Dynamic Analysis of Reverse Supply Chain with Employees Training Investment

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Abstract—This paper studies the reverse supply chain system composed of collectors, disassembly centers and remanufacturers, and constructs a system dynamics model of reverse recycling supply chain based on consumers' quality preference. Through simulation analysis, model well demonstrates the impact of the quality influencing factors on the market demand and each member's profit. The simulation result also shows that: the unit cost of employee training can affect the quality of the remanufactured products, promote the market demand and influence the profits of the collector, the disassembly center and the remanufacturer. Meanwhile, there is a big increase in the early stage and a stable growth in the later and the final stage. Additionally, the profits are positively correlated with the investment in employees' training. Specifically, when the investment in training increases, and the benefits of the reverse supply chain members will be promoted.

Index Terms—**System dynamics; Reverse supply chain; Quantity; Employee training**

I. INTRODUCTION

Along with the development of science and technology, and the improvement of people's living standards, the speed of product upgrading is accelerating, which produces a large number of used-products. Under the background of resource shortage and environmental pollution, people pay increasing attention to the rational use of resources. Recycling and remanufacturing of used-products can effectively reduce production cost, make resources rationally used and reduce environmental pollution, which bears certain economic effect, resource effect and environmental effect. As a strong support for sustainable development, reverse supply chain is a way to realize the dream of building a resource-saving and environment-friendly society.

The disposal of used-products includes recycling, dismantling and remanufacturing in reverse supply chain. Consumers' purchase intention for remanufactured products is based on product price and quality which includes service quality and product quality. Today, there is a growing demand from consumers for improved service quality and product quality. Although many elements of quality management in reverse supply chain are continuously transferred and interacted in the process, the remanufactured product quality and service quality are the most intuitionistic at the end of reverse supply chain.

This paper focuses on the quality of remanufactured goods which is reflected in the cost of remanufacturing. The input of production equipment, appraisal equipment and employee training represent the total cost of remanufacturing. To be specific, the employee's quality awareness, risk awareness and responsibility awareness can be measured with the funds invested in employee training while the maintenance of production equipment can be measured with the capital input of the production equipment, and the calibration degree of quality identification equipment can be measured with the fund input of appraisal equipment [1]. But how to satisfy the consumers' quality preferences, promote the end quality of the reverse supply chain, and improve each member's profits in the whole process?

In this paper, a system dynamics model was established based on the consumers' quality preferences, and the simulation tool Vensim PLE was used to simulate and analyze the impact of factors like the input of employee training on the reverse supply chain.

II. LITERATURE REVIEW

Being a complex problem which integrates the content of supply chain and quality management, supply chain quality management has been constantly innovated and explored, and called many scholars' attention in the recent years.

In terms of supply chain service quality, Sabine Limobourg investigated 200 consumers of Da Nang urban logistics service providers, and the statistical analysis showed that LSPs should pay more attention to service quality, such as transport links, and develop projects that consumers care about. In addition, the government should create a good environment for logistics service [2]. Aleksandra Gule identified and evaluated general usage models and methods for measuring services based on literature review and critical research methods. It is concluded that the research trend of logistics service quality is that the existing achievements of logistics service quality are still new and still full of vitality in the field of management science, and even more will be explored in the future [3]. Zhang Cuihua et al. studied the quality control problem of a service supply chain composed of a supplier and an integrator through the utility function of the members of the service supply chain established by game theory. It is concluded that the optimal utility of service supply chain is influenced by the service quality, the defect commitment in the service quality and the service price [4]. Jian Jie et al. explored the LSSC quality coordination problems by building a basic model of quality coordination for two-level cooperation of logistics service supply chain which took customer evaluation as a new parameter and gave a coordination method [5].

In terms of supply chain product quality, Deniz Besik et al. conducted a capability analysis by building a game theory model of supply chain competition based on the quality of fresh produce. In their model, beentaking the apple core farmers' market in Massachusetts as an example and proved the applicability of the supply chain network approach [6]. With regard to the quality problems in supply chain management, Mitali Sarkar et al. put forward an optimization model of production system to achieve the best output with the lowest cost [7]. Meanwhile, based on the uncertainty of recycling quality of used-products, Cheng Faxin et al. adopted the game theory to make decentralized and centralized pricing decisions for the closed-loop supply chain. They concluded that the quality threshold of remanufacturing would affect the profits of the closed-loop supply chain [8]. Besides, Fan Jianchang et al. established a game model of supply chain, studied whether enterprises' social responsibility would influence the quality of products in the supply chain, and realized supply chain coordination by improving the cost sharing contract and the quantity discount contract [9].

As an important system analysis tool, system dynamics is widely applied in supply chain researches. And there have been more and more researches conducted on supply chain quality management in system dynamics. Qian Ying extended the relevant theories of supply chain quality management, built a dynamics model of supply chain quality management system, and revealed the internal relations of various elements in the whole process of supply chain quality management [10]. And based on the manufacturing industry, Jin Hongmin et al. constructed a product quality system dynamics model, and through simulation reached the conclusion that the quality of product would first be increased significantly and then be kept in a stable state [1]. Additionally, Zhang Yuchun et al. analyzed the quality investment decisions of sellers and manufacturers by building a dynamic model of remanufacturing priority quality control system, and optimized the profit-sharing contract after making investment decisions [11].

III. MODEL

A. Assumption

This study is based on the following hypotheses.

(1) The reverse supply chain is composed of a single collector, a disassembly center and a remanufacturer. This paper only considers the remanufacturing of used-products, and does not consider the production of new products and homogeneous products.

(2)Remanufacturer sells the remanufactured products directly to consumers and recycles the used-products through third-party collector.

(3) The predicted output or order quantity at the upstream nodes of the reverse supply chain is generated according to the demand of the adjacent downstream nodes.

(4) In the reverse supply chain, the upstream nodes can generally meet the demand of the downstream nodes, that is, the orders from the collector to the disassembly center and the remanufacturer are all met, and there is no unit punishment when the orders cannot be met.

(5) The consumers' quality preference refers to the degree to which consumers feel satisfied by the quality of a commodity (or combination of commodities).

B. Stock-flow diagram

The reverse supply chain in stock-flow diagram consists of a collector, a disassembly center and a remanufacturer. Among them, the collector first recycles the used-products from the terminal consumers and transports them to the disassembly center for processing, and then, the disassembly center transports the products to the remanufacturer for remanufacturing, and finally the remanufacturer sells the remanufactured products to consumers.

Customers choose remanufactured products based on quality preference. Employee training investment is a one of factors influencing quality of remanufactured products. Market demand will change when remanufactured products affects customer satisfaction, which promotes changes in remanufactured orders, disassemble center orders and remanufacturer orders, and then effects the profits of collector, disassemble center and remanufacturer.

C. Equation

(1)Equations of level variable

Collector's Inventory = INTEG (collecting rate-shipment to disassembly center's inventory, 5000) (Units: piece)

Collector's order quantity = INTEG (disassembly center's order rate-collector's order completion rate (decreasing), 0) (Units: piece)

Disassembly center's Inventory = INTEG (shipment to disassembly center's inventory-shipment to remanufacturer, 10000) (Units: piece)

Disassembly center's order quantity = INTEG (remanufacturer's order rate-disassembly center's order completion rate (decreasing), 0) (Units: piece)

Remanufacturer's Inventory = INTEG (shipment to remanufacturer-sales, 7000) (Units: piece)

Remanufacturer's order quantity = INTEG (demand rate-remanufacturer's order completion rate (decreasing), 0) (Units: piece)

(2)Equations of rate variable

Collecting rate =collection quantity/collecting time (Units: piece/week)

shipment to disassembly center's inventory = MIN(Collector's Inventory, Collector's order quantity)/shipment time to disassembly center's inventory (Units: piece/week)

shipment to remanufacturer = MIN(Disassembly center's Inventory, Disassembly center's order quantity)/

shipment time to remanufacturer (Units: piece/week)

sales = MIN(Remanufacturer's Inventory, Remanufacturer's order quantity)/delivery time (Units: piece/week)

demand rate =normal market demand/demand time (Units: piece/week)

remanufacturer's order completion rate(decreasing)=sales (Units: piece/week)

remanufacturer's order rate = adjustment rate of remanufacturer's inventory+ expected demand (Units: piece/week)

disassembly center's order completion rate (decreasing) = shipment to remanufacturer (Units: piece/week)

disassembly center's order rate = adjustment rate of disassembly center's inventory+ expected remanufacturer's order rate (Units: piece/week)

collector's order completion rate (decreasing) = shipment to disassembly center's inventory (Units: piece/week)

(3)Equations of auxiliary variable

Collection quantity = RANDOM NORMAL (2000, 10000, 4000 ,1000, 2000) (Units: piece)

adjustment rate of collector's inventory = discrepancy of collector's inventory/adjustment time of collector's inventory (Units: piece/week)

discrepancy of collector's inventory = MAX (desired collector's inventory-Collector's Inventory, 0) (Units: piece)

desired collector's inventory = cover time of collector's Inventory*expected disassembly center's orders rate (Units: piece)

expected disassembly center's orders rate = SMOOTH(disassembly center's order rate, smoothing time of disassembly center) (Units: piece/week)

adjustment rate of disassembly center's inventory = discrepancy of disassembly center's inventory/adjustment time of disassembly center's inventory (Units: piece/week)

discrepancy of disassembly center's inventory = MAX(desired disassembly center's inventory-Disassembly center's Inventory,0) (Units: piece)

desired disassembly center's inventory = cover time of disassembly center's Inventory*expected remanufacturer's order rate (Units: piece)

expected remanufacturer's orders rate = SMOOTH(remanufacturer's order rate, smoothing time of remanufacturer) (Units: piece/week)

adjustment rate of remanufacturer's inventory = discrepancy of remanufacturer's inventory/adjustment time of remanufacturer's inventory (Units: piece/week)

discrepancy of remanufacturer's inventory = MAX (desired remanufacturer's inventory-Remanufacturer's Inventory, 0) (Units: piece)

desired remanufacturer's inventory = cover time of remanufacturer's inventory*expected demand (Units: piece)

expected demand = SMOOTH(demand rate, smoothing time of market demand)

(Units: piece/week)

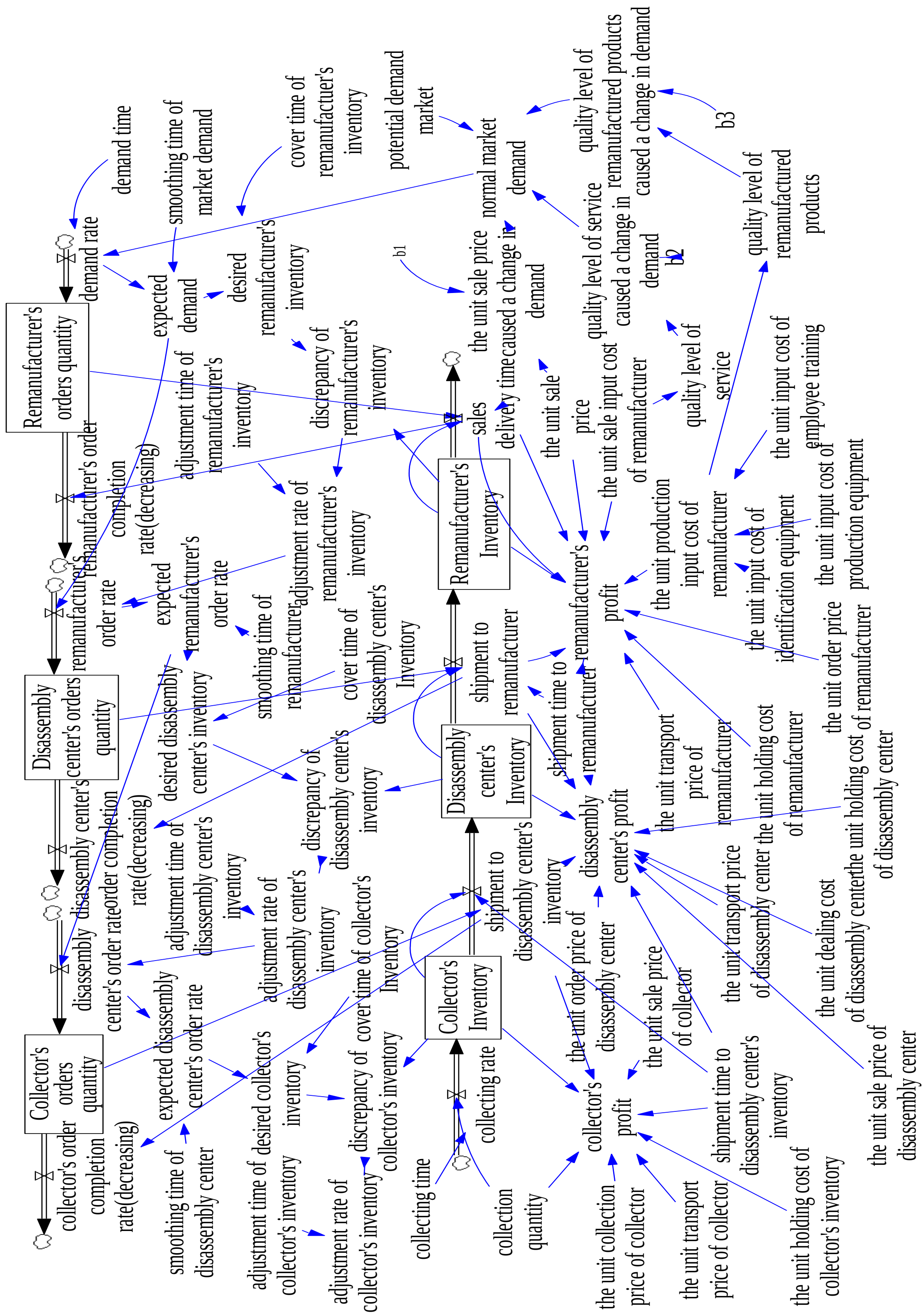

Fig.1 Stock-flow diagram

collector's profit = the unit collection price of collector*shipment to disassembly center's inventory*shipment time to disassembly center's inventory-the unit transport price of collector*shipment to disassembly center's inventory*shipment time to disassembly center's inventory-the unit holding cost of collector's inventory*Collector's Inventory-the unit sale price of collector*collection quantity (Units: yuan)

disassembly center's profit = the unit sale price of disassembly center*shipment time to remanufacturer*shipment to remanufacturer-the unit transport price of disassembly center*shipment to remanufacturer*shipment time to remanufacturer-the unit holding cost of disassembly center*Disassembly center's

Inventory-the unit order price of disassembly center*shipment to disassembly center's inventory*shipment time to disassembly center's inventory-the unit dealing cost of disassembly center*shipment to disassembly center's inventory*shipment time to disassembly center's inventory (Units: yuan)

remanufacturer's profit = the unit sale price*sales*delivery time-the unit transport price of remanufacturer*sales*delivery time-the unit sale input cost of remanufacturer*sales*delivery time-then unit holding cost of remanufacturer*Remanufacturer's Inventory-the unit production input cost of remanufacturer*sales*delivery time-shipment to remanufacturer*shipment time to remanufacturer*the unit order price of remanufacturer (Units: yuan)

normal market demand = potential demand market-the unit sale price caused a change in demand + quality level of service caused a change in demand + quality level of remanufactured products caused a change in demand (Units: piece)

the unit sale price caused a change in demand = b1*the unit sale price (Units: piece)

quality level of service caused a change in demand = b2*quality level of service (Units: Dmnl)

quality level of remanufactured products caused a change in demand = b3*quality level of remanufactured products (Units: Dmnl)

quality level of service = SQRT(1000*the unit sale input cost of remanufacturer) (Units: Dmnl)

the unit production input cost of remanufacturer = the unit input cost of employee training+ the unit input cost of production equipment+ the unit input cost of identification equipment (Units: yuan/piece)

quality level of remanufactured products = SQRT(10000*the unit production input cost of remanufacturer) (Units: Dmnl)

(4)Parameters

The other parameter values involved in the stock- flow diagram are listed in Table I.

Table I. Parameter settings

Parameter	Value	Units	Parameter	Value	Units
potential demand market	7000	piece	demand time	6	week
collecting time	4	week	adjustment time of collector's inventory	5	week
cover time of collector's Inventory	8	week	smoothing time of disassembly center	1	week
shipment time to disassembly center's inventory	1	week	adjustment time of disassembly center's inventory	5	week
cover time of disassembly center's Inventory	8	week	smoothing time of remanufacturer	1	week
shipment time to remanufacturer	1	week	adjustment time of remanufacturer's inventory	6	week
cover time of remanufacturer's inventory	8	week	smoothing time of market demand	1	week
delivery time	3	week	the unit collection price of collector	10	yuan/piece
the unit transport price of collector	1	yuan/piece	the unit holding cost of collector's inventory	1	yuan/piece
the unit collection price of collector	1	yuan/piece	the unit order price of disassembly center	10	yuan/piece
the unit dealing cost of disassembly center	1	yuan/piece	the unit sale price of disassembly center	30	yuan/piece
the unit transport price of disassembly center	1	yuan/piece	the unit holding cost of disassembly center	1	yuan/piece
the unit order price of remanufacturer	30	yuan/piece	the unit transport price of remanufacturer	1	yuan/piece
the unit holding cost of remanufacturer	1	yuan/piece	the unit sale price	300	yuan/piece
the unit input cost of production equipment	1	yuan/piece	the unit input cost of identification equipment	1	yuan/piece
b1	6		the unit input cost of employee training	1	yuan/piece
b3	3		b2	2	

IV. SIMULATION RESULTS

This paper mainly analyzes the impact of the remanufactured products' quality on the reverse supply chain, and with regard to the remanufactured products' quality, the impact of employee training on the reverse supply chain has been particularly analyzed. The simulation settings in this article are as follows: INITIAL TIME=0; FINAL TIME=50; TIME STEP=0.25. The following is whole analysis process of the model.

As an important factor in the unit remanufacturing cost of the product, the unit investment in employee training plays a certain role in products' quality and affects the results of each node in the whole reverse supply chain. When the unit investment in employee training is 1, 3 and 7, The changes of profits of all parties are shown in Fig.2 to Fig.4.

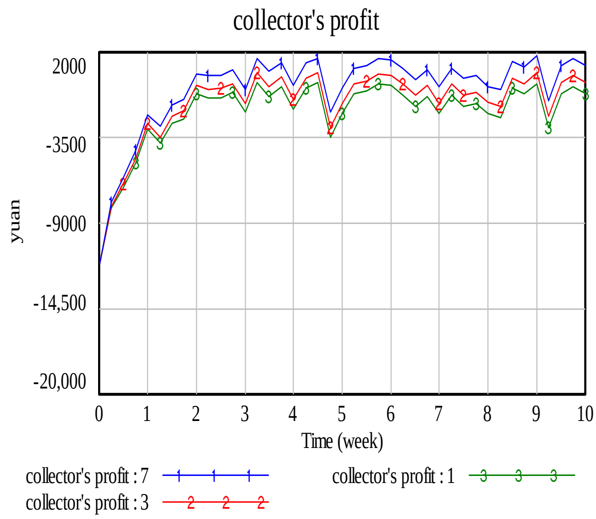

Fig. 2 Changing in the profits of the collector

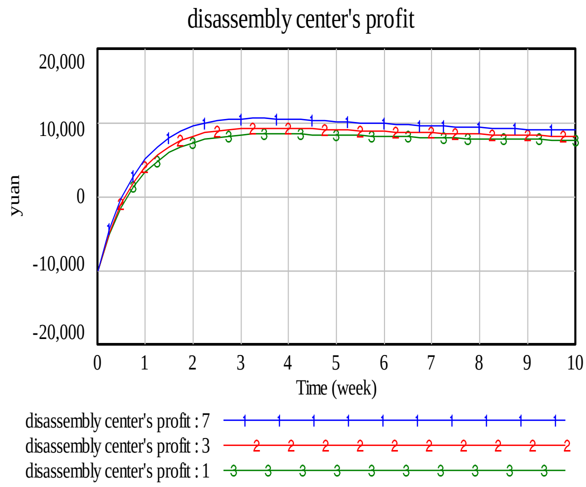

Fig.3 Changing in the profits of disassembly center

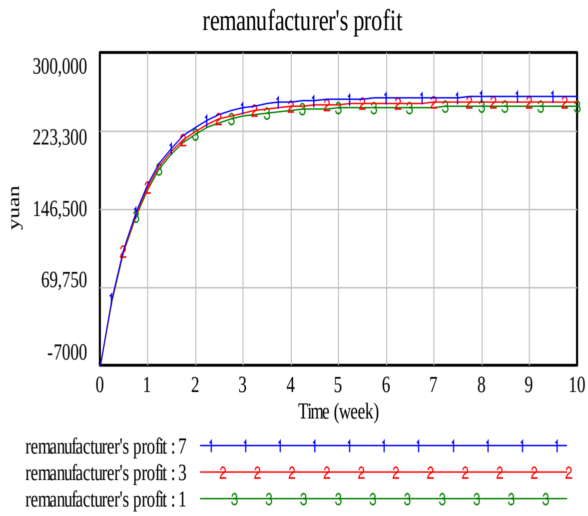

Fig. 4 Changing in the profits of remanufacturer

The simulation results show: the input in employee training has a certain influence on the recycling of the reverse supply chain in Fig.2 to Fig.4.

On the one hand, the profits of the collector, the disassembly center and the remanufacturer are affected by the investment in employee training. In the early stage, the profits of the collector, the disassembly center and the remanufacturer increase significantly, and then the growth rate of each node slows down and eventually becomes stable. The occurrence of such phenomenon may be as follows: when there is an obvious investment made by the company at the early stage, the quality of the remanufactured products will be highly improved, which will then make consumers who purchase such products highly satisfied and hence greatly improve the profits. However, according to the law of diminishing marginal benefit, when consumers' satisfaction in the later stage does not increase as the quality of the products fails to exhibit any more prominent improvements, the consumers' demand for remanufactured products will accordingly grow slowly, and become steady in the end.

On the other hand, with the increase in the input of employee training ordered by 1, 3 and 7, the profits of the collector, the disassembly center and the remanufacturer will also be increasing. In other words, the input in employee training is positively correlated with the profit of each node. Through training, employees will learn to pay particular attention to the quality of work, display a more responsible working attitude and be more cautious of any possible risks. As employees work more actively and responsibly, the quality of the remanufactured products will accordingly be highly improved, which will then make the consumers who purchase such products more satisfied and thus positively influence the market demand as well as the whole supply chain.

V. Conclusion

In this paper, we have built a system dynamics model of reverse supply chain based on consumers' quality preferences. The simulation results show that more input in employee training which is a part of the remanufacturing production costs, will lead to better product quality, greater market demand, and will also greatly benefit of the collectors, the disassembly centers and the remanufacturers in the whole reverse supply chain. Therefore, the members and managers in the reverse supply chain should not only pay attention to the technical input in product quality, such as the quality of production equipment and identification equipment, but should also strengthen the corporate culture and enhance staff's quality awareness, risk awareness and responsibility awareness so as to achieve much greater benefits.

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