Optimal practicable environmental model for canned tuna products

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ABSTRACT

This study aims to present an incorporated model between multi-objective linear programming (MOLP) and life cycle assessment (LCA). The model is to determine an appropriate choice of variables involved in the packaging system for canned tuna products. By the demonstration through a single-serve two-piece can, the results showed that the MOLP technique yielded feasible solutions in term of quantities of raw materials required to use in two-piece can for tuna products with satisfaction of various constraints pertinent to the production. The optimal solutions relating to objective functions of the environmental impact's carbon footprint and total economic cost relating to the packaging production are 4,767 kg CO_2 eq and $US 8,994.57[1] respectively. To this end, such optimal practicable environmental model can be beneficial as a decision-support tool not only to the production of canned tuna packaging, but also to other businesses alike to achieve an optimal packaging solution that compromises both economic and environmental aspects.

Keywords: multi-objective linear programming (MOLP), carbon footprint, economic cost, two-piece can, optimal solution

1. Introduction

For many manufacturers over the global regions, the environmental impact throughout a packaged-product's life cycle has become as important issue due to the present packaging directives and regulation for the environmental impact of all products. The manufacturers are not only experiencing an increasing concern in order to alleviate the environment pressure, but they have to seek ways to survive in the market competitiveness by reducing the production cost and achieving the high profit. Upon reacting to such conflict of interest, it is necessary to the manufacturers to make a decision in such a way that the environmental and economic issues are compromised.

Carbon footprint is now being applied in many products and has become part of public consciousness. It is an acclaimed measure of the emitted greenhouse gases (GHGs) produced through burning of fossil fuels for electricity, heating and transformation, and so on. The extent of GHG is expressed as kilograms of carbon dioxide equivalent (kgCO_2 eq) (Muthu et al., 2011). The approach for calculating the product carbon footprint into four steps: process mapping, determination of the problem boundaries, data collection, and calculation for carbon footprint. Carbon footprint is therefore the environmental information delivered from the product manufacturers to their consumers.

Costing issue is one of main considerations for most product manufacturers. In general, a higher product production cost may be incurred if manufacturers determine to opt for a superior packaging system in functionality in order to maintain the product quality. Also, it usually occurs that such packaging selection based upon the innovation concern can result in a contradiction as the environmental implication is increased. For instance, excessive product protection than necessary (over-packaging) is chosen and the packaging waste management at the end-of-life can be difficult. It is therefore important for manufacturers to select the right packaging system that can increase consumer satisfaction while having minimized environmental impact and economic cost (Monte et al., 2005; Poovarodom et al., 2011).

A single-served canned tuna has been responded the modern life-style. Through the product's life span, the associated costs related to the production of the canned tuna packaging include costs of raw materials, labors, manufacturing and operation, and last but not least, transportation. In the environmental aspect, all said activities of the canned tuna production could induce GHG emissions that directly influence the environment condition. It therefore has driven pressures to the food industry in order to reduce the carbon footprint associate with the product (Poovarodom et al. 2011).

Many studies for the environmental impact in food industry have emphasized solely one aspect without taking others into account. Poovarodom et al. (2011) showed that the manufacturing process of retort pouches and cups produced 60% and 70% less greenhouse gas emissions than that of metal cans. However, the overall carbon footprint of canned tuna in retort cups was 10% and 22% less than that in metal cans and retort pouches, respec-

[1] $US 8,994.57 (Equivalent to 287,826.13 THB; $US 1 = 32 THB)

tively. As the result, the retort cup packaging system possessed a significant advantage over metal can and retort pouch in term of overall GHG emissions. Packaging and its associated processing constituted significant fractions of the product's carbon footprint, ranging from 20% to 40%.

Zabaniotou and Kassidi (2003) compared the environmental impact of two egg packages made of polystyrene and recycled paper. The study indicated that recycled paper eggcups had less environmental impact than polystyrene ones. This is because, throughout its life cycle, the polystyrene eggcup had more contributions to acidification potential, and winter and summer smog, while recycled paper eggcup had contributions to heavy metal and carcinogenic substances.

Monte et al. (2005) adopted the life cycle assessment to determine a choice of coffee packaging. By comparing coffee packaging in five categories: 125-g cans, 250-g cans, 3-kg cans, cans with 36 single-use coffee servings, and poly-laminate bags with 40 single-use coffee servings (280g). The study indicated that the bigger packaging size of the metal cans, the more reduction of environmental impact. With a bigger size is only available for niche market and a smaller package is a marketing prerequisite, a laminated plastic bag is therefore recommended as an alternative, due to slight increase for the environmental impact.

Linear programming (LP) model can be incorporated with the life cycle assessment (LCA). This is because LCA is based on linear relationships between activities and environment burdens. LP can be used to allocate environmental impacts in the impact assessment of LCA. The LP solution not only gives the environmental optimum of system as a part of the improvement stage, but also incorporates economic and social aspects of the system (Azapagic and Clift 1988; Azapagic and Clift 1995). However, goals toward the economic and the environmental aspects usually contradict to each other. Multi-objective linear programming (MOLP) can be employed to resolve such conflicts and to determine the best compromised solution. MOLP is a multiple criteria decision making. It is concerned with mathematical optimization problems involving minimizing or maximizing multiple objective functions simultaneously. Optimal decisions need to be taken in the presence of trade-offs between two or more conflicting objectives. This approach provides a decision making tool which can help the businesses to identify a path to sustainable development by establishing good trade-off between economic cost and environmental performance in term of carbon footprint.

In this study, MOLP is developed as an optimal practicable environmental model in order to determine the appropriate choice of packaging system by using two-pieces can for the canned tuna products as a case study. The trade-off between two objectives between minimized total cost and minimized carbon footprint is considered. The aim of the study is to enhance the application of MOLP at the early stage of a new product development and a product improvement.

2. Methods

2.1. Functional unit and system boundary

The demonstration through a single-serve two-piece can packaging is used. The packaging features consist of chrome-coated steel for can and a pull-ring aluminum tab closure. The two-piece can considered in this study is the plain can (no printing on it). The 85-gram packaging size is considered. Such size is regularly available for retail and becomes standardized for one single serving (Figure 1).

The functional unit is defined as 90,000 cans, equivalent to one pallet of end shell and three pallets of can body. The model is developed under assumptions in which the production of tuna, filling, storage, and disposal are excluded. The system boundary is considered as cradle-to-gate (Figure 2). It spans the acquisition of raw materials, manufacturing, and transportation. Other additional packaging types used in each individual process such as tier sheets, low-density polyethylene (LDPE) film, paper pallet tags, and polypropylene (PP) strapping are also included in the study.

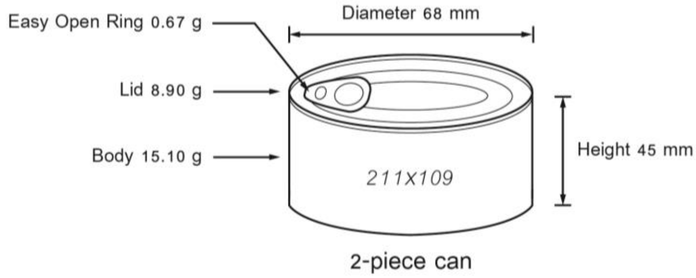

Figure 1. Two-piece can that use in the study.

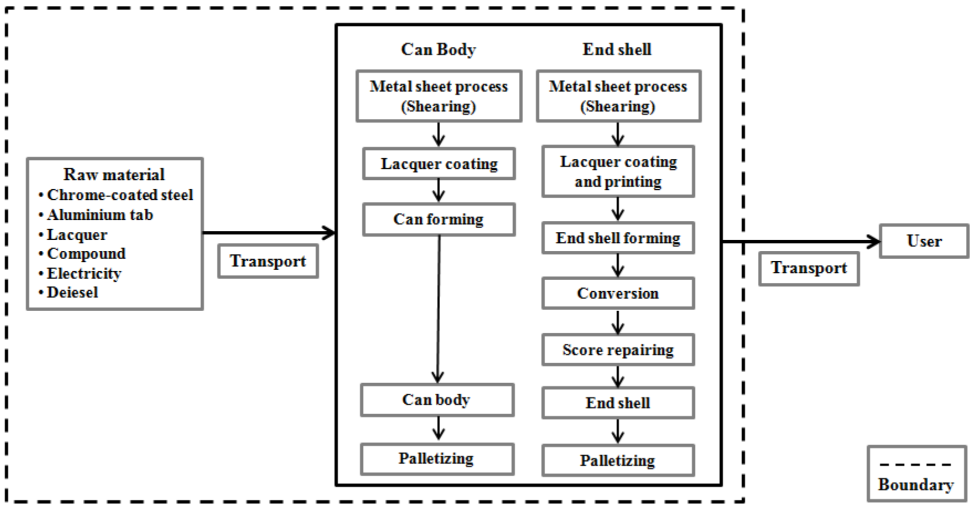

Figure 2. System boundary of two-piece can for tuna products.

2.2. Inventory analysis

Life cycle inventory (LCI) is collected from primary data (Table 1.). It is derived from questionnaires and by mean of interviewing personnel from can suppliers. Secondary data from literature and database are also used. Emission factors are obtained from Thai National Database (Thailand Greenhouse Gas Management Organization 2013) and some are provided from can suppliers.

Economic costs considered in this study include costs of materials, energy consumption, operation, and transportation. The unit costs are collected from can manufacturers.

Table 1. Information on raw materials and two-piece cans

Raw material	Source	Type of shipment	Distance (km)
TFS steel sheet	Thailand	Truck (10 wheels)	204
Lacquer A for can body	Thailand	Truck (6 wheels)	20
Lacquer B for can body	Thailand	Truck (6 wheels)	69
Lacquer C for end shell	Thailand	Truck (6 wheels)	36
Lacquer D for end shell	Thailand	Truck (6 wheels)	90
Lacquer E for end shell	Thailand	Truck (6 wheels)	36
Aluminum Tab	America	Ocean freighter	16,469
Solvent	Thailand	Truck (6 wheels)	30
Wax	Thailand	Truck (4 wheels)	50
Tab lube	America	Ocean freighter	16,718
Compound	Thailand	Truck (6 wheels)	36
Ink	Thailand	Truck (6 wheels)	80
Layer paper sheets	Thailand	Truck (10 wheels)	140
Linear low-density polyethylene	Thailand	Truck (6 wheels)	18
Polyethylene	Thailand	Truck (6 wheels)	33
Plastic strapping	Thailand	Truck (4 wheels)	30
Paper bag	Thailand	Truck (6 wheels)	20
Wood pallet	Thailand	Truck (6 wheels)	7

2.3. MOLP model

As previously mentioned, two objective functions considered in the study are total carbon footprint and total economic cost. The MOLP model is able to formulate and yield the optimal solution by using spreadsheet solver in Microsoft Excel. Steps for developing the model are described in the following.

Decision variables: The decision variables are quantity of raw materials and packages. The decision variables are expressed as X_j (quantity of raw materials in production of can body type *j* in kg) and Y_j (quantity of raw materials in production of end shell type j in kg). The decision variables are showed in Table 2.

Table 2. Decision variables for two-piece can system.

Production	Decision variable	Description	Unit
Production of can body (X_j)	X_1	Quantity of TSF steel sheets	kg
	X_2	Quantity of Lacquer A	kg
	X_3	Quantity of Lacquer B	kg
	X_4	Quantity of solvent	kg
	X_5	Quantity of wooden pallets	kg
	X_6	Quantity of layer paper sheets	kg
	X_7	Quantity of top wooden frames	kg
	X_8	Quantity of stretch film	kg
	X_9	Quantity of plastic strapping	kg
	X_{10}	Quantity of paper pallet tags	kg
Production of end shell (Y_j)	Y_1	Quantity of TSF steel sheets	kg
	Y_2	Quantity of lacquer C	kg
	Y_3	Quantity of lacquer D	kg
	Y_4	Quantity of lacquer E	kg
	Y_5	Quantity of solvent	kg
	Y_6	Quantity of ink	kg
	Y_7	Quantity of compound	kg
	Y_8	Quantity of Al Tab stocks	kg
	Y_9	Quantity of tab lube	kg
	Y_{10}	Quantity of repairing lacquer	kg
	Y_{11}	Quantity of wooden pallets	kg
	Y_{12}	Quantity of wrapping paper	kg
	Y_{13}	Quantity of shrink bag	kg
	Y_{14}	Quantity of stretch film	kg
	Y_{15}	Quantity of plastic strapping	kg
	Y_{16}	Quantity of paper pallet tags	kg

Objective functions: In order to determine the optimal solution for two-piece can system, two objective functions are minimized total carbon footprint (Z_1) and minimum total economic cost (Z_2).

$$Min\ z_1 = \sum_{j=1}^{n} e_{ij} x_j \quad \text{Eq. 1}$$

$$Min\ z_2 = \sum_{j=1}^{n} c_{ij} x_j \quad \text{Eq. 2}$$

where e_{ij} is emission factors related to raw materials, electricity, and transportation of raw material type *j* with objective *i* (i.e., *i* = 1, 2); C_{ij} is unit costs of raw materials, transportation, and operation for two-piece can system.

Constraints: Constraints concern mass balance and assured quantity of raw materials for two-piece can.

$$\sum_{j=1}^{n} x_j = m_b \quad \text{Eq. 3}$$

$$S_{j(\min)} \leq X_j \leq S_{j(\max)} \qquad \text{Eq. 4}$$

where m_b is process outputs; $S_{j(min)}$ and $S_{j(max)}$ are minimum and maximum quantity of raw material type *j* in each process.

Target values: Each objective has its target value (t_i). However, percentage deviation from each target value will be calculated. Later, the weighted percentage deviation of each objective function is also determined (Ragsdale CT 2007). In this study, the weights factors depend upon the importance of each objective and can be derived from the interview according to preference of can manufacturers. The weight of importance for total carbon footprint is 2.7 while the total economic cost has been given to 3.3.

$$\textit{Percentage Deviation} = \frac{\textit{Actual value} - \textit{Target value}}{\textit{Target value}} \qquad \text{Eq. 5}$$

$$\textit{Weighted percentage deviation} = \textit{Weight factor} \times \textit{Percentage deviation} \qquad \text{Eq. 6}$$

MINIMAX objective: It minimizes the worst-case values of a set of multivariate functions, possibly subject to linear constraints. The MINIMAX objective is going to minimize the maximum of weighted percentage deviation (Q) (Ragsdale CT 2007).

Objective function: *MIN: Q* Eq. 7

Constraint: *Weighted percentage deviation* $\leq Q$ Eq. 8

Decision variable: Q

The optimal solution: Considered by decision makers.

3. Results

In this section, the results of the study are divided into three parts. The first part showed target values of each objective. The second part indicated weighting scores. The third part showed the optimal solution that is compromised both objectives on the environmental and economic cost aspects for two-piece can.

With LP technique by considering a single objective function and solving to find the solution of each objective, The results can be found as shown in Table 3. It indicates that if only total carbon footprint as a single objective function is determined, the model yielded the value of 4,745 kg CO_2 eq while the total economic cost was $US 8,994.40 (Equivalent to 287,820.65 THB; $US 1 = 32 THB). However, if the total economic cost as a single objective function is determined, the model yielded the value of $US 8,993.31 while the total carbon footprint was increased to 4,781 kg CO_2 eq. According to the results, it seems apparent that both objectives contradict to each other. As the result, the LP model could not yield the optimal solution for both objective functions simultaneously. If there is one objective function producing a better result, the solution of the other objectives becomes worse. With this reason, MOLP is taken in in order to solve for the optimal solution. However, the weighting factor of importance is needed to apply as earlier mentioned in Section 2.3.

The weighting scoring is a valuable decision-making tool. It is used to evaluate alternatives based on specific evaluation criteria weighted by importance or priority (Zimmer DA 2011). By evaluating alternatives based on performance with respect to individual criteria, a value for the alternative can be identified. The weighting value enables an organization to narrow the list of options using criteria such as cost, quality and efficiency. In this study, the weighting scores of both objective functions are provided by can manufacturers. The weights of the total economic cost and total carbon footprint are 3.3 and 2.7, respectively. After applying the trade-off between two objective functions for two-piece can system, the optimal solution of MOLP model functions is shifted as shown in Table 4.

Table 3. Target values of two objective functions.

Objective function	Total carbon footprint (kg CO_2 eq)	Total economic cost ($US)	Target values	Unit
Minimized total carbon footprint	4,745	8,994.40	t_1 = 4,745	kg CO_2 eq
Minimized total economic cost	4,781	8,993.31	t_2 = 8,993.31	$US

Table 4. Objective values (Z) and the maximum weighted percentage deviation (Q)

Objective function	Weighting	Optimal objective value (Z)	Unit	Maximum weighted percentage deviation from the target values (Q)
Minimized total carbon footprint	2.7	4,767	kg CO_2 eq	0.000494547
Minimized total economic cost	3.3	8,994.57	$US	

The MOLP model represented the optimal solutions for two-piece can system. By considering the two objectives, with the functional unit of 90,000 cans, the subsequent results were 4,767 kg CO_2 eq for total carbon footprint (Z_1) and $US 8,994.57 for total economic cost (Z_2). The maximum weighted percentage deviation from the target values (Q) was 0.000494547 or alternatively speaking that the solutions were within approximately 0.000494547% of achieving the target solutions for the both objective functions. These solutions of this study were depending on weighting score determined by can manufacturers. Thus, it enables a decision maker to explore several solutions by adjusting the weighting scores. According to the optimal values of decision variables in the case study can be determined as showed in Table 5. The results indicate that all quantities of decision variables were within the assured range for the production. It is noted that for the production of can body (X_i), the quantity of TSF steel sheets was decreased. On the other hand, the quantities of lacquer A, lacquer B and solvent in this process were increased. For the production of end shell (Y_i), the quantity of TSF steel sheets was decreased. In addition, the quantities of Lacquer C, Lacquer D, Lacquer E, ink and compound in this process were also increased.

Table 5. Optimal quantities of decision variables for two-piece can system (functional unit = 90,000).

Production	Decision variable	Description	Optimal value	Unit
Can body (X_j)	X_1	TSF steel sheets	1038.85	kg
	X_2	Lacquer A	20.34	kg
	X_3	Lacquer B	13.65	kg
	X_4	Solvent	0.92	kg
	X_5	Wooden pallets	180.09	kg
	X_6	Layer paper sheets	66.56	kg
	X_7	Top wooden frames	36.02	kg
	X_8	Stretch film	2.16	kg
	X_9	Plastic strapping	0.36	kg
	X_{10}	Paper pallet tags	0.04	kg
End shell (Y_j)	Y_1	TSF steel sheets	677.58	kg
	Y_2	Lacquer C	8.25	kg
	Y_3	Lacquer D	7.13	kg
	Y_4	Lacquer E	11.35	kg
	Y_5	Solvent	0.79	kg
	Y_6	Ink	0.50	kg
	Y_7	Compound	2.40	kg
	Y_8	Al Tab stocks	56.59	kg
	Y_9	Tab lube	0.75	kg
	Y_{10}	Repairing lacquer	1.86	kg
	Y_{11}	Wooden pallets	22.31	kg
	Y_{12}	Wrapping paper	0.62	kg
	Y_{13}	Shrink bag	3.69	kg
	Y_{14}	Stretch film	6.69	kg
	Y_{15}	Plastic strapping	1.12	kg
	Y_{16}	Paper pallet tags	0.13	kg

4. Discussion

The optimal solution of the developed MOLP model with two objective functions of total carbon footprint and total economic cost for 2-piece can system is evaluated. The results show that the optimal value on objective functions has improved. However, further improvement can be established if the constraints are not too much restricted. The region of feasible solution will be subsequently expanded. In addition, a change in the weighting factors of importance may also be implemented in order to obtain a better solution.

5. Conclusion

The MOLP can be used as the optimal practicable environmental model for compromising relationship between the two main objectives involving the total economic cost and the environmental performance in term of total carbon footprint. The developed model in the study represented the optimal solutions for two-piece can system for the canned tuna products. By considering two objectives function in term of functional unit of 90,000 units, the results showed that the optimal solutions were 4,767 kg CO_2 eq for the total carbon footprint and $US 8,994.57 for the total economic cost. With the maximum weighted percentage deviation from the target values of 0.000494547%, the MOLP model yielded the optimal solution in term of quantities of raw materials required to use in the production of the two-piece can with satisfaction of various constraints pertinent to the production.

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