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Multi-Criteria Decision Approach for a Sustainable Reverse Logistics Network under Fuzzy Environment

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***Abstract*— Adoption of reverse logistics practices in existing supply chains has emerged as an important incentive for manufacturers to gain financial and competitive advantage. Growing environmental and social concerns are driving firms to incorporate sustainable strategies into designing of their reverse supply chain (RSC) network. A sustainable RSC can be attained by following the triple bottom line (TBL) philosophy i.e. economical, social and environmental development. In this paper, we develop a sustainable reverse logistics model for laptop manufacturers for handling of end-of-life (EOL) and end-of-use (EOU) product returns. In the first stage of the model, a hybrid method using Analytical Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solutions (TOPSIS) based on the criteria of TBL is applied to calculate weights for the three dimensions of sustainability. In the second stage, a three objective mixed integer linear programming model is developed in fuzzy environment which minimises the total cost, the environmental impact (in terms of CO_2e emissions) and maximises the social impact of the network utilising the weights of the objectives from the first stage. The social sustainability is tacked in the model by the management of social resources including training for the workers, fixed jobs as well as inclusion of variable jobs based on the quantity of returns. The model is validated through a case study and its societal, economical and environmental impact is discussed.**

Keywords- Triple Bottom Line, reverse logistics, TOPSIS, AHP, Fuzzy multi objective optimization.

I. INTRODUCTION

Sustainable development is defined by Brundtland Commission as ‘development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs’. Sustainability can be attained by restricted use of natural resources, waste minimization and by reducing the negative social and environmental impact of supply chain practices and decisions. Organizations can contribute to sustainable development by adding economic, ecological and social value to their supply chain [1]. Long term thinking is however needed in planning and designing a supply chain which is sustainable in the long run. Decisions made with regard to products and processes can have profound environmental and social implications [2]. In recent years, growing pressure from governmental and non governmental organizations (NGOs), have impelled the manufacturers to improve their environmental performance by integrating sustainability-conscious practices into supply chain logistics [3]. Although, mostly organizations incorporate such practices in the forward logistics, corporate sustainability can be achieved through an introduction of reverse logistics (RL) and building appropriate RL partnerships [4]. Reverse logistics practices can be efficiently adopted by companies to achieve competitive, financial and environmental gains [5]. Majority of studies have focused on the importance of taking economical and environmental responsibility of EOL products [6], [7], [8], [9], [10]. There are a considerable number of studies on integrating sustainability issues into reverse logistics network, but very few have considered the social aspect of sustainability [11]. Evaluating the social responsibility performance of reverse logistics on TBL approach can diachronically improve the corporate social responsibility (CSR) performance of a firm [12]. A RSC needs to be sustainable for reducing costs, mitigating the negative impact on environment and for being sensitive to societal concerns. In this regard, [13] proposed an integrated model to design a recovery network with respect to unifying perspective of sustainability by developing a framework of performance indicators for measuring reverse logistics performance based on the Triple Bottom Line approach. [14]considers the three pillars of sustainability in the network design problem of a closed loop supply chain model.

In this paper, we develop a reverse network design for EOL and EOU laptops in line with TBL objectives. The paper proposes a novel way of balancing the three aspects of sustainability. Various criteria for designing the RL network are considered. Environmental, economic and social impacts of the chosen criteria are evaluated using a hybrid method involving AHP and TOPSIS resulting in the determination of importance (weights) of the TBL aspects. Next, a multi objective mathematical programming model is developed under fuzzy environment, to design the sustainable RL network which minimizes the economic and environmental impact and maximizes the social impact. The multi echelon, multi product RL network determines the optimal number of products to be disassembled, and components to be fabricated, recycled or disposed. The environmental dimension includes controlling the ecological impact (carbon emissions) of reverse processes and social aspect is incorporated by creating optimal job opportunities and providing skilled training on job.

II. MODEL DESCRIPTION AND FORMULATION

Due to customer's initiative and government legislative, companies are under legal and social pressures to redesign their logistics network in order to mitigate the negative impact of environment as well as include social attributes into their design process. Henceforth, the objective of the companies has shifted from mere economical gains to environmental and social gains as well. In this article, we introduce a sustainable reverse logistics (RL) network, in which economic, environmental and social impacts are balanced. The network as shown in Fig 1, consists of collection centres (CCs), a dismantling centre (DMC), a component fabrication centre (CFC), spare market (SM), a recycling facility (RF) and a scrap facility (SF). EOL and EOU laptops are collected and are shipped to DMC for disassembly. Shipping of products from CCs to DMC is managed by the company. Based on the condition of the components retrieved, one of the three recovery options of fabrication, recycling or disposal is chosen. The amount of components being fabricated must depend on the demand of the spare market. Components to be recycled are sold to collection agents of RF for a fixed revenue, and rest of the components are sent to SF with a payment of fixed disposal fee. The environmental implications of reverse logistics are also taken into consideration by analysing the carbon emission due to reclamation activities of collection, disassembly, component fabrication and recycling and disposal. The social sustainability is tacked in the model by the management of social resources including training for the workers, fixed jobs as well as inclusion of variable jobs based on the quantity of returns. Inclusion of social dimension at a corporate level will help in improving the human capital of individuals. The objective is to minimise the total cost and environmental impact and maximise the social impact of the RL network.

We propose a two-stage model in which a hybrid AHP-TOPSIS methodology is applied in the first phase to obtain weights (importance) of the three objectives. In the second phase, a mixed integer linear programming model is developed to configure the proposed RL network which determines the flow of products and components across various facilities as well as determine the number of job created based on the return flow of products and components at CC, DMC and CFC.

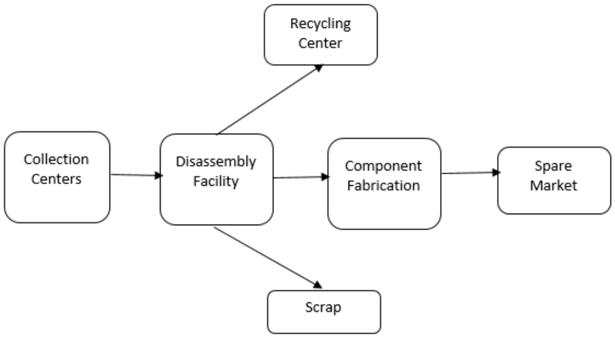

Fig 1. RL network design

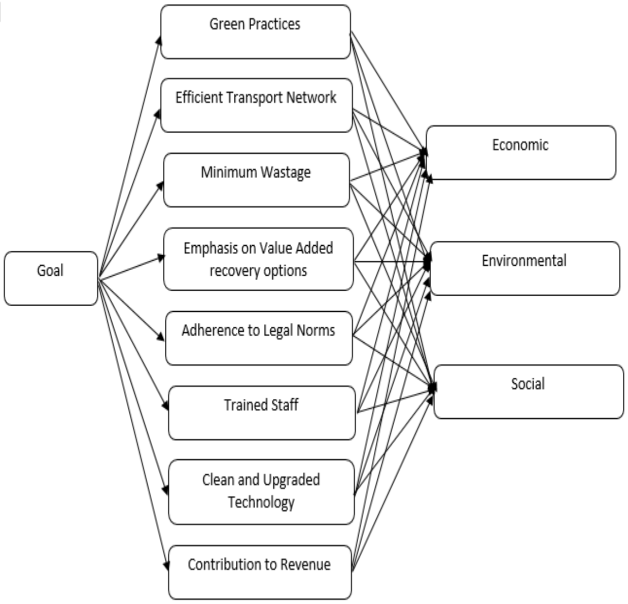

Fig 2. Criteria for AHP-TOPSIS.

A. *AHP-TOPSIS Methodology*

AHP method is combined with TOPSIS to determine the weights of objective functions (alternatives) based on the criteria requirements as shown in Fig 2 for the design of the RL network. AHP methodology [15] is used to derive weights for alternatives on the basis of numerous qualitative as well as quantitative criteria. These weights are then used in TOPSIS calculations [16] and final weights for the objective functions are derived.

The main steps of the AHP-TOPSIS method are as follows [17], [18]:

Step 1. Establish a pairwise comparison decision matrix A whose $(i, j)^{th}$ entry represents the quantified judgment on a pair of elements C_i, C_j which is rated by the nine-point scale where equal, moderate, strong, very strong and extremely important is represented by 1, 3, 5, 7, and 9, respectively. Also, 2, 4, 6 and 8 are used as intermediate values.

Step 2. Normalize the decision matrix and calculate the priorities of the matrix. To do this, divide each element of the matrix by its respective column sum value. The averages of rows of the resultant matrix are the relative priorities.

$$A=\left[a_{ij}\right]=\begin{array}{c|ccccc|} & C_1 & C_2 & & & C_n \\ C_1 & w_1/w_1 & w_1/w_2 & . & . & . & w_1/w_n \\ C_2 & w_2/w_1 & w_2/w_2 & . & . & . & w_2/w_n \\ . & . & . & & . & & . \\ . & . & . & & . & & . \\ . & . & . & & . & & . \\ C_n & w_n/w_1 & w_n/w_2 & . & . & . & w_n/w_n \end{array}$$

Step3. Check the consistency to determine the acceptance of the priority weighting (CR<0.1)

Calculate the eigen values of criteria, the consistency index (CI), the consistency ratio (CR) as:

$$Aw=\lambda w\,, CI=\frac{\lambda_{\max}-n}{n-1}\,, CR=\frac{CI}{RI} \quad where\ n\ is\ order\ of\ A$$

$$and\ \lambda_{\max}=\max\left\{\lambda_i\,, i=1,....n\right\}$$

Value of random index (RI) is taken from the table of RIs

n	1	2	3	4	5	6	7	8	9
RI	0	0	0.52	0.89	1.11	1.25	1.35	1.40	1.45

*Step4.*Determine the ideal (IS) and the negative-ideal solution (NIS) as follows:

$$A^*=\left\{v_1^*,v_2^*,.....v_n^*\right\}=\left\{\left(\max_j \mathrm{v}_{ij}\mid i\in I'\right),\left(\min_j \mathrm{v}_{ij}\mid i\in I''\right)\right\},$$

$$A^-=\left\{v_1^-,v_2^-,.....v_n^-\right\}=\left\{\left(\min_j \mathrm{v}_{ij}\mid i\in I'\right),\left(\max_j \mathrm{v}_{ij}\mid i\in I''\right)\right\}$$

where I' *and* I'' are associated with benefit and cost criteria respectively.

Step5 .Calculate the distance of each alternative from IS and NIS as:

$$d_j^*=\sqrt{\sum_{i=1}^{n}\left(v_{ij}-v_i^*\right)^2}\,, d_j^-=\sqrt{\sum_{i=1}^{n}\left(v_{ij}-v_i^-\right)^2}\,, j=1,2....J$$

Step 6. Calculate the closeness coefficient (CC_j) of each alternative (to be used as weights) as:

$$C_j^*=\frac{d_j^-}{d_j^*+d_j^-}\quad j=1,2,,,,J$$

B. *Assumptions and Limitations:*

1. The location of all facilities are known and fixed.
2. Distance between DMC and CFC is considered negligible.
3. There is no holding of inventory at any facility.
4. The recovery amount is calculated as a certain percentage of customer demand.
5. The disassembly and component fabrication costs together are less than procuring cost of new components.
6. Multi product and single period are being considered.
7. The capacity of the collection center, disassembly center and fabrication center are limited.
8. Setting up of facility costs is not considered.
9. The estimated emission rates of CO_2 equivalent are known.

C. *Sets*

I	set of products index by *i, i=1, 2… I*
J	set of components index by *j, j=1,2,…J*
L	set of collection centers (CC) index by *l, l==1, 2.., L*
D	dismantling center (DMC) index by *d*
F	component fabrication center (CFC) index by *f*
M	spare market (SM) index by *m*
R	recycling facility (RF) index by *r*
S	scrap facility (SF) index by *s*
W	set of fixed staff index by w
V	set of skilled staff index by v
K	set of return break index by *k, k= 1...*n_d / n_f

D. *Parameters*

T_{il}	transportation cost of shipping one unit of i^{th} product from l^{th} CC to DMC
C_{id}	per unit dismantling cost of i^{th} product
C_{jf}	per unit fabrication cost of j^{th} component
C_{js}	per unit disposal cost of j^{th} component
C_{wl}	Salary paid to the w^{th} fixed staff member at l^{th} CC
C_{wd}	Salary paid to the w^{th} fixed staff member at DMC
C_{wf}	Salary paid to the w^{th} fixed staff member at CFC
C_{vd}	Salary paid to the v^{th} skilled staff member at DMC
C_{vf}	Salary paid to the v^{th} skilled staff member at CFC
C_{hvd}	per hour cost of training for v^{th} skilled staff member at DMC
C_{hvf}	per hour cost of training for v^{th} skilled staff member at CFC
S_{jr}	per unit revenue gained from the recycling centre for j^{th} component
S_{jm}	per unit revenue gained from selling of j^{th} component at spare market *m*

E_{il}	emission rate of CO_2e for shipping one unit of i^{th} product from CC to DMC
E_{id}	emission rate of CO_2e from dismantling each unit of i^{th} product
E_{jf}	emission rate of CO_2e from fabrication of each unit of j^{th} component
E_{js}	emission rate of CO_2e from disposal of each unit of j^{th} component
E_{jr}	emission rate of CO_2e from recycling of each unit of j^{th} component
u_{ij}	utilization rate of j^{th} component in one unit of the i^{th} product
h_{vd}	number of hours of training for the v^{th} skilled staff member at DMC
h_{vf}	number of hours of training for the v^{th} skilled staff member at CFC
O_l	Capacity(in terms of number of units of products) of l^{th} CC
D_{il}	Demand of i^{th} product (in terms of number of units of products) of l^{th} CC
O_d	Capacity (in terms of number of units of products) of DMC
O_f	Capacity (in terms of number of units of components) of CFC
D_{jm}	Demand of j^{th} component at the spare market
η_l	job creation rate at l^{th} CC which is function of O_l
η_d	job creation rate at DMC which is function of O_d
η_f	job creation rate at CFC which is function of O_f
γ	maximum percentage of demand at CC returned
δ_j	maximum percentage of j^{th} component fabricated
ω_j	percentage of j^{th} components recycled
α_d	Number of products at DMC creating β_d number of skilled jobs
α_f	Number of components at CFC creating β_f number of skilled jobs

E. *Decision Variables*

R_{kd}	Binary variable equal to '1' if the total products to be dismantled fall in the k^{th} break, '0' otherwise
R_{kf}	Binary variable equal to '1' if the total components to be fabricated fall in the k^{th} break, '0' otherwise
X_{il}	Number of i^{th} products shipped from l^{th} CC
X_j	Number of j^{th} component at DMC
X_{jf}	Number of j^{th} component at CFC
X_{js}	Number of j^{th} component to be disposed
X_{jr}	Number of j^{th} component to be sent for recycling

F. *Fuzzy Multi-Objective Model Formulation (FMOM)*

Owing to imprecise information regarding the quantity and quality of returns, uncertainty is inherently present in real world reverse network problems, which can be handled by use of fuzzy set theory [19]. In this model, we are taking fuzziness into account in the objectives by considering decision maker's aspiration levels for the fuzzy objectives. We consider three fuzzy objectives to be optimised simultaneously.

$$\begin{aligned}\textit{Minimise } z_1 \cong\ & \sum_i\left(\sum_l (T_{il}+C_{id})X_{il}\right)+\sum_j\left(C_{jf}X_{jf}-S_{jm}X_{jf}+C_{js}X_{js}-C_{jr}X_{jr}\right)+\\ & \sum_{k=1}^{n_d}(k\beta_d)R_{kd}C_{vd}+\sum_{k=1}^{n_d}(k\beta_d R_{kd}h_{vd})C_{hvd}+\sum_{k=1}^{n_f}\left(k\beta_f\right)R_{kf}C_{vf}+\\ & \sum_{k=1}^{n_f}\left(k\beta_f R_{kf}h_{vf}\right)C_{hvf}+\sum_l \eta_l O_l C_{wl}+\eta_d O_d C_{wd}+\eta_f O_f C_{wf}\end{aligned} \tag{1}$$

$$\textit{Minimise } z_2 \cong \sum_i\left(\sum_l (\mathrm{E}_{il}+E_{id})X_{il}\right)+\sum_j\left(E_{jf}X_{jf}+E_{js}X_{js}-E_{jr}X_{jr}\right) \tag{2}$$

$$\begin{aligned}\textit{Maximise } z_3 \cong\ & \sum_{k=1}^{n_d}(k\beta_d)R_{kd}+\sum_{k=1}^{n_d}(k\beta_d h_{vd})R_{kd}+\sum_{k=1}^{n_f}\left(k\beta_f\right)R_{kf}+\sum_{k=1}^{n_f}\left(k\beta_f h_{vf}\right)R_{kf}\\ & +\sum_l \eta_l O_l+\eta_d O_d+\eta_f O_f\end{aligned} \tag{3}$$

The symbol $\cong$ reflects the vagueness in the objectives and can be interpreted as 'essentially equal to'. The first objective (Equation 1) minimises the cost of the RL network .It is the sum of the transportation cost from CC and dismantling cost for products; the cost of fabrication minus the selling price at spare market, disposal cost minus recycling revenue for components; cost associated with variable job creation and training of staff at the DMC and CFC; and the cost incurred for fixed jobs at CC, DMC and CFC. The second objective (Equation 2) minimises the environmental impact of the facilities in terms of CO_2 e. It consists of emissions due to transportation of products from CC to DMC, dismantling of products at DMC, and fabrication, disposal and recycling of components at CFC, SC and RC respectively. The third objective (Equation 3) maximizes the social impact in terms of job creation and training. It consists of variable job creation and training at the DMC and CFC; and the fixed jobs at CC, DMC and CFC.

Subject to constraints:

$$\sum_i X_{il} \le \gamma D_l \qquad \forall l \tag{4}$$

$$\sum_{i} X_{il} < O_{l} \quad \forall 1 \tag{5}$$

$$\sum_{i} X_{il} \geq 0.6 * O_{l} \quad \forall 1 \tag{6}$$

$$\sum_{l} \sum_{i} X_{il} < O_{d} \tag{7}$$

$$X_{j} = \sum_{l} \sum_{i} X_{il} \mu_{ij} \quad \forall j \tag{8}$$

$$X_{jf} \leq \delta_{j} X_{j} \quad \forall j \tag{9}$$

$$\sum_{j} X_{jf} \leq O_{f} \tag{10}$$

$$X_{jf} \geq D_{jm} \quad \forall j \tag{11}$$

$$X_{jr} = \omega_{j} X_{j} \quad \forall j \tag{12}$$

$$X_{js} = X_{j} - X_{jf} - X_{jr} \quad \forall j \tag{13}$$

$$n_{d} = \left\lceil {O_{d}}/{\alpha_{d}} \right\rceil \tag{14}$$

$$(k-1)\alpha_{d} \leq \sum_{l} \sum_{i} X_{il} \leq k\alpha_{d} \quad \forall k = 1, 2, ...n_{d} \tag{15}$$

$$\sum_{l} \sum_{i} X_{il} \leq \sum_{k=1}^{n_{d}} (k\alpha_{d}) R_{kd} \tag{16}$$

$$\sum_{k=1}^{n_{d}} R_{kd} = 1 \tag{17}$$

$$n_{f} = \left\lceil {O_{f}}/{\alpha_{f}} \right\rceil \tag{18}$$

$$(k-1)\alpha_{f} \leq \sum_{j} X_{jf} \leq k\alpha_{f} \quad \forall k = 1, 2, ...n_{f} \tag{19}$$

$$\sum_{j} X_{jf} \leq \sum_{k=1}^{n_{f}} (k\alpha_{f}) R_{kf} \tag{20}$$

$$\sum_{k=1}^{n_{f}} R_{kf} = 1 \tag{21}$$

$$\begin{gathered} X_{il}, X_{j}, X_{if}, X_{js}, X_{jr} \geq 0 \text{ and intergers} \\ R_{kd}, R_{kf} \in \{0,1\} \end{gathered} \tag{22}$$

Constraint (4) to (6) determine the amount of returns collected at each CC. Constraint (4) determines the amount of returns collected at CC which is a fraction of the demand while constraint (5) and (6) ensures an upper and lower bound on the amount of returns at CC. Constraint (7) is the capacity constraint for dismantling center. Constraint (8) determines the amount of components retrieved after dismantling. Constraint (9) is about the number of components fabricated. The capacity constraint for CFC is given by equation (10). Equation (11) determines that the number of components fabricated should be more than the demand of spare market. Constraint (12)-(13) determines the amount of components send for recycling and scrap. Constraints (14)-(21) determine the number of fixed and variable jobs at CC, DMC and CFC. Constraint (22) determines non negativity and binary variables.

G. Fuzzy Solution Algorithm

The sequential steps to solve the proposed FMOM ([20], [21]) are as follows:

Step 1: We first convert the fuzzy objective functions into crisp objective functions by defining corresponding membership functions which are expressed as follows:

$$\mu_{Z_1}(X) = \begin{cases} 1 & Z_1(X) \leq Z_1^0 \\ \dfrac{Z_1^* - Z_1(X)}{Z_1^* - Z_1^0} & Z_1^0 < Z_1(X) \leq Z_1^* \\ 0 & Z_1(X) > Z_1^* \end{cases} \tag{23}$$

$$\mu_{Z_2}(X) = \begin{cases} 1 & Z_2(X) \leq Z_2^0 \\ \dfrac{Z_2^* - Z_2(X)}{Z_2^* - Z_2^0} & Z_2^0 < Z_2(X) \leq Z_2^* \\ 0 & Z_2(X) > Z_2^* \end{cases} \tag{24}$$

$$\mu_{Z_3}(X) = \begin{cases} 1 & Z_3(X) \geq Z_3^0 \\ \dfrac{Z_3(X) - Z_3^*}{Z_3^0 - Z_3^*} & Z_3^0 > Z_3(X) \geq Z_3^* \\ 0 & Z_3(X) < Z_3^* \end{cases} \tag{25}$$

where Z_g^0 *and* Z_g^* $g = 1, 2, 3$ are aspiration and tolerance level of fuzzy cost, fuzzy environmental impact and fuzzy social impact respectively as per the decision maker's opinions.

Step 2: The FMOM problem is converted into an equivalent ordinary single objective mathematical problem as follows:

Maximise λ

subject to $\mu_{Z_g}(X) \geq \lambda$ g=1,2,3

Equations (3) to (22)

where $\lambda \in [0,1]$ represents the degree of satisfaction of the decision maker.

Step 3: Weights generated from AHP-TOPSIS are assigned to the objectives as per their relative importance and the problem is formulated as:

Maximise λ

subject to $\mu_{Z_g}(X) \geq w_g \lambda$ g=1,2,3

Equations (3) to (22)

$$w_g \geq 0, \ \sum_{g=1}^{3} w_g = 1, \ \lambda \in [0,1]$$

Step 4: The single objective mathematical problem is solved to get a compromised solution for the conflicting objectives.

III. NUMERICAL ILLUSTRATION

In this section, we are proposing the RL model for laptop manufacturer. The company wants to incorporate all the three dimensions of sustainability into its reverse logistics system to make its RL network truly sustainable. The network constituting the base problem consists of 10 CCs, one each of DMC, CFC, RF, SF and SM. Two variants of laptops are considered which constitute of 7 major parts viz. Battery, hard disk drive (HDD), CD/DVD drive, CPU board, AC adaptor, Main body and LCD. The amount of returned products collected from customers at each CC is at most equal to a fraction (γ =0.4) of the customer demand of each CC. Unit transportation cost which include the collection cost for first model of laptop are (T_{il}) Rs. 50, 60, 70, 80, 90, 100, 110, 120 and 130; and for second variant of laptop are Rs. 55, 65, 75, 85, 95, 115, 125 and 135 from collection centers. The products are transported to DMC, wherein the dismantling costs for the two variants are (C_{id}) Rs. 1000 and Rs. 1200. Once the laptops are disassembled, based on the quality of the retrieved, they are fabricated, recycled or disposed. The maximum percentage of j^{th} components fabricated (δ_j) are 0.2, 0.5, 0.5, 0.6, 0.5, 0.3 and 0.5 while percentage of j^{th} components recycled (ω_j) are 0.6, 0.2, 0.2, 0.3, 0.5, 0.2 and 0.5. The unit fabrication cost for the components (C_{jf}) are Rs. 400, 550, 200, 600, 350, 200 and 600; unit disposal cost (C_{js}) are Rs. 50, 55, 30, 50, 25, 120 and 60. The emission rates of CO_2e for shipping one unit of product from CC to DMC (E_{il}) are 0.05, 0.07, 0.09, 0.11, 0.13, 0.15, 0.17, 0.19 and 0.21 kg-CO_2 for first variant of laptop; 0.06, 0.08, 0.1, 0.12, 0.14, 0.16, 0.18 and 0.2 kg-CO_2 for the second variant. The emission from dismantling each unit of the product (E_{id}) are 3.04 and 3.56 kg-CO_2; the emission rate in kg-CO_2 from fabrication, recycling and disposal of each unit of components are as follows: (E_{jf})- 1.81, 0.73, 0.78, 1.59, 1.37, 0.91 ,3.41 , (E_{jr})- 0.69, 0.22, 0.15, 0.36, 0.51, 0.4, 0.66 and (E_{js})-1.01, 1.04, 1.01, 1.03, 1.05, 1.01, 1.08 respectively [22].

The salary paid for fixed staff members are Rs. 5000; Rs. 7000 and Rs. 9000 for CC, DMC and CFC and for skilled staff are Rs. 8000 and Rs 6000 for DMC and CFC. The other parameters are C_{hvd} =500; C_{hvf} =600; h_{vd} = 40; C_{hvf} =60. The capacities of DMC and CFC are 3000 products and 40000 components respectively. The capacities of CCs in terms of number of units of products are 250, 300, 250, 300, 200, 250, 250, 300, 150 and 150. The demand (D_{jm}) and revenue (S_{jr}) at the spare market are 500, 1400, 1500, 1600, 1500, 1000 and 1500 components and Rs. 1600, 1600, 700, 1500, 800, 700 and 1700. It is been assumed that for every 150 products, 10 skilled jobs are created at DMC while for every 1000 components, 20 skilled jobs are created at CFC. The fuzzy multi objective RL model focuses on determining the optimal flow of products and components across various echelons in order to simultaneously minimize the total cost, and the environmental impact in terms of CO_2 and maximize the social impact of the network.

IV. RESULTS

In the first stage of the model, based on the survey of literature, a number of various criteria were considered and a hybrid AHP-TOPSIS methodology is used in order to give weightage to the three dimensions of sustainability viz. economic, environmental and social. The normalized weights obtained are shown in table 1.

TABLE 1: Resultant weights by AHP-TOPSIS

	d_j^*	d_j^-	C_j^*	**normalized**
Economic	0.17032617	0.119108	0.41152	0.275907
Environmental	0.12497679	0.147176	0.540785	0.362574
Social	0.12499015	0.146263	0.539212	0.361519

In the second stage, a fuzzy mixed integer linear programming model is developed taking into account fuzziness in the objectives. The three objectives are converted into crisp forms using membership functions as defined by equations (23)-(25) with aspiration and tolerance levels of fuzzy cost, fuzzy environmental impact and fuzzy social impact as given in table 2.

TABLE 2: Aspiration and tolerance levels of objectives

Objective	Z_g^0	Z_g^*
Economic	3501200	7065350
Environmental	41015	78465
Social	57510	37810

The normalized weights of the first stage are assigned to the three goals. The resultant crisp single objective problem is solved in order to simultaneously minimize the cost, minimize the environmental impact and maximize the social impact. The problem is solved using LINGO 11.1 with the help of the above parameters. The compromised solution is Rs. 6267632; 59372.92 kg-CO_2 and 46520 for total cost, environmental impact and social objectives and 81.12 % aspiration of the decision makers is achieved. Results clearly show that all the three objectives are in conflict with each other. The model clearly compromises more on the cost to obtain the environmental and social benefits of the RL network.

The optimal flow of products from CCs (X_{il})are 100, 125, 100, 125, 100, 115, 135, 150, 60 and 45 for first variant of laptop and 100, 125, 70, 55, 20, 35, 15, 30, 30 and 45 for second variant of laptop. The optimal flow of components at fabrication center, recycling center and disposal centre are recorded in table 3 while table 4 demonstrates the number of jobs created.

TABLE 3: Number of components to be fabricated, recycled and disposed.

component	1	2	3	4	5	6	7
X_{jf}	2212	5531	5531	6637	5237	3318	5531
X_{jr}	6637	2212	2212	3318	5531	2212	5531
X_{js}	2212	3318	3318	1106	293	5531	0

TABLE 4: Number of jobs created at facilities

	No of units	No of Fixed jobs	No of Skilled jobs
Dismantling center	1650	90	110
Fabrication center	34000	100	680

V. CONCLUSION

Legislation and green and societal awareness among consumers is pushing companies to redesign their reverse logistics network in order to integrate all the three dimensions of TBL. In addition for financial and environmental edge, the companies have to incorporate social dimensions in order to gain competitive advantage and stay within the rubric of sustainability. In this paper, we have developed a sustainable reverse logistics model for laptop manufacturers for handling EOL and EOU product returns. In the first stage of the model, a hybrid method using AHP and TOPSIS based on the criteria of TBL was applied to calculate weights for the three dimensions of sustainability. In the second stage, a three objective fuzzy mixed integer linear programming model was solved to optimise the proposed RL network utilising the weights derived from the first stage. A trade-off among the three objectives i.e minimisation of cost and carbon emission and maximisation of social impact resulted in a compromised solution as per the decision makers' inputs. The proposed model can be used by decision makers in designing a cost effective RL network which incorporates environmental concerns such as reducing carbon emissions of the network and social benefits such creating optimum jobs and promoting skilled labour to uplift the human capital of individuals. The model can be extended for multi periods and uncertainty in the parameters can also be explored.

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