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A Fuzzy Cost-Benefit Function to Select Economical Products for Processing in a Closed-Loop Supply Chain

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ABSTRACT

The cost-benefit analysis of data associated with re-processing of used products often involves the uncertainty feature of cash-flow modeling. The data is not objective because of uncertainties in supply, quality and disassembly times of used products. Hence, decision-makers must rely on “fuzzy” data for analysis. The same parties that are involved in the forward supply chain often carry out the collection and re-processing of used products. It is therefore important that the cost-benefit analysis takes the data of both new products and used products into account. In this paper, a fuzzy cost-benefit function is proposed that is used to perform a multi-criteria economic analysis to select the most economical products to process in a closed-loop supply chain. Application of the function is detailed through an illustrative example.

Keywords: Closed-Loop Supply Chain, Fuzzy Sets, Cost-Benefit Function, Re-processing.

1. INTRODUCTION

The series of activities required for retrieving a used product from a consumer and either recovering its left-over market value or disposing it of, is called a reverse supply chain. An important driver for companies engaged in a reverse supply chain is that many used products represent a resource for recoverable value [3], [4]. Though direct reuse is infeasible in most cases, remanufacturing and recycling are the major recovery options applied in the process. Potential profitability from re-processing (*i.e.*, remanufacturing/recycling) of used products offers the possibility to satisfy customer demand with recovered used products, as well as with new products produced from raw materials in a forward supply chain (series of activities required to produce and distribute new products to customers). Furthermore, in practice, collection and re-processing of used products are often carried out by the same parties that are involved in a forward supply chain and hence, the reverse and forward supply chains are generally termed together as a closed-loop supply chain. A generic closed-loop supply chain is shown in Figure 1.

Economic analysis can be classified into two main groups [5], [6]: single criterion analysis and multi-criteria analysis. They are then divided into two subgroups: deterministic and non-deterministic. Single criterion and deterministic analysis contains discounted cash flow techniques (present worth, annual worth, etc). Single criterion and non-deterministic analysis contains sensitivity analysis, decision tree, Monte Carlo simulation, etc. Multi-criteria deterministic analysis contains Analytic Hierarchy Process, goal programming, dynamic programming, etc. Multi-criteria non-deterministic analysis contains fuzzy set theory, expert systems, and game theoretical models. In this paper, we use fuzzy set theory to perform multi-criteria non-deterministic economic analysis.

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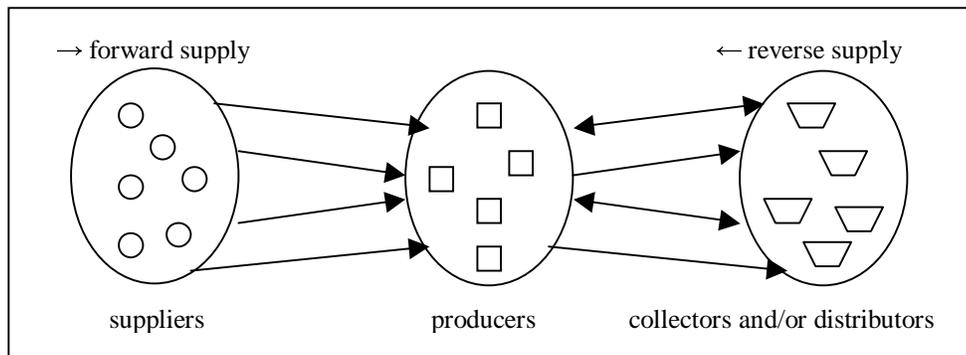


Figure 1. A Generic Closed-Loop Supply Chain

The cost-benefit function based technique provides for a more understandable approach of economic analysis, than the techniques involving rate of return, present worth, and future worth [5]. The cost-benefit function, in our context, can be defined as the ratio of the equivalent value of benefits associated with the object of interest to the equivalent value of costs associated with the same object. The equivalent value can be present worth, annual worth, future worth, etc. In this paper, the object of our interest is the product to be processed in a closed-loop supply chain. The cost-benefit function (F) is formulated as

$$F = \frac{B}{C} \quad (1)$$

where B represents the equivalent value of the benefits (revenues) and C represents the equivalent value of the costs. An F value greater than 1.0 indicates that the object is economically advantageous. A notable point here is that due to uncertainties in supply, quality and disassembly times of used products, decision makers must rely on experts' knowledge to obtain "fuzzy" data for calculating B , C and hence, F values (hence the term - fuzzy cost-benefit function).

For the convenience of the reader, we briefly introduce the fuzzy set theory in the next section. Then, in Section 3, we formulate the fuzzy cost-benefit function, and present the methodology to select economical products to process in a closed-loop supply chain. Section 4 presents a numerical example to demonstrate the application of the cost-benefit function, and Section 5 gives some conclusions.

2. FUZZY SET THEORY

Expressions like "not very clear", "probably so" and "very likely" can be heard very often in daily life. The commonality in such terms is that they are all tainted with imprecision. This imprecision or vagueness of human decision-making is called "fuzziness" in the literature. With different decision-making problems of diverse intensity, the results can be misleading if fuzziness is not taken into account. However, since Zadeh [12] first proposed fuzzy set theory, an increasing number of studies have dealt with imprecision (fuzziness) in problems by applying the fuzzy set theory. Our paper too makes use of this theory in formulating the cost-benefit function that selects economical products to process in a closed-loop supply chain. The concepts of the fuzzy set theory, which we utilize in the formulation, are as follows:

2.1. Linguistic Values and Fuzzy Sets

When dealing with imprecision, decision-makers may be provided with information characterized by vague language such as: high risk, low profit and good customer service. By using *linguistic* values like "high", "low", "good", "medium", "cheap", etc., people are usually attempting to describe factors with uncertain or imprecise values. For example, "weight" of an object may be a factor with an uncertain or imprecise value and so, its linguistic value can be "very low", "low", "medium", "high", "very high", etc. The fuzzy set theory is primarily concerned with quantifying the

vagueness in human thoughts and perceptions. The transition from vagueness to quantification is performed by applying the fuzzy set theory as depicted in Figure 2.

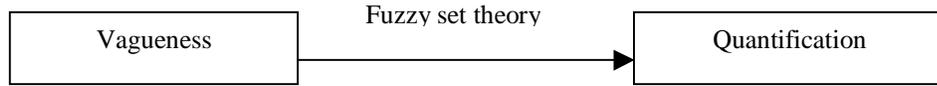


Figure 2. Application of Fuzzy Set Theory

To deal with quantifying vagueness, Zadeh proposed a membership function which associates with each quantified linguistic value a grade of membership belonging to the interval [0, 1]. Thus, a fuzzy set is defined as:

$$\forall x \in X, \mu_A(x) \in [0,1]$$

where $\mu_A(x)$ is the degree of membership, ranging from 0 to 1, of a quantity x of the linguistic value, A , over the universe of quantified linguistic values, X . X is essentially a set of real numbers. The more x fits A , the larger the degree of membership of x . If a quantity has a degree of membership equal to 1, this reflects a complete fitness between the quantity and the vague description (linguistic value). Whereas, if the degree of membership of a quantity is 0, then that quantity does not belong to the vague description.

The membership function can be viewed as an expert’s opinion. We use the term “expert” because an expert usually holds some required knowledge about relative problems while a layperson may not. For example, when a financial manager is asked what a “high annual interest rate” is, the possibility of 20% being “high annual interest rate” would be higher than that of 3%, 5% or 9%. Thus, the membership function, here, can be explained as the possibility of an interest rate being considered as “high”. A reasonable mapping from interest rate to its degree of membership about the fuzzy set “high annual interest rate” is depicted in Figure 3. This membership function looks like a typical cumulative probability function; however, here, the value of the membership function represents the possibility of a fuzzy event, while the value of a cumulative probability function represents the cumulative probability of a statistical event.

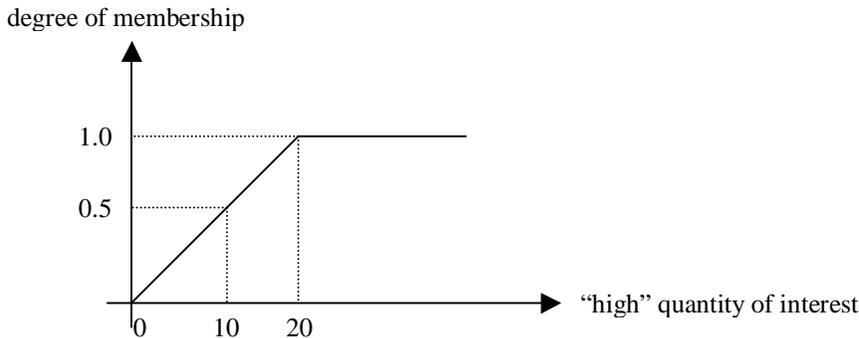


Figure 3. Mapping of Quantified “High” Interest Values to their Degrees of Membership

2.2. Triangular Fuzzy Numbers

A triangular fuzzy number (TFN) is a fuzzy set with three parameters, each representing a quantity of a linguistic value associated with a degree of membership of either 0 or 1. It is graphically depicted in Figure 4. The parameters a , b and c respectively denote the smallest possible quantity, the most promising quantity and the largest possible quantity that describe the linguistic value.

Each TFN, P , has linear representations on its left and right side such that its membership function can be defined as:

$$\begin{aligned} \mu_P &= 0, & x < a & & (2) \\ &= (x-a) / (b-a) & a \leq x \leq b & & (3) \\ &= (c-x) / (c-b) & b \leq x \leq c & & (4) \\ &= 0, & x \geq c. & & (5) \end{aligned}$$

For each quantity x increasing from a to b , its corresponding degree of membership linearly increases from 0 to 1. While x increases from b to c , its corresponding degree of membership linearly decreases from 1 to 0. The membership function is a mapping from any given x to its corresponding degree of membership.

The TFN is mathematically easy to implement, and more importantly, it represents the rational basis for quantifying the vague knowledge in most decision-making problems. Hence, we employ TFNs only to quantify the vagueness of the measures (for example, supply rate of used products) that we use to formulate the cost-benefit function.

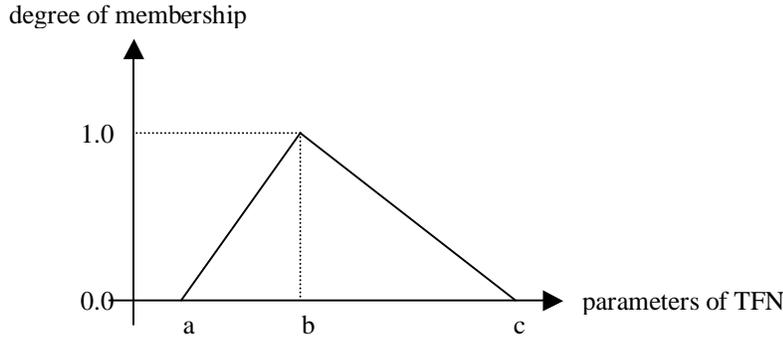


Figure 4. Triangular Fuzzy Number

The basic operations on triangular fuzzy numbers are as follows [1], [2], [11]:

For example, $P_1 = (a, b, c)$ and $P_2 = (d, e, f)$.

$$P_1 + P_2 = (a+d, b+e, c+f) \quad \text{addition;} \quad (6)$$

$$P_1 - P_2 = (a-f, b-e, c-d) \quad \text{subtraction;} \quad (7)$$

$$P_1 * P_2 = (a*d, b*e, c*f) \text{ where } a \geq 0 \text{ and } d \geq 0 \quad \text{multiplication;} \quad (8)$$

$$P_1 / P_2 = (a/f, b/e, c/d) \text{ where } a \geq 0 \text{ and } d > 0 \quad \text{division.} \quad (9)$$

2.3. Defuzzification

Defuzzification is a technique to convert a fuzzy number into a crisp real number. There are several methods to serve this purpose [9]. For example, the Centre-of-Area method [13] converts a fuzzy number $P = (a, b, c)$ into a crisp real number Q where

$$Q = \frac{(c-a) + (b-a)}{3} + a \quad (10)$$

Defuzzification becomes necessary when comparison between two or more fuzzy numbers is difficult to perform.

3. FUZZY COST-BENEFIT FUNCTION

Our fuzzy cost-benefit function consists of equivalent values of the following terms: new product sale revenue (revenue from selling new-products), reuse revenue (revenue from direct-sale/usage-in-remanufacturing of usable components of used products), recycle revenue (revenue from selling material obtained from recycling of unusable components of used products), new product production cost (cost to produce new products), collection cost (cost to collect used products from consumers), re-processing cost (cost to remanufacture/recycle used products), disposal cost (cost to dispose of the material left over after remanufacturing and/or recycling of used products), loss-of-sale cost (cost due to loss of sale, which might occur every now and then, due to lack of supply of used products), investment cost (capital required for the production facility and its machinery).

We make the following assumptions while formulating the cost-benefit function:

1. The product of interest in the reverse supply chain will be completely disassembled, and
2. All usable components of the product of interest in the reverse supply chain will be reused (for direct sale or in remanufacturing), and all the remaining ones will be recycled/disposed of.

3.1. Nomenclature

b_{ij}	probability of bad quality (broken, worn-out, low-performing, etc) of component j in product i ;
C_i	cost to produce one product i in the forward supply chain (\$);
CC_i	total collection cost of product i per period (\$);
CD	cost of re-processing per unit time (\$/unit time);
CF	recycling revenue factor (\$/unit weight);
CR_i	total recycle revenue of product i per period (\$);
CO_i	cost to collect one product i (\$);
DC_i	total disposal cost of product i per period (\$);
D_i	demand for product i in the forward supply chain (# of products);
DI_{ij}	disposal cost index of component j in product i (index scale 0 = lowest, 10 = highest);
DF	disposal cost factor (\$/unit weight);
E_{ik}	subassembly k in product i ;
FCB_i	fuzzy cost-benefit function for product i ;
i	product type;
IC_i	investment cost of product i (\$);
j	component type;
LC_i	loss-of-sale cost of product i (\$);
M_i	total number of subassemblies in product i ;
m_{ij}	probability of missing component j in product i ;
MC_i	total production cost of product i per period (\$)
N_{ij}	multiplicity of component j in product i ;
RCP_{ij}	percentage of recyclable contents by weight in component j of product i ;
RC_i	total re-processing cost of product i per period (\$);
RI_{ij}	recycling revenue index of component j in product i (index scale 0 = lowest, 10 = highest);
$Root_i$	root node (for example, outer casing) of product i ;
RV_{ij}	resale value of component j in product i (\$);
SP_i	selling price of product i in the forward supply chain (\$);
SR_i	total new product sale revenue of product i per period (\$);
SU_i	supply of product i per period in the reverse supply chain (# of products);
$T(Root_i)$	time to disassemble $Root_i$ (time units);
$T(E_{ik})$	time to disassemble subassembly k in product i (time units);
UR_i	total reuse revenue of product i per period (\$);
W_{ij}	weight of component j in product i (lb);
ΔBZ	incremental total revenues (between the challenger and the defender);
ΔCZ	incremental total costs (between the challenger and the defender).

3.2. Formulation

As mentioned earlier, the fuzzy cost-benefit function (FCB) of product i of interest consists of equivalent values (EV) of nine terms (*viz.*, total new product sale revenue per period (SR_i), total reuse revenue per period (UR_i), total recycle revenue per period (CR_i), total new product production cost per period (MC_i), total collection cost per period (CC_i), total re-processing cost per period (RC_i), total disposal cost per period (DC_i), loss-of-sale cost (LC_i), investment cost (IC_i)) as follows:

$$FCB_i = \frac{\text{EV of } (SR_i + UR_i + CR_i)}{\text{EV of } (MC_i + CC_i + RC_i + DC_i + LC_i + IC_i)}; \quad (11)$$

The following sub-sections explain how the above nine terms are calculated. Some of the terms are modified versions of those in [7] and [10].

3.2.1. Total new product sale revenue per period (SR)

SR of product i per period is influenced by the demand for new products per period (D_i) and the selling price of each new product (SP_i). This revenue equation can be written as follows:

$$SR_i = D_i \cdot SP_i; \quad (12)$$

Often, in practice, objective data is available to express D_i and SP_i as crisp real numbers. Hence, SR_i is a crisp real number too.

3.2.2. Total reuse revenue per period (UR)

UR of product i is influenced by the fuzzy supply of used product i per period (SU_i) and the following data of component of each type j in the product: the resale value (RV_{ij}), the number of components (N_{ij}), the fuzzy probability of missing (m_{ij}) and the fuzzy probability of bad quality (broken, worn-out, low-performing, etc) (b_{ij}). This revenue equation can be written as follows:

$$UR_i = \sum_j SU_i \cdot RV_{ij} \cdot N_{ij} \cdot (1 - b_{ij} - m_{ij}); \quad (13)$$

Since SU_i , b_{ij} and m_{ij} are expressed as fuzzy numbers, the resulting UR_i is a fuzzy number too.

3.2.3. Total recycle revenue per period (CR)

CR of product i is calculated by multiplying the component recycling revenue factors by the number of components recycled for materials content as follows:

$$CR_i = \sum_j \left[\frac{SU_i \cdot RI_{ij} \cdot W_{ij} \cdot RCP_{ij}}{\{N_{ij}(1 - m_{ij}) - N_{ij} \cdot (1 - b_{ij} - m_{ij})\}} \right] \cdot CF; \quad (14)$$

Note that each component has a percentage of recyclable contents (RCP_{ij}). RI_{ij} is the recycling revenue index (varying in value from one to ten) representing the degree of benefit generated by the recycling of component of type j (the higher the value of the index, the more profitable it is to recycle the component), W_{ij} is the weight of the component of type j and CF is the recycling revenue factor.

Since SU_i , b_{ij} and m_{ij} are expressed as fuzzy numbers, the resulting CR_i is a fuzzy number too.

3.2.4. Total new product production cost per period (MC)

MC of product i is calculated by multiplying the demand for new products per period (D_i) by the cost to produce one new product (C_i) as follows:

$$MC_i = D_i \cdot C_i; \quad (15)$$

Often, in practice, objective data is available to express D_i and C_i as crisp real numbers. Hence, MC_i is a crisp real number, too.

3.2.5. Total collection cost per period (CC)

CC of product i is calculated by multiplying the fuzzy supply of used products per period (SU_i) by the cost of collecting one used product from consumers (CO_i)

$$CC_i = SU_i \cdot CO_i; \quad (16)$$

Since SU_i is expressed as a fuzzy number, the resulting CC_i is a fuzzy number too.

3.2.6. Total re-processing cost per period (RC)

RC of product i can be calculated from the disassembly time of the root node (for example, outer casing [10]) of the product ($T(Root_i)$), the disassembly time of each sub-assembly in the product ($T(E_{ik})$) and the re-processing cost per unit time (CD) as follows:

$$RC_i = \left[T(\text{Root}_i) + \sum_{k=1}^{M_i} T(E_{ik}) \right] \cdot CD; \quad (17)$$

Depending upon the type (vague or objective) of data available of the disassembly times, RC_i is a fuzzy or crisp real number.

3.2.7. Total disposal cost per period (DC)

DC of product i is calculated by multiplying the component disposal cost by the number of component units disposed as follows:

$$DC_i = \sum_j \left[\frac{SU_i \cdot DI_{ij} \cdot W_{ij} \cdot (1 - RCP_{ij})}{\{N_{ij}(1 - m_{ij}) - N_{ij} \cdot (1 - b_{ij} - m_{ij})\}} \right] \cdot DF; \quad (18)$$

Note that DI_{ij} is the disposal cost index (varying in value from one to ten) representing the degree of nuisance created by the disposal of component of type j (the higher the value of the index, the more nuisance the component creates and hence it costs more to dispose it of), W_{ij} is the weight of the component of type j and DF is the disposal cost factor.

Since SU_i , b_{ij} and m_{ij} are expressed as fuzzy numbers, the resulting CR_i is a fuzzy number too.

3.2.8. Loss-of-sale cost (LC)

LC of product i represents the cost of not meeting its demand in a timely manner. This occurs because of the unpredictable supply of end-of-life products, as consumers do not discard them in a predictable manner. LC is difficult to predict and thus is usually guessed by “experts”, for a particular period of interest.

Due to the involvement of the experts’ guesses, LC_i is expressed as a fuzzy number.

3.2.9. Investment cost (IC)

IC of product i is the fixed cost of the production facility and the machinery required to process product i . Depending upon the type (vague or objective) of data available of the product and of the region where the production facility exists or is planned to be built, IC_i is a fuzzy or crisp real number.

3.3. Methodology

In order to select the most economical product to process in a closed-loop supply chain, from a set of candidate products, we use the following steps:

Step 1: Eliminate every candidate product whose FCB is less than 1.0.

Step 2: Assign the candidate product that has the lowest IC as the defender and the product with the next-lowest IC as the challenger.

Step 3: Calculate the ratio of the EV of incremental total revenue ΔBZ (between the challenger and the defender) to the EV of incremental total cost ΔCZ (between the challenger and the defender). If the ratio is less than 1.0, eliminate the challenger. Otherwise, eliminate the defender.

Step 4: Repeat steps 2 and 3 until only one product (which is the most economical one in the set) is left.

4. NUMERICAL EXAMPLE

We take three different products (Product-1, Product-2 and Product-3) whose structures are shown in Figures 5, 6, and 7 respectively. We assume that the supplies of all these products are perpetual. Hence, we take capitalized worth (CW) [8] as the EV. Therefore, FCB is nothing but the ratio of CW of total revenues to CW of total costs. The data necessary to calculate FCB of Product-1, Product-2 and Product-3 are given in Table 1, Table 2 and Table 3 respectively. Also, $T(\text{Root}_1) = 2$ min; $T(\text{Root}_2) = 1.5$ min; $T(\text{Root}_3) = 1.5$ min; $T(E_{11}) = 9$ min; $T(E_{21}) = 7$ min; $T(E_{22}) = 8$ min; $T(E_{31}) = 7$ min; $T(E_{32}) = 8$ min; $SU_1 = (200, 230, 250)$ products per year; $SU_2 = (210, 220, 230)$ products per year; $SU_3 = (600, 650, 700)$ products per year; $CO_1 = \$20$; $CO_2 = \$21$; $CO_3 = \$18$; $IC_1 = \$20000$; $IC_2 = \$25000$; $IC_3 = \$30000$; $D_1 = 900$

products per year; $D_2 = 850$ products per year; $D_3 = 1000$ products per year; $SP_1 = \$70$; $SP_2 = \$28$; $SP_3 = \$58$; $C_1 = \$25$; $C_2 = \$30$; $C_3 = \$28$; $LC_1 = \$(1000, 1500, 1700)$ per 3 years; $LC_2 = \$(1000, 1200, 1500)$ per 3 years; $LC_3 = \$(1900, 2000, 2100)$; $CF = 0.2$ \$/lb; $DF = 0.1$ \$/lb; $CD = 0.55$ \$/min.

Upon calculating revenues and benefits for each product, we get $FCB_1 = (2.13, 2.45, 2.88)$, $FCB_2 = (0.77, 0.84, 0.91)$ and $FCB_3 = (1.76, 2.11, 2.68)$. Defuzzifying these numbers using Equation 10, we get $FCB_1 = 2.49$, $FCB_2 = 0.93$ and $FCB_3 = 2.18$. Since FCB_2 is less than 1.0, we eliminate it from further analysis.

Now, since IC_1 is less than IC_3 , we consider Product-1 the defender and Product-3 the challenger. The defuzzified ratio of CW of ΔBZ to CW of ΔCZ is now calculated and is found to be 1.89, which is greater than 1.0. Hence, we eliminate the defender, i.e., Product-1. Therefore, the remaining product, i.e., Product-3 is the most economical product amongst the three products.

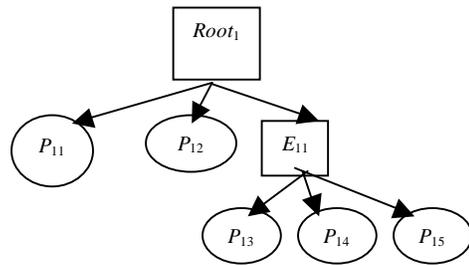


Figure 5. Structure of Product-1

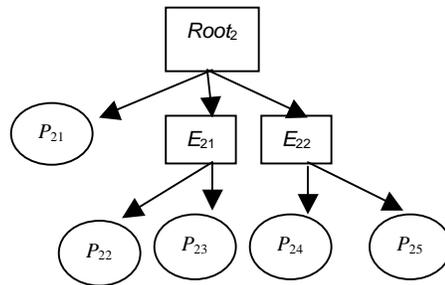


Figure 6. Structure of Product-2

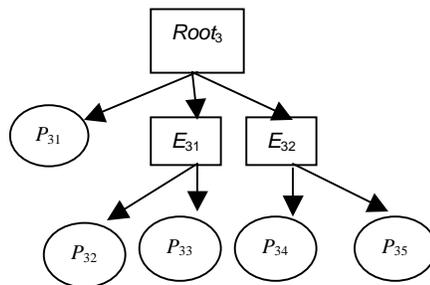


Figure 7. Structure of Product-3

Table 1. Data of Product-1

Component	RV_{1j} (\$)	N_{1j}	W_{1j} (lb)	RI_{1j}	RCP_{1j}	DI_{1j}	b_{1j}	m_{1j}
P_{11}	7.0	3	4.5	5	65%	6	(0.1, 0.1, 0.2)	(0.3, 0.4, 0.4)
P_{12}	8.0	4	6.5	5	50%	4	(0.5, 0.6, 0.7)	(0.1, 0.2, 0.2)
P_{13}	9.0	2	7.0	3	75%	4	(0.2, 0.3, 0.4)	(0.3, 0.4, 0.4)
P_{14}	6.9	1	2.7	9	35%	5	(0.2, 0.2, 0.3)	(0.1, 0.1, 0.2)
P_{15}	8.4	5	7.5	6	70%	1	(0.1, 0.1, 0.2)	(0.3, 0.4, 0.5)

Table 2. Data of Product-2

Component	RV_{2j} (\$)	N_{2j}	W_{2j} (lb)	RI_{2j}	RCP_{2j}	DI_{2j}	b_{2j}	m_{2j}
P_{21}	1.0	1	3.9	2	40%	3	(0.1, 0.1, 0.2)	(0.0, 0.1, 0.1)
P_{22}	1.5	3	1.5	4	20%	1	(0.1, 0.2, 0.2)	(0.0, 0.0, 0.0)
P_{23}	1.2	7	4.1	1	70%	2	(0.2, 0.3, 0.4)	(0.2, 0.2, 0.3)
P_{24}	2.5	4	3.2	5	90%	4	(0.3, 0.4, 0.5)	(0.1, 0.1, 0.2)
P_{25}	3.1	3	2.0	2	50%	2	(0.3, 0.4, 0.4)	(0.1, 0.1, 0.2)

Table 3. Data of Product-3

Component	RV_{3j} (\$)	N_{3j}	W_{3j} (lb)	RI_{3j}	RCP_{3j}	DI_{3j}	b_{3j}	m_{3j}
P_{31}	9.0	2	4.0	9	30%	4	(0.2, 0.3, 0.4)	(0.1, 0.2, 0.3)
P_{32}	8.0	5	5.0	7	60%	3	(0.1, 0.2, 0.2)	(0.1, 0.2, 0.2)
P_{33}	9.0	3	2.0	8	70%	1	(0.3, 0.4, 0.4)	(0.1, 0.2, 0.2)
P_{34}	7.0	2	6.0	9	25%	3	(0.2, 0.3, 0.3)	(0.3, 0.3, 0.4)
P_{35}	7.0	1	5.2	6	50%	2	(0.3, 0.3, 0.4)	(0.1, 0.1, 0.2)

5. CONCLUSIONS

Since new products sold by production facilities to consumers, are nowadays taken back for re-processing by the same facilities after the consumers discard those products (now called used products), it is very important that the facilities, while performing the cost-benefit analysis to select economical products to process, take into account, the costs and revenues involved in the reverse supply chain as well. To this end, in this paper, we formulated a fuzzy cost-benefit function, and performed a multi-criteria non-deterministic economic analysis to select the most economical product to process in a closed-loop supply chain. A numerical example was presented to demonstrate the usage of our fuzzy cost-benefit function.

REFERENCES

1. Chan, F. T., Chan, H. K. and Chan, M. H., "An integrated fuzzy decision support system for multi-criterion decision making problems," *Journal of Engineering Manufacture*, Vol. 217, 11-27, 2003.
2. Chiu, C.-Y. and Park, C. S., "Fuzzy cash flow analysis using present worth criterion," *The Engineering Economist*, Vol. 39, No. 2, 113-138, 1994.
3. Fleischmann, M., *Quantitative models for reverse logistics: Lecture Notes in Economics and Mathematical Systems*, Springer-Verlag, Germany, 2001.
4. Gungor, A. and Gupta, S. M., "Issues in Environmentally Conscious Manufacturing and Product Recovery: A Survey," *Computers and Industrial Engineering*, Vol. 36, No. 4, 811-853, 1999.
5. Kahraman, C., Tolga, E. and Ulukan, Z., "Justification of manufacturing technologies using fuzzy benefit/cost ratio analysis," *International Journal of Production Economics*, Vol. 66, 45-52, 2000.
6. Kolli, S., Wilhelm, M. R. and Liles, D. H., "A classification of scheme for traditional and non-traditional approaches to the economic justification of advanced automated manufacturing systems," *Economic and Financial Justification of Advanced Manufacturing Technologies*, Elsevier, Amsterdam, 165-187, 1992.
7. Pochampally, K. K. and Gupta, S. M., "A multi-phase mathematical programming approach to strategic planning of an efficient reverse supply chain network," *Proceedings of the IEEE International Symposium on the Electronics and the Environment*, 72-78, 2003.
8. Sullivan, W. G., Wicks, E. M. and Luxhoj, J. T., *Engineering Economy*, Twelfth Edition, Prentice Hall, New Jersey, 2003.
9. Tsaour, S., Chang, T. and Yen, C., "The evaluation of airline service quality by fuzzy MCDM," *Tourism Management*, Vol. 23, 107-115, 2002.
10. Veerakamolmal, P., and Gupta, S. M., "Analysis of design efficiency for the disassembly of modular electronic products," *Journal of Electronics Manufacturing*, Vol. 9, No. 1, 79-95, 1999.
11. Wang, M.-J. and Liang, G.-S., "Benefit/cost analysis using fuzzy concept," *The Engineering Economist*, Vol. 40, No. 4, 359-376, 1995.
12. Zadeh, L. A., "Fuzzy Sets," *Information and Control*, Vol. 8, 338-353, 1965.
13. Zhao, R. and Govind, R., "Algebraic characteristics of extended fuzzy number," *Information Science*, Vol. 54, 103-130, 1991.