An Integrated BOM Evaluation and Supplier Selection Model for a Design for Supply Chain System

Yuan-Jye Tseng, Li-Jong Su, Yi-Shiuan Chen and Yi-Ju Liao

Abstract In a supply chain, the design of a product can affect the activities in the forward and reverse supply chains. Given a product requirement, the components of the product can be designed with different specifications. As a result, the bill of material and the manufacturing activities will be different. Therefore, in different design alternative cases, there can be different decisions of supplier selection for producing the product. In this research, a new model for supplier selection and order assignment in a closed-loop supply chain system is presented. First, the design information of the design alternative cases are analyzed and represented in the form of a bill of material model. Next, a mathematical model is developed for supplier selection and order assignment by evaluating the design and closed-loop supply chain costs. Finally, a solution model using the particle swarm optimization method with a new encoding scheme is presented. The new model is developed to determine the decisions of design evaluation and supplier selection under the constraints of capacity and capability to achieve a minimized total cost objective. In this paper presentation, an example product is illustrated. The test results show that the model and solution method are feasible and practical.

Keywords Supply chain management · Closed-loop supply chain · Product design · Bill of material · PSO

1 Introduction

To design a product, there may be different ways to design the detailed specifications of the components and product. In order to satisfy the product requirement, different design alternative cases can be utilized to design the product. In the

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different design alternative cases, the components of the product can be designed with different shapes, dimensions, different materials, and other specifications. If the components and product are designed differently, the bill of material (BOM) of the product will be different. As a result, the downstream manufacturing activities will be affected. Therefore, the different design alternative cases can affect the decisions in the supplier selection and order assignment. It is necessary to evaluate how the different design alternative cases affect the supply chain.

In a product life cycle, the supply chain that performs the common activities such as manufacturing, assembly, transportation, and distribution can be described as a forward supply chain. In the reverse direction, the reverse supply chain performs the activities to process a product at the end of the product life cycle. The activities in a reverse supply chain can include recycle, disassembly, reuse, remanufacturing, and disposal.

If several design cases are available, the different design alternative cases can affect the decisions in supplier selection in the closed-loop supply chain. It is necessary to consider the design alternative cases prior to the actual production of the product. The different design alternatives cases can be modeled and analyzed based on different objectives to determine the best design. In addition, the order assignment and supplier selection can be analyzed and evaluated for the design.

In this research, the information of design of the components and the product is represented as BOM information. In the forward supply chain, the information of the components and product are represented as a BOM model. In the reverse supply chain, the components and product are represented as a reverse bill of material (RBOM) model. A design for closed-loop supply chain model is developed to find the suitable design case and the suitable suppliers in an integrated way (Fig. 1).

In the previous research, the problem and models of supplier selection have been discussed in the papers of Kasilingam and Lee (1996) and Humphreys et al. (2003). A literature review of supply chain performance measurement was presented in Akyuz and Erman (2010). The topics of reverse logics and closed-loop supply chains have been presented in French and LaForge (2006) and Kim et al. (2006). In Schultmann et al. (2006) and Alshamrani et al. (2007), the problems of close-loop supply chain were modeled and discussed. In Sheu et al. (2005) and Lu et al. (2007), the models for green supply chain management were presented. In Ko and Evans (2007), a genetic algorithm-based heuristic for the dynamic integrated forward and reverse logistics network was developed. In Yang et al. (2009), an optimization model for a closed-loop supply chain network was presented. In Kannan et al. (2010), the closed loop supply chain model was modeled and solved using a genetic algorithm approach. Based on the review, the product design and the supplier selection in the closed-loop supplier chain have not been evaluated in an integrated way. Therefore, in this research, a model for integrated evaluation of product design and the closed-loop supply chains is developed.

The cost items for the design activities include function, dimension, material, assembly operation, and manufacturing operation. The cost items for the forward supply chain activities include manufacturing cost, purchase cost, and transportation cost. The cost items for the reverse supply chain activities include recycle

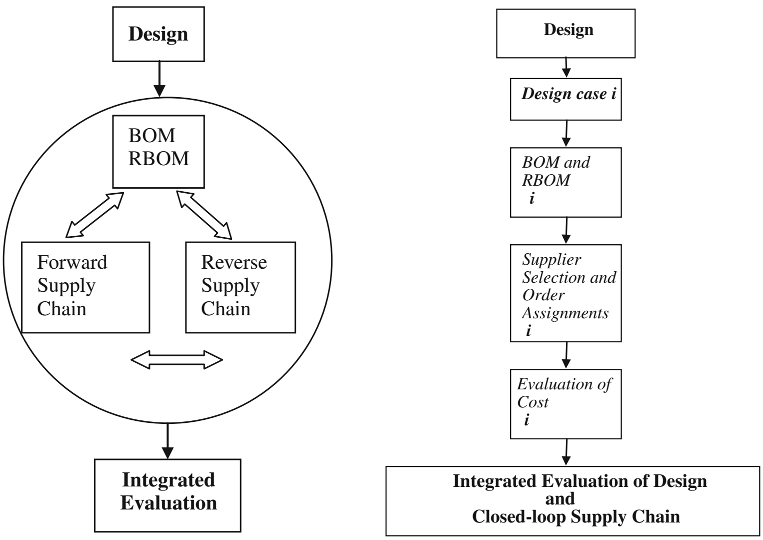

Fig. 1 The concept and model of design for closed-loop supply chain

cost, disassembly cost, reuse cost, remanufacturing cost, and disposal cost. The total cost is the sum of the above cost items. The constraints include the capacity and capability constraints. The mathematical model is developed to select the supplier and determine the order assignment for each supplier under the constraints of capacity and capability to achieve a minimized total cost objective.

In the previous research, the PSO algorithm has been successfully applied to many continuous and discrete optimizations (Kennedy and Eberhart 1997). The research in Banks et al. (2008) reviewed and summarized the related PSO research in the areas of combinatorial problems, multiple objectives, and constrained optimization problems. In this research, the solution method using the PSO approach is utilized. In the presentation, the test results are presented and discussed.

In this paper, Sect. 1 presents an introduction. Section 2 describes the mathematical model and PSO model of design for closed-loop supply chain. In Sect. 3, the implementation and application are illustrated and discussed. Finally, a conclusion is presented in Sect. 4.

2 The Design for Closed-Loop Supply Chain Model

2.1 Bill of Material and Reverse Bill of Material Models for Representation Design of a Product

In this research, the information of design of the components and product is represented in the form of a bill of material (BOM). In the forward supply chain,

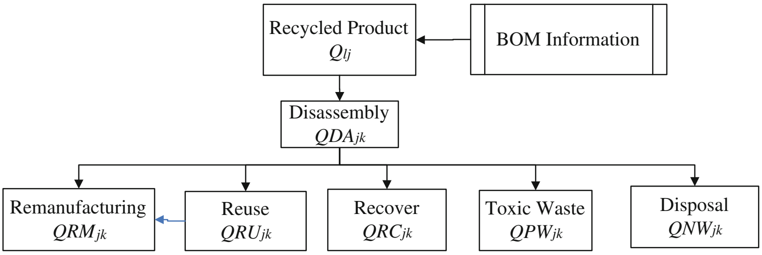

Fig. 2 The format of a reverse bill of material (RBOM)

the information of the components and product are represented as a BOM model. In the reverse supply chain, the components and product are represented as a reverse bill of material (RBOM) model (Fig. 2).

2.2 The Design for Closed-Loop Supply Chain Model

In this research a design for closed-loop supply chain model is presented. A brief description of the notations is as follows.

l	An order $l \in L$, $L = L_F \cup L_R$
L	All the orders
LF	Orders in the forward supply chain
LR	Orders in the reverse supply chain
i	A plant $i \in I, I = I_p \cup I_o$
I	All the plants
j	A product $j \in J_l$, J_l represents the products in order l
k	A component
x_{li}	A 0–1 decision variable representing whether order l is assigned to plant i
TC	Total cost
TPC	Cost of forward supply chain
TRC	Cost of reverse supply chain
TRB	Value of reverse supply chain
TUB	Value of reuse supply chain
TMB	Value of remanufacturing
TCB	Value of recovery
TUC	Cost of reuse operation
TNC	Cost of remanufacturing operation
TCC	Cost of recovery operation
TAC	Cost of disassembly operation
TWC	Cost of disposal operation
TSC	Transportation cost
TMC	Material cost

TFC Manufacturing cost

The model is briefly described as follows.

$$\text{Min } TC = TPC + TRC - TRB \tag{1}$$

$$TPC = TOC + TSC + TMC + TFC \tag{2}$$

$$TRC = TUC + TNC + TCC + TAC + TWC \tag{3}$$

$$TRB = TUB + TMB + TCB \tag{4}$$

$$TUC = \sum_{l \in L_R} \sum_{i \in I_p} \sum_{j \in J_l} \sum_{k \in K_{lj}} Q_{lj} \times QRU_{jk} \times CRU_{ijk} \times x_{li} \tag{5}$$

$$TNC = \sum_{l \in L_R} \sum_{i \in I_p} \sum_{j \in J_l} \sum_{k \in K_{lj}} Q_{lj} \times QRM_{jk} \times CRM_{ijk} \times x_{li} \tag{6}$$

$$TCC = \sum_{l \in L_R} \sum_{i \in I_p} \sum_{j \in J_l} \sum_{k \in K_{lj}} Q_{lj} \times QRC_{jk} \times CRC_{ijk} \times x_{li} \tag{7}$$

$$TAC = \sum_{l \in L_R} \sum_{i \in I_p} \sum_{j \in J_l} \sum_{k \in K_{lj}} Q_{lj} \times QDA_{jk} \times CDA_{jk} \times x_{li} \tag{8}$$

2.3 The Solution Model Using the Particle Swarm Optimization Method

The PSO algorithm is utilized for finding the solutions in the model. The PSO algorithm is an evolutionary computation method introduced by Kennedy and Eberhard (1997). In the PSO method, a particle is defined by its position and velocity. To search for the optimal solution, each particle adjusts its velocity according to the velocity updating equation and position updating equation.

$$v_{id}^{new} = w_i \cdot v_{id}^{old} + c_1 \cdot r_1 \cdot (p_{id} - x_{id}) + c_2 \cdot r_2 \cdot \left(p_{gd} - x_{id}\right) \tag{9}$$

$$x_{id}^{new} = x_{id}^{old} + v_{id}^{new} \tag{10}$$

This research applies the PSO method to the problem by developing a new encoding and decoding scheme. In the developed encoding scheme, a particle is represented by a position matrix. The elements in the position matrix are denoted as h_{pj}, where p represents a particle and l represents an order. The encoding of the position matrix is as follows

$$PL = \begin{matrix} & \begin{matrix} 1 & 2 & \cdots & l \end{matrix} \\ \begin{matrix} 1 \\ 2 \\ \vdots \\ p \end{matrix} & \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1l} \\ h_{21} & h_{22} & \cdots & h_{2l} \\ \vdots & \vdots & \ddots & \vdots \\ h_{p1} & h_{p2} & \cdots & h_{pl} \end{bmatrix}_{P \times L} \end{matrix} \quad (11)$$

where h_{pj} represents the position matrix of particle p,
where $p = 1, \ldots, E$, and $l = 1, 2, \ldots, L$.

The fitness function represents the objective of the PSO enumeration. The objective as shown in (12) is used as the fitness function.

$$\text{Min } Fitness = \text{Min } TC = TPC + TRC - TRB \quad (12)$$

The position matrix of a particle can be decoded into an order assignment set where each order l is assigned to a suitable plant i to achieve the objective of the fitness function. The assigned plant i can be determined by decoding h_{pj}. The total number of plants I is divided into several numerical zones. The assignment of order l to plant i can be determined by searching the numerical zone where h_{pj} falls in. After the PSO enumeration, the final particle represents an order assignment arrangement set in the closed-loop supply chain.

3 Implementation and Test Results

The mathematical model and the PSO solution model was implemented and tested. An example is modeled and illustrated. Product A is a simplified mobile phone as shown in Fig. 3. The BOM is shown in Fig. 4. The related data are modeled for implementation and testing. The cost items in the forward and supply chain are also modeled. Using the input data of the example product, the mathematical model are modeled and solved using the PSO model. The test results show that the models are feasible and efficient for solving the problem.

4 Conclusions

In this research presentation, the concept of design for closed-loop supply chain is developed. A mathematical model and PSO solution model is presented for integrated evaluation of the design and its closed-loop supply chain. The related BOM and RBOM are developed to represent the design information. The costs in design, forward supply chain, and reverse supply chain are modeled. A mathematical

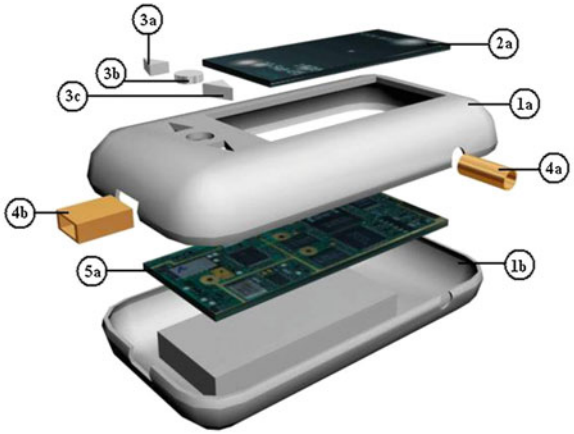

Fig. 3 Product A is a simplified mobile phone used for testing and illustration

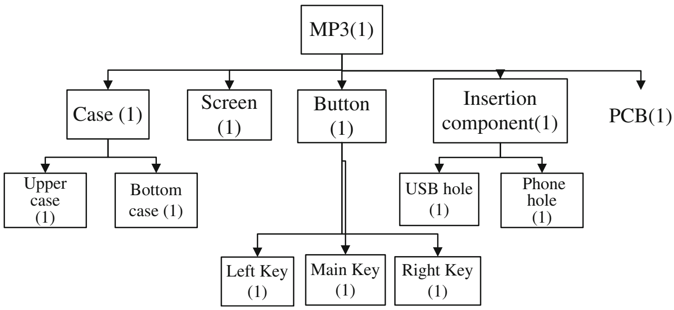

Fig. 4 The BOM of product A

model is presented for use in supplier selection and order assignment. The PSO solution model is presented to find solutions. An example is demonstrated in the presentation. The test results show that the models are feasible and useful for solving the design for closed-loop supply chain problem. Given a design, the order assignment and suppler selection can be analyzed and evaluated to achieve the objective of the fitness function of minimizing total costs of design, forward supply chain, and reverse supply chain. Future research can be directed to explore more detailed value and cost functions of design, and forward and reverse supply chain activities.

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