Production Planning for Closed Loop Supply Chain with Recycle Parts and Product Life Cycle

Ryuhei Kajiyama and Tomohiro Murata.

***Abstract*— Recently years, it is becoming important to build a "Closed Loop Supply Chain (CLSC)" that collects used products and reuses them. A CLSC is a way of recovering used products from the market and reusing parts to reduce production costs and improve the profit of the entire supply chain. Also, the Product Life Cycle has been shortened due to diversification of products and demand management becomes necessary to make total sales profit.**

Therefore, I thought two stage demand management with recycle parts in CLSC for Extending product life cycle is promising way. In fact, it is difficult to control the second demand amount for profit and the collection rate to satisfy it, so this research on addressing these problems is effective. Further, I formulate the method for the production planning with two stage demand management by Mixed Integer Programing optimization model. And maximize SCM total profit by controlling recovery rate and second demand start time.

***Index Terms*— Closed Loop Supply Chain (CLSC), Demand Management, Product Life Cycle, Reverse Logistics.**

I. Introduction

IN recent years, the demand for resources has increased. Also "Environmental protection" and “Resource saving” are becoming important. Therefore, there is a need to establish a Closed Loop Supply Chain (CLSC) that expands profits by reusing recycled parts obtained from it (Fig1).

Also, the Product Life Cycle has been shortened due to diversification of products and demand management becomes necessary to make total sales profit. Therefore, I thought two stage demand management with recycle parts in CLSC for Extending product life cycle is promising way (Fig2). In fact, there are few studies on CLSC, there is also no research combined with demand management in previous research. In addition, it is difficult to control the second demand amount for profit and the collection rate to satisfy it, so this research on addressing these problems is effective.

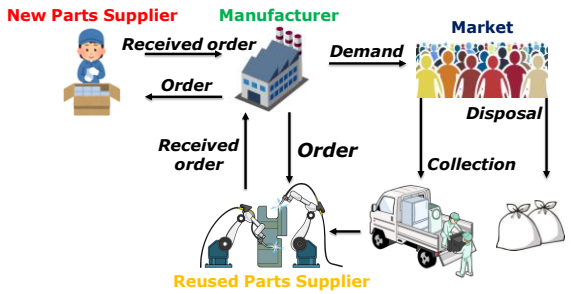

Fig1. Closed Loop Supply Chain

Ryuhei Kajiyama, Graduate School of Information, Production and Systems Waseda University, Japan (e-mail : ryuhei0554@akane.waseda.jp)
Tomohiro Murata, Professor Graduate School of Information, Production and Systems Waseda University, Japan (e-mail : t-murata@waseda.jp)

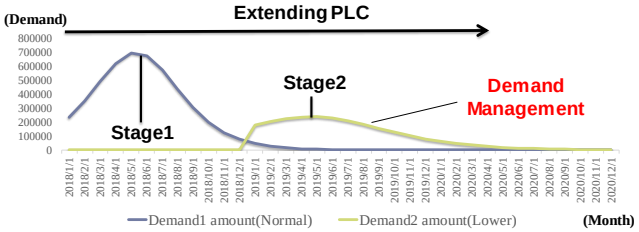

Fig2. Image of two stage demand management

II. Research Goal

In this research, proposing a novel production planning method for two stage demand management with recycle parts in CLSC model to maximize total sales profit.

In addition, considering the “collection rate” of the recovery product from the initial demand and the “sale start time” of the second demand in the CLSC model, the objective is to find a combination for max profit of the entire supply chain due to each fluctuation.

Also, formulating the model for the production planning with two stage demand management by Integer Programing optimization model and evaluating the proposed model with case study to find feasible condition to increase max profit.

Through four experiments, I examined the effectiveness of the model proposed in this research.

III. Survey of Related Research and Drawbacks

Summarized the previous research on the Closed Loop Supply Chain as follows. Kaya studied incentives and product reproduction. Samar studied the reproduction model considering the quality of recycled parts. Watanabe [1] collected used products by paying incentives and decided the optimal order amount according to the quality level of the collected products. Kainuma [2] is doing a lot of research on the recycling type supply chain, and He studied the effectiveness of VMI under the closed supply chain. Kaya [3] studied incentives and product reproduction. Samar [4] studied the reproduction model considering the quality of recycled parts.

However, there were no studies reusing parts recovered by CLSC for two stage demand.

Problem Description

A. Closed Loop Supply Chain model

The CLSC model proposed in this research is as shown in the figure (Fig3). The CLSC model consists of one

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manufacturer, one new parts supplier, and one recycled parts supplier. Manufacturers produce two products, "Normal Priced Product" and "Lower Price Product".

First of all, "Normal Priced Product" is distributed to the market. Later, these products are recycled by recycled parts supplier from the market by collection rate "c". Recycled parts supplier disassembles and inspect the collected products. Recycled parts are reused as "Lower Priced Product". Also, when demand can't be satisfied by recycled parts, it is procured new parts and manufacture products.

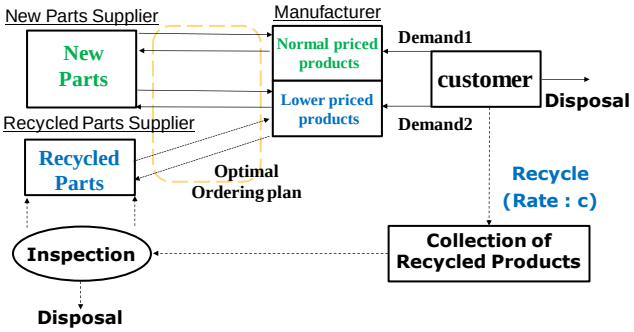

Fig3. Closed Loop Supply Chain model

B. Initial Demand Model (Bass Model)

Initial demand is expressed by using "Bass model". The result is as shown in the figure below (Fig4).

The Bass model is a demand forecasting model formulated by adding customer's purchasing behavior to the logistic curve. It is a model suitable for simulating the diffusion process of durable consumer products in particular. The Bass model is formulated as follows and is composed of "Maximum cumulative sales amount: m", "External influence factor: p", "Internal influence factor: q", and "Time: t".

$$D1_t = m(p+q)^2 \, e^{-(p+q)t} / (p + qe^{-(p+q)t})^2 \quad (1)$$

C. Collection Amount Model (Bass Model)

The amount of recycle products from the initial demand is determined by the following formulation. It is formulated by adding "Collection Start Time: Δ t" and "Collection Rate: C" to the initial demand model. (Fig4)

$$CL_t = c \times D1_{(t-\Delta t)} \quad (2)$$

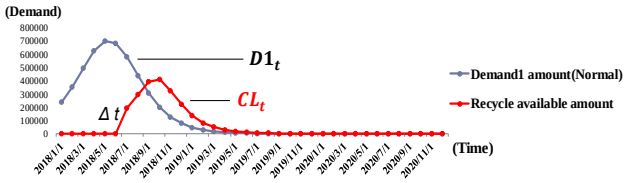

Fig4. Initial Demand and Collection Amount Curve

D. Second Demand Model (Bass Model)

The second demand is determined from the formulation that when Sales Start Time "s" is delayed, the total demand amount also decreases by "d" (Fig5). There is the following trade-off by adding conditions.

When sales start time is early, demand is high, but inventory of recycled parts is small and manufacturing price increases. When sales start time is later, demand decrease and it can't be got profit.

$$D2_{t,s} = \{m(p+q)^2 \, e^{-(p+q)t} / (p + qe^{-(p+q)t})^2\} \times \delta_s \times (1 - d \times (t-s))$$

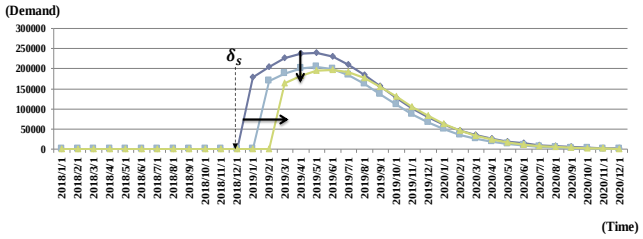

Fig5. Second Demand Curve

E. Max Profit Function

The formulation for obtaining the maximum profit is as follows.

Max Profit = Total sales of Lower priced Products
- (Procurement cost of Recycle parts + Procurement cost of New parts) - Inventory cost of Recycle parts

IV. Formulation of the Problem

A. Symbol

I set symbols for max profit function (Table1).

TABLE I
SYMBOL FOR MAX PROFIT FUNCTION

Symbol	Quantity
D1	Demand amount of "Normal Priced Products" at time t
D2	Demand amount of "Lower Priced Products" at time t
m	Total demand amount
p	Prospect of starting to use it under the influence of Ad
q	It is expected that the products will be affected by people
d	Demand reduction rate
IL_t	Inventory amount of "Lower Priced Products" at time t
ILC	Inventory cost of "Lower Priced Products"
CR_t	Amount of available recycle parts at time t
c	Collection rate of recycle products
PN_t	Procurement amount of new parts
PR_t	Procurement amount of recycle parts
PNC	Procurement cost of new parts
PRC	Procurement cost of recycle parts
PL	Price of "Lower Priced Products"
δ_s	Decision making [0, 1] of sale start time

Object Function for Max Profit

I formulated a function that decides "Optimal Sales Start time" for maximize profit. The expression is as follows. Also, calculate as below the procurement amount of recycled parts and inventory amount.

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$$PROTFIT(s) = \sum_{t=1}^{36} SPL \times D2_{t,s} - \sum_{t=1}^{36} ILC \times IL_t - \sum_{t=1}^{36} (PNC \times PN_t + PRC \times PR_t)$$

$$PR_t = \{(D2_{(t-1)} + D2_t + D2_{(t+1)})/3\} - IL_t$$

$$IL_t = IL_{(t-1)} + PR_{(t-2)}$$

V. Method to Solve the Problem

This research is solved by the following method. While changing the values of "collection rate" and "sales start time" to the formulated CLSC model, find the combination that will maximize profit under the given parameters. Also, simulation is done by coding in R language.

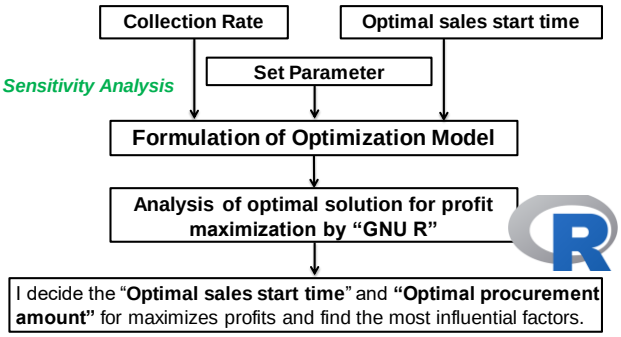

Fig6. Method to solve of my research

VI. Experiment

In this research, conducting "Four experiments". The contents of the experiment are as follows. In addition, each parameter was set as shown in Table 2. Similar values were used in all experiments.

TABLE 2
SET PARAMETERS

Symbol	Quantity	Value
T	Total Life Cycle	36 (Month)
p	Innovation effect for Demand1	0.03
q	Imitation effect for Demand1	0.5
m	Total amount of Demand1	5000000
p	Innovation effect for Demand1	0.06
q	Imitation effect for Demand1	0.25
m	Total amount of Demand1	5000000
c	Collection Rate	0.1 ~ 0.9
PNC	Procurement Cost of New Parts	70000
PRC	Procurement Cost of Recycle Parts	40000
ILC	Inventory Cost of recycle Parts	10000
SPL	Sale Price of Lower Priced Product	100000

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A. *Experiment1*

Finding "Optimal sales start time" and "Procurement plan and Inventory plan of recycle parts" under the given conditions. In this experiment, I set the collection rate as "0.5". The result is as follows (Fig7).

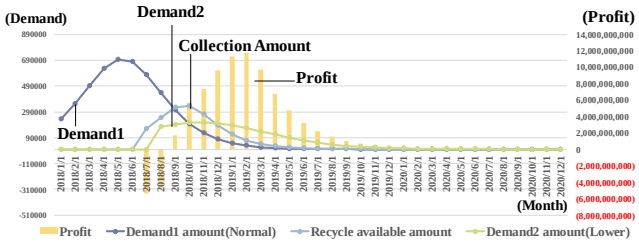

Fig7. Results under the given condition

Firstly, the reason why the profit became negative was that the recycled parts were not recovered enough to satisfy the demand, and because the procurement costs took to satisfy the demand with new parts, it can be said that this resulted.

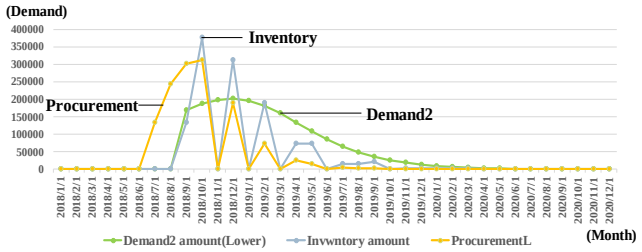

Fig8. Behavior of Inventory and Procurement Recycle Parts

The above figure shows the behavior of inventory amount and recovered amount of recycled parts.
When inventory amount increased more than demand, it was such a result because recycled parts were conditioned not to procure.

B. *Experiment2*

In this experiment, finding the combination of the sales start time "s" and collection rate "c" for max profit. In experiment 1, I decided the optimal sales start time under given conditions. In experiment 2, changing the sales start time and the collection rate of recycled parts and finds the combination with the maximum profit (Fig9).

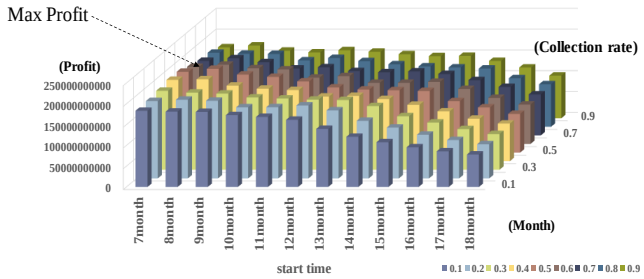

Fig9. Combination of the sale start time and collection rate

Overall, when collection rate was small and sale start time was delayed, max profit decreased. The reason is that when the total demand amount decreased, the sales start time was delayed and max profit decreased also.

Similarly, the lower the recovery rate, the lower the overall profit. It is thought that this is because the collection amount can't satisfy the demand amount and it was supplemented with new parts, so it took procurement cost.

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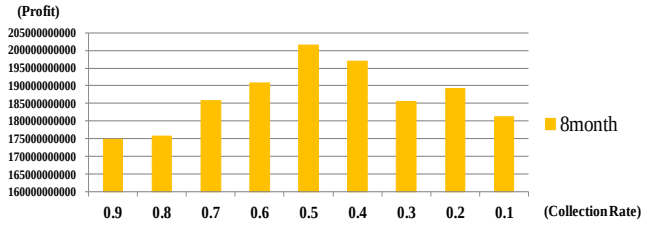

Fig10. Relationship Max Profit and Collection Rate

when collection rate is high, inventory cost increased, and when collection rate is small, because procurement costs of new parts are required, it is considered that the maximum profit was obtained at the collection rate of 0.5. At the time of this combination the maximum profit could be obtained "54322876667", which was about 15.7% better than when no second demand management was done (Fig11).

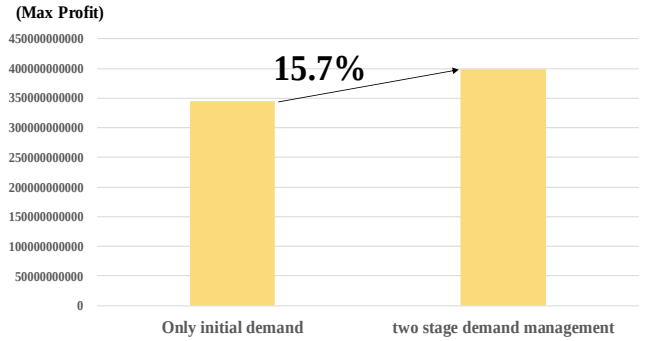

Fig11. Profit improvement rate

C. *Experiment3*

In this experiment, finding second demand boundary for getting profit by two stage demand management. In Experiments 1 and 2, the second demand was set to be less than 50% of the initial demand. By doing this experiment, I find the required demand for profit. By finding this necessary demand amount, it becomes a criterion as to whether or not profit will be obtained when forecasting demand. The conditions of the experiment are the combination of the sales start time and the collection rate for the maximum profit.

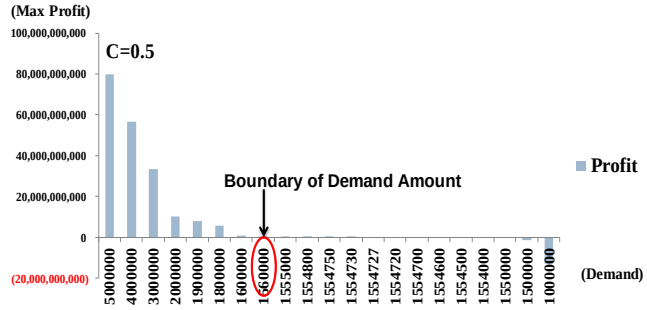

Fig12. Boundary of "Max Profit" and "Demand Amount"

Above figure shows the results of this experiment. The experiment started with the same amount of demand as the initial demand, and gradually decreased from there. As a result, I found that the required demand amount will be profitable even if it is even smaller than the demand amount set initially.

D. *Experiment4*

In this experiment, finding recycled parts cost boundary to get total profits by two stage demand management. Experiment 4 was performed under the same conditions as in Experiment 3. By finding the boundary of recycle parts cost, it is possible to increase profits. The cost of recycled parts was experimented from the same price as the new parts, and the cost was gradually reduced. When the price was equivalent to that of the new part, it was impossible to obtain profits as expected from the experiment. The price at which profit actually appears is about 3 times the price set at the beginning. The following figure is the result of this experiment, the circled position is the boundary.

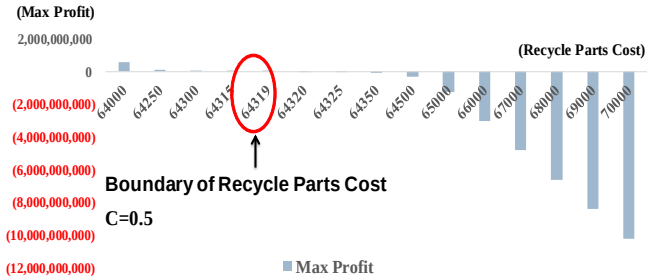

Fig13. Boundary of "Max Profit" and "Recycle Parts Cost"

VII. Conclusion

In this research, I created "Two Stage Demand" by creating CLSC model and reusing recycled parts, and expanded the profit. In addition, I formulated the CLSC model and simulated under constraint conditions and conducted five experiments. By coding in R language and changing parameters, I was able to satisfy all experiments. Through four experiments I found a combination for the maximum profit of "collection rate" and "sales start time" "lead time of recycle parts". I also found boundaries of recycled parts prices and demand amount for maximum profit.

However, I've already known that how much "demand amount" by Bass Model in this research, so I can say that it was a slightly different environment from the real problem.

For that reason, I would like to conduct a similar experiment under the circumstance where the amount of demand is uncertain in the future.

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