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Optimization of product refurbishment in closed-loop supply chain using multi-period model integrated with fuzzy controller under uncertainties

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Abstract

Nowadays, product refurbishment is one of the most profitable and environmental benefit processes, drawing more and more attention from both product manufacturers and customers. This paper structures and optimizes the process of product refurbishment, considering inventories and uncertainties. A multi-period model is established. To deal with the uncertainties, an innovative fuzzy controller embedded with a quality indicator is proposed. Numerical experiments have been carried out to test and demonstrate the optimization quality of the proposed method. The results of numerical experiments proved the effectiveness of the proposed fuzzy controller, that can deal with the uncertainties of supply and demand in an efficient way.

Keyword: Closed-loop supply chain, Product recovery, Product refurbishment, Fuzzy logic, Linear programming, Decision support system, Simulation

1.0 Introduction

Product recovery in closed-loop supply chain (CLSC) is commonly defined as the actions of the collection and recovery of returned products in supply chain management. The management of product recovery has been increasingly received significant attention because of the environmental concerns, legislative requirements, consumer interest in green products, and the market image of manufactures [1]. Generally, there are more actors (e.g., remanufacturing and recycling companies, the customer in its role as a supplier for EOU or EOL equipment, etc.), more process (e.g., collection, disassembly, and remanufacturing of products, etc.), and more delays within these processes for a closed-loop supply chain in comparison with the original supply chain [2]. Moreover, product return processes are also significantly affected by the high degree of uncertainty in terms of the quality, quantity, and time of products being returned from the market [3].

The processes of product recovery includes product recycling, remanufacturing, refurbishment, reuse and resell, etc. Among these processes, product refurbishment is one of the most profitable and environmental benefit processes, drawing more and more attentions of both product producers and customers. Many electronic producers have implemented products collection and refurbishment programs. Take Apple for example, this company takes the lead in introducing refurbished products into the market called "apple certified refurbished products". These certified refurbished products including many versions of ipad and macbook, which are available on the Apple website. Another example is one of the most popular electronic products company of China called MEIZU. This company also has implemented the similar refurbish plan, especially in the products of cell phones. Due to strong quality guarantee and relatively low price, the market of certified refurbished products grows fast nowadays.

In the process of product refurbishment, returned products will be tested and classified as relatively good quality ones and relatively poor quality ones. Those relatively poor quality return products will be disassemble into return components, while relatively good quality products will directly be refurbished using those return components disassembled from poor quality products. Fig. 1 shows the structure of product refurbish in CLSC.

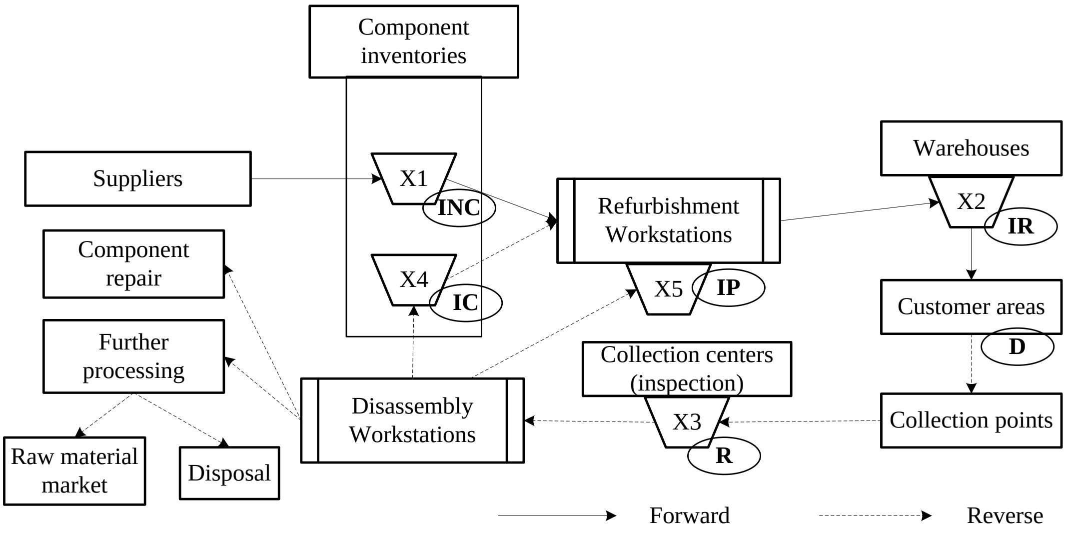

Fig. 1 Product refurbish in CLSC

Due to the producer's responsibility, companies have to accept all of the returned products irrespective of quality. Hence their comes several research questions in product refurbishment.

(1) At the beginning of product refurbishment, the decision center has to make the decision of which returned product to refurbish and which to disassemble into returned components as the inventory replenishment. This decision is not just related to the quality of returned products. In order to optimize the total cost of refurbishment in CLSC, many factors have to be considered in this decision. For example, the inventory of returned components, the uncertainty of demands and supplies, the capacity of disassemble and refurbish workstations, etc.
(2) In the process of product refurbishment, one of the important and complicate problem is the uncertainty of both the demands and supplies. The supplies here means the returned products. How to settle the uncertainty of both input and output?
(3) One of the most difficult problems in dealing with the uncertainties of both supplies and demands is lied on the attributes of returned products. The uncertainty in returned products is not only the quantity but also the quality. That means the uncertainty of supplies further distributes on both quantity and quality, which makes the decision become much more difficult.

This paper devotes to find answers to these research questions outlined above. The contribution of this paper is as follow.

(1) This paper structured and optimized the process of product refurbishment,

considering inventories and uncertainties with multi-periods. In the literatures, few of researches have been inspected the process of returned products refurbishment in CLSC.

(2) In this research, a novel fuzzy controller embedded with quality indicator has been proposed. Numerical experiments proved the effectiveness of the proposed fuzzy controller. This proposed fuzzy controller can deal with the uncertainties of supplies and demands in an efficient way. Additionally, the quality indicator enhances the ability of the proposed fuzzy controller in dealing with uncertainties in both quantity and quality.

This paper is structured as follow. Section 1.0 is the introduction. Section 2.0 discusses the related literatures of product refurbishment in CLSC, and reveals its importance. Section 3.0 introduces the problem in this paper. Section 4.0 formulates the mathematical model of this problem. Section 5.0 is the methodology part, and explains the proposed fuzzy controller embedded with quality indicator. In order to prove the effectiveness of the proposed method, Section 6.0 implements a numerical example. Section 7.0 analysis the results and Section 8.0 concludes this research and puts forward some future research directions.

2.0 Literature Review

In general, a close-loop supply chain(CLSC) network is comprised of multiple customers, parts, products, suppliers, remanufacturing subcontractors, and refurbishing sites. A three-stage model considering evaluation, network configuration, and selection and order allocation is developed by Amin et al. [4]. In the first stage, a new quality function deployment (QFD) model is proposed together with the fuzzy sets theory to assess the relationship between customer requirements, part requirements, and process requirements. In the second stage, a stochastic mixed-integer nonlinear programming model is used to configure the close-loop supply chain network. In the third stage, suppliers, remanufacturing subcontractors, and refurbishing sites are selected and order allocation is determined. The strategic level decisions concern the amounts of goods flowing on the forward and reverse chains, while the tactical level decisions relate to balancing disassembly lines in the reverse chain. In order to evaluate effects of randomness with respect to recovery, processing and demand volumes on the design decisions, a stochastic model was developed by Chouinard et al.[2] for designing logistics networks with a consideration of reverse logistics.

In recent years, several papers have been published about reverse logistics (RL) and closed-loop supply chain networks. Zarei et al. [5] presented a conceptual framework of the reverse logistics network to manage the whole recovery process efficiently. A mathematical model was developed with some specific assumptions and solved by the genetic algorithm for simplicity. Because of the uncertain of demands and returned products, two types of risks of overstocking and under stocking of multiproduct should be considered in the forward supply chain. Zhou et al [6] developed a multiproduct CLSC network equilibrium model, which comes with the context of oligopolistic firms that compete non-cooperatively in a Cournot-Nash framework under a stochastic environment. To tackle the uncertainty associated with the quantity of returned products, a stochastic programming model for waste stream acquisition systems is proposed by Behdad et al. [7]. Nie et al. [8] developed three close-loop supply chain model and conducted a comparison for the three models in the light of the retail price, demand, return rate, and the profits received by the supply chain members.

In order to minimize total disassembly cost, the sequencing of disassembly operations can be regarded as a single-period partial disassembly optimization (SPPDO) problem. Tsai [9] proposed a label correcting algorithm to find an optimal partial disassembly plan with the assumption that a definite reusable subpart is obtained from the original return and then used this algorithm in a heuristic procedure to solve the SPPDO problem. Li et al. [10] proposed a multi-objective reverse logistics network optimization model to improve the quality post sale repair service. To solve the established multi-objective optimization model, a Non-dominated Sorting Genetic Algorithm II (NSGA-II) is applied and its performance is evaluated by the comparison with a genetic algorithm based on weighted sum approach and Multi-objective Simulated Annealing (MOSA).

With a consideration of the optimization of manufacturing and remanufacturing sharing the same critical and limited resource, Chen et al. [11] developed a multi-integer linear programming model to solve production planning problems in hybrid manufacturing-remanufacturing systems and solved problem using a Lagrangian decomposition based method. Chen et al. [12] also described a job scheduling model of refurbishing process. In the model, the refurbishing process is considered as a two-stage flow shop including disassemble products and refurbish the parts, and a heuristic approach, based on LP relaxation, is presented and two met heuristic algorithms, based on iterated local search and ant colony optimization, are developed.

In order to minimize costs, an integrated model is described by Ozceylan et al. [13]. Loomba et al.[14] used a Markov decision process to examine the role of sorting used products before disassembly for parts retrieval and remanufacturing under stochastic variability based on customer demand. Lehr et al. [15] used system dynamics to capture the high complexity of reverse logistics processes and analysis the dynamic behavior of close-loop supply chains comprehensively. Kaya et al. [16] also developed a large-scale mixed integer model to capture all characteristics of the reverse supply chain system, and two-stage stochastic optimization and robust optimization approaches are used to analyze the system behavior.

3.0 Problem Description

In this research, the focus is the refurbishment of returned products in a closed-loop supply chain. Fig. 2 shows the structure and flows in this system.

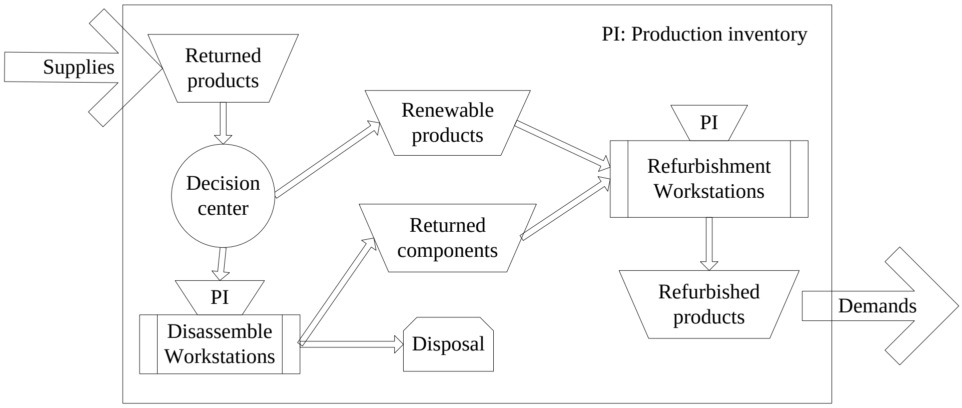

Fig. 2 The structure and flows in the considered system

In this system, the input is the collected returned products at the collection center, which called supplies. The output is the finished-refurbishing products to fulfilling the demands of the customers. In this problem, the demands of customers mean the demand of refurbished products only, the demands of brand new products are not in consideration. The input and output are shown as the beginning and termination of this system in Fig. 2.

In a refurbishment factory, there are two kinds of workstations, called disassembly workstation and refurbishment workstation. These two kind of workstations work in parallel. Refurbishment workstations in period t use the returned components in disassembly workstations and also the renewable products from period $t-1$. In Fig. 2, the rectangle shows the workstations, the trapezoid shows the inventories, and the arrows shows the process flow of the problem.

Two steps are considered during the process of refurbishment. Multi-periods are considered in this problem. Take period *t* for example. In period *t*, Step One is implemented in the decision center. In this decision center, it classifies the returned products into two categories. Returned products in Category 1 are with good quality for refurbishment which called renewable products. These renewable products will be refurbished in the next period at refurbishment workstations. Returned products in Category 2 are those with relatively not so good quality for disassembly. These products will be disassembled in this period at disassembly workstations. After disassemble, the useful parts are send to the components inventory, which called returned components. While the waste parts are disposal. In period *t+1*, work stations produce the refurbished products using renewable products and returned components from period *t*. After refurbish and quality test, the finished products, called certificated refurbished products, are sold to fulfill the demands of customers.

In this system, the objective is to minimize the total cost in multi-periods including the disassemble costs in disassembly workstation, the refurbish costs in refurbishment workstations, the inventory costs of returned products, renewable products, returned components and finished products, the shortage costs of returned components in the process of refurbishment, and the shortage costs of finished products.

In this system, the returned products, played as supplies are uncertain in both quantity and quality, which made this problem complicate to deal with. This is also the focus and contribution of this research. In this system, a fuzzy controller embedded with the quality indicator is developed. Numerical experiments show that this proposed method can deal with the uncertainty of demands, returned quantity and returned quality in an effective way.

4.0 Model Formulation

In this problem, the objective is to minimize the total cost in multi-periods production process. The indices, parameters and decision variables are shown as follows.

Indices

i	returned product *i*
j	returned product *j*
t	time period *t*

Parameters

rc_i	unit refurbish cost of returned product *i*
dc	unit disassemble cost of each returned product
n	the quantity of returned products in consideration batch

R_i	quality vector of returned product *i*
vc_j	unit inventory cost of returned component *j* for each period
vq_j^t	inventory quantity of component *j* in period *t*
Q_t	returned quantity of returned products in period *t*
D_t	customer demands of finished products in period *t*
rvc	unit inventory cost of each returned product for each period
rvq_t	inventory quantity of returned products in period *t*
fvc	unit inventory cost of each finished product for each period
fvq_t	inventory quantity of finished products in period *t*
rsc_j	unit shortage cost of component *j*
fsc	unit shortage cost of finished product
rsq_j^t	shortage quantity of component *j* in period *t*
fsq_t	shortage quantity of finished products in period *t*
rq_t	the quantity of refurbished products in period *t*
dq_t	the quantity of disassemble products in period *t*
$reduq_j^t$	the quantity of component *j* reduced in period *t*
$incrq_j^t$	the quantity of component *j* increased in period *t*

Decisions Variables

$$x_i^t = \begin{cases} 1 & if\ \ returned\ \ product\ \ i\ \ is\ \ refurbished\ \ in\ \ period\ \ t \\ 0 & otherwise \end{cases}$$

Objective function:

$$\min \quad TC = PC + IC + SC \tag{1}$$

$$PC = \sum_{i=1}^{n} dc \cdot (1 - x_i) + \sum_{i=1}^{n} x_i \cdot R_i \tag{2}$$

$$IC = \sum_t \sum_j vq_j^t vc_j + \sum_t rvc \cdot rcq_t + \sum_t fvc \cdot fcq_t \tag{3}$$

$$SC = \sum_t \sum_j rsc_j \cdot rsq_j^t + \sum_t fsc \cdot fsq_t \tag{4}$$

The objective is to minimize the total cost which contains the processing cost in both disassemble workstation and refurbish workstation, the inventory cost of returned components, renewable products and finished products, and also the shortage cost of returned component and finished products in the objective function (1) to (4). The total cost contains the processing cost in both disassemble workstation and refurbish workstation, the inventory cost of returned components, renewable products and finished products, and also the shortage cost of returned component and finished products. The processing costs are shown in Equation (2). Equation (3) displays the inventory costs and Equation (4) indicates the shortage costs.

Subject to

$$Q_t = rq_t + dq_t \qquad \forall t \tag{5}$$

$$\sum_i x_i^t = rq_t \qquad \forall i,t \tag{6}$$

$$\sum_i (1 - x_i^t) = \mathrm{dq}_t \qquad \forall i,t \tag{7}$$

$$vq_j^{t+1} = vq_j^t - reduq_j^t + incrq_j^t \qquad \forall j,t \tag{8}$$

$$fvq_{t+1} = fvq_t + rq_t - D_t \qquad \forall t \tag{9}$$

Constraint (5) indicates that all the returned products are processed either to refurbish or disassemble in each period. Constraints (6) and (7) show the equations of the binary decision variable. Constraint (8) restrains the inventory of each component in each period. Constraint (9) explains the inventory of finished products.

5.0 Methodology

To deal with this complicate problem including uncertainty in quantity and quality of returned products and customer demands, fuzzy controller is implemented. This methodology contains three parts. Section 5.1 introduces the ceiling and bottom boundaries of the considered returned products. Section 5.2 explains the proposed fuzzy controller. Section 5.3 decrypts the indicator within the proposed fuzzy controller in detail.

5.1 Calculation of boundaries

Among all the returned products, three categories in quality are classified, good quality ones, medium quality ones, and poor quality ones. For those good quality returned products, the cost of refurbish is low, and the profit of selling such refurbished products is abundant, even using brand new components during the refurbishment. Hence, returned products with good quality will directly send to refurbishment. For those poor quality returned products, refurbishment is non-profitable, so they will directly send to disassemble. In normal cases, returned products with good quality and poor quality are the minority. The majority of the returned products are with medium quality which need to decide to refurbish of disassemble. In this section, the ceiling and bottom of the medium quality returned products are calculated.

In a returned product, for each useful component, the objective is to minimize the total costs. The parameters are shown in Table 1.

collection price + test cost + disassemble cost + clean cost <= a% * brand new price

$$\sum_{i\in U} price_i^{col} + \text{Testcost1} + \text{Discost} + \sum_{i\in U} clean_i + \sum_{j\in \bar{U}} recycling_j \le \alpha \sum_{i\in U} price_i^{re} \qquad (10)$$

A is the set of all components in one returned products.

U is the set of useful components in each returned products.

$$\bar{U} = \{ i \mid i \in A, i \notin U \} \qquad (11)$$

Table 1 Parameters of total costs

$price_i^{col}$	The collection price of component *i* within one returned product.
$price_i^{re}$	The purchase price of refurbished component *i*
$clean_i$	The clean cost of each useful component *i* in the returned product.
Testcost1	The initial inspection cost of the returned product.
Discost	The disassembly cost of one returned product.
$recycling_j$	The process cost of the non-useful components in one returned product.

In this research $recycling_j$ is set to be zero.

profit = resell price - (collection cost + refurbish cost + operating cost + market cost)

operating cost contains transportation cost and inventory cost, etc.

$$profit = price^{sell} - \sum_{i\in U} price_i^{col} - \sum_{j\in \bar{U}} replace_j - \sum_{j\in \bar{U}} price_j^{new} - \text{Testcost2} \qquad (12)$$

The profit rate is monotonic increasing with the collection price of one returned product.

5.2 Proposed Fuzzy Controller

To implement a fuzzy controller, three main processes are followed, fuzzification, inference engine, and defuzzification. Fig. 3 shows the main parts of a fuzzy controller. The inputs are returned products quantity and demands in each period. The output is the change of indicator. Section 5.2.1 explains the fuzzification in this problem, Section 5.2.2 displays the fuzzy rules, Section 5.2.3 describes the defuzzification.

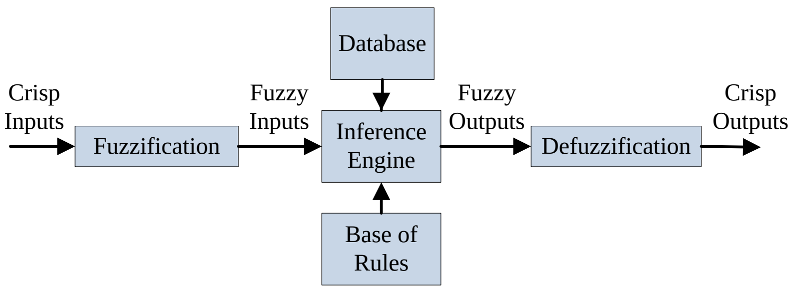

Fig. 3 Main parts of a fuzzy controller

5.2.1 Fuzzification

The proposed fuzzy controller in this problem is to deal with the problem of the supplies and demands uncertainty. The supplies in this system is the quantity of returned products. In this problem, the member function of the returned products quantity and demands are shown in Fig. 4 and Fig. 5. Fig. 6 shows the membership function of change of indicator. Fig. 4 and Fig. 5 are the fuzzy input. Fig. 6 is the fuzzy output.

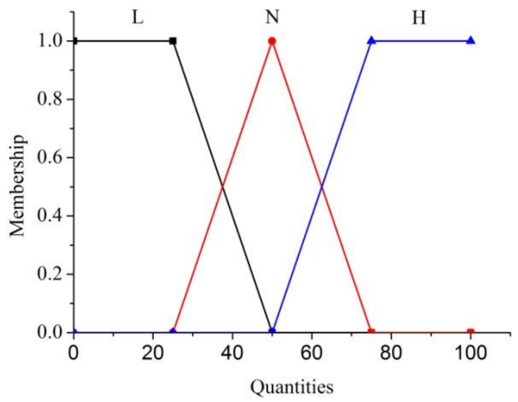

Fig. 4 Membership function of returned products quantity

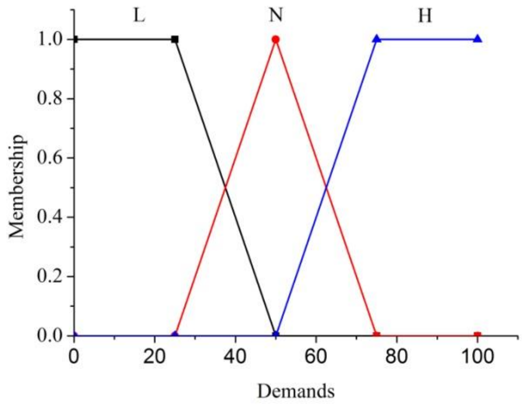

Fig. 5 Membership function of demands

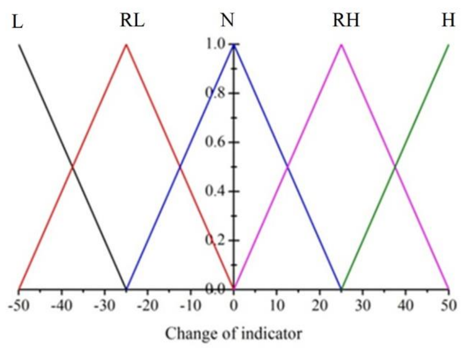

Fig. 6 Membership function of change of indicator

5.2.2 Fuzzy Rules

In this inference engine, fuzzy rules are the basic of inference. Table 2 shows the fuzzy rules implemented in this problem. In this problem, the focus is on the uncertainty of the returned products and demands. In this part, a finished refurbished returned product is assumed to be produced from a renewable returned product and several needed components. The situation of the finished refurbished returned product assembling from the returned components is not in consideration. The optimization is for multi-periods. In this step, the optimization in the decision center. Since the quality of the returned products are irregularity, the decision center has to decide which returned product to renew and which to disassemble in each period. Meanwhile, to deal with the uncertainty of supplies and demands, fuzzy controller is implemented to solve this problem.

In time period *t*, D means final demands, shown in Equation (13), R means the returned products with medium quality ones.

D=customer demands - finished products' inventory - renewable products' inventory (13)

Table 2 shows the rules table to control the uncertainty of quantity of returned products. It also consider the uncertainty of demands.

D: the total demands of the finished refurbished products. (H, N, L)

R: the quantity of returned products with medium quality. (H, N, L)

Here, H means high, N means normal, L means low.

CI: change of indicator. (L, RL, N, RH, H)

Here, L means low, RL means relatively low, N means normal, RH means relatively high, H means high.

Table 2 Rules table of Fuzzy Controller

If D is H, R is RH	Then indicator is N
If D is H, R is N	Then indicator is RL
If D is H, R is RL	Then indicator is L
If D is N, R is RH	Then indicator is RH
If D is N, R is N	Then indicator is N
If D is N, R is RL	Then indicator is RL
If D is L, R is RH	Then indicator is H
If D is L, R is N	Then indicator is RH
If D is L, R is RL	Then indicator is N

5.2.3 Defuzzification

In the defuzzification of this problem, the method of center of area is selected. The general equation is

$$Y = \frac{\sum_{j=1}^{N} w_j \overline{C_j A_j}}{\sum_{j=1}^{N} w_j \overline{A_j}} \tag{14}$$

where w, C and A denote the weight, center of gravity and area respectively for each individual implication result.

5.3 Proposed Score System and Indicator

The objective of the fuzzy controller in this problem is to solve the problem of uncertainty of returned products quantity and quality, which means the supplies uncertainty in two aspects and minimize the total manufacturing costs. In the decision center, it is necessary to decide the process of each returned products. Since the quality of each product is different, each product is scored according to its quality. The focus of the decision center is to decide the indicator of among different scores to classify the returned products properly. The fuzzy controller here is to control the indicator according to the uncertainty of the returned products quantity. Fig. 7 shows the concept of the fuzzy controller. In Fig. 7, the ceiling boundary is the refurnish line, the bottom boundary is the disassemble line.

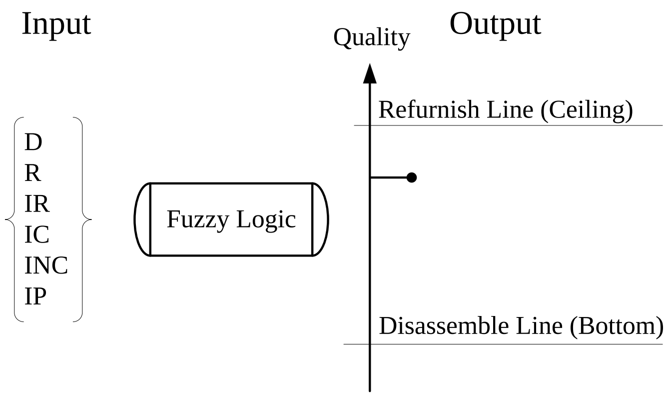

Fig. 7 The concept of the fuzzy controller

For each component, the score is the product of inventory coefficient and component value. The coefficient is different for each component in each period, the higher the coefficient is, the short of inventory this component is and so the important the component is. Table 3 shows an example of score a returned products through its components.

Table 3 The score of components

components	1	2	3	4	5	6	7	8	9	10	Total
value	20	49	15	56	80	4	8	98	30	50	---
coefficient	0.5	1.0	0.7	0.3	0.4	0.2	0.9	0.3	0.6	0.8	---
pre-score	10	49	10.5	16.8	32	0.8	7.2	29.4	18	40	213.7
scores	4.7	22.9	4.9	7.86	15.0	0.4	3.4	13.8	8.4	18.7	100

6.0 Numerical Experiment

To demonstrate the effectiveness of the fuzzy controller, an numerical experiment is implemented in this part. Section 6.1 shows the initial data generation. Section 6.2 shows the calculation and the results.

The assumptions are as follow.

(1) The collection cost of returned products is only related to the quality of that returned products.

(2) The quality and quantity of returned products in each period is uncertain, which means that both the uncertainties of the quality and quantity are considered in this scenario.

(3) The demand of refurbished products is uncertain in each period, which means the uncertainty of the demands is in consideration.

(4) The capacity of disassemble is not considered, the capacity of refurbishment is not considered.

6.1 Initial Data Generation

Since the proposed problem is the optimization of daily production planning in the refurbish process, the period here is set to 7 days. According to some data in one factory from China, the initial inventory of remanufactured products is 50, the initial inventory of renewable products is 40. Table 4 shows the demand of refurbished products. Table 5 shows the initial inventories of returned components and new components. Fig. 8 shows the initial inventories of returned and new components. Table 6 shows the quantity of returned products in all the periods. Fig. 9 displays the variation tendency of the demands and supplies. Table 7 shows the unit inventory cost of each component in each period. In this experiment, the collection cost of each returned products is 30% of its real value. The sell price of each refurbished product is 75% of brand new product.

Table 4 The demand of refurbished products

periods	1	2	3	4	5	6	7
demand	80	65	110	90	50	85	80

Table 5 The initial inventory of returned and new components

components	1	2	3	4	5	6	7	8	9	10
reused inventory	15	20	30	20	40	50	20	40	30	20
new inventory	10	10	10	10	10	10	10	10	10	10

Table 6 The quantity of returned products

periods	1	2	3	4	5	6	7
practical	100	90	120	110	120	120	90

Table 7 Unit inventory cost of each component in each period

components	1	2	3	4	5	6	7	8	9	10
unit inventory cost	0.2	0.5	0.1	0.6	0.1	0.8	0.4	0.1	0.7	0.2

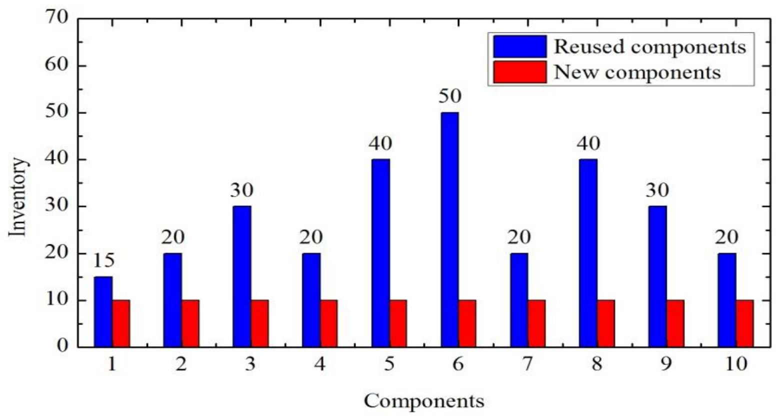

Fig. 8 The initial inventories of returned and new components

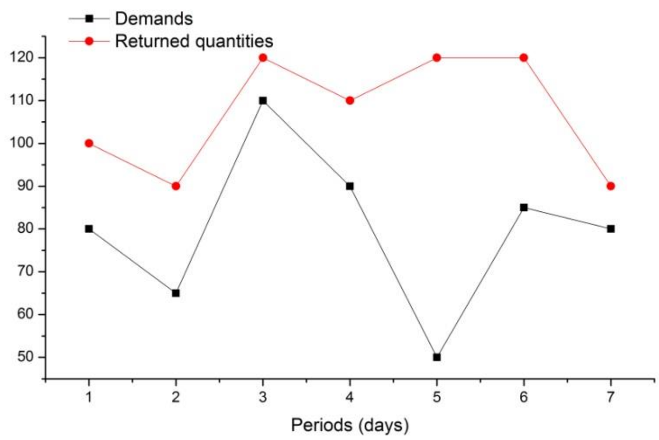

Fig. 9 The variation tendency

As for the returned products, since the quality of each returned product is different, all of them in each period have to be generated and displayed. To obtain the information of components, Apple iPad 4 LTE A1459 is used as an practical example.

Ipad is mainly divided into the following 10 parts: Battery pack, Display, Cameras, Touch screen, Memory, Processor, Wireless section-BB/RF/PA (Module), User interface & Sensors & Combo Module (WLAN/BT/FM), Mechanical/ Electro-Mechanical/Other and Box Contents. All company names, product names, and service names mentioned are used for identification only and academic analysis. The value analyses presented in this case study are estimated from generally available data. Therefore the actual values may be different from these estimates. Table 8 shows the components information in iPad.

Table 8 Components information

No.	Name	Estimated value	Percent	Damage rate
1	Battery pack	20.27	6.33%	55%
2	Display	77.73	24.27%	65%
3	Cameras	16.31	5.09%	30%
4	Touch screen	22.71	7.09%	40%
5	Memory	47.72	14.9%	20%
6	Processor	23.00	7.18%	15%
7	Wireless section-BB/RF/PA (Module)	41.50	12.96%	25%
8	User interface & Sensors & Combo Module (WLAN/BT/FM)	15.00	4.68%	10%
9	Mechanical/ Electro-Mechanical/Other	50.50	15.77%	85%
10	Box Contents	5.50	1.72%	90%
	Total	320.24	100%	

According to the damage rate in Table 8, the returned products in the first period is generate. 1 means the returned components is in good quality, which can be reused, 0 means the returned components is damage. All the returned products with different components status are shown in Appendix.

Products scores are calculated according to the estimated value in Table 8. Here, the first period is taken for example. The coefficient decided according to the returned components inventory in the first period. Table 9 shows the score process of one returned product.

Table 9 Score process of one returned product

Components	1	2	3	4	5	6	7	8	9	10
Inventory	15	20	30	10	40	80	20	40	30	20
Coefficient	0.85	0.8	0.7	0.9	0.6	0.2	0.8	0.6	0.7	0.8
Value	20.27	77.73	16.31	22.71	47.72	23.00	41.50	15.00	50.50	5.50
Status	1	0	1	1	0	0	1	1	0	1
Score	17.2	0	11.4	20.4	0	0	33.2	9.0	0	4.4
The score of this product is 95.6										

6.2 Calculation and Results

In this problem, a JAVA program is written to implement the fuzzy controller. In this fuzzy controller, Mamdani-Type fuzzy inference is used. Using the input data in Section 6.1, the results of indicators in seven periods are shown in Table 10. Table 11 shows the profit of each period.

Table 10 Indicators of seven periods

Periods	1	2	3	4	5	6	7
Indicators	74	60	89	69	95	90	82

Table 11 Profits of seven periods

Periods	1	2	3	4	5	6	7	Total
Profits	12580	11024	14635	15846	12007	10059	13546	89697

To further understand the characteristic of the proposed method on dealing with uncertainty. Further experiments are implemented. In order to further test the performance of proposed fuzzy controller, periods are increased in further experiments. Since the considered problem is under the condition in stable period of product life cycle, the demands and the supplies are set to approximately equal. The quantity of returned products are randomly generated between 150 to 200, the demands are randomly generated between 120 to 160. In this experiment, 7 to 50 periods are considered. For simplicity, Table 12 only shows the demands and returned products of 10 periods.

Table 12 Supplies and demands of 10 periods

Periods	1	2	3	4	5	6	7	8	9	10
Supplies	169	182	150	174	162	192	155	178	186	189
Demands	140	158	124	135	139	142	130	139	159	121

After calculation, the results of total profits average unit profits are shown in Table 13. Fig. 9 shows the tendency of the average unit profits, which indicates the performance of proposed fuzzy controller. From Fig. 10, it can be seen that, when the considered periods increase, the unit profits tend to steady, and the increased slowly.

Table 13 Results of periods increased

Cases	1	2	3	4	5	6	7	8	9	10
Considered periods	7	10	15	20	25	30	35	40	45	50
Demands	728	1387	2018	2768	3564	4172	4849	5575	6265	6981
Total profits	89920	166578	253057	344893	448351	526506	614368	708026	795029	887983
Unit profits	123.5	120.1	125.4	124.6	125.8	126.2	126.7	127.0	126.9	127.2

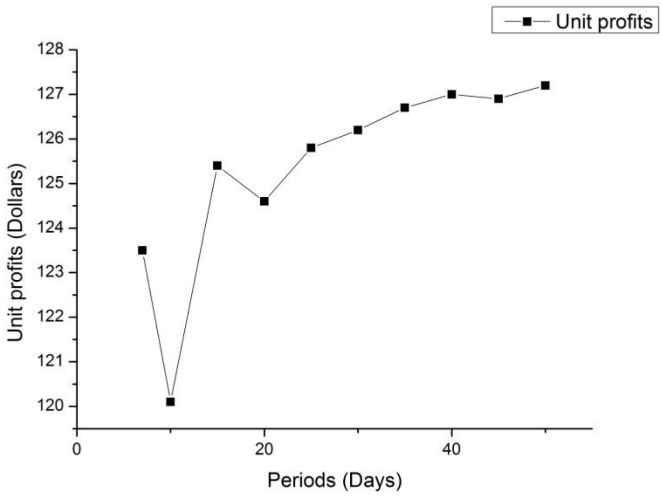

Fig.10 Tendency of unit profits

7.0 Analysis

To analysis the ability of proposed fuzzy controller of dealing with uncertainties, additional experiments are implemented as benchmarking. In this benchmarking, the indicator is set to unchangeable. The parameters and initial data are the same as the experiments with fuzzy controller. The experiments are implemented under the condition of seven periods. From Table 10, it can be seen that the indicators of each period are distributed from 60 to 95. So in this experiment, the indicator is set to 70, 80 and 90. Table 14 shows the calculation results of this experiments. For convenience of comparison, the costs are used instead of profits.

Table 14 Comparison results

Indicators	Fuzzy controller	60	70	80	90
Total costs	8076	10612	9568	9611	9846
Inventory costs	4624	5039	4943	5481	6763
Processing costs	3344	4682	4029	3512	2359
Penalty costs	108	891	596	618	724

From Table 14, it can be inspected that the performance of the proposed fuzzy controller is much well than the unchangeable indicator. All of the total costs, inventory costs, processing costs and penalty costs are less than the condition of 60, 70 and 80. For the experiment with indicator set to 90, although the processing costs of fuzzy controller is a few higher, other costs are much lower, the total costs is still much lower. This analysis prove the effective ability of the proposed fuzzy controller on dealing with uncertainties.

8.0 Conclusions and Future Research

Products refurbishment become more and more important nowadays. Optimization of products refurbish process need to be studied. From the description in this paper, it can be understand that the production planning in the returned products refurbishment is not the normal production planning problem. The uncertainty of the quantity and quality of the returned products make the problem much more complicate. In this paper, a fuzzy controller with value indicator is proposed to solve the uncertainty of the returned products quantity considering the various quality of the returned products. The results of the numerical example shows that the proposed fuzzy controller can solve this multi-period uncertainty problem in effective way.

This paper structured and optimized the process of product refurbishment, considering inventories and uncertainties with multi-periods. Numerical experiments proved the effectiveness of the proposed fuzzy controller. This proposed fuzzy controller can deal with the uncertainties of supplies and demands in an efficient way. Additionally, the quality indicator enhances the ability of the proposed fuzzy controller in dealing with uncertainties in both quantity and quality.

In the current research, the variety of returned products quality is considered instead of the uncertainty of returned products quality. In the future research, the uncertainty of returned products quality will be considered. During different product life cycle, the relationship between customer demands and returned products are diverse, so several scenario of different life cycle will also be considered.

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