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A DECISION MODEL FOR REVERSE LOGISTICS SERVICE PROVIDERS IN DETERMINING ROBUST OPTIMAL PROCESSING QUANTITIES OF RETURNED PRODUCTS

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ABSTRACT

Reverse logistics covers a serial of activities in dealing with returned products from consumers, including collecting, reusing and recycling. Implementing reverse logistics is much more complicated and expensive than forward logistics to an enterprise. Meanwhile, the systematic patterns for handling transportation, storage, processing and management processes of these activities are still called for. Consequently, to reduce the reverse logistics cost and focus on its core business, an enterprise prefers outsourcing these activities in this manner. Previous studies focused on the selection of processing facilities and the infrastructure design of reverse logistics distribution channels for third-party reverse logistics service providers. In contrast, this research aims to deal with the issues of reverse logistics from different viewpoint. We propose a decision model for a reverse logistics service provider under the context of uncertain, multi-period, multi-type returned/recycled products and multiple processing facilities environment. The major focus of this model is on determining the robust optimal quantities of customer orders and robust optimal processing quantities of returned products for each processing facility. To deal with the issues of uncertainties, the model applies the scenario-based robust optimization approach. Further information on experiment results and implications can be found in this paper.

***Keywords**:* reverse logistics service, decision model, robust optimization

1. INTRODUCTION

In recent years, developed countries pay much more attention to environmental protection. One reaction in this manner is to make strictly regulations. WEEE, the regulation from European Union, is the most well-known example in this regard. Such regulations request product manufacturers responsible for retrieving and dealing with their products being sold out. To satisfied such requests, manufacturers start adding environmental protection issues into the core of their corporate strategies, thus making reverse logistics being part of the product life cycle. The coverage of reverse logistics, generally speaking, includes retrieving used products from consumers, and reprocessing them returned to the market. However, the cost reverse logistics is often higher than that of the cost of forward logistics. What is worse, the channel for transporting, storing, processing and managing returned products is still under construction. Enterprises have difficulties in controlling the variation of returns processing. Therefore, owing to concerns on cost expenditure and efficiencies, it is not surprised that enterprises prefer outsourcing these activities to third-party reverse logistics service providers, thus making the third-party reverse logistics service being a trend [4, 9].

However, although the issues of the location selection problems of recycling centers and that of reverse logistics transportation paths arrangement have been widely studied in recent years, there is little research emphasizing on the quantity determination issues of reverse service providers. In this paper, we provide the solution of multiple processing facilities which how to make their strategies of recycle services, and propose a remanufactured resource order and recycled processing quantity order decision model of creating maximum profit for reverse service providers. In terms of uncertain issues, our proposed model uses the scenario-based robust optimization approach. Based on the above proposed decision model, it will help the reverse services providers to maximize their profits under the consideration of recycling, remanufacturing, purchasing and transportation.

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2. LITERATURE REVIEW

2.1 Reverse logistics

There are a couple of studies defining reverse logistics. For instance, according to Fleischmann *et al.* [4], reverse logistics starts with retrieving used products from consumers, going through activities of re-manufacturing, and finally putting this resource to the market again. Carter and Ellram [3] regard reverse logistics as a collection of processes, which include recycling, reusing and deducting. Nonetheless, the coverage of narrow-focused reverse logistics is through selling network to retrieve products and to remanufacture them. And, it can help reduce the purchase of raw materials from forward suppliers, and help reduce possible environmental pollution in the meantime. Thus, that is no wonder that reverse logistics being said great chance for enterprises.

However, if the focus is on the driving forces that made reverse logistics dynamic and hard for control, two critical issues for reverse logistics service providers can be identified through literature. The first issue is on product recycling itself, which deals with the recycled quantities, information of the material structure of products, the quality of product recovery, and the demand of remanufactured products. The second issue is on the process of reverse logistics, which deals with plans for the process flow, facilities and transportation of recycled centers. These driving forces of uncertainties, generally speaking, have serious impact on purchase, producing and stock management of manufacturers, thus leading to the business decision of outsourcing to the third-party reverse logistics services providers.

As a consequence, the effect of economies of scale on reverse logistics services are found recently; and, studies on reverse logistics design become popular [1, 5, 15]. For example, Beamon [1] proposed an extended supply chain model. In contrast to the traditional supply chain (which is composed of suppliers, manufactures, delivers, retails and customers), Beamon's extended model adds three extra components: recycle, reuse and collection, with its further focus on the semi-closed settings. Guide *et al.* [5] proposed a recovery enabling system, which described used goods retrieved from consumers, with its emphasis on processes of reuse. This process will help manufacturers reduce negative impact on the environment, whereas those enterprises use the recycled resources may reduce its procurement cost in the meantime. In terms of key activities of reverse logistics, Krumwiede and Sheu [9] classify all the processes into three stages: retrieving products, transportation, and post-processes of products returning back (e.g., repairing, remanufacturing, disposal handling).

2.2 Reverse logistics model

Once emphasizing activities on processing returned goods, Louwers *et al.*'s model [11] on decisions of site selection of discarded carpet worth pays attention to. In their model, the nodes of the reserve logistics include sources, returned centers and factories for processing, and the goal of this model is to find out the minimum total cost. Shih [14] built up a model based on the case of computer retrieval and process in Taiwan. In this model, although its goal is the same to that of Louwers *et al.* [11], while Shin added further practical constraints, especially the subsidy and take-back rates derived from Taiwanese regulations.

Moreover, in Ko and Evans' [7] model, the emphasis is on how a third-party logistics (3PL) provider determine the best logistics network (for both forward and reverse ones), including the locations for setting up logistics centers. And, Ko and Evans addressed the importance of transportation of goods return, location of storage and returns repaired. Zhang *et al.* [18] added uncertain factors, such as random quantity of disposals, in their model, so as help highlight the practical situation of 3PL. However, although Zhang *et al.* apply fuzzy theory in dealing with uncertain issues in this study, while the real problems that 3PLs suffer have not been solved. This is mainly because that Zhang *et al.*'s model assumes 3PLs simply serve for activities of collection, transportation and storage of returns, while do not take activities relevant to decompose and post-process on returned goods.

2.3 Robust optimization

Kouvelis and Yu [8] highlight that the uncertainty issue is critical for decision making, while it is hard to dispel in most cases. Thus, they suggest that decision models should take uncertainties into account, thus help decision makers find out optimal solutions for practical applications. In cases of reverse logistics, not surprisingly, uncertainty is regarded as one of the key characteristics. However, traditional models tend to solve problems in a much more static context, thus taking little efforts dealing with uncertain factors that enterprises suffered in the real world.

Recently, the practice of defining uncertainties as random variables has been widely adopted in resolving the above challenge. Yet, the approach of applying the probability model is still hard in settings and measurement, thus calling for alternatives for model revision.

Based on such viewpoint, Mulvey *et al.* [12] proposed a robust optimization approach for large-scale system applications in this manner. Mulvey *et al.* extended linear programming into multi-purpose scenarios programming, which help identify the insensitivity solution for uncertain factors being defined. According to Mulvey *et al.*, if we can find an optimal solution for all scenarios through linear programming, the solution being found has the property of robust. However, as well-known, it is almost impossible to get an optimal solution for all scenarios in the real word. That is, there must be a trade-off between optimal solution and the degree of robust. A practical approach in determining the trade-offs is through adding penalty functions within the model.

Basically, we see different studies modeling penalty functions through a variety of approaches. Realff *et al.* [13], for instance, designed nine scenarios (there are high, median and low degree) in their robust optimization model, and analyzed the casual effects derived from uncertainty of recycled products and remanufactured materials. Butler *et al.* [2] combined Lagrangian approach and robust optimization to keep stability in a long-term planning. Hong *et al.* [6] designed a robust optimization model in dealing with the e-scrap system; issues being dealt in this model include collecting, transporting, and processing of electronic discarded products, accompanying with returned rates, reused ratio and selection of recycled centers. Hong *et al.* defined different scenarios in each problem and found out the optimal solution of each plan.

3. THE DECISION MODEL

From the previous literature on reverse logistics, the following important lessons are learnt: (1) in terms of the network structure, the key nodes of a reserve logistics system should include at least sources, returned centers and factories for processing. And, (2) in terms of modeling of uncertainties, simple approaches for dynamic models, such as sensitive analysis and random plan, are not applicable; in contrast, scenario-based robust optimization approach would be a better alternative.

Thus, this research aims to propose a decision model, which helps reverse logistics service providers determine the robust optimal quantities of customer orders and robust optimal processing quantities of returned products in each processing facility, under the context with uncertainties, multi-period, multi-type recycled products, and multi-processing facilities. More specifically, as shown in Figure 1, the reverse logistics ecosystem is composed of returned sources, hubs for collection, post-processing factories, enterprises (for using recycled products), the used (or secondary) markets, and disposal centers.

With regard to the methods being applied in the model, the authors firstly uses linear programming (LP) to construct the basic model, and apply the scenario-based robust optimization approach in dealing with uncertain issues, wishing that the outcome of this model can really bring values and suggested solution to the practice.

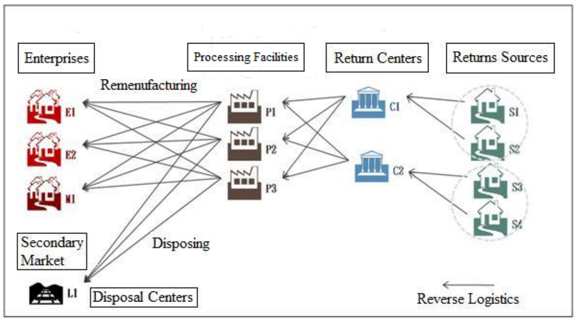

Figure 1. Model structure of this research

3.1 Assumptions and basic settings

1. Services providers own a variety of facilities, ranging from returned centers, processing factories, and transportation vehicles. There is no limitation of capacity and no time lags between transportation between nodes of the ecosystem.
2. Reverse logistics service providers have to pay for the returns purchased, but they can declare subsidy from government according to the number of processed returned items.
3. The key driving force for enterprises purchasing recycled materials is the regulation; meanwhile, enterprises will purchase recycled items from specific brands / ranges owing to concerns of the needs of new products.
4. The remanufacturers can sell recycled items to different enterprises for different prices.
5. Remanufactured materials can be sold to the secondary market by spot price.
6. The bill of material (BOM) of returned products is one-level decomposition. In particular, there are n recycled materials (i.e., K1 to Kn); besides, for a given recycled material, there are n brands (i.e., B1 to Bn), as shown in Figure 2.

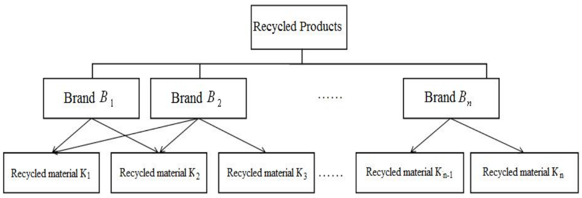

Figure 2. BOM's structure of returns

3.2 Descriptions of the decision model

This model is composed of two parts; Part I deals with the case of single, static context, and is solved by linear programming. Part II deals robust optimal solutions under multi-period, uncertain situations through the scenario-based robust optimization model.

3.2.1 Single scenario model (part I)

As seen in Equation 1, the objective function is to maximize the net profit (i.e., total revenue minus total cost) of a reverse logistics service provider. For the revenue side, total revenue is the sum of revenue from remanufactured materials sold and subsidy. In particular, the revenue of a reverse logistics service provider can be further decomposed into several parts: (1) from sold-out: the order of actually accepted quantity QPEtbkpe multiply purchasing price E_ pricetbke; (2) sold to secondary markets: the order of actually accepted quantity QPMtbkpm multiply price M_ pricetbkm; and (3) subsidy: C_Subsidyi multiply QSCtisc means the subsidy of recycled products, and P_Subsidyi multiply QPtip is the subsidy of returns processing (see Equation 2).

With regard to the cost side, it is composed of 5 major parts, namely transportation cost, storage cost, fixed cost, processing cost, and purchasing cost. Purchase cost is calculated by unit purchasing cost of return PCti multiply transportation quantity QSCtisc (see Equation 3).

Processing cost is the accumulation of costs for all processing factories dealing with returns OCti multiply transportation quantity QPtip (see Equation 4).

Fixed cost equals to the summation of the fixed costs of each facility (e.g., C_FixCostc indicates the fixed cost of return centers) (see equation 5).

Transportation cost is measured by transportation fee between two nodes (as TCsctisc is the cost of node *s* to *c*) multiplies distance Dscsc and the corresponding quantity of transportation (see Equation 6).

Storage cost is the aggregated number of return centers' costs, plus the cost of processing facilities. In particular, return centers' costs equals to the summation of C_INVtic (the quantity of initial inventory plus the returns from the return sources minus quantity sent to processing facilities) multiply unit cost of storage C_InvCosttic. Whereas the storage cost of processing facilities is the sum of unit storage cost P_InvCosttip multiply inventory P_INVtbkp (see Equation 7).

All the indexes and remarks of each symbol can be found in Table 1, whereas the parameters of profit, parameters of cost, parameters of boundary, parameters of scenario and variables of decision can be found from Table 2 to Table 6.

Table 1. Index sets used in model formulation

Suffix	Description	Primary Index Sets	Description
$i \in I$	a recycled product	I	Set of recycled products
$b \in B$	a brand	B	Set of brands
$k \in K$	a recycled material	K	Set of recycled materials
$t \in T$	a period	T	Set of periods
$s \in S$	a return source	S	Set of return sources
$c \in C$	a return centers	C	Set of return centers
$p \in P$	a processing facility	P	Set of processing facilities
$e \in E$	an enterprise	E	Set of enterprises
$l \in L$	a disposal center	L	Set of disposal centers
$m \in M$	a secondary market	M	Set of secondary markets

Table 2. Parameters of profit

Variables of Profits	Description
E_price_{tbke}	Price of recycled material *k* of enterprise's brand *b* in the period *t*
M_price_{tbkm}	Price of brand b's recycled material k of secondary market in the period *t*
$C\_subsidy_i$	Subsidy of recycled product *i*
$P\_subsidy_i$	Subsidy of recycled product *i* of processing facility

Table 3. Parameters of cost

Variables of Costs	Description
Dsc_{sc}	Shipping distance between return source s and return center c
Dcp_{cp}	Shipping distance between return center c and processing facility p
Dpe_{pe}	Shipping distance between processing facility p and enterprise e
Dpm_{pm}	Shipping distance between processing facility p and secondary market m
Dpl_{pl}	Shipping distance between processing facility p and disposal center
$TCsc_{tisc}$	Shipping cost of recycled product i between return source s and return center c in the period t
$TCcp_{ticp}$	Shipping cost of recycled product i between return center c and processing facility p in the period t
$TCpe_{tbkpe}$	Shipping cost of b brand’s recycled material k between processing facility p and enterprise e in the period t
$TCpm_{tbkpm}$	Shipping cost of b brand’s recycled material k between processing facility p and secondary market m in the period t
$TCpl_{tpl}$	Shipping cost of disposals between processing facility p and disposal center l in the period t
$OCti$	Processing cost of disposal i in the period t
$PCti$	Procurement cost of recycled product i in the period t
$C\_InvCost_{tic}$	Storage cost of recycled product i of return center c in the period t
$P\_InvCost_{tkp}$	Storage cost of recycled material k of processing facility p in the period t
$C\_FixCost_{c}$	Fix cost of return center c
$P\_FixCost_{p}$	Fix cost of processing facility p
G_{tibk}	Average rate of b brand ‘s recycled material k created from recycled product i in the period t
GL_{ti}	Average disposal rate of recycled product i in the period t

Table 4. Parameters of boundary

Decision Variables	Description
$MaxQ_{tis}$	Quantity of recycled product i, provided from return source s in the period t
E_Demand_{tbke}	Demand for b brand’s recycled material k of enterprise e in the period t
M_Demand_{tbkm}	Demand for b brand’s recycled material k of secondary market m in the period t
C_ULimit_{tic}	Capacity of return center c for recycled product i in the period t
P_ULimit_{tip}	Capacity of processing facility p for recycled product i in the period t
K_ULimit_{tkp}	Capacity of processing facility p for recycled material k in the period t
P_LLimit_{tip}	Minimum quantity of processing facility p for recycled product i in the period t
Qpl_{tpl}	Quantity of shipping from processing facility p disposal center l in the period t
C_INC_{tic}	Quantity of shipping from processing facility p disposal center l in the period t
P_INV_{tbkp}	Inventory amount of b brand’s recycled material k in processing facility p in the end of period t
Qp_{tip}	Quantity of recycled product i, processed by processing facility p in the period t
Qbk_{tbkp}	Quantity of b brand’s recycled material k from recycled product i, created by processing facility p in the period t

Table 5. Parameters of scenario

Parameters of Model	Description
ω	Variables of scenario
$Probability_{\omega}$	Probability of scenario ω
$Netprofit_{\omega}$	Optimal solution of scenario ω in robust optimization model
$OptimalProfit_{\omega}$	Optimal solution of scenario ω in single scenario model
α_{ω}	Deviation of scenario ω in robust optimization model
K	Range of penalty

Table 6. Decision variables

Decision Variables	Description
QSCtisc	Shipping quantity of recycled product *i* from return source *s* to return center *c* in the period t
QCPticp	Shipping quantity of recycled product *i* from return center *c* to processing facility *p* in the period *t*
QPEtbkpe	Shipping quantity of *b* brand's recycled material *k* from processing facility *p* to enterprise *e* in the period *t*
QPMtbkpm	Shipping quantity of *b* brand's recycled material *k* from processing facility *p* to secondary market *m* in the period *t*

As for the detailed mathematics functions are presented as follows:

$$\text{Max Profit} = \text{Revenue} - \text{Transportation Cost} - \text{Purchase Cost} - \text{Processing Cost} - \text{Storage Cost} - \text{Fixed Cost} \quad (1)$$

Revenue =

$$\sum_t \sum_b \sum_k \sum_p \sum_e QPE_{tbkpe} \times E\_price_{tbke} + \sum_t \sum_b \sum_k \sum_p \sum_m QPM_{tbkpm} \times M\_price_{tbkm} + \sum_t \sum_i \sum_s \sum_c QSC_{tisc} \times C\_subsidy_i + \sum_t \sum_i \sum_p QP_{tip} \times P\_subsidy_i \quad (2)$$

$$\text{Purchase Cost} = \sum_t \sum_i \sum_s \sum_c PC_{ti} \times QSC_{tisc} \quad (3)$$

$$\text{Processing Cost} = \sum_t \sum_i \sum_p OC_{ti} \times QP_{tip} \quad (4)$$

$$\text{Fixed Cost} = \sum_c C\_FixCost_c + \sum_p P\_FixCost_p \quad (5)$$

Transportation Cost =

$$\sum_t \sum_i \sum_s \sum_c (TCsc_{tisc} \times Dsc_{sc} \times Qsc_{tisc}) + \sum_t \sum_i \sum_s \sum_c (TCsc_{tisc} \times Dsc_{sc} \times Qsc_{tisc}) + \sum_t \sum_b \sum_k \sum_p \sum_e (TCpe_{tbkpe} \times Dpe_{pe} \times Qpe_{tbkpe}) + \sum_t \sum_b \sum_k \sum_p \sum_m (TCpm_{tbkpm} \times Dpm_{pm} \times Qpm_{tbkpm}) + \sum_t \sum_p \sum_l (TCpl_{tpl} \times Dpl_{pl} \times Qpl_{tpl}) \quad (6)$$

Storage Cost =

$$\sum_t \sum_i \sum_s \sum_c (C\_InvCost_{tic} \times C\_Inv_{tic}) + \sum_t \sum_b \sum_k \sum_p (P\_Inv_{tkp} \times P\_Inv_{tbkp}) \quad (7)$$

In terms of the constraints of this model, they are described as following:

As shown in Equation 8, the first constraint helps ensure that the distribution quantities to return centers QSCtisc never exceed the maximum of each return source MaxQtis.

In Equation 9, the second constraint help guarantee that the distribution remanufactured quantities of reverse logistics services providers QPEtbkpe do not exceed demand of enterprises E_Demandtbke. If the enterprise does not need the remanufactured materials, then the demand is 0. Similar constraint for that of the secondary market is represented as that of Equation 10.

The third constraint is about the flow issue. As shown in Figure 3 and Equation 11, the initial inventory of each return centers C_INV(t-1,i,c) plus the quantities of return sources minus the distribution quantities in the interim period equal to final inventory C_INVtic. Remanufactured materials final inventories of processing facilities P_INVtbkp are same as return centers (as shown by Equation 12).

Equation 13 further sets up the returned items, which are sent to processing facilities, will be processed in current period. It means that optimal returns of processing facility equal to the sum of different return centers QCPticp in every period.

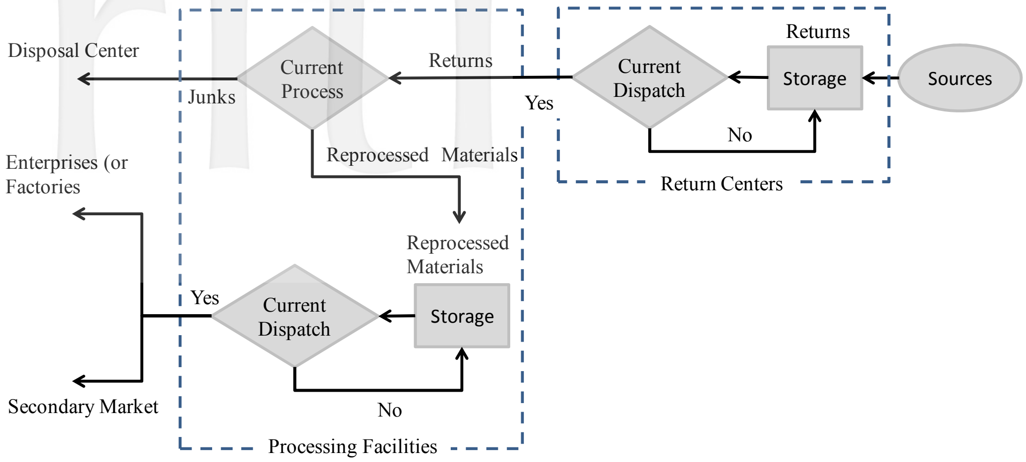

Figure 3. Returns process flow

One retrieved product can be apart of several brands and several kinds of recycled materials in returns processing facilities. Gtibk represents the average reused rate of recycled materials kind *k*, brand *b* from tearing apart of a retrieved products *i* at period *t* (Equation 14). If the rate is greater than 1, it means that the retrial product had more than one kind of this part. GLti means the average disposal rate of retrieved products *i* in period *t*. Qpltpl is the total quantities which are transported to disposal centers (Equation 15).

With it comes to the constraints on capacity, the following requests are made. Equation 16 and Equation 17 help ensure that the returns of returned centers C_ULimitic and that of the recycled materials of processing facilities K_ULimikp never exceed storage capacity of the plant. Moreover, Equation 18 helps ensure that the amount of processing quantities can not exceed process technical capacity of each facility P_ULimitip. Finally, the lower capacity limitation P_LLimitip comes from the law (as show in Equation 18 and Equation 19).

subject to:

$$QSC_{tisc} \le MaxQ_{tis} \qquad \forall t,i,s,c \tag{8}$$

$$\sum_p QPE_{tbkpe} \le E\_Demand_{tbke} \qquad \forall t,b,k,e \tag{9}$$

$$\sum_p QPM_{tbkp} \le M\_Demand_{tbkm} \qquad \forall t,b,k,m \tag{10}$$

$$C\_INV_{tic} = C\_INV_{(t-1,i,c)} + \sum_s QSC_{tisc} - \sum_p QCP_{ticp} \forall t,i,c \tag{11}$$

$$P\_INV_{tbkp} = P\_INV_{(t-1,bk,p)} + Qbk_{tbkp} - \left(\sum_e QPE_{tbkpe} + \sum_m QPM_{tbkpm}\right) \qquad \forall t,b,k,p \tag{12}$$

$$Qp_{tip} = \sum_c QCP_{ticp} \times \qquad \forall t,i,p \tag{13}$$

$$Qbk_{tbkp} = \sum_i Qp_{tip} \times G_{tibk} \qquad \forall t,b,k,p \tag{14}$$

$$Qpl_{tpl} = \sum_i \sum_p Qp_{tip} \times G_{tpl} \qquad \forall t,p,l \tag{15}$$

$$\sum_s QSC_{tisc} + C\_INV_{t-1,ic} \le C\_ULimit_{ic} \quad \forall t,i,c \tag{16}$$

$$\sum_b Qbk_{tbkp} + \sum_b P\_INV_{t-1,bkp} \le K\_ULimit_{kp} \quad \forall t,k,p \tag{17}$$

$$P\_LLimit_{ip} \le Qp_{tip} \qquad \forall t,i,p \tag{18}$$

$$Qp_{tip} \le P\_ULimit_{ip} \qquad \forall t,i,p \tag{19}$$

3.2.2 The robust optimization model (part II)

By referring the scenario-based robust optimization approach of Butler *et al.* [2], uncertain factors are modeled through scenarios. That is, a set of specific parameters used to represent a specific scenario $w \in \Omega$.

As show in Equation 20 and Equation 21, our robust optimization is implemented by introducing the penalty variable λ and the robust deviation α_ω into the model. λ is the penalty of deviating from the net profit of scenario, whereas α_ω stands for the net profit difference between of single scenario and robust optimization.

$$Maximize \quad \sum_{\omega \in \Omega} \{\rho_\omega(R_\omega(Y_\omega, X)) - \lambda\alpha_\omega\} \tag{20}$$

$$subject\ to: \quad \frac{O^*_\omega - R_\omega(Y_\omega, X)}{|O^*_\omega|} \le \alpha_\omega \tag{21}$$

Butler *et al.* [2] derive the optimal net profit of each single scenario as the parameter of the constraints in the robust optimization model. To calculate the net profit difference O*ω between single scenario model and robust optimization model in the robust approach. It is called a robust deviation, and can be represented as that of Equation 21. The objective function is to maximize the sum of each scenarios its net profit of single scenario (Rω(Yω,X)) multiplying its occurrence probability (ρω) minus penalty (λ * αω)

(Equation 20). The optimal solution derived under this situation is called robust optimal solution, and its corresponding net profit in each scenario is very near to the optimal net profit of each scenario. However, according to Lin [10], the decision maker is hard to decide the value of penalty λ; thus, Lin assigned a constant K as the controlled average robust deviation in his research.

Thus, we adopt the above approaches. In particular, in Part II, our objective function of the robust optimization model is set as the sum of net profit of each single scenario Netprofitω multiply probability of scenario Propabilityω (Equation 22). For the robust net profit of each single scenario, it equals to the revenue under each scenario ω minus the total cost (Equation 23). Equation 24 ensures that the optimal solution of each single scenario as one parameter in the robust optimization model. Finally, we identify the robust deviation and control them within the specific limitations (equation 25). As for the remaining parts, they are same as that of the model of single scenario case (Part I).

$$Maximize \quad \sum_{\omega} Net\Pr ofit_{\omega} \times \Pr obability_{\omega} \tag{22}$$

$Netprofit_{\omega}$=
Revenue(ω) - Transportation Cost(ω) –
Purchase Cost(ω) - Processing Cost(ω) –
Storage Cost(ω) -Fixed Cost(ω) (23)

subject to:

$$\frac{Optimal\Pr ofit_{\omega} - Net\Pr ofit_{\omega}}{Optimal\Pr ofit_{\omega}} = \alpha_{\omega} \qquad \forall \omega \tag{24}$$

$$\sum_{\omega} \Pr obability_{\omega} \times \alpha_{\omega} \le K \qquad \forall \omega \tag{25}$$

4. THE EXPERIMENT AND ITS FINDINGS

In this session, the authors use sample data testing the feasibility of the proposed decision model. Most of the data are mainly applied from Hong *et al.* [6], whereas we refer to Yang [17] for the remaining ones unable accessed from Hong [6]. As well, for the practical parameters, in particular the subsidy and regulations for processing facilities, we direct apply that from the Taiwanese Environmental Protection Administration with minor revision, as shown in Table 7. The revenue of the recycle material is not a constant. In the experiment, different role of buyer (enterprise or secondary market) at different time period pays different price to buy the recycled material.

The settings of this experiment covers three kinds of recycled products, two brands, two kinds of remanufactured materials, twelve return sources, eight processing facilities, six enterprises, one secondary market and one disposal center. For every returned center, the returned sources are distributed in the neighborhood area, which implies that the returned sources will not be transported outside the range.

Table 7. Parameters' value of subsidy and regulations

Parameter	Value	Parameter	Value	Parameter	Value
$C\_Subsidary_{i1}$	207.5	$C\_Subsidary_{i3}$	219.5	$P\_Subsidary_{i2}$	133
$C\_Subsidary_{i2}$	159.5	$P\_Subsidary_{i1}$	101	$P\_Subsidary_{i3}$	259

Unit：$

Because of reverse logistics is more uncertain than forward logistics, the planning time horizon is to be shortened. More specifically, the time horizon of this experiment is about four periods, each period represents for one month. The model does not consider the location planning of return centers and processing facilities (since they are already set up and fixed), neither the processing facilities operate in each period (because the facilities are not considered to be closed).

The configuration of this experiment is depicted in Figure 4.

In this experiment, settings about the capacity and fixed cost of processing facility are applied from Yang *et al.* [12], whereas the distance of each two nodes refers to Hong's [6]. It divided recycled area into twelve parts, and there is at least one recycled center of each part. The position of each node is determined through random methods, and the distance of each two nodes is calculated by the Euclidean. The results of our experiment can be found from Table 8 to Table 12.

With regard to the uncertainty issue of reverse logistics, this research identifies two levels (i.e., high vs. low) to present the variation of each uncertainty. Moreover, in this experiment, four categories of uncertainties are specified, thus resulting in 16 scenarios: the quantities of recycled products, rate of remanufactured materials produced, demand of enterprises or secondary market, purchasing price of remanufactured materials for enterprises or secondary market. Furthermore, we assume that the probability of each scenario taking place is the same (i.e., 6.25% of each scenario). For instance, in Table 13, scenario one (i.e., o1) represents that the reverse logistics service provider faces the situations of high return amount, high output rate, high demand and high price during planning period in the future. The optimal net profits and solutions of all single scenarios are found out first, then being taken as the parameters in multiple scenarios robust optimization model. Robust solution is the robust optimal order of remanufactured materials and the robust optimal quantities of processing facilities for maximum business profit in a period.

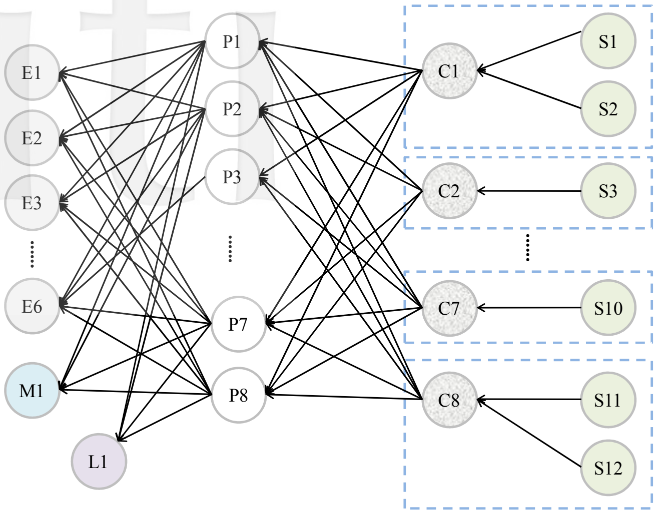

Figure 4. The configuration of the experiment

Table 8. Parameters' value of distance from return sources to recycled centers

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
Dsc_{s1c1}	59	Dsc_{s4c3}	66	Dsc_{s7c5}	8	Dsc_{s9c6}	23	Dsc_{s11c8}	36
Dsc_{s2c1}	36	Dsc_{s5c3}	23	Dsc_{s8c6}	63	Dsc_{s10c7}	52	Dsc_{s12c8}	67
Dsc_{s3c2}	36	Dsc_{s6c4}	43						

Table 9. Parameters' value of distance from recycled centers to processing facilities

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
Dcp_{c1p1}	87	Dcp_{c2p1}	131	Dcp_{c3p1}	250	Dcp_{c4p1}	271	Dcp_{c4p1}	121
Dcp_{c1p2}	147	Dcp_{c2p2}	135	Dcp_{c3p2}	76	Dcp_{c4p2}	168	Dcp_{c4p2}	236
Dcp_{c1p3}	209	Dcp_{c2p3}	67	Dcp_{c3p3}	130	Dcp_{c4p3}	84	Dcp_{c4p3}	179
Dcp_{c1p4}	269	Dcp_{c2p4}	198	Dcp_{c3p4}	51	Dcp_{c4p4}	119	Dcp_{c4p4}	313
Dcp_{c1p5}	295	Dcp_{c2p5}	227	Dcp_{c3p5}	405	Dcp_{c4p5}	348	Dcp_{c4p5}	113
Dcp_{c1p6}	245	Dcp_{c2p6}	95	Dcp_{c3p6}	268	Dcp_{c4p6}	191	Dcp_{c4p6}	75
Dcp_{c1p7}	382	Dcp_{c2p7}	215	Dcp_{c3p7}	354	Dcp_{c4p7}	228	Dcp_{c4p7}	203
Dcp_{c1p8}	345	Dcp_{c2p8}	172	Dcp_{c3p8}	243	Dcp_{c4p8}	102	Dcp_{c4p8}	234
Dcp_{c5p1}	230	Dcp_{c5p6}	86	Dcp_{c6p3}	126	Dcp_{c6p8}	29	Dcp_{c7p5}	333
Dcp_{c5p2}	315	Dcp_{c5p7}	118	Dcp_{c6p4}	221	Dcp_{c7p1}	377	Dcp_{c7p6}	212
Dcp_{c5p3}	226	Dcp_{c5p8}	209	Dcp_{c6p5}	284	Dcp_{c7p2}	351	Dcp_{c7p7}	109
Dcp_{c5p4}	361	Dcp_{c6p1}	275	Dcp_{c6p6}	132	Dcp_{c7p3}	239	Dcp_{c7p8}	99
Dcp_{c5p5}	111	Dcp_{c6p2}	239	Dcp_{c6p7}	125	Dcp_{c7p4}	317		

Unit：Kilometer

Table 10. Parameters' value of distance from processing facilities to secondary markets/disposal centers

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
Dpl_{p1l1}	173	Dpl_{p4l1}	216	Dpl_{p7l1}	164	Dpm_{p2m1}	224	Dpm_{p5m1}	282
Dpl_{p2l1}	178	Dpl_{p5l1}	216	Dpl_{p8l1}	129	Dpm_{p3m1}	112	Dpm_{p6m1}	128
Dpl_{p3l1}	80	Dpl_{p6l1}	62	Dpm_{p1m1}	264	Dpm_{p4m1}	209	Dpm_{p73m1}	135
Dpm_{p8m1}	38								

Unit：Kilometer

Table 11. Parameters' value of distance from processing facilities to enterprises

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
Dpe_{p1e1}	60	Dpe_{p2e1}	175	Dpe_{p3e1}	219	Dpe_{p4e1}	295	Dpe_{p5e1}	263
Dpe_{p1e2}	208	Dpe_{p2e2}	36	Dpe_{p3e2}	106	Dpe_{p4e2}	86	Dpe_{p5e2}	368
Dpe_{p1e3}	138	Dpe_{p2e3}	267	Dpe_{p3e3}	210	Dpe_{p4e3}	344	Dpe_{p5e3}	82
Dpe_{p1e4}	381	Dpe_{p2e4}	353	Dpe_{p3e4}	241	Dpe_{p4e4}	316	Dpe_{p5e4}	339
Dpe_{p1e5}	106	Dpe_{p2e5}	136	Dpe_{p3e5}	89	Dpe_{p4e5}	214	Dpe_{p5e5}	215
Dpe_{p1e6}	336	Dpe_{p2e6}	263	Dpe_{p3e6}	162	Dpe_{p4e6}	208	Dpe_{p5e6}	359
Dpe_{p6e1}	231	Dpe_{p6e5}	100	Dpe_{p7e3}	209	Dpe_{p8e1}	347	Dpe_{p8e5}	197
Dpe_{p6e2}	237	Dpe_{p6e6}	207	Dpe_{p7e4}	116	Dpe_{p8e2}	237	Dpe_{p8e6}	48
Dpe_{p6e3}	95	Dpe_{p7e1}	369	Dpe_{p7e5}	230	Dpe_{p8e3}	256		
Dpe_{p6e4}	217	Dpe_{p7e2}	335	Dpe_{p7e6}	179	Dpe_{p8e4}	100		

Unit：Kilometer

Table 12. Parameters' value of shipping cost

Parameter	Value	Parameter	Value	Parameter	Value	Parameter	Value
$TCsc_{ti1sc}$	0.1328	$TCcp_{ti2cp}$	0.03496	$TCpe_{tk1pe3}$	0.7524	$TCpm_{tk1pm}$	0.2360
$TCsc_{ti2sc}$	0.12616	$TCcp_{ti3cp}$	0.0339	$TCpe_{tk2pe1}$	0.7942	$TCpm_{tk2pm}$	0.2242
$TCsc_{ti3sc}$	0.1222	$TCpe_{tk1pe1}$	0.8360	$TCpe_{tk2pe2}$	0.63536	$TCpl_{tpl}$	0.0368
$TCcp_{ti1cp}$	0.0368	$TCpe_{tk1pe2}$	0.6688	$TCpe_{tk2pe3}$	0.7148		

Unit：$/Kilometer * Kilogram

Table 13. The optimal net profit under different scenario (H: High, L: Low)

Scenario	Returns	Throughput rate	Demand	Price	Net profit under the single scenario	Net profit under the Robust Optimization
o1	H	H	H	H	10008370	4207283
o2	H	H	H	L	8157596	3054051
o3	H	H	L	H	9099155	4207283
o4	H	H	L	L	7581810	3054051
o5	H	L	H	H	10334740	4826519
o6	H	L	H	L	8582550	3673287
o7	H	L	L	H	9617960	4826519
o8	H	L	L	L	8119753	3673287
o9	L	H	H	H	4741299	3094693
o10	L	H	H	L	3230131	1941461
o11	L	H	L	H	4419504	3094693
o12	L	H	L	L	3005949	1941461
o13	L	L	H	H	4038311	3713929
o14	L	L	H	L	2867789	2560697
o15	L	L	L	H	3988191	3713929
o16	L	L	L	L	2817622	2560697

The decision maker can get the robust optimal solution for insensitivity of uncertainties of the environment, and reduce the loss caused from environmental changes by this decision model. The whole experiment is executed through Lingo software. The 16 scenarios (i.e., o1 to o16) have their corresponding optimal profit of each single scenario, and set up sixteen solutions to be the input parameter values for multiple scenarios model. They are the parameters OptimalProfito1 to OptimalProfito16 for the multiple scenarios robust optimization model. After the simulation, we get a set of robust optimal solutions, which describe corresponding information of each period, the robust optimum handling quantities of a product in each processing facility and the robust optimal order of remanufactured materials for each costumer. We then got one robust optimal net profit which was the objective value in multiple scenarios robust optimization model in the same time. The value was 3,383,990, which represents for the sum of each robust net profit with its weight of probability.

From the outcome, it is clear to find that the robust net profit is lower than the optimal net profit for a specific scenario. But the environment of reverse logistics is filled with uncertainties, it is improper only adopting a deterministic approach to help in making decisions under this kind of environment. If we assume the scenario o1 will occur, then firstly build the linear programming model for o1 as well as solve it to get the optimal solution for o1, and use this solution to run the business. And if very fortunately (only 6.25%) o1 is really occurred, then we get the best net profit. But most of the cases (93.75% >> 6.25%), other scenarios are occurred, and then we may get trouble. The optimal solution of o1 is may an infeasible solution or a mediocre feasible solution of other scenarios. The proposed decision model adopting scenario-based robust optimization approach can get the insensitivity satisfied and feasible solution (called robust optimal solution) for uncertain factors, and reduce the loss caused from environmental uncertainties. It means that although robust optimization is may not the best solution, it is the most stable one for each scenario and can reduce the loss caused from environmental changes.

The robust deviation of scenario o is calculated as (OptimalProfito - NetProfto) / OptimalProfito. Table 14 shows the robust deviation in each scenario. According to the information, smaller robust deviation implies smaller difference between the single scenario profit and robust optimization profit. In other words, if the robust deviation of a scenario is large, it means adoption of the optimal solution of this single scenario has high profit while with high risk in the meantime. If decision makers does not consider other scenarios and carries on excessive investment, it might result in unexpected great loss. Thus, such a claim, combining with the experimental data of this research implies that the proposed model of the robust optimization can reduce the risk of uncertainty, but may sacrifice the high profit under some extreme scenarios.

In addition, based on the results shown in Table 15, we can make further suggestions as following. First of all, because the objective function of this proposed model is profit maximization, the demands of the recycling materials requested by enterprises and secondary market (with no penalty) are not required to be satisfied. Besides, according to Table 15, we observe that the processing quantity of many processing facilities in many period only meet the minimum requirement that is set in the experiment (i.e., the number is set to 10).

Table 14. Robust deviations of 16 scenarios

Scenario	o1	o2	o3	o4
Robust Deviation	57.96%	62.56%	53.76%	59.72%
Scenario	o5	o6	o7	o8
Robust Deviation	53.30%	57.20%	49.82%	54.76%
Scenario	o9	o10	o11	o12
Robust Deviation	34.73%	39.90%	29.98%	35.41%
Scenario	o13	o14	o15	o16
Robust Deviation	8.03%	10.71%	6.88%	9.12%

The fulfilled rates of the enterprises' demands and sales quantities of the recycling materials to the secondary market are also not high. In particular, most of the profit comes from the subsidy of government. Thus, based on such information, we may say that the revenue purely from sales of recycled materials may not cover the extra costs of transportation and processing of returns; thus, for a reverse logistics service provider, it is better way to keep returns in the returned centers sp that they can get subsidy and do not need to pay for extra costs. If such a claim really comes true in the real world, the authors believe that such a situation may reduce the effect of subsidy for environmental protection, thus the government has better redesign the supplementary package with subsidy.

Table 15. Robust optimal processing quantity for each facility in each period

Period		t =1							
Processing Facility		p1	p2	p3	p4	p5	p6	p7	p8
Product	i1	331.00	305.97	10.00	10.00	10.00	152.03	10.00	1727.73
	i2	523.00	536.00	10.00	10.00	10.00	469.00	10.00	783.00
	i3	981.00	780.27	10.00	10.00	10.00	611.00	10.00	922.04
Period		t =2							
Processing Facility		p1	p2	p3	p4	p5	p6	p7	p8
Product	i1	281.58	60.23	10.00	10.00	10.00	169.88	10.00	1571.96
	i2	823.00	719.00	10.00	10.00	10.00	73.23	10.00	1871.77
	i3	938.00	758.00	10.00	10.00	10.00	881.00	10.00	211.91
Period		t =1							
Processing Facility		p1	p2	p3	p4	p5	p6	p7	p8
Product	i1	156.00	506.00	10.00	10.00	10.00	563.29	10.00	1189.00
	i2	631.00	606.77	10.00	10.00	10.00	640.55	10.00	1456.55
	i3	672.71	887.46	10.00	10.00	10.00	885.00	10.00	922.09
Period		t =2							
Processing Facility		p1	p2	p3	p4	p5	p6	p7	p8
Product	i1	1212.46	359.00	10.00	10.00	10.00	304.00	10.00	1295.00
	i2	325.00	501.00	10.00	10.00	10.00	451.66	10.00	1743.11
	i3	845.00	762.77	10.00	10.00	10.00	517.00	10.00	570.00

5. CONCLUSION

This research proposed a decision model in determining the robust optimal quantities of customer orders and robust optimal processing quantities of returned/recycled products in each processing facility to help reverse logistics service providers generate more profits from the business. The decision maker can take into account the operation data into the model, and solve the uncertainty by applying multiple scenarios, thus coming out the quantities of processing capacity as well as the order of the recycled materials in the future periods. The decision maker also can get the robust optimal solution for insensitivity of uncertainties of the environment, and reduce the loss caused from environmental changes.

Besides, according to our experiment results, we can make further implications for the business. As mentioned by Ting and Huang [16], the incomplete recycled materials situation will impact the business model of reverse logistics services providers. Since the enterprises'/customers' demand of recycled materials and the supply of returned products are unstable (it will cause the profit of reverse logistics services unstable either) and a good reverse logistics processing plan is difficult to make (the remanufacturing environment is filled with uncertainties), if the revenue of selling recycled materials is not much higher than the extra derived costs of transportation and processing of returned products, reverse logistics services providers might be less interested in dismantling, inspecting and repairing of returned products. A better strategy for reverse logistics services providers is to keep returned products in the returned centers, since such a practice may help them gain subsidy from the government, without further expenditure for processing. Such a phenomenon may reduce the value of subsidy in terms of environmental protection (i.e., for a reverse logistics services provider, its processing quantity of returned products is just meet the minimum requirement of the law), so the government needs the supplementary package with subsidy.

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逆物流服務商穩健最佳退回商品處理量之決策模式

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摘要

逆物流（reverse logistics）爲將產品從消費者處回收，並將此資源再利用之一連串活動；其相關成本往往比正物流（forward logistics）高，且對於回收之產品，在運送、儲存、處理、管理方面亦無規律通路，較正物流增加了許多的複雜性和不確定性；企業往往將這些活動外包給專業逆物流服務商（reverse logistics service providers）。而逆物流服務商亦有其利潤、成本、相關法規之考量，過去此方面研究多以逆物流服務商之回收處理廠的廠址選擇及設置爲主。本研究提出一決策模式，針對擁有多個處理廠的逆物流服務商，於考慮具不確定性及多時期、多型態的退回商品時，幫助其決定最適再生物料收受訂單數量及個別逆物流處理中心之最適處理量。因應模式中不確定因子，本研究採用以情境爲基礎的穩健最佳化（robust optimization）方法求得模式的穩健解。

關鍵詞：逆物流服務，決策模式，穩健最佳化

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