Optimizing a Solid Waste Management Model using Particle Swarm Optimization

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Abstract

In today's world, the number of industries is increasing geometrically for accomplishing the demand of a rapidly growing population. With this growing number of industries, the total amount of production is also accelerating. And no production is possible without generating waste. Appropriate waste management is an appropriate way for making the world a comfortable habitat. To achieve the apex of the competitive production process, ecological incorporated manufacturing and recycle planning is of incredible significance. So non-avertable byproducts and wastes ought to be recycled by the manufacturer. In this study, a mathematical model is developed for optimizing the cost of recycling and solid waste management. For optimization Particle Swarm Optimization (PSO) method is used to identify the level of disposed solid waste and recycled solid waste. Another meta-heuristic algorithm named Genetic Algorithm (GA) is used for evaluating the efficiency of the result getting from PSO.

1. Introduction

Management of waste is a process by which waste is controlled appropriately from the generation of waste to the final phase of waste management. This incorporates the gathering, transport, treatment and transfer of waste, together with checking and guideline of the waste administration process (Pongrácz, 2003). Waste can be solid, fluid, or vaporous and each sort has distinctive strategies for disposal and the executives. In this study, only solid waste is considered. Form the study of different industries shows that there is a large gap exist between theory and practical implementation of different waste management process only because of thinking that waste management is expensive. But with appropriate management of waste the cost can be reduced. There is a strong connection between ecological coordinated effort and sustainability execution (Kjaerheim, 2003). The contribution of this study is to emphasize the ecological concern as an unseparated part of the industrial organization. Next contribution is environmental thinking along with cost minimization. With the appropriate management of waste, the cost of the production process is automatically reduced (Bruno, 2016). In this study, recycle and dispose of waste is considered as the two process of managing solid waste. Conversion of waste material into a useful material is known as recycling process. Thus, the cost of production can be optimized. The steps of solid waste management are collecting the waste from production floor, storing them for proper management, passing through a treatment process, recycling the suitable material, finally, disposing the rest of the waste. So, recycle and dispose are the two main process of managing solid waste. Waste is disposed when there is no value exist in the waste that can be used for production of new goods (Costi, 2004). In this study, mathematical models for recycle and disposal cost are developed. Then the model will be solved with Particle Swarm Optimization (PSO) approach. Finally, compare the result with a metaheuristic algorithm known as Genetic Algorithm (GA).

2. Literature Review

Eco-efficiency is perceived as an imperative instrument to assess all the while the natural and the financial difficulties of an organization (Carvalho, 2017). In present business condition, just as contending on expense and profitability, associations have another attention on sustainability (Zhang, 2016). Some research works deals with mathematical or simulation analysis for analyzing the relationship between recycle, reuse and rework (Govindan, 2014). Condition arranged conduct of organizations where the recycling of non-risky mechanical side-effects and different squanders has been executed without administrative system (Herczeg, 2017). Natural consumption has driven associations to play a critical job in planning ecologically agreeable, recyclable items to supplement upgrades in the ecological principles of administrations (Sagnak, 2016). Financially, organizations benefit by access to less expensive sourcing, staying away from disposal costs, and increasing additional profit from selling the side-effects. Environmentally, the benefits are diminished characteristic asset utilization and waste disposal and decrease of emanations to air, water, and soil from the generation of the spared crude materials (Herczeg, 2017). The first is from the National Environment Council (CONAMA), which has set down a goal meaning for controlling dispose and naturally proper administration of utilized batteries, especially identifying with their accumulation, reuse, recycling, and treatment or final disposal (Bruno, 2016). the utilization of materials and vitality is improved, and side-effects from one industry fill in as crude materials for other industries, reducing disposal of waste and loss of assets. Sometimes, organizations keep away from disposal costs by providing their natural waste to nearby homesteads as opposed to arranging it in a landfill and ranchers acquire modest natural manure on horticultural soils in the locale, improving soil properties and sparing the use of mechanical composts (Herczeg, 2017). Many metaheuristic algorithms are developed for solving different types of optimization problem. Some of these algorithms are: Genetic Algorithm, Taboo Search, Bat Algorithm, Ant Colony Approach, Simulating Annealing, Neural Network, Evolutionary Algorithm, Cuckoo Search, Firefly Algorithm, Fuzzy Simulation, Harmony Search etc. (Hachana, 2013). Another metaheuristic algorithm for solving global optimization problem is PSO. It is a nature inspired algorithm which is developed by Kennedy and Eberhart analyzing social behavior of flock of birds (Kennedy, 1997). Since then many researchers used this algorithm to find optimal solution for inventory control problem. PSO is enough for solving single objective optimization problem but to solve a problem consisting multiple conflicting objective a modification is required (Park, 2014). Genetic algorithm, mainly a population-based optimization approach. There is an established process for this algorithm. there is a build in code in MATLAB for this approach (Davis, 1991).

3. Problem Formulation

For green supply chain company need to minimize waste. The only way of waste minimization is to manage waste appropriately. For this reason, this study considers the management process for solid waste. Among them recycling and disposing solid waste in industries are considered. The goal is to identify different criteria for waste management and using this formulate a mathematical model. Finally, combining all these models formulate an objective function for cost minimization.

3.1 Assumptions

For model formulation in this study some criteria are assumed to convenience the process. They are:

- Independent demand rate of items.
- Demand rate is constant in each period.
- No volume discounts.

3.2 Notation

The following parameters and decision variables are used for items, i = 1,2,.........,n.

Parameters
D_i : Demand of each product per period
Cr_i : Recycle cost of each product
Cd_i : Disposal cost of each product
U_d : Upper bound of dispose per period
U_r : Upper bound of recycle per period
Lr_i : Level of recycle per period
Ld_i : Level of solid dispose per period
W_t : Total amount of solid waste per period

Cost function is developed in following manner:

Amount of recycle = $\sum Lr_i \times D_i$
Amount of dispose = $\sum Ld_i \times D_i$
Recycle Cost = $\sum Lr_i \times D_i \times Cr_i$
Disposal Cost = $\sum Ld_i \times D_i \times Cd_i$

Now,
$\alpha = (\sum Lr_i \times D_i) / \{(\sum Lr_i \times D_i) + (\sum Ld_i \times D_i)\}$
$\beta = (\sum Ld_i \times D_i) / \{(\sum Lr_i \times D_i) + (\sum Ld_i \times D_i)\}$

3.3 Objective Function

Minimize

$$Z = \alpha \times \sum Lr_i \times D_i \times Cr_i + \beta \times \sum Ld_i \times D_i \times Cd_i$$

3.3 Constraints

Recycle has an upper limit above which the cost of recycle becomes higher

$$\sum Lr_i \leq U_r$$

Dispose has an upper limit above which the cost of dispose becomes higher

$$\sum Ld_i \leq U_d$$

Summation of amount of recycle and amount of dispose is equivalent to the total solid waste

$$\sum Lr_i \times D_i + \sum Ld_i \times D_i = W_t$$

And

$$\alpha + \beta = 1$$

Non-negativity constraints are:

$$Lr_i, Ld_i > 0$$

Where, i = 1,2,........,n; where n is the number of items.

4. Methodology

There are different metaheuristic methods to solve single-objective linear programming problem and among them Particle Swarm Optimization is the most efficient one. Genetic algorithm (GA) is the most famous evolutionary algorithms with a verity type of application. Many well-known optimization problems were solved by GA approach. Moreover, it is mainly population-based optimization approach.

4.1 Particle Swarm Optimization

PSO is a rational optimization algorithm. It belongs to a group of optimization algorithm called metaheuristics. PSO is based on swarm intelligence and is enlightened by behavior of creature, like- fish and bird. It is a simple optimization approach, researcher used it widely in various area of science and engineering, like- machine learning, data mining, operation research, etc. PSO is first introduced by James Eberhart and Russell C. Kennedy in the year of 1995. Originally, they were working to build a model to describe the social behavior of the animals, like- the flock of birds and the school of fish. However, they realized that their model is capable of solving optimization problems. So, PSO was proposed by them based on their working.

Working Principle of PSO

Particle swarm optimization contains a population of candidates called swarm. Swarm have a candidate of solution called particle. Every particle in the swarm is an applicant solution for the optimization problem. The particles try to find the best solution of the optimization problem by contracting with each other. They keep finding the best one till every particle in the swarm have found that best solution of the optimization problem. So, there are two principles of PSO algorithm for the cooperation of the particles. They are-

- Communication: informing the best solution of a particular particle to the other particles in the swarm.

- Learning: when particles move towards one another they actually learn about the location better solution. It is the concept of better which is the main problem that has to be solved.

Steps of PSO

The simplified steps of the PSO algorithm for the single-objective case are:

- Initialize the swarm
- For each particle in the swarm:
  - Select leader
  - Update position
  - Update velocity
- Update global best
- Repeat

Mathematical model of motion

The particles have a position in the investigation area of the optimization problem (Bai, 2010). For particle *i*, position vector is y_i, which is a member of search space Y where, $y_i(t) \in$ Y. Here t is the time index to distinguish between discrete time steps and it shows the iteration number of the algorithm. Every particle in the swarm have velocity denoted by $v_i(t)$. It is also a vector and belongs to the same space. In the space particles interact with and learn from each other by obeying a simple rule to find the best solution the optimization problem. Every particle find their personal best denoted by $p_i(t)$ called the local best solution. $g(t)$ is known as the global best solution. First location of the particle *i* is $y_i(t)$ and velocity is $v_i(t)$. Particles move toward the personal best and then to the global best and gain an updated position denoted by $y_i(t+1)$ and the addition of these beginning and end vector has a velocity of $v_i(t+1)$. So, the equation for updating the position is:

$$y_i(t + 1) = y_i(t) + v_i(t + 1)$$

Where,

$$v_i(t + 1) = wv_i(t) + C_1(p_i(t)-y_i(t)) + C_2(g(t)-y_i(t))$$

A simplified approach is used to standardize the PSO equation and that is

$$v_i(t + 1) = wv_i(t) + C_1r_1(ypbest_i-y_i(t)) + C_2r_2(ygbest-y_i(t))$$

Where,
w= inertia coefficient
C_1, C_2 = acceleration coefficients
$r_1, r_2 \in (0,1)$

5. Result and Analysis

For optimization PSO and GA methods are used in this study. MATLAB R2017 b is used to solve the developed model for recycle cost, disposal cost. Finally, to develop objective function the developed models are combined. For finding the solution which is optimum PSO approach is coded in MATLAB. The outcomes of this solution process are:

- Optimum solution for recycle cost
- Optimum solution for disposal cost
- Graphical (normal, log-log) representation of PSO solution convergence
- Total elapsed time to reach solution
- Comparison between PSO and GA method

5.1 Optimum Solution for Recycle Cost

Table 5.1: Optimum solution for recycle cost

Iteration No.	C_1	C_2	w	nPop	Optimum Cost ($)	Elapsed Time (sec.)
300	2.5	1.5	1	100	1150	48.751

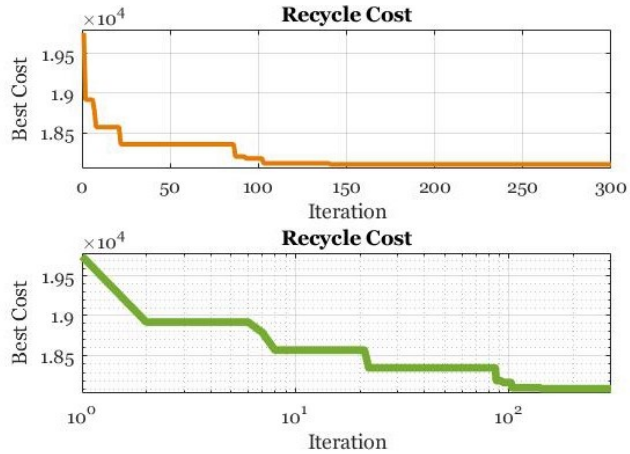

Figure 5.1: Graphical (normal and log-log) representation of PSO for recycle cost

From the graph one can easily understand that the best recycle cost (Swarm) is converging to the optimum (global) recycle cost.

5.2 Optimum Solution for Disposal Cost

Table 5.2: Optimum solution for disposal cost

Iteration No.	C_1	C_2	w	nPop	Optimum Cost ($)	Elapsed Time (sec.)
300	2.5	1.5	1	100	842	43.273

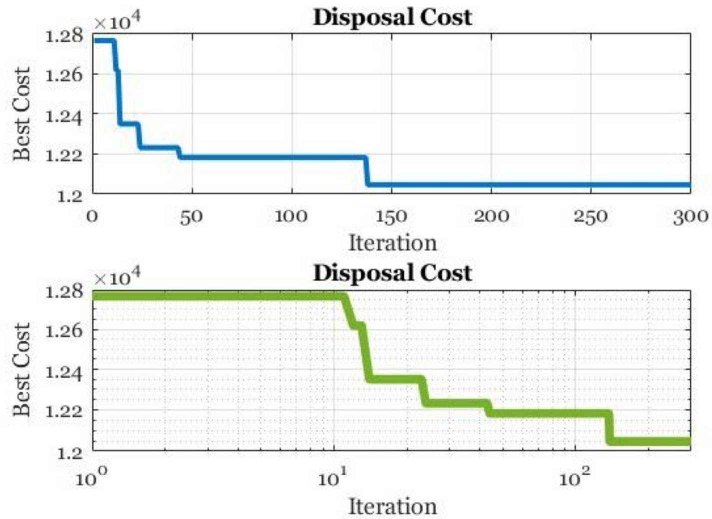

Figure 5.2: Graphical (normal and log-log) representation of PSO for disposal cost

From the graph one can easily understand that the best disposal cost (Swarm) is converging to the optimum (global) disposal cost. Log-log graph is used to visualize the convergence step clearly. From the table 1 the optimum cost for recycle can be got and from table 2 the optimum cost for dispose can be got.

5.3 Comparison between PSO and GA method

In this study basically the deviation (%) of the optimum cost value getting from GA method from PSO method is calculated.

Table 5.3: Comparison between PSO and GA method

Different Cost	Optimum Value from PSO ($)	Optimum Value from GA ($)	Deviation from PSO (%)
Objective Function Value	1992	1947	2.25

Bar Chart Representation of comparing between PSO and GA method

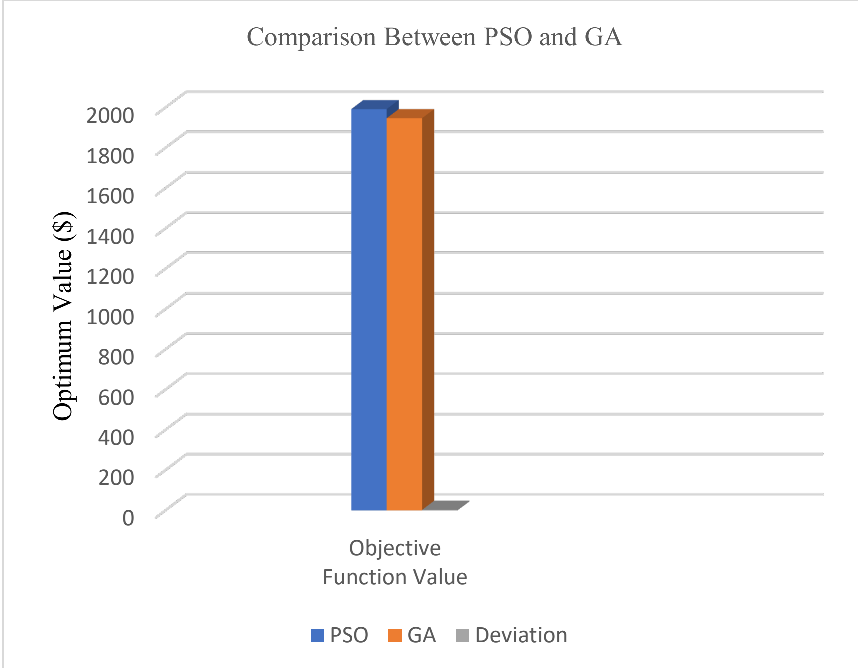

Figure 5.3: Comparison Between PSO and GA Method

As PSO and GA two are population-based optimizing approach, it can be compared easily. From this bar chart representation one can easily interpret that there is a small difference between PSO and GA method. It also indicates the computational efficiency of PSO is high. Moreover, for optimizing any problem population-based approach PSO can be used undoubtfully.

6. Conclusion

In this study, mathematical model is developed for optimizing the cost for the management of solid waste. For developing this model recycle cost, disposal cost is considered. Fixed demand rate per period and no volume discount are assumed for formulating the objective function. At first, cost function is developed for these systems separately. Then the objective function is developed by combining all these separate mathematical models. PSO and GA methods are used for optimizing the model. The optimum solutions obtained from PSO and GA methods are all most same. There is a very small deviation (<2.5%) between these two optimum objective function values.

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Biographies

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