on the stage of manufactures, the material is pulled into the system on the basis of the storage and the shipment. However, the distributors and retailers in the middle and lower of supply chain play the role of distributaries, the push strategy is applied.

The operation of the system is caused by the products removal. Because the change of market environment can lead to the uncoordinated communication between enterprises in the supply chain, it can avoid the extension of multi-stage response time. The input of material can be computed by "amount of empty Card = total amount of Card- amount in storage- amount on traffic". It can be expressed by the following formula simply:

$$E(t) = C - I(t) - S(t)$$

(1)

Where E(t) is the amount of empty card at time t; C is the total amount of the pre-establish card in the supply chain; I(t) represents the total storage amount in the supply chain at time t; S(t) represents the total amount of shipment in the supply chain at time t.

2.2 Indicators Evaluated the Performance of Control Strategies

To assess the performance of the strategies, the following signs and variables are introduced, they are:

m (1, 2, ……M), n (1, 2, ……N), p (1, 2, ……P) :manufacturers, distributors and retailers respectively;

t (1,2……T) : the running days;

$I_{k1}(t)$ (*k* represents *m*, *n* or *p*): the inventory count of the first kind of product in node *k* at the end of the day *t*;

$I_{k2}(t)$ (*k* represents *m*, *n* or *p*): the inventory count of the second kind of product in node *k* at the end of the day *t*;

c_{k1} (*k* represents *m*, *n* or *p*): the unit inventory cost of the first kind of product in node *k*;

c_{k2} (*k* represents *m*, *n* or *p*): the unit inventory cost of the second kind of product in node *k*;

$O_{p1}(t)$: the shortage count of the first kind of product in node *p* at the end of the day *t*;

$O_{p2}(t)$: the shortage count of the second kind of product in node *p* at the end of the day *t*;

os_{p1}: the unit shortage cost of the first kind of product of node *p*;

os_{p2}: the unit shortage cost of the second kind of product of node *p*;

dj_{p1}: the price of the first kind of product of node *p*;

dj_{p2}: the price of the second kind of product of node *p*;

$g_p(t)$: the total requirement count of all kinds of products of node *p* at the day *t*;

$x_p(t)$: the sales volume of all kinds of products of node *p* at the day *t*;

$x_{p1}(t)$: the sales volume of the first kind of product of node *p* at the day *t*;

$x_{p2}(t)$: the sales volume of the second kind of product of node *p* at the day *t*;

In this paper, to assess the performance of the different strategies, the total inventory cost, the shortage loss, the customer satisfaction rate and the inventory turnover rate are took as the evaluation indicators, the denotations of these variables are as follows respectively:

The sum of inventory cost of retailers, distributors and manufacturers is the total inventory cost when the supply chain runs a cycle:

$$E_I = \sum_{t=1}^{T} \begin{aligned} &\Big(\sum_{p=1}^{P}(I_{p1}(t)\cdot c_{p1} + I_{p2}(t)\cdot c_{p2}) \\ &+\sum_{n=1}^{N}(I_{n1}(t)\cdot c_{n1} + I_{n2}(t)\cdot c_{n2}) \\ &+\sum_{m=1}^{M}(I_{m1}(t)\cdot c_{m1} + I_{m2}(t)\cdot c_{m2})\Big) \end{aligned} \tag{2}$$

The total shortage loss of the supply chain that runs a cycle:

$$E_S = \sum_{t=1}^{T}\Big(\sum_{p=1}^{P}(os_{p1}\cdot O_{p1}(t) + os_{p2}\cdot O_{p2}(t))\Big) \tag{3}$$

The total operating cost is the sum of total inventory cost and total shortage loss, It can be expressed:

$$E_T = E_I + E_S \tag{4}$$

The satisfaction rate of the supply chain (the service level of the supply chain):

$$F_r = \frac{\sum_{t=1}^{T}\sum_{p=1}^{P} x_p(t)}{\sum_{t=1}^{T}\sum_{p=1}^{P} g_p(t)} \times 100\% \tag{5}$$

The inventory turnover rate is the ratio of the sales amount to the inventory cost. The sales amount is the product of the unit price of goods by the sales units.

$$R_I = \frac{\sum_{t=1}^{T}\sum_{p=1}^{P}(dj_{p1} x_{p1}(t) + dj_{p2} x_{p2}(t))}{E_I} \tag{6}$$

From the formula (2)-(6), when the multi-echelon inventory system of supply chain is controlled by RFID-Enable CONWIP control strategy, the above five assess indicators are all the independent functions of the decision variables. But their accurate expressions are difficult to give, because the random factors in the supply chain make the variables indeterminate. If using analytic method to solve the problem, many assumptions can lead to erroneous results. Therefore, the simulation model of the system is built based on the principle of discrete event system simulation in the paper.

III. DESIGN AND REALIZATION OF SIMULATION MODEL

3.1 Simulation strategy

Because there are fewer event types and the relations among events are simpler, this paper set up the simulation model with the simulation policy of event scheduling. That is, the future events are all put into the event table, when the simulation program is running, the events table is scanned continuously, and the simulation clock is pushed to the time of the first happened event, it is incremental over time[15].

3.2 Simulation model

The basic steps of constructing simulation model:

(1)Confirming state variables, control variables and statistical variables;

(2)Confirming events in the system, writing corresponding program;

(3)Confirming future event table;

(4)Confirming the priority of event.

The control variable in the system is total number of the electronic card (i.e. TNmax); state variables are the stock and the transport quantity of every enterprise; statistical variables are the total shortage loss, total inventory cost, total operating cost, satisfaction rate and inventory turnover rate of the supply chain.

3.3 Simulation program

The system has applied the mature object-oriented programming technology with Visual 2010/C#. There are manufacturer class, distributor class, retailer class and customer class in the program, the member variables of related classes include state variables and statistical variables, and they can be updated with the operation of the program. Therefore, the structure of the program is clear. The program can realize the simulation model and it can be modified based on the actual situation.

IV. SIMULATION EXPERIMENT AND RESULTS ANALYSIS

a. Parameters setting for simulation experiment

To analyze the performance of the RFID-Enable CONWIP strategy, various structural systems are simulated and analyzed. Due to space limitations, there are only three systems that are shown in the figure below.

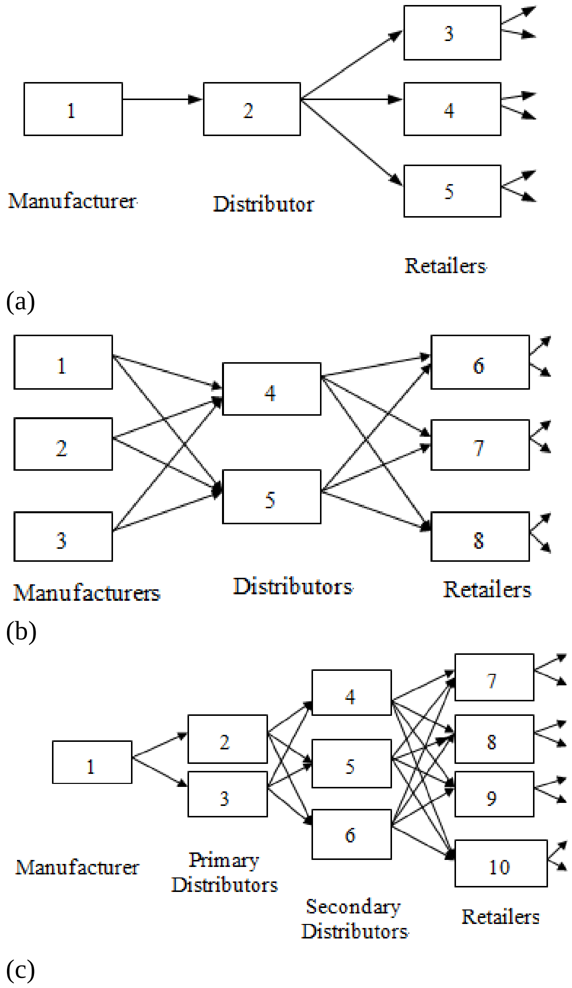

Fig.1 Structural diagram of the three kinds of system

Two kinds of products are considered in the simulation, it is assumed that the demand of each kind of product at the retailers is a random variable which follows Poisson distribution. Every enterprise in the supply chain is likely to be out of stock, however we only calculate the shortage loss of the retailers. The transport time from manufacturers to primary distributors is 3 days, others are all 1 day. One cycle of the simulation system includes 100 days. The prices of the two kinds of products are 10 and 12 respectively.

The total number of electronic card determines the quantity of products in the supply chain that is controlled by RFID-Enable CONWIP strategy, so it is a key factor of the system and it can be obtained by experiments in this paper. The total amount of cards of the structure a, b and c are 86, 126 and 214 respectively.

The RFID-Enable CONWIP strategy is compared with (s,S) strategy and push strategy. The (s, S) values of each node are obtained by the simulation based optimization approach[15]. The specific parameters of the above three systems are shown in Table 1 and Table 2.

b. Results analysis

Because the multi-echelon inventory problem is influenced by uncertainties. To make the simulation results much more actual and credible, every system controlled by each strategy runs 100 times to get the mean of every statistical variable. The experiment results are given in table 3. The ratio of the standard deviation and the expectation is included in table 3. The value can reflect that the times of simulation is reasonable, and it can also reflect that the simulation model has sufficient stability. The inventory turnover rate comparison of b system controlled by each strategy is shown in figure 2. The X-axis of figure is simulation cycle and Y-axis is the turnover rate.

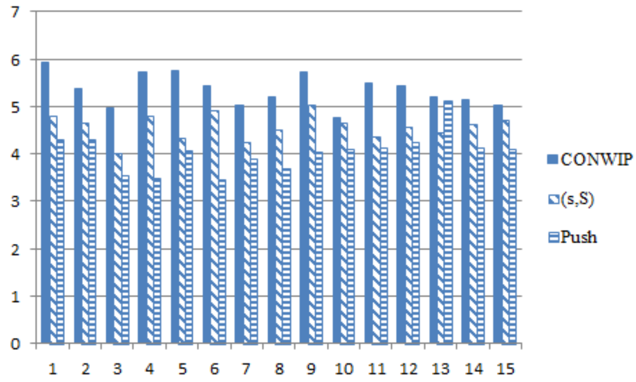

Fig.2 The inventory turnover rate comparison of b system controlled by each strategy

The simulation results show: In the case of the same structure and parameters, the total cost of RFID-Enable CONWIP strategy are the lowest, because of the high storage, the customer satisfaction rate of Push are the highest.

Figure 2 shows the comparison of the inventory turnover rate in the first 15 cycles of the b structure. As shown in the figure: the turnover rate of CONWIP strategy are greater than that of Push and (s,S) strategies, the higher the value, the greater the effect of unit inventory play. Through experiment, the total amount of RFID-Enable electronic Card can be set based on the inventory status and the state of market demand. That is, the RFID-Enable CONWIP strategy has the characteristics of flexibility. In addition, the policy parameters have great impact on the system performance besides the control strategy.

Table 1. Parameters of the first kind of the product

	Parameters	1	2	3	4	5	6	7	8	9	10
a	The initial storage	5	5	5	5	5					
	Unit inventory cost	0.4	0.5	0.4	0.7	0.6					
	Unit shortage loss			6	6	6					
	Parameters of Poisson distribution			3	2	2					
	Parameters of (s,S) strategy	(2,24)	(6,24)	(6,18)	(6,20)	(7,15)					
b	The initial storage	8	8	8	8	8	8	8	8		
	Unit inventory cost	0.4	0.3	0.7	0.5	0.6	0.4	0.7	0.6		
	Unit shortage loss						6	6	6		
	Parameters of Poisson distribution						3	2	2		
	Parameters of (s,S) strategy	(4,15)	(2,15)	(2,7)	(5,16)	(7,12)	(6,17)	(5,15)	(6,7)		
c	The initial storage	20	10	10	10	10	10	5	5	5	5
	Unit inventory cost	0.2	0.3	0.7	0.5	0.6	0.8	0.7	0.4	0.6	0.5
	Unit shortage loss							6	6	6	6
	Parameters of Poisson distribution							2	4	5	1
	Parameters of (s,S) strategy	(5,28)	(4,11)	(4,17)	(4,20)	(3,11)	(5,11)	(6,9)	(3,26)	(5,14)	(3,7)

Table 2. Parameters of the second kind of the product

	Parameters	1	2	3	4	5	6	7	8	9	10
a	The initial storage	5	5	5	5	5					
	Unit inventory cost	0.5	0.4	0.3	0.5	1.0					
	Unit shortage loss			8	8	8					
	Parameters of Poisson distribution			2	1	2					
	Parameters of (s,S) strategy	(3,20)	(5,20)	(6,19)	(5,14)	(5,17)					
b	The initial storage	8	8	8	8	8	8	8	8		
	Unit inventory cost	0.5	0.2	0.5	0.4	0.8	0.3	0.5	1.0		
	Unit shortage loss						8	8	8		
	Parameters of Poisson distribution						2	4	1		
	Parameters of (s,S) strategy	(4,9)	(2,8)	(2,6)	(5,22)	(6,13)	(5,13)	(6,12)	(2,9)		
c	The initial storage	20	10	10	10	10	10	5	5	5	5
	Unit inventory cost	0.2	0.5	0.6	0.6	0.8	0.5	0.5	0.7	0.4	0.5
	Unit shortage loss							5	5	5	5
	Parameters of Poisson distribution							3	3	3	2
	Parameters of (s,S) strategy	(4,15)	(4,20)	(7,18)	(3,13)	(2,14)	(5,11)	(2,25)	(6,20)	(3,16)	(2,22)

Table 3. The Statistical Variables of the Three Kinds of Systems Controlled by Strategies

	Strategy	Inventory Cost Expectation, Ratio of the Standard Deviation and Inventory Cost Expectation		Shortage Loss Expectation, Ratio of the Standard Deviation and Shortage Loss Expectation		Total Cost Expectation, Ratio of the Standard Deviation and Total Cost Expectation		Satisfaction Rate Expectation, Ratio of the Standard Deviation and Satisfaction Rate Expectation	
a	CONWIP	996.04	13.86%	1383.30	13.96%	**2379.34**	7.73%	80.67	2.33%
	(s,S)	1341.74	17%	2061.80	18.44%	3403.54	9.70%	73.42	4.71%
	Push	3041.85	11.34%	190.78	34.74%	3232.63	12.13%	**97.11**	0.93%
b	CONWIP	2392.16	5.18%	1580.88	14.68%	**3973.04**	6.41%	81.6	2.82%
	(s,S)	2677.11	5.72%	1777.84	17.45%	4454.95	6.17%	81.52	3.19%
	Push	3362.57	10.2%	1017.86	15.54%	4380.43	9.04%	**88.78**	1.70%
c	CONWIP	2648.63	5.63%	2573.69	15.58%	**5222.32**	7%	80.03	2.86%
	(s,S)	1849.35	7.57%	4264.73	11.19%	6114.08	5.92%	66.06	3.84%
	Push	9368.93	13.25%	2320.37	7.93%	11689.3	10.78%	**81.23**	1.73%

V. CONCLUSIONS

In the paper, the RFID-Enable CONWIP strategy on the basis of RFID-Enable electronic Card is applied to multi-echelon inventory system of supply chain distribution networks. The strategy model is built and the simulation system is developed, with the help of the system, we can evaluate the performance of the strategy. Through the comparison with the RFID-Enable (s,S) and Push strategies, the RFID-Enable CONWIP strategy can save the total cost and improve service level effectively. In conclusion, this strategy should be applied to the practice.

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