

A Reverse Logistics Model for Optimization in Waste Collection

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Abstract

Sustainability has become a major concern in the development of human society. This requires solution of certain issues and involves social, technical, legislative, and other factors. An important concern is to minimize the generation of wastes, prevent environmental deterioration caused by the generation of wastes, and to enhance the value of recovery from the wastes. The reverse logistics network is helpful in this regard as its mission is to collect and transport used products and packages based on the balance of cost and environment. A good reverse logistics network is important for firms to gain more profits. This paper proposed a linear programming model for reverse logistics in which collection is done when the recyclables bin is half full. This limit can be varied from place to place, depending on the collection of recyclables. The model aimed to reduce transportation cost by setting up a schedule for collection and took into account the profit obtained by recycling. It also considered a penalty for late collection so that there is no piling up of waste, thus reducing the probability of items deteriorating due to weather or moisture content.

Keywords : linear programming, mathematical modelling, reverse logistics, recycling of waste

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Reverse logistics focuses on the backward flow of materials from customer to supplier, and the main objective is maximization of value from the returned items. In the context of waste management, it includes product returns, reduction at source, recycling, material substitution, reuse of materials, waste disposal, and so forth. It differs from waste management as it focuses on the addition of value to a product to be recovered ; whereas, waste management involves mainly the collection and treatment of the waste products that have got no new use. All activities in the process of reuse, recycling, and disposal of products, as well as their associated components and materials fall under this category .The most important feature in reverse logistics is collecting products, which have to be recovered, and transportation of such products to various centres, which make use of these goods. When goods are collected in a planned manner, it reduces wastage of time and other resources. A common collection bin is used to collect all recyclables, and a citizen's watch committee can take care of this. Once it reaches a particular level, say 50%, a trigger is sent to a central point, which co-ordinates dispatch of vehicles. Once the recyclable waste is collected by the vehicles, it is dispatched to different centres, which make use of such products, either directly or by reworking on them.

Literature Review

Luttwak (1971) defined reverse logistics as “the reverse process of logistics”. Rogers and Tibben-Lembke

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(1999) defined it as a focus on the backward flow of materials from customer to supplier (or alternate disposition) with the goals of maximizing value from the returned item and/or assuring its proper disposal. In the context of waste management, it includes product returns, reduction at source, recycling, materials substitution, reuse of materials, waste disposal, and so forth. It differs from waste management as it focuses on the addition of value to a product to be recovered; whereas, waste management involves mainly the collection and treatment of the waste products that have got no new use. All activities involved in the reuse, recycling, and final disposal of products, their associated components and materials come under reverse logistics. Furthermore, Kannan, Pokharel, and Kumar (2009) and Lee, Kang, Hsu, and Hung (2009) showed that there would be cost savings in transportation, inventory carrying as well as in waste disposal along with an increase in customer loyalty and sales by implementing reverse logistics.

Many researchers have studied the facility location problem for reverse logistics. Caruso, Colorni, and Paruccini (1993) gave one of the first models to localize the centre of recovery and described a management system for solid waste in Lombardy region of Italy. They dealt with a multi-objective model which included collection, transportation, recycling, and disposal. Kroon and Vrijens (1995) proposed a mixed linear program model to minimize the total treatment cost of reusable containers. Barros, Dekker, and Scholten (1998) presented a model for recycling in the Netherlands and their objective was to minimize the total cost of the recovery network. Marin and Peligrin (1998) described a mixed linear program model for secondary products recovery. Their assumption was that the quantity of secondary products is proportional to the amount of primary and that returns are not necessarily returned to the outlet that delivered the product, but can be returned at any open site.

Jayaraman, Patterson, and Rolland (2001) used the linear programming model, which consisted of many collection sites, treatment site, and many clients to design a network for recovery of the end of life products. Their objective was to determine the number of collection sites and to initiate treatment so that the total cost of distribution was minimized. In their model, there was an intermediary collection centre and returns could be routed directly to the treatment centre, and the capacity was limited.

Barros et al. (1998) discussed the design of a network for the recycling of sand cases that came while sieving building waste. Here, they dealt with the main problem tackled is the determination of a number and location of depots of the sand. Kleinedam, Lambert, Blansjaar, Kok, and van Heijningen (2000) considered the choice between paper incineration and recycling. Chang and Wei (2000) discussed the possibilities of recycling household waste in Taiwan.

Realf, Ammons, and Newton (2004) gave a mixed integer linear program for carpet recycling in England and analyzed a set of alternative scenarios which were identified by the decision maker and provided a near-optimal solution for network design. Ahluvalia and Nema (2006) gave a multi-objective linear model for the recovery of obsolete computers in New Delhi. They included various risks like risk in transport of hazardous materials in different sites of the network. Lu and Bostel (2007) used linear programming model with the objective of minimizing the operational costs of the logistics network for product recovery at the end of life. They used it to determine collection sites, recycling, and landfill for the recovery of waste materials while limiting the capacity of sites.

A linear programming model to locate sites in a reverse logistics network was given by Yu, Li, and Su (2007). These sites were used for disassembling, cleaning, and sorting of used products and from these places, these would be transported to centres, which used the parts to manufacture new goods. Buhrkal, Larsen, and Ropke (2012) presented a vehicle routing approach with the objective of minimizing the distance of transportation of end-of-life goods, which were collected by local authorities and major manufacturers' distribution centres to four regional recycling centres. Sheu (2008) considered waste reverse logistics of nuclear power generation and formulated a linear multi objective optimization model to optimize the operations of both nuclear power generation and the corresponding induced waste reverse logistics.

Benaissa and Benabdelhafid (2010) presented a mixed linear program model in which the objective was to minimize the costs of returns of the end of life product at various time periods. It facilitated taking decisions on opening and closing sites, and they used CPLEX to solve the mathematical program. Mounir, Afifa, and Habib

(2011) gave a model to address the end life product treatment problem and established a multi-product and multi-time location of sites for the reverse logistics of such products. This can be applied to varied structure reverse logistics network and can determine the state of sites, their openness, closure, available capacity, and material flow between the various entities of the logistics network. Their objective was to minimize the logistics costs. They considered that the returns quantity is determinist and that investment in the capacity of a site is fixed and used CPLEX to solve the mathematical program.

Model for Reverse Logistics

The proposed model aims at a schedule for waste collection depending upon the type of recycled waste collected in the common collection bins. Each area/zone has some common collection bins placed at strategic locations. Contractors are employed to collect household waste, which is segregated at source. This involves spreading awareness and educating people about the importance of segregation. Segregated waste is transported to common collection points where, again, there are 3 bins for dry (unwanted, like dust, etc.), wet (which can be composted) recyclable, and those to be sent to the incinerator. At the common collection center, recycling items are sent to the sorting unit as soon as it fills up to the required capacity. This capacity can be varied from zone to zone as per historical data collected. In areas where small, medium, or large industries are situated, there can be a level of say, 60%, 50%, and 40%, which will ensure that the waste does not overflow outside the bins by the time the vehicle arrives for collection. The upper limit fixed at each common bin reduces the accumulation of waste at these bins, avoiding ugly pileups. This is a motivation for people to segregate waste.

Once the bins are filled to the designated capacity, a trigger is sent to a central place from where vehicles are dispatched for collection. All articles in the bin are taken to a sorting place and can be sorted into various categories, those which can be sold / sent to manufacturing units as they are; those which can be disassembled, cleaned, and sold; those which are to be sold to scrap dealers; and finally, those which are sent to landfills as the goods have no utility value. The objective of this model is to maximize profit by reuse of the recycled goods while considering vehicle routes on a series of six consecutive working days (Monday to Saturday). A time constraint is also incorporated in the model.

Each vehicle can undertake only one route each day, starting and ending at a depot, and the same heterogeneous vehicle fleet is available each day, although all vehicles need not necessarily be used on any particular day. This, of course, follows the receiving of signals from various collection bins. Each location may only be visited by one vehicle on any given day.

↳ **Time Windows** : Collections from common bins have to be made on specified fixed days of the week; each bin has its own associated time window, the same each day, when a collection can be made. From the bins, material has to be taken to recycling units and from there, recycled goods have to be transported to various stores which sell these products. If a vehicle reaches early, it can pick up the goods, but it should not exceed the upper time limit.

↳ **Vehicle Capacity** : A heterogeneous /homogenous fleet of vehicles is available. Vehicle capacities are specified by payload and not by volume.

↳ **Driving Constraints** : All trips start at the same time - rounds are assumed to start at the same time and the total working hours of crew is according to the regulations.

↳ **Distances and Travel Time Between Sites** : There were many distances to be covered, that is, collection from individual houses to common collection points, from there to recycling units, from recycling units to stores/ units where recycled products are sold/used. Also, from recycling units to landfills and incinerators.

↳ **Demand** : The weight of materials (kg) available to be collected from a common collection bin is known (as we can fix a limit for trigger). The amount of waste from recycling units can be computed by considering the average and standard deviations.

↳ **Servicing Time** : The time needed to collect materials from sites is assumed to be known and are fixed values. These can be obtained by the logs of drivers. There will be a positive correlation between weights of items and time for collection. Different time taken will be:

(1) Time to collect from individual houses and transport it to common collection bin- responsibility of contractor (a fixed sum can be paid).

(2) Time taken to bring from common collection bins to sorting unit.

(3) Time taken to clean/ recycle items.

(4) Time taken to transport from sorting unit to shops/other manufacturing units/ further disassembly and landfills.

(5) Time taken to load and transport from shops/other manufacturing units/ further disassembly to landfills or to incinerators.

(6) There is a transport cost associated with all these.

↳ **Values of Goods** : Value of goods is specific to each area/location of bin. For example, some areas may generate more recyclables, some may generate less. Some areas may be located far off from recycling units and from shops selling such goods and manufacturing units using recycled parts.

↳ **Penalty** : A penalty can be imposed when a bin is full and is not collected.

↳ **Minimum Percentages Fill Level to be Collected** : This can be determined by specifying the limit, say 50% of the bin. This also takes care that no vehicle comes to collect unnecessarily.

Model Formation

Indices:

i = the various collection centres in each area/zone,

j = sorting centres in each area/zone,

k = shops selling recycled items/ godowns,

l = disassembly units,

m = manufacturing units,

n = landfills,

s = scrap dealers,

R_{j1c} = Cost/ unit of recycled items of type 1 (which can be sold directly in shops) at sorting centre j ,

R_{j2c} = Cost/ unit of recycled items of type 2 (which can be sold directly to some manufacturing units) at sorting centre j ,

R_{j3c} = Cost/ unit of scrap items (which can be sold directly to some scrap dealers) at sorting centre j ,

Q_{j1c} = Quantity of recycled items of type 1 (which can be sold directly in shops) at sorting centre j ,

Q_{j2c} = Quantity of recycled items of type 2 (which can be sold directly to some manufacturing units) at sorting centre j ,

Q_{j3c} = Quantity of scrap items (which can be sold directly to some scarp dealers) at sorting centre j ,
 C_{saj} = Cost /unit of sorting waste of type 'a' at sorting center j ('a' can have different values),
 Q_{saj} = Quantity of waste of type 'a' sorted at sorting center j ('a' can have different values),
 O_{saj} = Operating cost /unit of sorting waste of type 'a' at sorting center j ('a' can have different values).

Objective Function

Max z = Benefits - Costs

where,

Benefits = $R_{j1c} * Q_{j1c} + R_{j2c} * Q_{j2c} + R_{j3c} * Q_{j3c} + Penalties$

Penalties: $(X_i - 0.5C_i) * P_i$

where,

X_i = Amount collected at collection bin i ,

C_i = capacity at collection bin i ,

P_i = penalty / kg or unit for every excess.

This can vary from place to place, depending on the type of recyclables which are deposited in areas. For example, in residential areas, recyclables may not be more.

Costs = Fixed costs + sorting costs + transportation costs + penalties + Miscellaneous costs

Fixed Cost = One time investment + Monthly fixed costs

One Time Investment = Cost of vehicles + setting up cost of sorting centres + setting up cost of recycling units + setting up cost of disassembly centre = F_{1j}

Monthly Fixed Costs = operating costs and maintenance of vehicles/ month or week + fuel cost + labor cost of drivers and sorting personnel + operating costs and maintenance of sorting centre + operating costs and maintenance of disassembly centres = F_{2j}

The above two costs can be calculated for every region/ area as it is a fixed quantity and can vary only slightly.

Miscellaneous Costs = training of personnel in disassembly centres + extra drivers + others = M (can be calculated for each sorting centre/disassembly centre and can be clubbed. It can be a stochastic variable as well. This will minimize complexity of the model.)

Sorting Costs = $\sum \sum C_{saj} * Q_{saj} + \sum \sum O_{saj} * Q_{saj}$

Transportation Costs = $\sum \sum C_{ij} Q_{ij} + \sum \sum C_{jk} Q_{jk} + \sum \sum C_{jl} Q_{jl} + \sum \sum C_{jm} Q_{jm} + \sum \sum C_{jn} Q_{jn} + \sum \sum C_{js} Q_{js} + \sum \sum C_{lk} Q_{lk} + \sum \sum C_{lm} Q_{lm} + \sum \sum C_{ln} Q_{ln} + \sum \sum C_{ls} Q_{ls}$

C_{ij} = cost/ unit of transporting from collection centre i to sorting centre j ,

C_{jk} = cost/ unit of transporting from sorting centre to shops selling recycled items/ godowns,

C_{jl} = cost/ unit of transporting from sorting centre to disassembly units,

C_{jm} = cost/ unit of transporting from sorting centre to manufacturing units,

C_{jn} = cost/ unit of transporting from sorting centre to landfills,

C_{js} = cost/ unit of transporting from sorting centre to scrap dealers,

C_{lk} = cost/ unit of transporting from disassembly units to shops selling recycled items/ godowns,

C_{lm} = cost/ unit of transporting from disassembly units to manufacturing units,
 C_{ln} = cost/ unit of transporting from disassembly units to landfills,
 C_{ls} = cost/ unit of transporting from disassembly units to scrap dealers,
 C_{ms} = cost/ unit of transporting from manufacturing units to scrap dealers,
 Q_{ij} = quantity transported from collection centre i to sorting centre j ,
 Q_{jk} = quantity transported from sorting centre to shops selling recycled items/ godowns,
 Q_{jl} = cost/ unit of transporting from sorting centre to disassembly units,
 Q_{jm} = quantity transported from sorting centre to manufacturing units,
 C_{jn} = cost/ unit of transporting from sorting centre to landfills,
 Q_{js} = quantity transported from sorting centre to scrap dealers,
 Q_{lk} = quantity transported from disassembly units to shops selling recycled items/ godowns,
 Q_{lm} = quantity transported from disassembly units to manufacturing units,
 Q_{ln} = quantity transported from disassembly units to landfills,
 Q_{ls} = quantity transported from disassembly units to scrap dealers,
 Q_{ms} = quantity transported from disassembly units to scrap dealers.

Constraints

$$\sum \sum Q_{ij} \leq Cap_j \quad (1)$$

$$\sum \sum \sum Q_{ijt} = \sum \sum \sum Q_{jkt} + \sum \sum \sum Q_{jlt} + \sum \sum \sum Q_{jmt} + \sum \sum \sum C_{jnt} \quad (2)$$

$$\sum Q_{jl} \leq Cap_l \quad (3)$$

$$\sum Q_{jm} + \sum \sum Q_{lm} \leq Req_{man} \quad (4)$$

$$a_e \leq t_{ij} \leq a_l \quad (5)$$

$$\sum Q_l \geq MinD_m \quad (6)$$

$$\sum \sum C_{jn} + \sum \sum Q_{ln} \leq Cap_n \quad (7)$$

$$\sum \sum Q_{jk} + \sum \sum Q_{lk} \leq D_k \quad (8)$$

$$\sum \sum Q_{js} + \sum \sum Q_{ls} + \sum \sum Q_{ms} \leq D_s \quad (9)$$

$$C_{ij}, C_{jk}, C_{jl}, C_{jm}, C_{jn}, C_{js}, C_{lk}, C_{lm}, C_{ln}, C_{ls}, C_{ms}, Q_{ij}, Q_{jk}, Q_{jl}, Q_{jm}, C_{jn}, Q_{js}, Q_{lm}, Q_{ln}, Q_{ls}, Q_{ms}, Q_{ijt}, Q_{jkt}, Q_{jlt}, Q_{jmt}, C_{jnt} \geq 0$$

states that the total quantity transported from i to j cannot exceed the capacity of the sorting centre ; (2) is regarding all wastes transported to sorting centre j from collection bin i on any day should be cleared (This constraint has one more variable ' t ' which indicates time ; (3) suggests that the total quantity transported from j to i cannot exceed the capacity of the disassembly centre ; (4) is about the total quantity transported from sorting centre j to manufacturing unit m + the total quantity transported from disassembly unit l to manufacturing unit m cannot exceed the requirement of the manufacturing centre ; (5) considers the pickup and drop from i to j should be between earliest and latest times, as specified by the zones and its constituent spots of waste generation ; (6) is about the quantity at disassembly unit should be more than the min demand at manufacturing units as this will avoid unnecessary trips ; (7) is the constraint that the total quantity from sorting j to landfill n and disassembly unit l to landfill n cannot exceed capacity of landfill n ; (8) is the constraint that total quantity transported from sorting centre j to shop n + the total quantity transported from disassembly centre l to shop n cannot exceed the demand at shop n , whereas (9) states that the total quantity transported from sorting centre j to scrap dealer s + the total quantity transported from disassembly centre l to scrap dealer s + the total quantity transported from manufacturing unit m to scrap dealer cannot exceed the demand at scrap dealer.

Conclusion

A properly planned collection system reduces time, money, effort, and personnel required for collecting waste. In the model proposed, collection of recyclable waste happens at a preset limit and only when this limit is reached, the vehicles are dispatched. The various centres which make use of such items have to be identified by policy makers and urban planners. Routing can then be done to minimize time and fuel consumption. Time windows ensure that these vehicles ply only during certain time windows and are not an eye sore during business hours. Penalty imposed on late collection will deter piling up of waste. To avoid excesses in the bins, a slightly lower limit can be set for sending a trigger so that by the time the limit is reached, collection vehicles arrive at the spot.

Managerial Implications

A proper management of waste generated is heavily dependent upon the collection system. The success of a waste management scheme is assured when the load to landfills and incinerators is reduced, and a major portion is recycled and reused. By fixing a time frame and limit for collection, the segregated goods are transported to the recycling/ compost unit faster so that the value of recycling/ composting is maximized. By fixing a sensor to detect the amount of waste collected, it is possible to plan a proper route for collecting from places, which have sent a trigger.

Limitations of the Study and Scope for Further Research

The model has to be tested under real life scenarios. Proper segregation and adherence to pick up levels and time windows are crucial for the implementation of the model. A pilot study can be done in a densely populated residential area wherein common bins can be fitted with sensors and routing can be made. It can further be developed exclusively for recycled goods in industrial areas.

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