# Multi-criteria product recovery decision model for time sensitive returns

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## Abstract

Proposed ITL-TOPSIS approach address issue of disposition-decision making under uncertainty & incomplete information in a more precise manner. This paper capture the affect of time sensitive products on disposition decision by comparing the ranking of optimal EOL options for short life cycle and long life cycle returned products.

**Keywords**: Product recovery decision making, Time sensitive products, Interval 2-tuple linguistic TOPSIS (ITL-TOPSIS)

### Introduction

Nowadays, due to Extended Producer Responsibility (EPR) and legislative regulations, Product Recovery Systems (PRS) have become imperative (Choudhary et al. 2014). Due to the increasing significance of PRS, enterprises are now becoming more sensitive towards increasing environmental awareness, sustainable development, and value recovery from returns (Srivastava and Srivastava 2006). The volume of products entering PRS is increasing rapidly as products at an estimated $100 billion value are being returned every year, about 6 percent of the sales (Stock 2001). In a developing country such as India, an estimated 146,000 tons of e-waste is generated each year with a growth of 10 percent every year (Agrawal et al. 2014). A risk is being posed due to the hazardous elements present in e-wastes, especially in countries with limited environmental regulations. According to Keong (2008), virgin resources of about 240,000 tons can be saved, if all customers across the globe return just one used mobile device. It is equivalent to reducing the greenhouse gases to the same level as in removing 4 million vehicles from the road. Therefore, to impede the exploitation of resources and to curb the risks associated with such waste, the regulatory and voluntary initiatives towards PRS are growing. Further, the scope of PRS is far greater than just fulfilling the legislative obligations since it provides economical benefits from the returns and expands the competitive abilities of the organization (Choudhary and Madaan 2013). It also assists in the building of recovery strategies that can enhance consumer relations and increase product sales (Prahinski and Kocabasoglu 2006).

The PRS encompasses five operations (Guide and Van Wassenhove 2002): Product Acquisition (Collection of returns from customers), Reverse Logistics (Gate-keeping, Transportation, Warehousing, and Inventory management), Inspection and disposition (Assessment of returns for suitable recovery option selection), Reconditioning (Value reclamation from returns through operations such as repair, cannibalization, remanufacturing and recycling etc.) and Distribution and Sales (Developing secondary markets for reclaimed products). The aforementioned recovery operations provide an outline of PRS but do not show the way for suitable allocation of an EOL options for effective value retrieval from product returns. Rogers and Tibben-Lembke (1999) suggested that organizations can increase the efficiency of their PRS by focusing on developing a decision making system and selecting suitable EOL options as early as possible. In this line, the paper proposes a multi attribute product recovery decision model to identify the most optimal EOL alternative for recovering value from product returns. Although models have been proposed in previous works, they select the suitable recovery alternative mostly on the basis of cost/benefit analysis only. So there is a requirement for a holistic recovery decision model which takes into account both the qualitative and quantitative factors simultaneously. Such a model can also contribute towards developing recovery strategies for organizations that are already involved or likely to initiate product recovery operations involving time sensitive returns.

The major challenge faced by the enterprises is to recover the value from the returns as multi-recovery options are available. It is even more complicated for time sensitive products e.g. laptops, computers etc. as, they have a high value erosion rate of about 1% per week and fall under the category of Short Life Cycle (SLC) goods (Hui and Gongqian 2011). Accordingly, the varied life cycles of products can influence the preference order of reprocessing options (such as resale, recycle etc.). Although, literature is available on the effect of time sensitive products on PRS design, there is a lack of research related to its effect on product recovery decision making. The present research will determine the ranking of optimal EOL options for time sensitive with short life cycles.

The literature available on recovery decision making is sparse due to the ambiguities involved in EOL option selection (e.g. recycle, remanufacture, disposal etc.) while considering multiple criteria (e.g. legislative, environment etc.) (Madaan et al. 2012). However, to overcome this complexity some decision models have been suggested that deal with linguistic terms, they undergo information loss while processing, resulting in erroneous decisions (Liu et al. 2014). Additionally, in many situations experts are uncertain about their judgments on reprocessing options and provide incomplete assessments in different linguistic terms. This paper presents *a novel multi criteria decision making (MCDM) technique integrated with the interval 2-tuple linguistic representation model* which overcomes the above mentioned limitations. Suggested method can also be considered as extended TOPSIS with interval 2-tuple linguistic variables for decision-making. So, the aim of this paper is 1) to propose a comprehensive product recovery decision making model for PRS considering both the quantitative and qualitative aspects; 2) to introduce a flexible MCDM technique, Interval 2-tuple linguistic TOPSIS (ITL-TOPSIS), for selecting the appropriate recovery option under an environment of ambiguity and incomplete information; 3) to determine the suitable EOL options for time sensitive products products with high value erosion rates.

## Literature Review

Product recovery systems have become a primary managerial focus from a cost view point and the impending influence on consumer loyalty (Skinner et al. 2008). Consequently, in order to retain customers in today's highly competitive market, organizations are required to strategically manage their PRS. Accordingly, Stock and Mulki (2009) stated that the determination of most suitable reprocessing alternatives by accurately evaluating each product return is necessary for the improvement of PRS effectiveness. Bufardi et al. (2004) presented the approaches to handle all the phases of EOL option selection, i.e. constituting a set of reprocessing alternatives; identifying the relevant factors (social, economical and environmental) to evaluate the options and finally choosing the most appropriate MCDM technique to address the problem. This study was further extended by Chan (2008), who recommended the use of Grey Relational Analysis for the ranking of reprocessing options under the environment of uncertainty. Another methodology for making recovery decisions, the "multi-criteria matrix", was introduced by Iakovou et al. (2009) and considers various aspects, such as residual value, environmental burden, weight, quantity and ease of disassembly of each component. Further, Jun et al. (2007) focused only on the recovery cost and recovery quality of the products returned while addressing the issue of product recovery optimization. In addition, another study was conducted by Staikos and Ramford (2010) to identify the best EOL alternative among recycle, reuse, disposal and incineration for the footwear industry depending on environmental, economical and technical aspects.

Various studies have emphasized on different recovery alternatives. Thierry et al. (1995) performed one of the early research studies in this context and illustrated a standard return process which included the three separate product recovery options; Reuse, Product recovery Management (repair, refurbish, remanufacture, recycle and cannibalization) and Waste management (incineration and land filling). Johnson and Wang (1995) considered that the reclamation process is a combination of remanufacture, re-use, and recycle. Brito and Dekker (2003) classified the recovery process into direct recovery and process recovery. Subsequently, these recovery options are stratified by various researchers. According to Hazen et al. (2012), decision makers are required to analyze and recognize the opportunities associated with all the recovery options, while selecting the most favorable one. In this paper, the EOL options considered to address the various recovery situations are Resale, Repair, Refurbish, Remanufacture, Cannibalization, Recycle and Disposal. The complete representation of PRS considering all the explained recovery options is as depicted in Figure 1.

Although, a large amount of product returns enter the PRS, organizations are able to reclaim only a fraction of the value of the returned goods, due to the delays in EOL option selection (Guide et al. 2006). Subsequently, there is a need for a comprehensive recovery decision making model which can assist organizations in determining the optimal disposal alternative for the returns. For developing such a model, it is necessary to identify and analyze the various criteria, which is the basis for determining the most appropriate recovery option. Although studies are present on the time value of returned products, an important aspect in recovery systems, it is found missing in the literature as a criterion for the selection of the optimal recovery option. Most of the studies have not considered the time during which the product has been used before being returned. The present research takes into account the time value of time sensitive products and shows the affect of depreciation rate on the EOL alternative selection. Based on the literature and consultation with experts having good knowledge of PRS, the following criteria have been identified for the selection of a suitable reprocessing option: Product Recovery Value (PRV); Marginal Value of Time (MVT); Reprocessed Quality (RQ);

Novel Resources requisite (NRR); Environmental Impact (EI); Market Scenario (MS); and Profit (P).

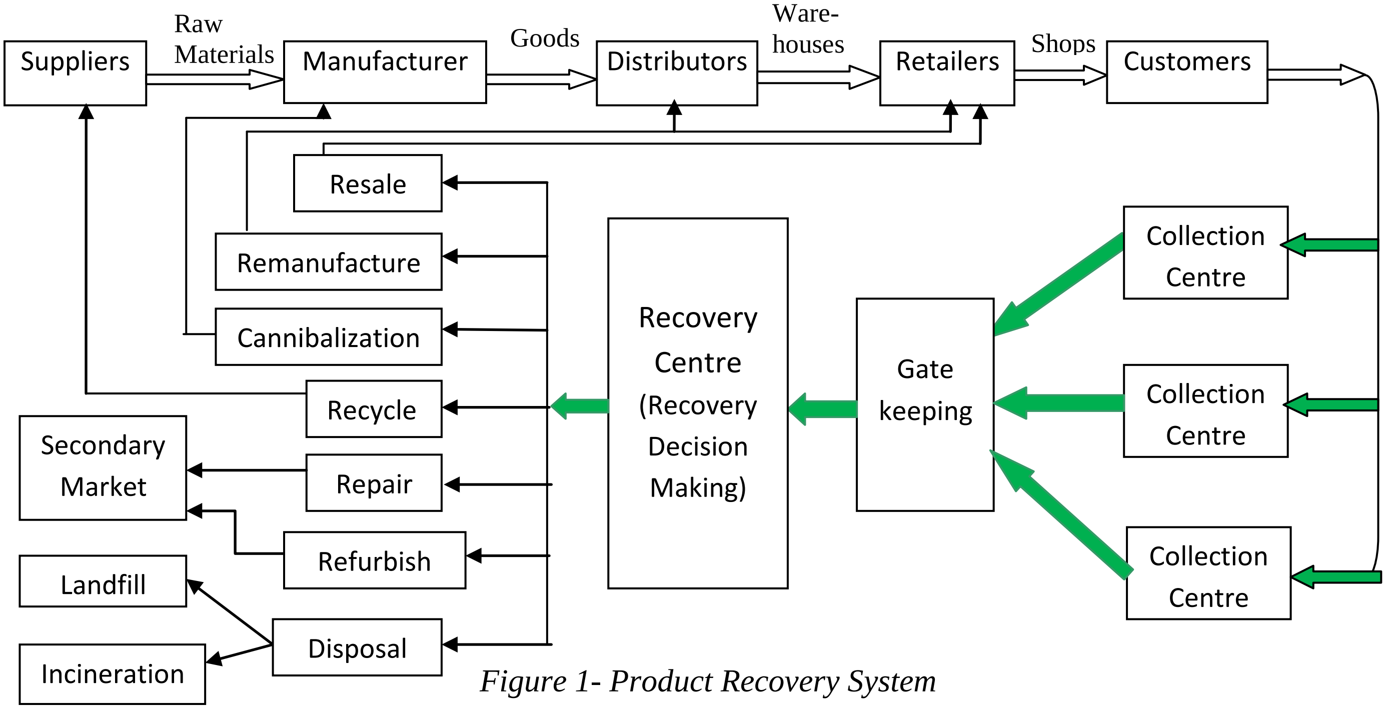

*Figure 1- Product Recovery System*

Most studies have not attempted to develop a decision framework that considers all the aspects of decision making. This paper proposes an absolute recovery decision making model that assimilates all the recovery options and all the significant criteria to determine the optimal recovery alternative. The criteria for recovery option selection are often conflicting, so decision makers need to find the EOL alternative that constitutes a consensus among all the various aspects. Consequently, a MCDM technique is required to obtain the optimal reprocessing option. This research introduces a flexible MCDM technique, extended TOPSIS with interval 2-tuple linguistic model, to determine the appropriate EOL option, while considering all the uncertainty.

## Methodology

In this area of recovery decision making, a large number of ambiguities are present and the information available is mostly incomplete. Since qualitative criteria are also involved, the opinion of the experts is usually first recorded in linguistic terms and then is processed accordingly. The techniques as presented in the literature undergo information loss during linguistic information processing which in turn leads to imprecise results. The technique presented in this paper, extended TOPSIS with interval 2-tuple linguistic model, overcomes this limitation and can efficiently process the linguistic information. It uses modified TOPSIS method to solve linguistic MCDM problems where the weights of the attributes are in the form of 2-tuple linguistic variables, and the values of the attributes are in the form of interval 2-tuple linguistic variables. Furthermore, it has the capability to provide accurate results with incomplete information in ambiguous environments. It allows decision makers to utilize diverse linguistic terms to express their judgments with different granularity of uncertainty. So, this methodology consisting of the interval 2-tuple linguistic representation model is more appropriate and accurate for handling decision making problems. For the details and preliminaries of the technique, Liu et al. (2014) is recommended.

Consider a MCDM problem that has $l$ decision-makers $DM_k$ (k = 1, 2,…,$l$), m alternatives/options $A_i$ (i = 1, 2,…, m), and n decision criteria $C_j$ (j = 1, 2,…, n). A weight, $\lambda_k > 0$ (k = 1, 2, . . ., $l$) satisfying $\Sigma_{k=1}^{l}\lambda_k = 1$, is assigned to each decision maker to show their significance in the decision making process. Let $(d_{ij}^{k})$ be the linguistic information provided by the kth decision maker, $DM_k$ on the assessment of $A_i$ with respect to $C_j$ which is represented in the form of linguistic decision matrix $D_k = (d_{ij}^{k})_{m\ x\ n}$. Let $w_j^k$ be the linguistic weight given to $C_j$ by $DM_k$ so $w_k = (w_1^k, w_2^k, ..., w_n^k)^T$ is the linguistic weight vector given by the kth decision-maker to all the criteria. Moreover, different linguistic term sets can be used by the decision makers to state their opinions. The procedure of ITL-TOPSIS can be described as follows:

**Step 1:** Record the assessment of various alternatives on all the decision criteria provided by the decision makers in linguistic scales of their preference, represented in the form of a linguistic decision matrix $D_k = (d_{ij}^{k})_{m\ x\ n}$.

**Step 2:** Translate the linguistic decision matrix into interval 2-tuple linguistic decision matrix $\widetilde{R_k} = (\tilde{r}_{ij}^{k})_{m\ x\ n} = \left[\left((s_{ij}^{k}, 0), (t_{ij}^{k}, 0)\right)\right]_{m\ x\ n}$, where $s_{ij}^{k}, t_{ij}^{k} \in S$, S = {$s_i$| i = 1,2,...,g} and $s_{ij}^{k} < t_{ij}^{k}$.

**Step 3:** This step is to aggregate the decision-makers' opinions to get the comprehensive interval 2-tuple linguistic decision matrix $\tilde{R} = (\tilde{r}_{ij})_{m\ x\ n}$ and the cumulative 2-tuple linguistic weight of every criterion $(w_j, \alpha_{wj})$ as shown in Equations (1) and (2).

$$\tilde{\boldsymbol{r}} = [(s_{ij}, \alpha_{ij}), (t_{ij}, \varepsilon_{ij})]$$
$$= \text{ITWA}\left([(s_{ij}^{1}, 0), (t_{ij}^{1}, 0)], [(s_{ij}^{2}, 0), (t_{ij}^{2}, 0)], \ldots, [(s_{ij}^{l}, 0), (t_{ij}^{l}, 0)]\right)$$
$$= \Delta\left[\sum_{k=1}^{l}\lambda_k \Delta^{-1}(s_{ij}^{k}, 0), \sum_{k=1}^{l}\lambda_k \Delta^{-1}(t_{ij}^{k}, 0)\right], \quad i = 1,2,..., m;\ j = 1,2,..,n. \quad (1)$$

$$(w_j, \alpha_{wj}) = \text{TWA}\left[(w_j^1, 0), (w_j^2, 0), \ldots, (w_j^l, 0)\right]$$
$$= \Delta\left[\sum_{k=1}^{l}\lambda_k \Delta^{-1}(w_j^k, 0)\right], \quad j = 1,2,...n. \quad (2)$$

**Step 4:** This step involves construction of weighted interval 2-tuple linguistic decision matrix $\widetilde{R}' = (\tilde{r}_{ij}')_{m\ x\ n}$, as given in Equation (3).

$$\tilde{r}_{ij}' = \left[(s_{ij}', \alpha_{ij}'), (t_{ij}', \varepsilon_{ij}')\right] = (w_j, \alpha_{wj}) \times \left[(s_{ij}, \alpha_{ij}), (t_{ij}, \varepsilon_{ij})\right)$$
$$= \Delta\left[\Delta^{-1}(w_j, \alpha_{wj}) \bullet \Delta^{-1}(s_{ij}, \alpha_{ij}), \Delta^{-1}(w_j, \alpha_{wj}) \bullet \Delta^{-1}(t_{ij}, \varepsilon_{ij})\right], \quad i = 1, 2, \ldots, m;\ j = 1,2, \ldots, n. \quad (3)$$

**Step 5:** This step involves the determination of 2-tuple linguistic positive-ideal solution $A^+$ and 2-tuple linguistic negative-ideal solution $A^-$ as given below in Equations (4)-(6).

$$A^+ = [\ (r_1^+, \alpha_1^+), (r_2^+, \alpha_2^+), \ldots\ldots, (r_n^+, \alpha_n^+)],$$
$$(4)$$
$$A^- = [\ (r_1^-, \alpha_1^-), (r_2^-, \alpha_2^-), \ldots\ldots, (r_n^-, \alpha_n^-)],$$

where,

$$(r_j^+,\alpha_j^+) = \begin{cases} \max\{(t_{ij},\varepsilon_{ij})\}, & \text{for benefit criteria} \\ \min\{(s_{ij},\alpha_{ij})\}, & \text{for cost criteria} \end{cases} \quad j = 1,2, \ldots n, \quad (5)$$

$$(r_j^-,\alpha_j^-) = \begin{cases} \min\{(s_{ij},\alpha_{ij})\}, & \text{for benefit criteria} \\ \max\{(t_{ij},\varepsilon_{ij})\}, & \text{for cost criteria} \end{cases} \quad j = 1,2, \ldots n, \quad (6)$$

**Step 6:** Determine the separation measures, $D^+$& $D^-$, for each alternative on the basis of the n-dimensional Euclidean distance of interval 2-tuples, as shown in Equations (7) and (8).

$$D_i^+ = \Delta\sqrt{\sum_{j=1}^{n}\left[\left(\Delta^{-1}(s'_{ij},\alpha'_{ij}) - \Delta^{-1}(r_j^+,\alpha_j^+)\right)^2 + \left(\Delta^{-1}(t'_{ij},\varepsilon'_{ij}) - \Delta^{-1}(r_j^+,\alpha_j^+)\right)^2\right]}$$

$i$ = 1,2,...,m, (7)

$$D_i^- = \Delta\sqrt{\sum_{j=1}^{n}\left[\left(\Delta^{-1}(s'_{ij},\alpha'_{ij}) - \Delta^{-1}(r_j^-,\alpha_j^-)\right)^2 + \left(\Delta^{-1}(t'_{ij},\varepsilon'_{ij}) - \Delta^{-1}(r_j^-,\alpha_j^-)\right)^2\right]}$$

$i$ =1,2,..., m. (8)

**Step 7:** Calculate the relative closeness coefficient of each alternative $A_i$ with respect to the 2-tuple linguistic positive-ideal solution $A^+$, which is computed as presented in Equation (9).

$$RC_i^+ = \Delta\left(\frac{\Delta^{-1}(D_i^-)}{\Delta^{-1}(D_i^+) + \Delta^{-1}(D_i^-)}\right), \text{ where } 0 \le \Delta^{-1}(RC_i^+) \le 1. \quad (9)$$

**Step 8:** Obtain the final ranking of the alternatives on the basis of the relative closeness coefficient to the ideal alternative by arranging them in descending order. This means that the alternative having a higher value of $RC_i^+$, appears first in the ranking position and is the required optimal alternative, and is better than the others.

## Application of ITL-TOPSIS to EOL option selection for time sensitive products

The light consumer electronic durables such as laptops, computers etc are believed to have a short life span of about 5 years. In this particular case, we are considering a time sensitive electronic product, which is been returned after a span of two years usage. For the evaluation of recovery options with respect to the selected criteria, judgments are taken from an expert committee of three decision makers ($DM_1$, $DM_2$ and $DM_3$) working in an organization handling the electronic returns. The importance of all decision makers is considered to be equal in this case. Based on these judgments most, suitable EOL option is determined by applying the steps of ITL-TOPSIS methodology (as described in previous section) as follows:

**Step1**: The assessment of all seven alternatives provided by the decision makers are shown in Table 1. The linguistic term sets employed by the decision makers are as follows:

A ($DM_1$) ⟶ [$a_0$=Very Poor (VP),$a_1$= Poor (P), $a_2$=Fair (F), $a_3$=Good (G), $a_4$=Very Good (VG)]

B ($DM_2$) ⟶ [$b_0$=Very Poor (VP),$b_1$= Poor (P), $b_2$= Moderately Poor (MP),$b_3$=Fair (F),$b_4$= Moderately Good (MG), $b_5$= Good (G), $b_6$=Very Good (VG)]

C ($DM_3$) ⟶ [$c_0$=Extremely Poor (EP),$c_1$= Very Poor (VP),$c_2$= Poor (P),$c_3$= Moderately Poor (MP), $c_4$=Fair (F), $c_5$= Moderately Good (MG), $c_6$= Good (G), $c_7$= Very Good

(VG), $c_8$= ExtremelyGood (EG)]

The relative importance of the seven criteria is also evaluated by the decision-makers with a set of 7 linguistic terms, D, which are denoted as follows, and are shown in Table 2.

D (Weights) ⟶ [$d_0$=Very Low (VL),$d_1$= Low(L), $d_2$= Medium Low (ML), $d_3$=Medium (M), $d_4$= Medium High (MH), $d_5$= High (H), $d_6$=Very High (VH)]

**Step 2:** The linguistic assessments presented in Table 1 and Table 2 are translated into interval 2-tuple linguistic variables and 2-tuple linguistic variables respectively, according to Step 2 of the methodology.

*Table 1- Linguistic Decision Table*

| Decision Maker | End of Life Options | Product Recovery Value | Marginal Value of Time | Processed Quality | Novel Resources Requisite | Environmental Aspect | Market Scenario | Profit |
|---|---|---|---|---|---|---|---|---|
| DM1 | Resale | F | F | F | VG | VG | G | G |
| | Repair | VG | VG | G | G | VG | VG | VG |
| | Refurbish | G | G | G | F | F-VG | G-VG | G-VG |
| | Remanufacture | P-F | P | VG | VP-P | P-G | P | P |
| | Cannibalization | P | P | P | P | P-G | P | P |
| | Recycle | F | F | G | F | P | F | F |
| | Disposal | VP | VP | P | G | VP | VP | VP |
| | | | | | | | | |
| DM2 | Resale | MG | G-VG | MG | G | G-VG | MG | MG |
| | Repair | VG | G | G-VG | G | G-VG | G-VG | G |
| | Refurbish | G | MG-VG | G | MG | MG | G | G |
| | Remanufacture | MP | P | G | MP | F | MP | P-MP |
| | Cannibalization | P | MP | MP | P | MP | P-MP | P |
| | Recycle | F | F | F-G | MP-F | P | F | F-MG |
| | Disposal | VP | P | VP | G | VP | P | VP |
| | | | | | | | | |
| DM3 | Resale | G | G | MG | G-EG | VG-EG | G | G |
| | Repair | VG-EG | VG | G-VG | VG | VG | EG | VG |
| | Refurbish | VG | G-VG | G | G | VG | VG | G |
| | Remanufacture | MP-F | MP | VG | P | MG | F | P |
| | Cannibalization | MP | P | MP | MP | F | MP | MP |
| | Recycle | MG | F | F | F | MP | MG | MG |
| | Disposal | VP | VP | P | F | EP | VP | VP |

*Table 2- Assigned Weights for Criteria*

| Decision Makers | Product Recovery Value | Marginal Value of Time | Processed Quality | Novel Resources Requisite | Environmental Aspect | Market Scenario | Profit |
|---|---|---|---|---|---|---|---|
| DM1 | H | H | MH | ML | MH | VH | VH |
| DM2 | VH | MH | M | M | M | VH | H |
| DM2 | MH | M | MH | M | ML | H | VH |

**Step 3:** The aggregated interval 2-tuple linguistic assessment and aggregated weights of the criteria are computed with Equations (1) and (2), and are given in Table 3.
**Step 4:** The comprehensive weighted interval 2-tuple linguistic decision matrix is structured by Equation (3) and is shown in Table 4.

*Table 3: Aggregated Interval 2-tuple Linguistic Decision table*

| End of Life Options | Product Recovery Value | Marginal Value of Time | Processed Quality | Novel Resources Requisite | Environmental Aspect | Market Scenario | Profit |
|---|---|---|---|---|---|---|---|
| Resale | Δ[0.639, 0.639] | Δ[0.694,0.750] | Δ[0.694,0.750] | Δ[0.861,0.944] | Δ[0.903, 1] | Δ[0.722,0.722] | Δ[0.722,0.722] |
| Repair | Δ[0.958, 1] | Δ[0.903,0.903] | Δ[0.778,0.875] | Δ[0.819,0.819] | Δ[0.903, 0.958] | Δ[0.944, 1] | Δ[0.903,0.903] |
| Refurbish | Δ[0.819, 0.819] | Δ[0.722,0.875] | Δ[0.778,0.778] | Δ[0.639,0.639] | Δ[0.0.681,0.847] | Δ[0.819,0.903] | Δ[0.778,0.861] |
| Remanufacture | Δ[0.319, 0.444] | Δ[0.264,0.264] | Δ[0.903,0.903] | Δ[0.194,0.278] | Δ[0.458, 0.625] | Δ[0.361,0.361] | Δ[0.222,0.278] |
| Cannibalization | Δ[0.264, 0.264] | Δ[0.278,0.278] | Δ[0.319,0.319] | Δ[0.264,0.264] | Δ[0.361, 0.528] | Δ[0.264,0.319] | Δ[0.264,0.264] |
| Recycle | Δ[0.542, 0.542] | Δ[0.500,0.500] | Δ[0.583,0.694] | Δ[0.444,0.500] | Δ[0.264, 0.264] | Δ[0.542,0.542] | Δ[0.542,0.597] |
| Disposal | Δ[0.042, 0.042] | Δ[0.097,0.097] | Δ[0.167,0.167] | Δ[0.694,0.694] | Δ[0, 0] | Δ[0.097,0.097] | Δ[0.042,0.042] |

*Table 4: Comprehensive Weighted Interval 2-tuple Linguistic Decision table*

| End of Life Options | Product Recovery Value | Marginal Value of Time | Processed Quality | Novel Resources Requisite | Environmental Aspect | Market Scenario | Profit |
|---|---|---|---|---|---|---|---|
| Resale | Δ[0.532, 0.532] | Δ[0.463,0.500] | Δ[0.424,0.458] | Δ[0.382,0.419] | Δ[0.452, 0.5] | Δ[0.682,0.682] | Δ[0.682,0.682] |
| Repair | Δ[0.798, 0.833] | Δ[0.602,0.602] | Δ[0.476,0.535] | Δ[0.364,0.364] | Δ[0.452,0.479] | Δ[0.891,0.944] | Δ[0.852,0.852] |
| Refurbish | Δ[0.682, 0.682] | Δ[0.482,0.584] | Δ[0.475,0.475] | Δ[0.284,0.284] | Δ[0.340,0.424] | Δ[0.773,0.852] | Δ[0.734,0.813] |
| Remanufacture | Δ[0.266, 0.370] | Δ[0.176,0.176] | Δ[0.552,0.552] | Δ[0.086,0.123] | Δ[0.229,0.313] | Δ[0.341,0.341] | Δ[0.210,0.262] |
| Cannibalization | Δ[0.220, 0.220] | Δ[0.185,0.185] | Δ[0.195,0.195] | Δ[0.117,0.117] | Δ[0.181,0.264] | Δ[0.249,0.301] | Δ[0.249,0.249] |
| Recycle | Δ[0.451, 0.451] | Δ[0.334,0.334] | Δ[0.356,0.424] | Δ[0.197,0.222] | Δ[0.132,0.132] | Δ[0.512,0.512] | Δ[0.512,0.564] |
| Disposal | Δ[0.042, 0.035] | Δ[0.065,0.065] | Δ[0.102,0.102] | Δ[0.308,0.308] | Δ[0, 0] | Δ[0.092,0.092] | Δ[0.040,0.040] |

**Step 5:** The 2-tuple linguistic positive-ideal solution $A^+$ and 2-tuple linguistic negative-ideal solution $A^-$ are determined with the help of Equations 4 – 6 and are given below:

$$A^+ = [\Delta(0.833), \Delta(0.602), \Delta(0.552), \Delta(0.419), \Delta(0.5), \Delta(0.944), \Delta(0.852)]$$

$$A^- = [\Delta(0.042), \Delta(0.065), \Delta(0.102), \Delta(0.086), \Delta(0), \Delta(0.092), \Delta(0.040)]$$

**Step 6:** The separation measures, $D^+$ & $D^-$, of each alternative from the above computed positive-ideal solution and negative-ideal solution are determined with Equations 7-8 and are shown in Table 5.
**Step 7**: The closeness coefficient of each alternative is calculated with the help of Equation 9, as shown in Table 5.

*Table 5- Separation measure and closeness coefficient*

| End of Life Options | $D_i^+$ | $D_i^-$ | $RC_i^+$ | Rank |
|---|---|---|---|---|
| Resale | 0.660 | 1.797 | 0.731 | 3 |
| Repair | 0.137 | 2.318 | 0.944 | 1 |
| Refurbish | 0.439 | 2.009 | 0.820 | 2 |
| Remanufacture | 1.641 | 0.970 | 0.371 | 5 |
| Cannibalization | 1.822 | 0.608 | 0.250 | 6 |
| Recycle | 1.19 | 1.25 | 0.512 | 4 |

| | | | | |
|---|---|---|---|---|
| Disposal | 2.354 | 0.314 | 0.117 | 7 |

**Step 8:** The ranking of the EOL alternatives for a two year old time sensitive electronic product is determined on the basis of the relative closeness coefficient, and the final results obtained are as follows:

Repair >Refurbish>Resale>Recycle>Remanufacture>Cannibalization>Disposal --- (10)

From the results, it can deduced that for a two year old electronic product return with short life cycle, repair is the most feasible recovery option, followed by refurbish, resale and so on.

## Conclusions and Discussion

In the present scenario, as customers are becoming environmentally aware, enterprises are opting for product recovery systems to handle returns in order to gain competitive advantage in the market. However, the major challenge faced by these enterprises is to decide the appropriate recovery option for value reclamation as multi-recovery alternatives are available. This problem of suitable EOL option selection is quite complex as it involves multiple reprocessing options as well as various criteria. The present research addresses this issue of product recovery decision making and proposes a comprehensive decision model considering all the significant criteria that can assist organizations in handling returns. Additionally, we introduce a flexible methodology, ITL-TOPSIS, which is more accurate in processing the linguistic information as compared to other methods present in the literature. The techniques used in the literature for attending to this issue of recovery undergo a loss of information during linguistic processing, leading to imprecise results. However, ITL-TOPSIS uses the interval 2-tuple linguistic representation model which has the capability to tackle this problem of decision making without sacrificing linguistic information. Moreover, the study focuses on the influence of time sensitive products on recovery decision making by determining the ranking of optimal EOL options for SLC returned products.

The study successfully develops and implements a comprehensive decision model to guide enterprises in the selection of optimal recovery options for time sensitive returns. The model takes into account both the qualitative and quantitative aspects, making it more practical and realistic. Furthermore, in order to overcome the complexity and ambiguity involved in the process of product recovery decision making, the methodology of ITL-TOPSIS is proposed, which can accommodate the decision maker’s preferences, as well as any lack of data. Unlike the other techniques, this methodology can express the results in the initial expression domain, which avoids loss and distortion of information during linguistic information processing. Subsequently, the results obtained by the application of ITL-TOPSIS methodology show that repair is the most suitable recovery option for time sensitive products with high value erosion rates, such as mobiles, laptops etc.

Although, the paper presents a comprehensive framework and a holistic approach to address the problem of decision making in PRS, the results obtained cannot be generalized for all short life cycle. Nevertheless, they are applicable to similar kinds of product ranges. It will be interesting to include wider range of products having longer life cycles and to compare their optimal EOL options in future work.

**References**


Agrawal, S., R. K. Singh, Q. Murtaza. 2014. Forecasting product returns for recycling in Indian electronics industry. *Journal of Advances in Management Research* 11 (1): 102-114.

Brito, M. P., P. Dekker. 2003. A Framework for Reverse Logistics. *Erasmus Research Institute of Management Report Series Research in Management*

Bufardi, A., R. Gheorghe, D. Kiritsis, P. Xirouchakis. 2004. Multicriteria decision-aid approach for product end-of-life alternative selection. *International Journal of Production Research* 42: 3139–3157.

Chan, J. W. K. 2008. Product end-of-life options selection: grey relational analysis approach. *International Journal of Production Research* 46: 2889–2912.

Choudhary, D., J. Madaan. 2013. Hierarchical decision modeling approach for risk prioritization in sustainable supply chain. *In the proceedings of International Conference on Humanitarian Logistics*, India.

Choudhary, D., J. Madaan, R. Narain. 2014. An Integrated Decision Model for Selection of Third Party Recovery Facilitator (3PRF) for Product Recovery Operations. *Journal of Operations and Supply Chain Management* 7 (2): 79-101.

Guide, D. R. V., L. Van Wassenhove. 2002. The Reverse Supply Chain. *Harvard Business Review* 80 (2): 25-26.

Guide, D. R. V. Jr., C. S. Gilvan C, L. Van Wassenhove, J. D. Blackburn. 2006. Time Value of Commercial Product Returns. *Management Science* 52 (8): 1200-1214.

Hazen B. T., D. J. Hall, J. B. Hanna. 2012. Reverse Logistics Disposition Decision-Making Developing : A Decision Framework Via Content Analysis. *International Journal of Physical Distribution & Logistics Management* 42 (3): 244-274.

Hui, H., L. Gongqian. 2011. Design Strategy for the Reverse Supply Chain Based on Time Value of Product. *Journal on Innovation and Sustainability* 2 (1): 76 – 80.

Iakovou, E. et. al. 2009. A methodological framework for end-of-life management of electronic products. *Resources, Conservation and Recycling* 53: 29–339.

Johnson, M. R., Wang, M. H. 1995. "Planning product disassembly for material recovery opportunities" *International Journal of Production Research* 33: 3119–42.

Jun, H.B., M. Cusin, D. Kiritsis, P. Xirouchakis. 2007. A multi-objective evolutionary algorithm for EOL product recovery optimization: turbocharger case study. *International Journal of Production Research* 45: 4573–4594.

Keong, L. M. 2008. Nokia Kiosks Collect Phones for Recycling. Available at: http://news.cnet.com/8301-11128_3-10045417-54.html (accessed date October 27, 2014).

Liu, H. C., M. L. Ren, J. Wu, Q. L. Lin. 2014. An interval 2-tuple linguistic MCDM method for robot evaluation and selection. *International Journal of Production Research* 52 (10): 2867–2880.

Madaan, J., P. Kumar, F. T. S. Chan. 2012. Decision and Information Interoperability for Improving Performance of Product Recovery Systems. *Decision Support Systems* 53 (3): 448–457.

Prahinski, C., C. Kocabasoglu. 2006. Empirical Research Opportunities in Reverse Supply Chains. *Omega* 34: 519 – 532.

Rogers, D. S., R. S. Tibben-Lembke. 1999. Going Backwards: Reverse Logistics Trends and Practices. Reno, NV: *Reverse Logistics Executive Council.*

Skinner, L. K., P. T. Bryant, R. G. Richey. 2008. Examining the impact of reverse logistics disposition strategies. *International Journal of Physical Distribution & Logistics Management* 38 (7): 518-539.

Srivastava, S. K., R. K. Srivastava. 2006. Managing Product Returns for Reverse Logistics. *International Journal of Physical Distribution & Logistics Management* 36 (7): 524-540.

Staikos, T. S. Rahimifard. 2007. A decision-making model for waste management in the footwear industry *International Journal of Production Research* 45 (18-19): 4403-4422.

Stock, J. R. 2001. The 7 Deadly Sins of Reverse Logistics. *Material Handling Management* 56 (3): pp. 5-11.

Stock, J. R., J. P. Mulki 2009. Product Returns Processing: An Examination of Practices of Manufacturers, Wholesalers/Distributors, and Retailers. *Journal of Business Logistics* 30 (1).

Thierry, M., M. Salomon, J. VanNunen, L. VanWassenhove. 1995. Strategic Issues in Product Recovery Management. *California Management Review* 37 (2).