*i*Journals: International Journal of Software & Hardware Research in Engineering (IJSHRE)
ISSN-2347-4890
Volume 10 Issue 8 August 2022

Designing the Reverse Logistics of Newspaper Collection from Household by a Paper Recycling Unit: A Linear Programming Model

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Abstract:

In an industry where the logistics is designed to deliver the product to its customers, in a recycling industry it is an assortment of logistics and reverse logistics. It implies that the recycling industry has to design the logistics not only for delivering the products to the customer on time but also for collecting the old or not fit for use products for the purpose of recycling. The logistics of a recycling plant aims at smooth operations of the industry as well as on time delivery of the recycled products to the customers. The comprehensive intention of the present study is to design the reverse logistics of a paper recycling plant in the city of Mumbai. The recycling plant employs daily wagers for a period of 6 hours a day with a remuneration for collecting the unused newspaper from the households. The other costs incurred by the recycling plant is in the form of employing workers, repairing cost, transportation cost and others. The objective of this paper is to optimize the profit of the company by optimizing the cost related to collection of unused newspapers, transportation and number of workers employed. The problem under consideration is represented as a linear programming problem (LPP) and solved using the Particle Swarm Optimization (PSO) algorithm. The optimal value computed by the PSO algorithm is ₹285646. Finally, an in-depth study of the paper recycling industries is also conducted.

Keywords: Reverse logistics, Particle Swarm Optimization, Linear Programming Problem, Newspaper recycling, Transportation cost

1. Introduction

In this technologically advanced era, the sustainability of an industry is solely dependent on the customer-based market where the paradigm of an ideal product is often changing, and the demand for newer and customized products is at a record high. In such a scenario, logistics can play a crucial role to thrive in this competitive market where the company's prime objective is to meet the burgeoning demand of the customers by delivering them with quality products on or before time. This has forced the companies around the world to develop and design efficient as well as effective logistics.

In general logistics of a company is defined as the flow of products between the points of origin to the point of consumption to meet the requirements of end-customers. The tangible resources that are managed in logistics may vary from material, equipment, supplies etc. to perishable items such as food and other consumable goods [1]. From the perspective of the administration of an industry logistics plays a very important role in maintaining the customer's loyalty. On the other hand, from the customer's point of view, effective logistics indicates the discipline of a company. Designing effective logistics assures a strong industry customer relationship [2].

Unlike, for an industry where the logistics is designed to deliver the product to its customers on or before time, in a recycling industry it is an assortment of logistics and reverse logistics [3]. It implies that the recycling industry has to design the logistics not only for delivering the products to the customer on time but also for collecting the old or not fit for use products for the purpose of recycling. The logistics of a recycling plant aims at smooth operations of the industry as well as on time delivery of the recycled products to the customers.

With the growing research in the field of sustainability people are getting more conscious about the exploitation of the natural resources which lead to the increased use of recycled products. With the advancement made in technology, recycled products are preferred due to the fact that it is cheaper and the performance is at par with the non-recycled products [4]. When it comes to paper communications, the paper industry is a mature industry which has considerable potential to cause environmental damage in different stages of product life [5]. Therefore, recycled paper is the greenest option as it uses less energy, water, and produces lower carbon emissions than the manufacturing of non-recycled paper [6]. Paper can be recycled 4 to 5 times thereby reducing the amount of waste to landfill. With advances in technology and processes, it is hard to differentiate between recycled and non recycled paper.

1.1. Review of the contemporary literatures

Reverse logistics (RL) models are defined as the study of manufacturing, transportation, storage and inventory control of end of use or end of life products [7]. RL model studies operations for the purpose of capturing values of the discarded or rejected products which are considered as waste. Designing an effective as well as efficient RL system provides competitive advantage for generating economic and environmental benefits.

Waste generation is a global problem [8]. Disposal and recycling of the waste requires a good amount of the knowledge and information about the waste generated worldwide [9]. The issue of urban solid waste (USW) generated from the industries and the household requires immediate solutions due to the rapidly escalating costs. It is estimated that in the United States of America USW has increased by 285 % from the year 1960 to 2006 with a growth rate of 7562 % of plastic waste [10]. Figure 1 represents the percentage of the developing countries lacking minimal access to waste management in the form of bar graph [11].

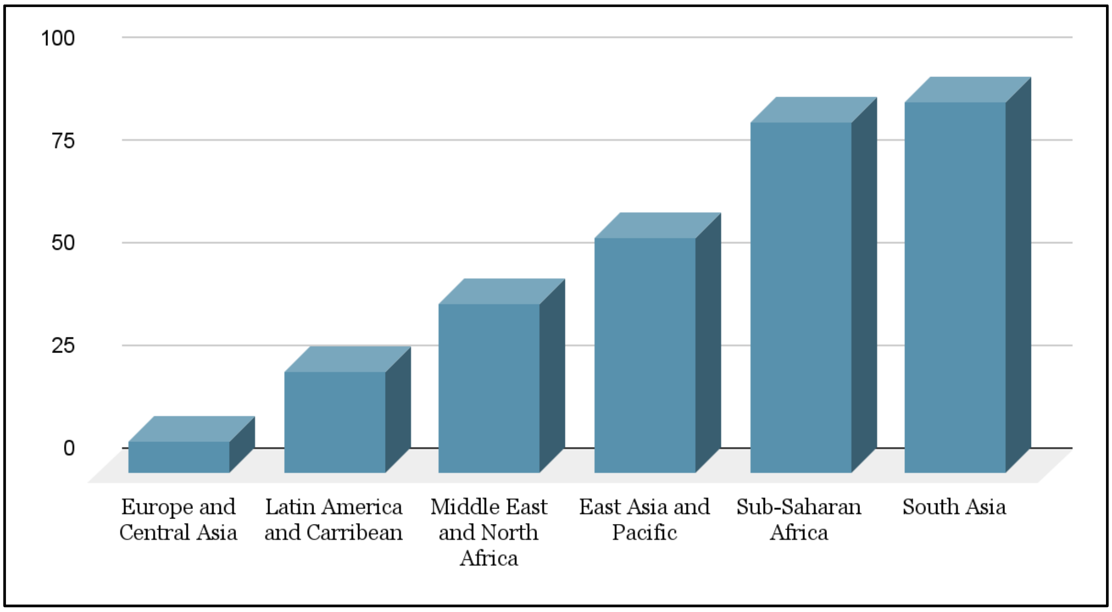

Figure 1: Bar graph presentation of the developing countries without minimal access to waste management

There are different RL models for collecting waste generated in the form of plastics. The design of RL networks (RLNs) is an uncertain long-term decision, the main stochastic variables of the inflows and outflows of the process are the quantity, quality, and estimating the demand of raw material associated with the RLN design. The reverse management of solid waste (SW) has been studied through cost models [11] and classification, composition, and treatment models [12]. In [13], proposed an RL model on the perspective of sustainability and uncertainty in the decision-making process to satisfy European Union taxes on revaluation. Setting the correct RL can be economically beneficial, in the same way, a bad design can be detrimental to the company. Based on these premises, the authors state that during the past decade, the design of RLNs only focused on operational research and mathematical modeling. Currently, the environmental impact complements the models that initially focused on production, economic benefits, and logistics. The decision-making of the RLNs works in conditions of uncertainty, and important decisions are often made in these conditions [14]. The literature review prepared in [15] showed that there is little research on the design of RLNs, which integrate uncertainty and sustainability. Some exceptions are presented in recent publications [16]. Therefore, it is necessary to develop an advanced tool for better decision-making in the design of RL systems, under market fluctuations and sustainable considerations.

According to reference [17] most of the mathematical models developed in an uncertain environment focus only on the expectation of the objective value (minimum cost and maximum benefit) and the risk of decision-making. According to reference [18], the expectation value is seldom considered in the design of the RLNs. According to [19], this problem has been identified and solved using a solution method based on multicriteria scenarios. Many literature were reviewed for the study but limiting it to the application of RL in solid wastes.

1.2. Motivation and Novelties

From the literature reviewed for the study, it is observed that there is a limited number of research works done in designing the RL logistics of a paper recycling plant. Therefore, ~~in~~ this paper models the costs related to the RL of a paper recycling plant in the form of LPP. The objective of the LPP model is to maximize the profit of the company by minimizing the costs associated with the RL such as transportation cost, fuel cost and number of bag makers employed for making the paper bags. The model will also try to optimize the amount of paper collected so that there is no bottleneck formation in the production process.

The remainder of the paper is drafted in the following format. The section 2 of the paper discusses the problem of designing RL for paper collection for a recycling plant. Section 3 of the paper discusses the methodology in brief which is followed by the results and discussion in section 4. The section 5 is the conclusion of the paper.

2. The case study

This section of the paper, briefly describes the problem statement, assumptions and the mathematical modeling of the case study considered.

2.1. Problem statement

The problem considered in the study is to design the RL of a paper recycling plant in Mumbai, Maharashtra. The paper recycling plant employs daily wagers to collect the used newspaper from the houses and brings them to the recycling plant. The newspapers are weighed in the recycling plant and wages are calculated accordingly with an addition of ₹1500/- (Rupees one thousand five hundred only) per day. The additional amount of ₹1500/- is paid for hiring the daily wager. The daily wagers employed by the recycling plant use different modes of transportation for traveling and collecting used newspapers from the houses. The different modes of transportation involve using pick-up vans, motorcycle, tricycle and by walking. The fuel cost for the fuel driven vehicles are paid by the recycling plant. They are paid ₹ 250 per day for fuel and the remaining amount is reimbursed on submission of the valid fuel cash memo. The newspapers are turned into paper bags which are sold at ₹3.40/- per piece and 40 paper bags can be manufactured from 1 Kg of newspaper. The objective of the study is to design the reverse logistics in such a way that the cost for collecting the used newspapers is minimized without formation of bottlenecks. Whereas from the perspective of the daily wagers their aim is to collect more used newspapers so that they could maximize their profits.

2.2. Assumptions

In order to fulfill the objective of the problem considered in the study certain assumptions are made which are as follows:

a. All the daily wagers are hired for a period of 6 hours a day.
b. It takes approximately 20 minutes for each daily wager to collect the unused newspapers from every household.
c. It takes ₹1200 and ₹500 per repair for the pickup vans and motor tricycle respectively.
d. The frequency of the repair is twice per month.
e. On an average the daily wagers traveling by walking, motor tricycle and pickup vans collecting the newspaper visits the recycle plant thrice, twice and once respectively.
f. On an average the daily wagers traveling by walking, motor tricycle and pickup vans can collect 25 Kg, 360 Kg and 850 Kg respectively.
g. All Sundays are holidays.

2.3. Problem formulation

The problem considered in the study is formulated in the form of a linear programming problem (LPP). The objective of the LPP is to minimize the cost of the RL incurred by the company as well as to maximize the profit of the daily wager. The different cost associated with the RL is shown in table 1.

Table 1: List of different cost associated with RL

Sl. no.	Cost category		Cost (in ₹)
1	Fuel charges		250 per day
2	Repairing charges	Pickup vans	1200 per repair
3		Motor tricycle	500 per repair
4	Cost of purchasing the papers from houses (C_h)		10 per Kg
5	Cost of purchasing the papers from daily wagers (C_d)		24 per Kg
6	Selling price of 1 paper bag (S_p)		3.40/-
7	Daily wages of the paper bags makers		600/-

2.3.1. Modeling

Considering that the weight of unused newspaper collected from the households in a month be x and the weight of unused newspaper turned to paper bags be y. The representation of the problem considered in the study is represented in the form of LPP. The objective functions and the constraints are as follows:

Objective functions:

$$\text{Max Z} = \text{sales} - \text{total cost} \qquad \text{(i)}$$

The total cost in Eq. (i) is the sum of the cost of the RL for collecting used newspaper by all the three modes of transportation. The sales in Eq. (i) is defined as Eq. (ii)

$$\text{sales} = S_p * \text{no. of pieces per Kg} * y$$

Substituting the values, we get:

$$\text{sales} = 136 * y \qquad \text{(ii)}$$

Eq. (ii) is the amount collected per month from selling the paper bags.

$$\text{cost} = C_d * x + F_c + R_c + n.600 \qquad \text{(iii)}$$

Eq.(iii) is the total cost incurred by the company from collecting the unused newspaper till converting it to paper bags. The n in Eq. (iii) is the number of paper bag makers in a month. The value of the repairing cost (R_c) incurred by the company per month is as follows:

For motor tricycle: $R_c = ₹1000/-$

For pickup vans: $R_c = ₹2400/-$

The value of the fuel cost (F_c) incurred by the company per month is as follows:

$$F_c = \frac{d}{m} * 111.35 \qquad \text{(iv)}$$

Where ₹111.35/- is the cost of petrol as on 1st July, 2022 and number of working days is considered as 26 days, d is the distance traveled by the daily wagers and m is the mileage of the vehicle.

For motor tricycle: $m = 55\ kmpl$

For pickup vans: $m = 20\ kmpl$

Therefore, the total cost in Eq. (i) is computed as follows:

$$\text{total cost} = 4500 + C_d * (x_w + x_t + x_v) + \left(\frac{d_t}{55} + \frac{d_v}{20}\right) * 113.5 + 3400 + n.600 \qquad \text{(v)}$$

Subject to:

$$x_w \in (0, 1950] \qquad \text{(vi.a)}$$

$$x_t \in (0, 18720] \qquad \text{(vi.b)}$$

$$x_v \in (0, 22100] \qquad \text{(vi.c)}$$

The Eqs. (vi.a), (vi.b) and (vi.c) represents the amount of unused newspaper collected by the daily wagers per month

$$d_t \in (0, 5200] \qquad \text{(vii.a)}$$

$$d_v \in (0, 7800] \qquad \text{(vii.b)}$$

The Eqs. (vii.a) and (vii.b) represents the distance covered by the daily wagers for collecting the unused newspaper per month

$$n \in (0, 400] \quad \text{(viii)}$$

The Eqs. (viii) constraints the daily paper bag makers employed by the company per month.

3. Methodology

PSO [20] is categorized as a swarm-based evolutionary computational single objective optimization algorithm. The evolutionary algorithm garnered attention from the academicians and researchers worldwide, mainly due to its ease of use and evaluating optimized value by individual thinking and social interaction. The algorithm for PSO replicates the food searching ability of a flock of birds commonly called 'swarm'. The swarm in PSO is a conglomeration of searching agents typically termed as 'particles'. 20 – 50 number of particles is the most common size of a swarm [21]. All the particles of the swarm are evaluated by the fitness function whose objective is either to minimize or maximize the value constrained by the physical nature of the problem. In PSO, every particle is characterized by position and velocity. The particles move within the boundary of search space and locate and remember the best position concerning the objective function. This information is communicated to the next particles of the swarm who adjust their position and velocities based on the information received on the good positions. The velocity and position of the particle are updated according to the Eq. (ix) and (x).

$$V_{i,itr+1} = w.V_{i,itr} + rnd_1.C_1.\left(P_i - X_{i,itr}\right) + rnd_2.C_2.\left(P_g - X_{i,itr}\right) \quad \text{(ix)}$$

$$X_{i,itr+1} = X_{i,itr} + V_{i,itr+1} \quad \text{(x)}$$

Where the $V_{i,itr+1}$ is the velocity for the i^{th} particle for the $(itr + 1)^{th}$ iteration, $X_{i,itr+1}$ is the position for the i^{th} particle for the $(itr + 1)^{th}$ iteration, rnd_1 and rnd_2 are two random numbers in the range $[0, 1]$. P_i is the position for the best value of i^{th} particle, and P_g is the position for best value among all the particles.

Eq. (ix) consists of three parts; the first part is called the inertia part that deals with exploration as well as exploitation capabilities of the particles in the swarm. The w in the equation is the weight factor that acts as a control mechanism for eliminating the exorbitant velocity of the swarm [22]. The value of w is computed as follows:

$$w = w_{max} - \frac{w_{max} - w_{min}}{itr_{max}} * itr_i \quad \text{(xi)}$$

Where w_{min} *and* w_{max} is the initial and final weights, itr_{max} is the maximum number of iterations and itr_i is the value of the i^{th} iteration. The second part of the cognition part is the ability of the particles to locate and remember the personal best position within the search space. In the PSO algorithm, the particles keep track of the position which is associated with the personal best solution (p_{best}) obtained from the fitness function [23]. The third part is the social part due to which the particles share the information and update their position. It is because of this part in the equation where the p_{best} of each particle in every iteration is compared to evaluate the optimal solution termed as global best (g_{best}). C_1 and C_2 are the learning factors for the cognition and social part of the velocity update equation. The most common values for the two learning factors $C_1 = C_2 = 2$ [24]. The steps for PSO are shown as a flowchart in figure 2.

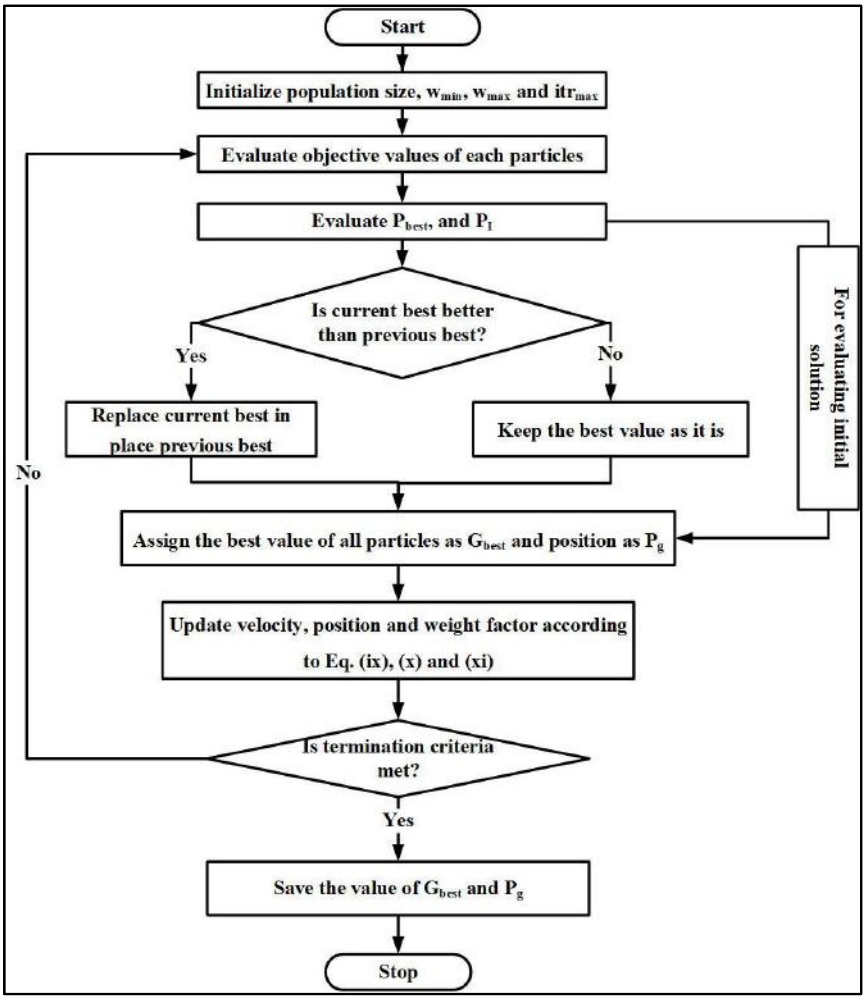

Figure 2: Flowchart for standard PSO

4. Results and discussion

The PSO algorithm discussed in section 3 is employed to compute the optimal value for the problem under consideration. In this process the value of the different parameters considered for the PSO algorithms are tabulated in table 2.

Table 2: Value of the PSO parameters

Sl. no.	**Parameter**	**Value**
1	C_1	2
2	C_2	2
3	w_{max}	1
4	w_{min}	0
5	No. of iterations	100

The PSO model is stopped computing the best solution once the number of iteration increases the maximum allowable iteration. The value of the best solution computed in every iteration is shown in figure 3.

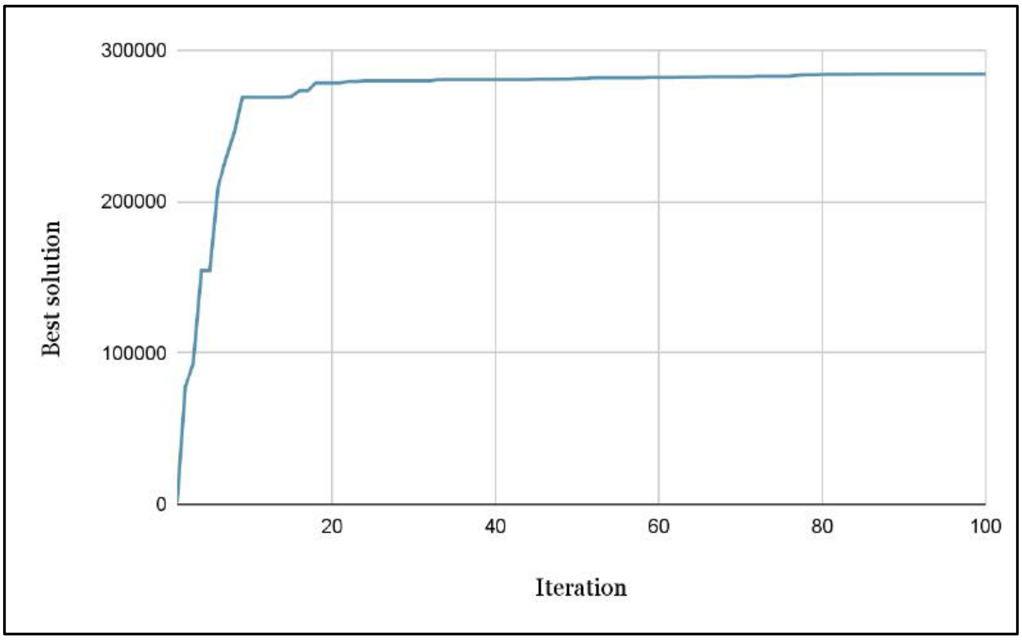

Figure 3: Best solution graph

The optimal solution computed from by the PSO algorithm is ₹285646.00 when the unused paper collected by the daily wagers traveling by:

a. Walking is 500 Kg per month.
b. Motor tricycle is 1550 Kg by traveling a distance of 5200 KM per month.
c. Pickup van is 4250 Kg by traveling a distance of 7800 KM per month.
d. Employing 400 bag makers.

5. Conclusions

Although there are many researchers that have worked on designing the RL of a company, there exists very little literature that has ever tried to design the RL for a paper recycling plant. The comprehensive intention of the present study is to design the RL of a paper recycling plant in such a way that the profit margin of the company is maximized and also that there is no bottleneck formation in the production. In this paper PSO algorithm is applied to compute the RL of a paper recycling plant. The company employs daily wagers for collecting the unused newspaper from the household for a period of 6 hours per day. The daily wagers travel around the city by walking, motor tricycle and pickup vans. The fuel price as well as the repairing cost for the vehicles are paid by the company. Also the company hires bag makers for converting the unused newspapers into paper bags which are sold at ₹ 3.40 per bag. The objective of the present study is to maximize the profit of the company by designing the RL in such a manner that the daily wagers as well as the bag makers do not suffer any loss. The optimal solution computed from by the PSO algorithm is ₹285646.00 which is evaluated when the daily wagers collecting newspaper by walking, motor tricycle and pickup vans must collect 500 Kg, 1550 Kg and 4250 Kg per month of the unused newspapers. Moreover for the company to be in maximum profit the optimal distance to be traveled by the motor price cycle and the pickup Van is 5200 KM and 7800 KM per month. This paper provides better knowledge for further implementation of soft-computing techniques to design the RL of a paper recycling plant.

Acknowledgement

I would like to express my heartfelt gratitude to all the tutors and mentors of On My Own Technology pvt. ltd. for extending their help in carrying out the particular project. It is because of their help that I am able to conduct the research. I shall remain ever grateful for their help and generosity.

Conflict of interest

The authors would like to declare that the paper is a result of the project work conducted by high school students of Mumbai, Maharashtra, India. The authors would like to declare that no fundings in any form is received for carrying out this research work.

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