

Optimisation of Electronic Waste Recycling Network and Reverse Logistics-A Literature Review

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ABSTRACT

India is anticipating its marketplace to be flooded with consumer electronics and durables, as it is expecting a 15% CAGR growth in consumer electronics by 2015. According to ASSOCHAM, rise in disposable incomes and young demographic population of the country are contributing enormously to the rising demands. Easy financing options are encouraging the large middle-income groups of the country towards large scale consumption of consumer electronics. This results in high rates at which devices are getting outdated and getting replaced with new ones adding to electronic waste (e-waste). Such End-of-Life (EOL) devices are still left with value, as the rate at which replacement is taking place does not allow the consumer to fully utilize the product. Such leftover values could be recapitulated through activities, such as refurbishment and recycling with reverse logistics. The present process of e-waste management is analyzed and further improvements and modifications would be suggested.

While discussing the various industry practices of reverse logistics, the research paper deliberates importance for organisations to strategize and implement reverse logistics for better returns. Inspired by the reverse SCM in Army reverse pipelining the same has been visualised of improvement of reverse logistics in consumer-centric chains. Various challenges faced by organisations which are implementing the reverse SCM are also discussed and certain strategies are also conferred in the discussion.

This research paper also debates a mixed-integer linear programming formulation for the formation of a reverse supply chain system for WEEE using optimisation-based warehouse location model for recapitulating the orphaned value from EOL products.

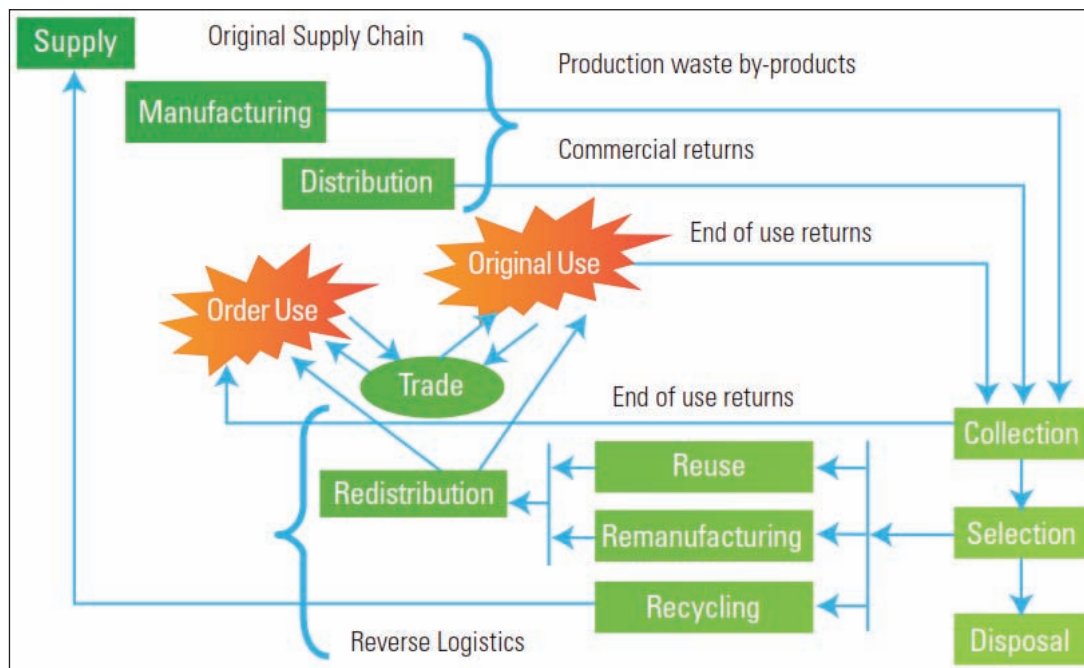
Keywords: Mixed-Integer Linear Programming, Reverse Logistics, WEEE, Warehouse Location Problem (WLP), (LORA)

INTRODUCTION

India is developing a stronger tenacity towards a culture of consumerism. Shelf life and replacement rates in electronic goods are extremely high. Companies are preparing and strategising themselves towards shorter product life cycles to cope up with the consumer's anticipation for the release of products which are high in performance and low in price. Waste Electrical and Electronic Equipment (WEEE) add up to 8% of municipal solid wastes (ASSOCHAM, n.d.).

An estimate of 50 MT (metric tons) of e-waste is generated worldwide every year. These e-wastes have been a major component of municipal solid waste (Schwarzer *et al.*, 2005). A report by the United Nations has predicted a growth of e-wastes for the year 2020; it has estimated

a 500% rise for India and 400% rise for China on their 2007 levels. Furthermore, e-waste from discarded mobile phones in India, is expected to grow by 18 folds by 2020 (Young, 2010). India is generating 13 lakh metric tons e-waste every year, out of which computers contribute 86%; other sectors such as telecommunication equipment at 12%, electrical equipment at 8%, medical equipment at 7% (ASSOCHAM, 2014). Less than 2% of that gets recycled due to improper infrastructure and policies in place. In India, Electronics Industry Market Research and Knowledge Network (EIMRKN), has projected e-wastes from discarded computer and mobiles to rise above the \$17 billion by 2014 with a generation of 40-70 MT (metric tons) (IAER, 2009). For optical telecommunication components market in India, the rise is estimated to be \$11.3 billion by 2015 from \$3.8 billion of 2008 (Electronics.ca Research Network, 2009).

Figure 1: Simplified Schematics of Reverse SCM (ASSOCHAM, n.d.)

REVERSE LOGISTICS-PRACTICES AND CHALLENGES

Practices

Reverse logistics are concomitant with the movement of recycling, material substitution, reuse, disposal, refurbishment, repair, and remanufacturing; hence it is the physical flow of products, components and materials from end users to re-users. This would value firms towards contributing to environmental protection. Hence cost efficient methods are determined for commercially optimal disposal of EOL products. An efficient reverse logistics needs proper planning and implementation of an effective inbound flow of e-waste and related information for value recovery.

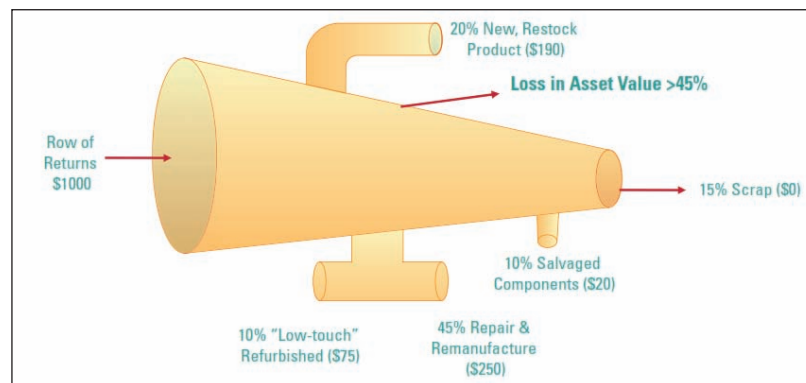
EOL products, generally, flow through product acquisition which is one level in the reverse flow of the goods. Reverse logistics follows the goods from retailer to facility for consolidation or deconsolidation after inspecting and disposition of the goods. Status and condition of the goods are assessed for proper information flow and to make profitable decisions. Re-manufacturing and refurbishment follow, where goods are repaired to its original specifications. The last stage is marketing the products generated after the 3R process in secondary markets.

Approximately 45% of the product value is lost through reverse supply chain, majorly due to degradation of products through remanufacturing or salvaged. In electronics industry the value dissipation is 1% every week, so prompt decisions are required in this case.

Certain regulations in India mandate producers or companies to collect back and recycle their goods after the goods' value is perceived to be deteriorated by the end-user. This is to ensure that salvaged goods do not contribute to hazardous waste, for environmental protection.

Centralised reverse supply chain delivers cost efficiency and since the returns are consolidated and shipped in bulk; transportation costs are reduced. Facilities instead of the retailers participate in primary value evaluation. As processing costs are reduced, economies of scale are attained. But for products which lose value over time, testing has to be preponed by using a decentralised technique, the retailers/ resellers who are experts at value assessment would restock the products immediately. Through this, vendor-management is a sub-goal reached.

Army's Distribution Management (DM), formerly velocity management, is an improved process to reduce waiting time – customer waiting time (CWT) - for a delivery in forward logistics. The same is applicable and appropriate for reverse logistics where velocity of the reverse chain is still consistent. RL pipeline through DMI decreases the

Figure 2: Shrink Line Shows how EOL Goods Have Various Factors with High Time Value Depreciation

amount of inventory investment (Diener, n.d.). This is called as Define-Measure-Improve approach.

D-M-I approach comprises of 3 phases- Define phase, Measure phase, and Improvement phase. During definition of the process customers, inputs and outputs are determined, while in measure phase, metrics are defined and data is identified; baseline performances are determined and performance driver are diagnosed for which reports and feedback are provided. To improve this process, goals are established

Challenges

Unlike the demands encountered in forward logistics, demands in RL are hard to forecast and involves larger time lags. Magnitude of shipment is a challenge while forecasting, hence inventory management is quite tedious. Inventory holding costs are high due to probable lower-valued items. It involves many-to-one transportation and products are not uniform. The product packaging is often damaged. The destination or routing is also unclear (Tibben-Lembke & Rogers, 2002).

In reverse logistics, customers demand flexible and hassle-free return policies. Volume management optimisation is heavily complex as the goods flow in irregular intervals of time and have to be restocked estimated for resale. Data management is a prerequisite, without which time and energy is wasted in segregation and decide the state and further process of the goods. Expertise at handling the disposition would help in maximum extraction of the left over value in EOL products. Law and regulatory bodies abiding process are a mandate and hence informal disposition is not allowed. Similar to supplier selection at the procurement stages, 3PLs have to be selected consciously as they would hold key expertise in waste management and would suggest best possible practices

for the company.

Logistics costs are heavy in case of reverse supply chain. Transportation costs are high due to lower-volume channels. Rate of obsolescence is extremely high due to multiple delays while waiting for full-truck-loads where collection time periods nor the process for handling of variable packaging is standard. Diagnosis in case of decentralized reverse supply chain would involve much greater time periods for consolidation, item-by-item. Factors such as refurbishment and repacking are unique to reverse logistics, while on the positive side, there is much less shrinkage of batch due to meagre thefts as there is limited use without repair. The inventory holding costs are less in comparison (Tibben-Lembke & Rogers, 2002).

FORMULATION OF REVERSE LOGISTICS

This research paper talks about designing the distribution system using quantitative approach of mixed-integer linear programming to solve the warehouse location problems (WLP)(Wolfe, n.d.).

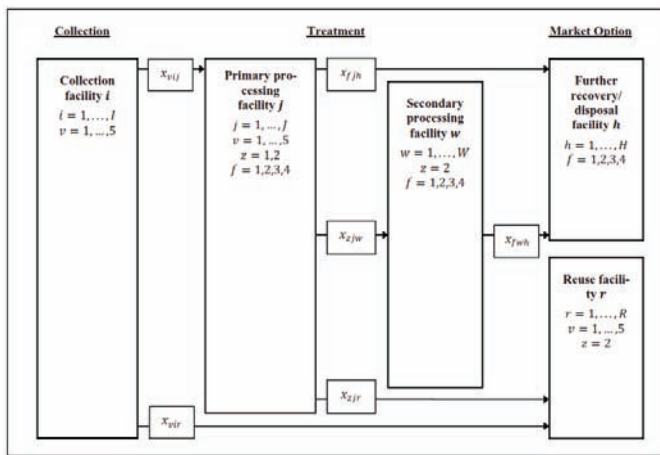
Considering three stages in framing design for reverse logistics as major products stretches the processing stages. Spatial proximity of the reuse locations have to be given due consideration while framing the design. Hence the facilities for disposal, recovery and reuse preferences are considered in LPM – linear programming model.

Initially at the collection stage, appliances are segregated for reuse or recycling purpose; any further progress from this stage has environmental safety into consideration. In the primary process stage, components' segregation is further branched into 3 phases; components with in-house treatment, components transferred to reuse facilities, and components pushed to secondary processing facilities where components are further processed for full recovery

and eventually market options such as reusing facility recipients of both, appliances and components, recovery and incineration etc.

The proposed model comprises 3 different recovery levels – product, component and material level. In the product level, the documentation of the devices and its peripheries are mentioned. Component and material levels are the dismantled phases.

Figure 3: Reference of Mathematical Optimisation Model for WLP (Wolfe, n.d.)



Indices:

Facilities: i – Collection facilities, h – Farther disposal facilities, r – Reuse facilities, j – Primary processing facilities, w – Secondary processing facilities;

Appliances and types: v = 1 for refrigerators, 2 for air coolers, 3 for TV sets, 4 for PCs and 5 for washing machines;

Processes: z = 1 for in-house processing and 2 for other methods;

Materials: f = 1 for ferrous metals, 2 for non-ferrous metals, 3 for non-metal fractions and 4 for residues.

Parameters and Variables:

Costs: C_{vij} - Transportation costs for v from i to j, similarly for C_{fjh} , C_{zjw} , C_{fwh} , C_{vir} and C_{zjr} ; $d(j)$ – investment for installation of primary processing facilities j and $d(w)$ for installation of secondary processing facilities w;

Mass feeds of appliances: e_{vi} , e_{zj} and e_{zw} for v type of collection facility i, z type for 1⁰ processing facility j and z type for 2⁰ facility w;

Processing capacities: $Cap(j)$ - Capacity of primary processing facilities j, $Cap(w)$ – Capacity of secondary processing facilities w, $Cap(hf)$ – Capacity of further recovery facility h for material fraction f, Capacity for reuse facility r for type v and type z;

Mass of appliances transported: $X(vij)$ – mass of appliance v transported from facility i to j; similarly other $X(vir)$, $X(fjh)$, $X(zjw)$, $X(zjr)$ and $X(fwh)$.

Proportion of components: $q(vir)$, $q(zjr)$ - Proportion of reusable commodities type v at facility I, z at facility j respectively;

Binary variables: $Y(j) = 1$ for all j is installed else zero same with $Y(w)$

Objective function to be minimised for crucial costs is summation of (Wolfer *et al.*, 2011):

$$\begin{aligned} & \sum_{v=1}^V \sum_{i=1}^I \sum_{j=1}^J C_{vij} * X_{vij} + \sum_{v=1}^V \sum_{i=1}^I \sum_{r=1}^R C_{vir} * X_{vir} + \\ & \sum_{f=1}^F \sum_{j=1}^J \sum_{h=1}^H C_{fjh} * X_{fjh} + \sum_{z=1}^Z \sum_{j=1}^J \sum_{w=1}^W C_{zjw} * X_{zjw} + \\ & \sum_{z=1}^Z \sum_{j=1}^J \sum_{r=1}^R C_{zjr} * X_{zjr} + \sum_{f=1}^F \sum_{w=1}^W \sum_{h=1}^H C_{fwh} * X_{fwh} \\ & + \sum_{j=1}^J d_j * y_j + \sum_{w=1}^W y_w * dw; \end{aligned}$$

which is subjected to the following:

Decision making for recovery at the collection facilities is on

$$\sum_{j=1}^J x(vij) + \sum_{r=1}^R x(vir) = e(vi);$$

Components are dismantled in the 1⁰ processes for pre-treatment; the primary process equation is as follows (Schwarzer *et al.*, 2005):

$$\sum_{r=1}^R X(vir) = q(vir) * e(vi);$$

Components are broken down into further fractions in the 2⁰ processes; the secondary process equation is as follows:

$$\sum_{j=1}^J X(vij) = (1 - q(vir)) * e(vi);$$

Maximising process capacity:

$$\sum_{v=1}^V \sum_{i=1}^I X(vij) \leq Cap(j) * y_j;$$

Constraints for appliances for processing, disposal, recovery and reuse facilities:

$$\sum_{h=1}^H X(fjh) + \sum_{w=1}^W X(zjw) + \sum_{r=1}^R X(zjr) = e(zj);$$

$$a(zv) \sum_{v=1}^V \sum_{i=1}^I X(vij) = e(zj);$$

Mass fed into final treatment process:

$$\sum_{h=1}^H X(fjh) = a(fz) * e(zj);$$

$$\sum_{r=1}^R X(zjr) = q(zjr) * e(zj);$$

$$\sum_{w=1}^W X(zjw) = (1 - q(zjr)) * e(zj);$$

Prevention of secondary processing facilities being overfed:

$$\sum_{j=1}^J X(zjw) \leq Cap(w) * y(w);$$

$Y(j)+Y(w)$ (For all shared candidate locations);

Regulates the flow of goods for regular inflow and outflow of material:

$$\sum_{h=1}^H X(fwh) = e(zw);$$

$$\sum_{j=1}^J X(zjw) = e(zw);$$

$$\sum_{h=1}^H X(fwh) = a(fz) * e(zw);$$

Processing capacity for maximum allowable feed for disposal for material fractions and appliances respectively:

$$\sum_{h=1}^H X(fwh) + \sum_{w=1}^W X(fwh) \leq Cap(hf)$$

$$\sum_{i=1}^I X(vir) + \sum_{j=1}^J X(zjr) \leq Cap(rvz)$$

Thus the mathematical WLP is formulated with material flows and transshipment facilities taken into consideration.

IMPROVEMENTS FOR RECOVERY IN REVERSE NETWORK

Strategic management of a company involves efficient supply chain and logistics to impact the bottom-line of the company. One such technique is networking through online marketplaces where manufactures or value seekers meet 3rd party logistics (3PL) for collaboration. These 3PLs specialize in the operations such as repairing,

repacking and testing. They develop methods for cost controlling and effective return rate management.

Build-to-order combined with direct sales is a logical way to minimise return chain from the end-user to ODM. Inventory holding is reduced marginally as statistically the return rates are approximately 5%; which is half of the rest of industry.

Critical segments where metrics indicate longer delays are focused on; as stated by Dowlatshahi (2000), operational factors, in such process segments are customer, cost benefit analysis, transportation, warehousing, SCM, remanufacturing recycling, and packaging for reverse logistics system. These seven operational factors are taken into consideration while redesigning the reverse supply chain (LORA, n.d.).

Army reverse logistics pipeline has most prominent techniques of value recovery as component replenishments are chief causes for inventory restoration. 'Reparable' goes through Level of Repair Analysis (LORA) to economically tune for reuse when in unserviceable state and the 'Consumables' are disposed as it has reached its EOL, while in inventory for repair, components with high service ability should be processed first to reduce inventory investment and cost for its maintenance.

Integration of reverse pipeline with that of the forward could realise economies of volume through core competencies like distribution centers. Such integrations are cost-effective with implementations of milk runs. Historical demands should give accurate ideas of stock holding and increased customer waiting time.

MANAGEMENT OF REVERSE LOGISTICS

Indian companies ought to manage their EOL products as they are obliged under the environmental protection act. Proper management would impact the bottom line and would impact in reduction of carbon footprint and reduction in hazardous waste through formal recyclers. Certain key management factors are zero returns, refurbishments, asset recovery, gate-keeping, and Reverse Logistics Information systems.

Standard Processing

A major challenge faced by Indian companies is to maintain a standardised process which impels continuous communication about the problems faced in reverse supply chain. Good reverse supply chains have a CRM

established at the retailers as collection centres and here is where the communication is initiated. These small steps taken would save many labour hours and end up in quality decisions.

Third Party (3PL)

Many companies over years have analysed their areas of expertise and have restricted a few functions in-house. Of these functions, reverse logistics was outsourced analysing that revenues could be maximised by outsourcing reverse supply chain to third party logistics. These companies are majorly reverse suppliers hence are able to generate profits from bundling activities.

Web-based Secondary Markets

Disposition of EOL products by provision of a direct channel to the consumer, hence control over the product's status can be identified. Prompt feedback for the flow of products in the web-based market place is used to assess the credibility of the channel for that particular product.

Zero Returns

The manufacturer transfers the responsibility to dispose the product after utility to the retailer. The retailer in return is reimbursed some amount for disposition. Thus the manufacturer saves himself from the process and offsets that with the cost paid to the retailer. Scenarios such as double dipping of the producer cannot be prevented and the onus is upon the retailer to formally dispose the goods.

LIMITATIONS

Increase in product development has reduced the shelf time of many products yet raising the quality of the products scrapped in terms of their components. But growth in product development is a double edged sword. For example, repair and re-use good market's share are being attracted with comparative cheaper rates each time. Improper SCP would imply delays in reverse supply chain, thus preserving the intrinsic market value is highly critical.

CONCLUSION

Electronic waste is considered the fastest upward segments, it is compulsory to institute a feasible means for

curbing vice to diminish or disregard pollution and its effect on environment. Global e-wastes are growing at exponential levels raising apprehensions about source efficiency and possess direct health and environmental threats. Hence there is a pressing need for methodology to mitigate the hazardous risk possessed by e-waste. For which this paper has taken up an issue – warehouse location problem–for determining physical configurations of a reverse logistics system which is formulated using mixed-integer linear programming for formal WEEE recycling.

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