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A Shared Information-Based Petri Net Model for Service Parts Planning

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A SHARED INFORMATION-BASED PETRI NET MODEL FOR SERVICE PARTS PLANNING

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ABSTRACT

A considerable amount of electronic products are returned after sales, especially in such an economic downturn situation. After repair and refurbishment, the used products can be returned into the markets which fulfill the forward supply chains into a close loop. In this paper, we consider the service parts planning in the beginning of product rolling plan together with the sales through quantities to minimize the inventory level in the period of product lifecycle. A Petri Net is used to model a simple closed-loop supply chain with shared sales information. PUSH and PULL inventory policies are used in this research. Finally, it is investigated how a third party service provider uses this mechanism to improve the accuracy of inventory planning.

Keywords: Petri Nets, reverse supply chains, service parts planning, closed-loop supply chains

INTRODUCTION

Reverse supply chains become a manifest subject in the manufacturing industry of electronic products not only because it introduces a lot of e-waste, but also theoretically it can repair, refurbish the returned defectives and then re-sell to the markets to gain profits which makes the supply chain as a closed loop.

However, the industry is not benefited from this operation because of the unexpected cost of service parts during the after sales service. The uncertain quantities of returned defectives increase the difficulty of service parts planning and preparation which lead to over stock or backlog of returned defectives. The former will run short of cash flow and increase the inventory, and the latter will cause customer complaints.

Information sharing plays an important role and changes some rules in supply chain management. Quick responses and vendor managed inventory (VMI) improve the lead time of inventory. Moreover, efficient consumer response (ECR), collaborative planning forecasting and replenishment (CPFR) all base on and benefit from information sharing.

The industry is seeking for an efficient and effective way to minimize the inventory level but not impact on the service quality at the same time. Moreover, the business model of after sales is changing: brand owners do not buy warranty services from manufactures any more. That’s why there are rooms for third party service providers to grow in these years.

The purpose of this research is to use a Petri Net to model a common closed-loop supply chain framework, and to provide a systematic way to predict the incoming quantities of returned defectives and to prepare the service parts so the back log of returned defectives can be avoided, and keep the minimum numbers of service parts that won’t impact the service quality. In this research, a single stock point of third-party service provider is proposed. Together with shared information, a Petri Net model is used to depict a common closed-loop supply chain process in practice.

LITERATURE REVIEW

Inventory replenishment policy has been studying for a long time. Economic order quantity (EOQ) was first introduced by Ford Harris in 1913 [11], which provided an economic way for purchasing at a fixed period with fixed quantities if the demand is fixed. It was unnoticed for many years before its rediscovery in 1988 [9]. The initial study of increasing demand of inventory policy was done by Resh [23]. After that, many researchers developed other heuristic models and technique by iterative numerical algorithms or two-equation model of analytical inventory policy [21]. Supply Chain Council [27] also suggests SCOR model to improve the operational efficiency with minimum inventory level by demand planning and information transparency [13][27]. The above are all about deterministic solutions that consider when and how many. The pattern of inventory replenishment in reverse supply chains is not deterministic. There is no obvious information when and how many defectives will be returned; therefore, EOQ and any other deterministic solutions are not applicable.

Shared information can be inventory, sales, demand forecast, order status, and product schedule [17][38]. Shared information among supply chains can also help to shorter lead time and smaller batch sizes. Information can be demand, inventory data [3], or quantities of installed base [8][14].

In the past 10 years, the study of reverse supply chains, or closed-loop supply chains become a prominent topic over last decade. A literature survey on quantitative model for inventory and production planning in closed-loop supply chains reveals the research aspects by the stock points [2]. Systems with one stock point [6][15][37] use manufactured and remanufactured item inventory (MRII) to fulfill services. Two stock points systems [29][33][34][35] utilize used item inventory (UII) and remanufactured item inventory (MII), or MRII, to fulfill the demand; systems with three stock points [24] or multiple stock points [28][30][19 use UII, MII, MRII, new material inventory (NMI) or multiple of them to provide the inventory services. Some researches [20][31] assume demand rate as normal distributions, [12] even assumes both demand rate and return rate follow normal distribution, segment product lifecycle into introduction, growth, maturity and decline four sections with different demand rate, and calculate the minimum cost of lot size respectively. IBM [10] proposes an analytic inventory control model and a simulation model that helps to reduce procurement cost. [35] also showed that manufacturing lead-time has higher impact and cost than remanufacturing lead-time in the PUSH and PULL control strategies.

Petri Nets have been using to model business [26][32], IT systems [16][18], and supply chains [4][36]. Researches also propose a methodology to bridge the gap between business process modeling and specification [7].

A PETRI NET MODEL FOR CLOSED-LOOP SUPPLY CHAINS

A Petri Net Model for Supply Chains

A supply chain consists of all parties involved, directly or indirectly, in fulfilling a customer request. The supply chain not only includes the manufacturer and suppliers, but also transporters, warehouses, retailers, and customer themselves [5].
A normal supply chain can be modelled as the following Petri Net as Figure 1.

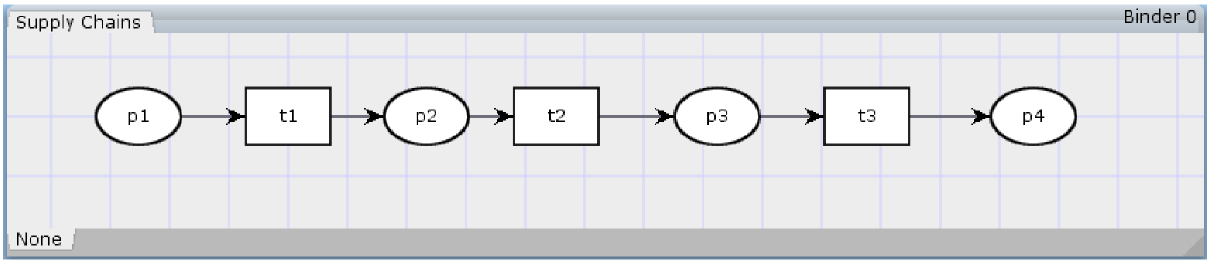

Figure 1. A Petri Net Model for Common Supply Chains

When a new product is introduced into the markets, a product rolling plan will be come along with the manufacturing plan. A product rolling plan includes when and how many to be manufactured in a period of time.
All places and transactions are described in Table 1.

Table 1. Descriptions of Petri Nets of Supply Chains

Places	Descriptions	Transitions	Descriptions
p1	start	t1	rolling plan
p2	plan for manufacture	t2	manufacturing
p3	product ready	t3	sell through
p4	sold to customers		

A Petri Net Model for Closed-Loop Supply Chains

The logistics of after sales services together with product lifecycle management is considered as a closed-loop supply chain. In this research, we use two stock points to describe our model as Figure 2.

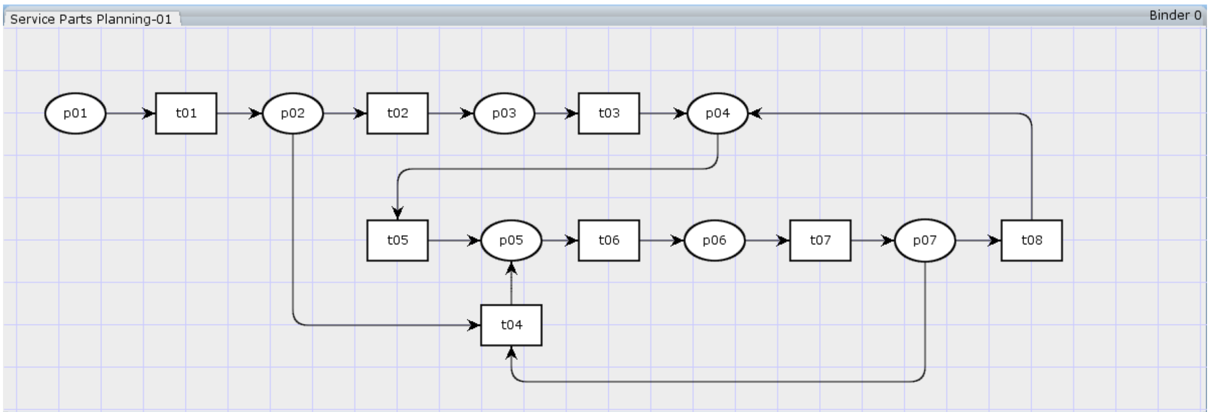

Figure 2. A Petri Net Model for Closed-Loop Supply Chains

In a closed-loop supply chain, customers return their defectives to the service centers, then pass to the authorized service partner (ASP). ASP not only receives and repair the defectives but also orders new parts to fulfill the service turnaround time (TAT) even the manufacturing cost is higher than remanufacturing (van der Laan et al., 1999). After remanufacturing and refurbishment, the goods will be returned to customers. The descriptions of the Petri Net for Figure 2 are described in Table 2.

Table 2. Descriptions of the Petri Net for Closed-Loop Supply Chains

Places	Descriptions	Transitions	Descriptions
p01	start	t01	rolling plan
p02	plan for manufacture & services	t02	manufacturing
p03	product ready	t03	sell through
p04	customers receive	t04	new service parts orders
p05	receive defectives(RMA)	t05	customer return
p06	receive new parts	t06	remanufacturing
p07	inventory re-calculation	t07	refurbishment
p08	close RMA	t08	finish
		t09	return to customers

INDUSTRIAL STUDY

Mathematical Notations

RP[t]: product rolling plan
D[t]: returned defective quantity at time t
FD[t]: forecast demand at time t
S[t]: shipping quantity at time t
w: warranty period
It: inventory level at time t
Flt: forecast inventory level at time t
Lt: lead time at time t
ARP_t: after sales quantity of repair parts at time t
IRP: initial quantity of repair parts
MFR: mean failure rate
t: product annual failure rate of service part item at time t

Mathematical Models

We follow the flows of the model as described as above. Table 3 shows a 8-month new product introduction (NPI) plan from a notebook ODM in China market in year 2010.

Table 3. NTI Plan

Month	1	2	3	4	5	6	7	8
Rolling Plan Qty	22985	45743	47987	25976	73860	39753	38294	6005

The targets of in-warranty after sales service are the goods which have been sold to the customers but are returned due to malfunction or non-customer-induced defectives. It is easy to transform NPI into accumulated service quantity in warranty period as Figure 3 shows. The total in-warranty service duration of this product launch is 17-month which is eight-month rolling period plus nine-month in-warranty period.

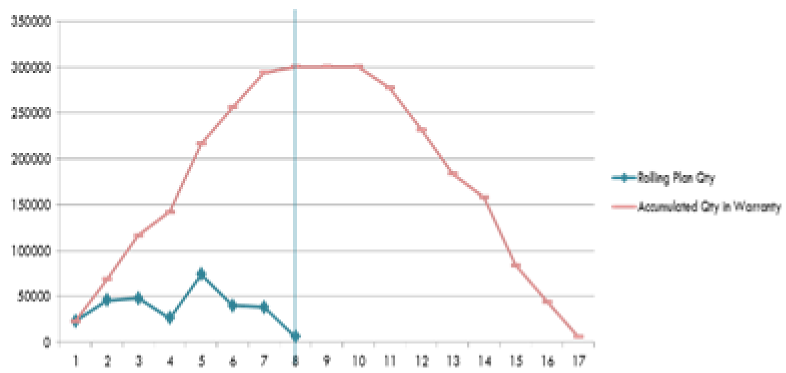

Figure 3. NPI quantities and quantities under warranty

The IRP of three-month inventory for service parts are pushed to the ASP. The quantities can be calculated by the follow formula

$$IRP = I_1 = \sum_{i=1}^{3} RP[i] * MFR * 3 \qquad (1)$$

Inventory numbers are deducted in the end of every month, and order is fulfilled in the beginning of every month. Negative balanced number means short of inventory.

There is no more ARP in the next two months; therefore, the next inventory level is

$$I_2 = I_1 - D[1] \quad (2)$$

$$I_3 = I_2 - D[2] \quad (3)$$

During the warranty period, defective products are returned to service center. Together with product shipping quantities, the revised failure rate can be calculated as sum of returned quantities divided by total shipping quantities.

$$\alpha_{x-1} = \frac{\sum_{i=1}^{x-1} D[i]}{\sum_{i=1}^{x-1} S[i]} \quad (4)$$

The inventory level of next forecasting period at time x can be calculated by using revised failure rate at time x-1, multiplies the number of quantities that are expected in the period of time x.

$$FD[x] = \alpha_{x-1} * \sum_{i=1}^{x} RP[i] \quad (5)$$

And the purchase quantity for time x is the expected service quantities minus the quantities in the end of time period x-1 only when FD[x] is greater than I_{x-1}.

$$FD[x] - I_{x-1} \quad (6)$$

Therefore, the beginning inventory level of time x equals to the ending inventory of time x-1 plus the purchasing quantity for time x.

$$I_x = FD[x] - (I_{x-1} - D[x-1]) \quad (7)$$

If the parts venders can not provide the service parts to the end of the warranty period, the last buy will be triggered. Last buy happens during the warranty period, and it means to issue one purchase order to fulfill service inventory to the end of service period.

Last buy at time x denotes:

$$\alpha_{x-1} * (RP[w] - RP[x]) - I_{x-1} \quad (8)$$

where x < w.

The earlier the last buy is triggered, the higher risk insufficient or over stock there will be.

Evaluations and Results

The above inventory information is from Run Service Pte. Ltd., a Singapore-based third party service provider for computer, communication and consumer product after sales services. One key part (single item) is considered as the defective item. NPI plans and shipping quantities were shared by OEM and ODM. After sales service information can be transparent to ODM and OEM by the third party service provider.

Table 4. Initial data with inventory calculation

Month	1/S	1/E	2/S	2/E	3/S	3/E	4/S	4/E	5/S	5/E	6/S	6/E	7/S	7/E	8/S	8/E
Rolling Plan Qty	22985		45743		47987		25976		73860		39753		38294		6005	
Accumulated Qty In Warranty	22985	22985	68728	68728	116715	116715	142691	142691	216551	216551	256304	256304	294598	294598	300603	300603
Theoretical Service Items	38		114		194		237		360		427		490		501	
PUSH IRP	346															
Return		20		102		150		201		382		411		486		519
revised avg. AFR		0.01044		0.01596		0.01566		0.01617		0.01807		0.01844		0.0188		0.0192
PULL ARP							189		282		345		443		461	
S. Inventory Level		326	326	224	203	74	263	-12	270	-112	233	-178	265	-221	240	-279

Table 4 shows how IRP and ARP are calculated. In the beginning, three-month IRP inventory were calculated with initial failure rate, and pushed to a third party ASP. After that, ARP can be calculated on revised failure rates and projected quantities in warranty period. The initial failure rate is used by the average and experiences from the industry. In the mean while, the failure rate is keeping revised in every month. No last buy happened in this research. Service parts are deducted from inventory in the end of every month, and ordered parts are arrived and added into inventory in the beginning of every month, respectively.

The result of inventory level is shown as Figure 4.

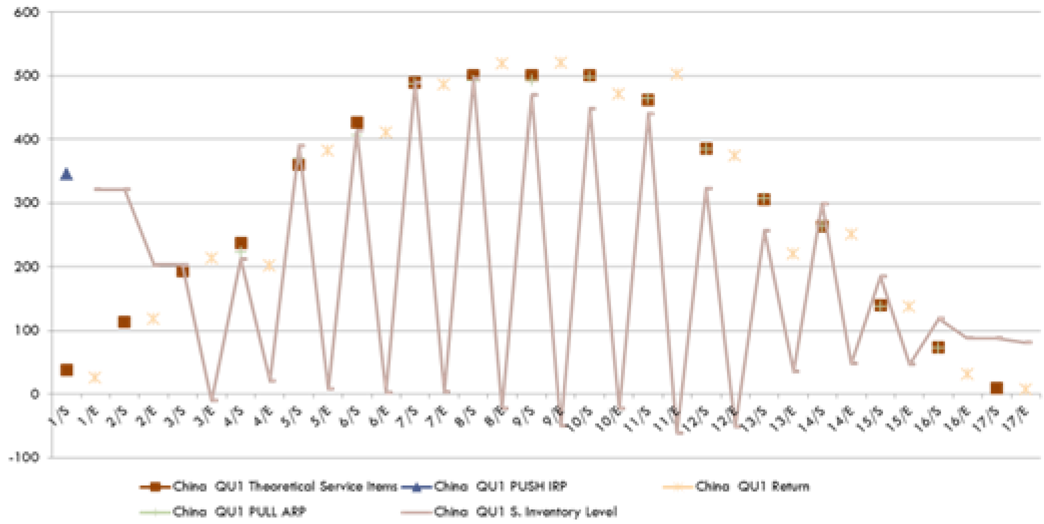

Figure 4. Inventory Level

In this study, an eight-month product plan together with nine-month warranty period was used. It happened six times that inventory was below the demand, and the short of service rates are between 4% and 14%; moreover, overstock rates are 1% to 19% in the previous 14 months which is better than the industrial experience of 20% [25]. The overstock rates of the last three months are extremely high partially because less return defectives in the end of warranty period. Anyway, it is an interesting topic to study what if the abnormal (much higher or less than average) returns happen, and how to adopt a better replenishment policy in the end of warranty period to avoid over stock in the end.

CONCLUSIONS

In this research, we propose a heuristic model of information sharing among ODM, OEM and the third party service providers to provide service parts planning for after sales services. In this model, both PUSH and PULL policies are used, and the service parts planning mechanism is easier and simpler than previous research [12] because of fewer variables and assumptions; moreover, service information as a service can also be a new business model fed back to ODM and OEM in the future.

However, there are still rooms for improvements. In this model, safety stock is not considered, therefore, backlogs happen. It can be solved by introducing service level to define safety stock, or consider some algorithm like statistical process control used in manufacture process control. Furthermore, the model can be extended with the product lifecycle more than just warranty period [1], and the reversed bullwhip effect [22] must be also considered to be prevent. A high-level Petri Nets for closed-loop supply chains can also help to construct a robust model.

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