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A Goal Programming Approach to Reduce Plastic Waste for Sustainable Packaging Design

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Plastic pollution is a serious concern throughout the world. As plastic is mouldable, durable, light and inexpensive so it can be used in multiple application where packaging is the most significant sector of use. Plastic pollution can be mitigated via incorporating innovative technologies in packaging design. Planning of designs in packaging industry also need to include conflicting goals of various criteria like energy consumption, carbon emission and profit. In this paper, a goal programming model is proposed for solving multi-criteria problem in which each criterion is incorporated on priority basis to achieve targeted goals. Targeting of plastic waste is prime objective and remaining targeted goals are attained on priority basis. Several technologies are considered for producing Polyethylene Terephthalate bottles for storing soft drink. The deviation variables calculated by solving the model yield the requirement of best innovative technologies for achieving goals. These deviation variables act as a facilitator to achieve the goals.

1. Introduction

Packaging plays an important role in protection and preservation of food products from outer amalgamation. Ideal packaging needs to be inert toward hazards and should not allow molecular transfer from or to food products. The major roles of packaging are containment, transportation, marketing and communication (Marsh and Bugusu, 2007). As plastic is mouldable, durable, light and inexpensive so it can be used in multiple application where packaging is the most significant sector of global plastic use (Brooks et al., 2018). Huge amount of plastic wastes are produced throughout the world but slight attention has been given to manage these wastes. Management of plastic waste is very challenging task as recycling plants are less profitable and it has been reported that only 9 % of plastic wastes are recycled globally and majority of these wastes are incinerated or released toward land or ocean (Jambeck et al., 2015). Recently, Majid et al. (2018) reviewed innovation and future prospect of technologies for food packaging. From 1988 to 2016, China led the import of plastic waste for recycling and reuse which resulted in a huge burden to their waste management. In order to curtail their waste burden, a complete ban on the import of plastic waste has been imposed in 2017 (Xu et al., 2020). This move encouraged other countries to put a ban on plastic use to a large extent. Recently, Padgelwar et al. (2019) reviewed waste management scenario of India to reduce plastic waste. They reported that the Indian government banned the use of thin plastic, as only 40 % of overall plastic wastes were recycled and reused via existing facilities. The development towards the ban is not significant as less attention is given for innovation in developing feasible techniques to replace plastic with similar low-cost material (Padgelwar et al., 2019). The banning of plastic waste also force industries to change their packaging design. This change in design restrict the plastic burden at initial stage i.e. reducing the use of plastic before reuse and recycle. The reduction of plastic utilization at source is studied by Sluisveld and Worrell (2013). This restriction needs to be complemented by innovative technologies and material substitution in packaging design. Therefore, economical packaging design technology which produces less plastic waste is needed.

Hekkert et al. (2000) presented the possibility of 9 % reduction of carbon emission by utilizing lighter packaging and achieving 10 % reduction of emission via material substitution in primary packaging. Use of reusable packaging instead of single-use plastic can be promising for reducing emission by 32 %. Also, lighter packaging requires less fuel for transportation and reduces carbon emission and energy consumption. The energy

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associated with the primary packaging includes energy consumption for raw material production, packaging manufacturing, transportation, collection of waste, recycling and waste processing (Hekkert et al., 2000). The driving impact of innovation in technology for improving energy efficiency have been studied by Miao et al. (2018). The shift in technology depend on environmental, economic and social condition. The state-of-art technology that provides long term benefit should be included in industries. Similarly, Viswanathan et al. (2018) presented outline of opportunities and problems related to achieve the target of carbon emission reduction for reducing global warming. Sinha and Chaturvedi (2018) presented pinch analysis based approach to calculate in-between carbon emission caps for process industries. Recently, Lammers (2019) discussed latest development in technology for the management of process safety lifecycle. Similarly, Sinha and Chaturvedi (2019) reviewed several works for technology upgradation to mitigate carbon emission and energy consumption. The implementation of economical packaging design technologies which minimize carbon emission, energy consumption, plastic waste are highly needed. Earlier, Leung et al. (2009) presented goal programming model for planning of production process which is based on prioritiy of each objective. Later, Jayaraman et al. (2016) presented multi-criteria model by using weighted goal programming technique for best possible resource allocation with conflicting objectives. From above literature review it can be noted that, plastic waste minimization with the view of minimizing carbon emission, energy consumption and maximizing profit in a prioritised manner has not been done. In this paper, a goal programming model is proposed to minimize plastic waste, carbon emission, energy consumption for food packaging design. The technique determines the best compromise solution for obtaining maximum profit upon considering every criterion on priority basis. In this view, problem statement and model formulation are discussed in next sections.

2. Problem Statement

A goal programming model is developed for packaging industry which consider four sustainability criteria viz. carbon emission, energy consumption, plastic waste and profit. Consider an industry producing packaging material of various designs where every design uses specific technology for manufacturing. For a planning horizon, given:

- Minimum production of packaging material P_i of each design by using i^{th} ($i=1,2,3,..,n$) technology (t of packaging material)
- Projected goal G_j to be achieved for j^{th} ($j=1,2,3,..,m$) criteria along with their priority.
- Waste Factor WF_i of each design that remain as waste after reuse and recycle (t of plastic waste/t of packaging material)
- Emission Factor EF_i corresponding to each design (t of CO_2/t of packaging material)
- Specific Energy Consumption SEC_i corresponding to each design (GJ/t of packaging material)
- Profit Factor PF_i corresponding to each design ($/t of packaging material). It includes the profit obtained in production, recycle and reuse of packaging materials.

Objective:

- Minimizing deviation of projected goals on priority basis. The deviation can be of two types i.e. wanted and unwanted, where unwanted deviation need to be minimized. These obtained deviation may act as a facilitator for achieving goals.

3. Goal programming model formulation

Multi criteria decision making problems are often common in real world. It give an opportunity to derive compromise solution upon satisfying multiple criteria involve in the model. In goal programming problem every criterion has a targeted value that needs to be achieved. Goal programming is simple to use (Jayaraman et al., 2016) due to which it can be applied to diverse domain of applications like stock management, human resource, marketing, quality control, production and operation management.

A model is developed by utilizing the model of Leung et al. (2009) for achieving best compromise solution. The structure of goal programming and linear programming are similar to each other. Goal programming introduces auxiliary deviation variable that act as ‘facilitator’ and not as a ‘decision maker’ to frame the model. There are two types of deviation variables; negative deviation (d^-) for under-achievement of the goal and positive deviation (d^+) for over-achievement of the goal. These negative and positive deviations depict the gap between goal and realized result. Goals are of the form of linear equation which include the deviation variables. Unlike the linear programming model that directly determine the solution via optimizing objectives, the goal programming tries to minimize unwanted deviations between aspiration level of goal and optimal solution. Two types of constraints are present in goal programming problem-system and goal constraints. By following linear programming, the system constraints are framed while additional constraints are goal constraints. The goal programming model minimizes unwanted deviations in lexicographical way. This approach determines optimal solution of overall

problem by sequentially solving several sub-problems which occur on priority basis for each goal. According to priority, a sub-problem is solved for minimizing unwanted deviation variable of current goal. Then, this deviation variable value becomes a constraint for the next sub-problem which is solved for minimizing unwanted deviation of subsequent goal on priority basis (Romero, 2004).
In the following statement sets, indices, parameters and variables for the model are defined.

Sets

i	index of technology used for a packaging design
j	index of criteria

Indices

I	Set of technology used for packaging design
J	Set of criteria

Parameters

P_i	Minimum production of packaging material of a design by using i^{th} technology
G_j	Projected goal to be achieved for j^{th} criteria
WF_i	Waste factor of a design by using i^{th} technology
EF_i	Emission factor corresponding to i^{th} technology
SEC_i	Specific energy consumption corresponding to i^{th} technology
PF_i	Profit factor corresponding to i^{th} technology
A_{ij}	Influence of i^{th} variable for achieving goal of j^{th} criterion

Variables

x_i	Production of packaging material by using i^{th} technology
d_j^+	Positive deviation variable for over-achievement for j^{th} criteria
d_j^-	Negative deviation variable for under-achievement for j^{th} criteria

The goal programming model for multi criteria problem is as follows:
System constraint is defined in Eq(1):

$$\text{Minimum production} \leq P_i \qquad i \epsilon I \tag{1}$$

Goal constraint is defined in Eq(2):

$$\sum_{i=1}^{n} (A_{ij} \times x_i) + d_j^- - d_j^+ = G_j \qquad j \epsilon J \tag{2}$$

where $d_j^-, d_j^+ \geq 0$ and $d_j^- \times d_j^+ = 0$ for every j^{th} criteria
The objective function for achieving multiple goals can be expressed by Eq(3) which minimizes unwanted deviations in lexicographic manner:

$$\text{Lexicographically minimize } Z = \{d_{j=1}^+, d_{j=2}^+, d_{j=3}^+, d_{j=4}^-\} \tag{3}$$

Figure 1 shows the flowchart for the goal programming approach.

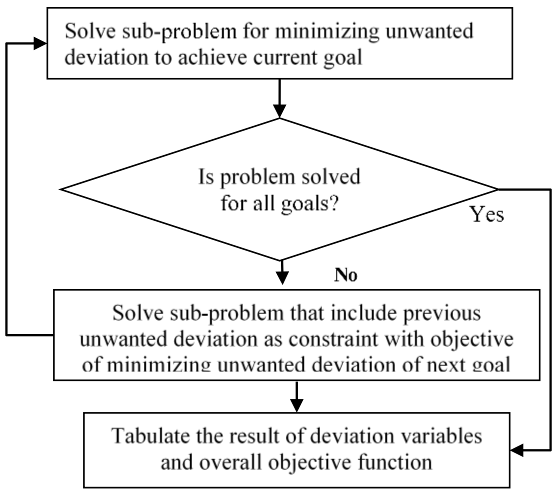

Figure 1: Lexicographic goal programming for reducing plastic waste. Adapted from Molavi et al. (2020)

4. Illustrative example for PET packaging of soft drinks

Consider a company which produces Polyethylene Terephthalate (PET) for the packaging of soft drink. PET is a lightweight plastic which is made semi-rigid or rigid due to which it becomes more impact resistant and protect liquids inside the bottle. Four technologies (T_1, T_2, T_3 and T_4) are employed for different packaging designs. Table 1 shows minimum production requirement of different designs in (t).

Table 1: Minimum production of four designs via different technology

Technology	Minimum production of packaging material (t)
T_1	100
T_2	100
T_3	150
T_4	175

Table 2 shows the WF_i, EF_i, SEC_i and PF_i corresponding to various technologies. Weight fraction is fraction of plastic left behind as waste after recycle and reuse. The weight fraction of several technologies are assumed or it can be determined for a specific region based on reusability and recyclability capacity of packaging materials. The energy consumption and carbon emission associated with the primary packaging include raw material production, packaging manufacturing, transportation, collection of waste, recycling and waste processing (Hekkert et al., 2000). The value of carbon emission and energy consumption are taken from Hekkert et al. (2000). Profit is the amount generated from recycling and reusing of packaged plastics. Table 3 shows value of several criteria and their growth percentage that need to be achieved after 5 y.

Table 2: Weight fraction, emission factor, specific energy consumption and profit factor corresponding to several packaging designs

Technology	WF_i (t plastic waste/t of packaging material)	EF_i (t CO_2/t of packaging material)	SEC_i (GJ/t packaging material)	PF_i ($/t of packaging material)
T_1	0.20	2.3	83.8	3
T_2	0.30	2.4	84.5	5
T_3	0.40	3.0	90.0	2
T_4	0.15	2.0	80.0	7

Table 3: Current values of criteria and their growth percentage after 5 y

Criteria	Present Value	Growth
Plastic waste	116.66 t waste	20 %
Carbon emission	769.23 t CO_2	30 %
Energy consumption	36,000 GJ	25 %
Profit	1,600 $	25 %

The equation for achieving goal in order to restrict plastic waste is given in Eq(4).

$$0.2 \times x_1 + 0.30 \times x_2 + 0.40 \times x_3 + 0.15 \times x_4 + d_1^- - d_1^+ = 140 \quad (4)$$

This equation limits plastic waste to desired goal, so the unwanted deviation i.e d_1^+ should be minimized. The equation for achieving goal in order to restrict carbon emission is given in Eq(5).

$$2.3 \times x_1 + 2.4 \times x_2 + 3 \times x_3 + 2 \times x_4 + d_2^- - d_2^+ = 1{,}000 \quad (5)$$

This equation limit carbon emission to desired goal, so the unwanted deviation i.e d_2^+ should be minimized. The equation for achieving goal in order to restrict energy consumption is given in Eq(6).

$$83.8 \times x_1 + 84.5 \times x_2 + 90 \times x_3 + 80 \times x_4 + d_3^- - d_3^+ = 45{,}000 \quad (6)$$

This equation limit energy consumption to desired goal, so the unwanted deviation i.e d_3^+ should be minimized.

The equation for achieving goal in order to get minimum profit 2,000 $ is given in Eq(7).

$$3 \times x_1 + 5 \times x_2 + 2 \times x_3 + 7 \times x_4 + d_4^- - d_4^+ = 2000 \quad (7)$$

This equation is for attaining profit of desired goal, so the unwanted deviation i.e d_4^- should be minimized. Objective function for the multi-criteria problem is given by Eq(8).

$$\text{Lexicographic minimize } Z = \{d_1^+, d_2^+, d_3^+, d_4^-\} \quad (8)$$

Table 4: Deviation variables of four criteria

Variables	Value
d_1^-	3.750
d_1^+	0
d_2^-	0
d_2^+	270
d_3^-	670
d_3^+	0
d_4^-	0
d_4^+	325

The goal programming model is solved in GAMS 24.8.5 by using CPLEX solver. The interpretation of the result shown in Table 3 are as follows:
For targeting plastic waste, constraining of plastic waste is the only rigid goal and have first goal priority which need to be lesser than 140 t plastic waste. The positive deviation of zero shows that the goal is achieved and negative deviation of 3.75 t of plastic waste shows that the waste is lesser than the desired goal. For targeting carbon emission, positive deviation of 270 t of CO_2 insist that goal is over achieved so cleaner technology (T_4) needs to be included for manufacturing packaging material for limiting emission under desired goal. For the goal of energy consumption, positive deviation of zero shows that the goal is achieved and negative deviation of 670 GJ shows that the energy consumed is lesser than the required goal. For the goal of profit, negative deviation of zero shows that the goal is achieved and positive deviation of 375 $ shows that the profit is higher than the required goal.

5. Conclusion

Planning of designs in packaging industry need to combine several conflicting goals. A goal programming model is developed for solving multi-criteria problem and deviation variables are determined which provide requirement of innovative technologies. For plastic waste, a negative deviation of 3.75 t of waste depicts under achievement i.e. waste generated is lesser than the targeted waste. For carbon emission, a positive deviation of 270 t of CO_2 is obtained that shows that goal is over achieved so use of cleaner technology (T_4) needs to be included for packaging design in order to restrict emission under targeted value. The goal programing model reduces carbon emission and energy consumption along with plastic waste in lexicographical manner. The developed model gives flexibility to the planner to alter their goals and deviation variables facilitate the planner for developing and implementing cleaner technologies to achieve overall sustainable development.

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