World Academy of Science, Engineering and Technology
International Journal of Industrial and Manufacturing Engineering
Vol:10, No:2, 2016

Binary Programming for Manufacturing Material and Manufacturing Process Selection Using Genetic Algorithms

Saleem Z. Ramadan

Open Science Index, Industrial and Manufacturing Engineering Vol:10, No:2, 2016 publications.waset.org/10003522/pdf

Abstract**—**The material selection problem is concerned with the determination of the right material for a certain product to optimize certain performance indices in that product such as mass, energy density, and power-to-weight ratio. This paper is concerned about optimizing the selection of the manufacturing process along with the material used in the product under performance indices and availability constraints. In this paper, the material selection problem is formulated using binary programming and solved by genetic algorithm. The objective function of the model is to minimize the total manufacturing cost under performance indices and material and manufacturing process availability constraints.

Keywords**—**Optimization, Material selection, Process selection, Genetic algorithm.

I. Introduction

ENGINEERING materials usually have many requirements to meet simultaneously. To name some, it must support load, hold pressures, resist wear, and conduct electricity. The designer in the other hand has some limitations regarding the appropriate material to select. To name some, the designer may be concerned about the material cost, the manufacturing cost, the weight of the product, the size of the product, and the temperature range that the selected material can hold. These concerns impose constraints on the selection of the appropriate material. Therefore, the designer needs a systematic way to evaluate his/her options. This systematic way must take into consideration the material and manufacturing process. This matter makes the material and manufacturing process selection a mutli-objective optimization problem that must be carried out before the design for manufacturing can begin [13] as the design stage affects 70-80% of the final product cost [14].

The material selection problem is concerned with the determination of the right material for a certain product to optimize certain performance indices in that product such as mass, energy density, and power-to-weight ratio [1].

Usually the values of the performance indices depend on: the function of the product, the geometry and the dimensions of the product, and the environment under which the product should work. These three factors determine the possible set of manufacturing materials that can be used in manufacturing the product. Unfortunately, not all the available manufacturing materials are feasible for manufacturing the product due to practical limitations such as the available manufacturing processes in the company. This matter calls for modifying the classical material selection problem to involve not only the selection of the manufacturing material but also the selection of the manufacturing process simultaneously.

Traditionally, material selection based on performance indices is done by materials selection chart [2]. Reference [3] developed a method for materials–selection and implemented it in software. The proposed method simultaneously optimizes the selection of the material and the shape. Acoustics has been an active region for material selection especially for composite materials. The formulation of discrete design optimization for fiber orientation, composite laminated plates, and number of plies was discussed in [4]. Reference [5] minimized the acoustic power radiation using topology optimization of laminated composite structures by introducing solid isotropic material with penalization (SIMP) model. Reference. [6] studied the static loading stacking sequences with various glasses to carbon ratio in a hybrid composite laminated structure. Ref. [1] illustrates how multi-objective optimization can be applied to material selection.

Most of the literatures concern with either the process selection [7] or the material selection [8]-[10]. Little work considered optimizing both the material selection and the process selection [11].

This paper is concerned with optimizing the selection of the process along with the material used in the manufacturing process under performance indices constraints. The paper formulates the problem using binary programming and uses genetic algorithm to solve the model. The objective function of the model is to minimize the total manufacturing cost under performance indices constraints and material and manufacturing process availability.

The rest of the paper is organized as follows: Section II discusses the assumptions and notations used in this paper. Section III presents the model formulation. Section IV discusses the genetic algorithm used in this paper. Section V presents the conclusions.

II. Assumptions and Notations

Consider the material selection problem in which a product needs to be manufactured with a certain number of key performance indices, a finite number of available manufacturing materials, and a finite number of possible manufacturing processes. The problem is concerned with the determination of the right material for the product and the

S. Z. Ramadan is with the Department of Mechanical and Industrial Engineering, Applied Science Private University, Jordan P.O. Box 166 Postal Code 11931, Amman, Jordan (e-mail: s_ramadan@asu.edu.jo).

Open Science Index, Industrial and Manufacturing Engineering Vol:10, No:2, 2016 publications.waset.org/10003522/pdf

right manufacturing process to minimize the total manufacturing cost under performance indices constraints and material and manufacturing process availability. The aim of this paper is to model this problem as a non-linear binary programming using genetic algorithm. The notations for this model are as:

- D: A vector containing the product dimensions.
- $V(D)$: The volume of the product as a function of the product dimensions D
- M: set of available materials for manufacturing the product.
- $\|.\|$: The cardinality of the set
- n:Thetotal number of available materials that can be used in manufacturing the product. i.e. $\|M\|$.
- x_i: A binary indicator variable for the material i where $i = 1, 2, 3, \dots n$
- C_{m_i}: The cost per unit volume of material i
- θ_i: The set of possible manufacturing processes for material i
- K_i: The total number of possible manufacturing processes for material$i$. i.e. $\|\theta_i\|$
- X_{mf}: The set of available manufacturing processes in the company
- y_{ik}: a binary indicator variable for the possible manufacturing process k of material i where $k = 1, 2, 3 \dots, K_i$.
- $C_{mf_{ik}}$: The manufacturing process cost per unit volume of material i when manufacturing process k is used.
- N_{MP}: The total number of key properties needed in the product.
- LB_jandUB_j are lower bound and upper bound for material property j respectively where $j = 1, 2, 3, \dots, N_{MP}$
- $MP_{ij}(D, x_i)$: The value of the j^{th}performance index for material i as a function of product dimensions D.

III. Model Formulation

The cost of the product can be divided in two parts: the direct material cost, which is a function of the quantity of the selected material, and the conversion cost (Direct labor and overhead) which is a function of the selected manufacturing process. The direct material cost for a product can be calculated as the volume of the product times the material cost per volume unit.

Mathematically the direct material can be expressed as:

$$V(D)\sum_{i=1}^{n} x_i C_{m_i}, \tag{1}$$

where x_i is 1 if the i^{th} material is selected for manufacturing and 0 otherwise.

It should be noticed here that $\sum_{i=1}^{n} x_i$ is 1 as only one material will be selected to produce the product.

The conversion cost is a function of the manufacturing process used. It can be calculated by multiplying the product volume with the manufacturing process cost per unit volume for the manufacturing process used.

Mathematically the conversion cost can be expressed as:

$$V(D)\sum_{i=1}^{n}\sum_{k=1}^{K_i} y_{ik} C_{mf_{ik}}, \tag{2}$$

where y_{ik} is 1 if the manufacturing process k is selected for manufacturing the product with material $i$and 0 otherwise.

It should be noticed here that $\sum_{i=1}^{n}\sum_{k=1}^{K_i} y_{ik}$ is 1 as only one manufacturing process will be selected to produce the product.

Combining the direct material and the conversion costs together gives the total manufacturing cost of the product which is our objective function in this model.

Mathematically, the objective function of this model is

$$min\ Z = V(D)\left[\sum_{i=1}^{n} x_i C_{m_i} + \sum_{i=1}^{n}\sum_{k=1}^{K_i} y_{ik} C_{mf_{ik}}\right] \tag{3}$$

The full selection model is given by

$$min\ Z = V(D)\left[\sum_{i=1}^{n} x_i C_{m_i} + \sum_{i=1}^{n}\sum_{k=1}^{K_i} y_{ik} C_{mf_{ik}}\right] \tag{4}$$

s.t

$$LB_j \le \sum_{i=1}^{n} x_i MP_j(D, x_i) \le UB_j \qquad \forall j = 1, 2, \dots, N_{MP} \tag{5}$$

$$x_i \le \left\|\theta_i \cap X_{mf}\right\| \qquad \forall i = 1, 2, \dots, n \tag{6}$$

$$y_{ik} \le x_i \qquad k = 1, 2, \dots, K_i,\ \forall i = 1, 2, \dots, n \tag{7}$$

$$\sum_{i=1}^{n} x_i = 1 \tag{8}$$

$$\sum_{i=1}^{n} x_i = 1 \tag{9}$$

$$D \ge 0 \tag{10}$$

$$y, xbinary \tag{11}$$

Equation (1) is the objective function that calculates the costs of material (direct material) and the manufacturing process (conversion costs) selected for the product under consideration.

The set of inequalities (2) are the inequalities pertain the performance indices constraints. The set of inequalities (3) guarantees that for material i to be selected, at least one of the possible manufacturing processes for that material must be in the set of available manufacturing processes in the company, i.e., if we cannot process the material in the company, the material will not be selected.

The set of inequalities 4 sets the binary indicator variable y_{ik} to zero if the possible manufacturing process for material i is not in the set of available manufacturing processes in the company. The set of inequalities 5 and the set of inequalities 6 guarantee that only one material and one manufacturing process will be selected respectively. The set of inequalities 7 sets the dimensions of the product to real positive values. Finally, the set of inequalities 8 sets all decision variables y_{ik} and x_i to binary variables.

IV. Genetic Algorithm

As the complexity of the kind of problems that the computers have to deal with increase, the deterministic

Open Science Index, Industrial and Manufacturing Engineering Vol:10, No:2, 2016 publications.waset.org/10003522/pdf

optimization algorithms or exact methods such exhaustive enumeration, Box Decomposition, and Branch and Bound is hard to implement because the size of the problem grows exponentially with number of variables and thus the time complexity of them is as worse as the exhaustive enumeration. [15].

This matter calls for adapting other kinds of optimization methods. Randomized heuristic methods, which use a set of rules to determine which individual solution from the solution space should next be generated and tested, is proved to be efficient in these circumstances.

Genetic algorithm (GA), as one of the randomized heuristic methods, imitates the natural selection in Darwin's theory [12]. It improves the population of the solutions (the individuals) by iterative applications of crossover and mutation operators. The solutions are represented by vectors called chromosomes in which the elements of the vectors are the genes.

The objective function is used to evaluate the fitness of the individuals (chromosomes) in the population; hence the objective function is usually called the fitness function. The fitness of each chromosome is calculated and is used as a base for the selection of the parents in the next generation through selection operator.

Crossover operator is usually used to produce offspring through mixing the genes of two or more chromosomes together in a step called reproduction. This step helps the algorithm in exploring the sample space of the problem adequately. Moreover, the genetic algorithm employs mutation operator to mutate the offspring in a step called mutation. The aim of the mutation step is to exploit the information accumulated over the generation by searching in the neighborhood of the promising regions found by the reproduction step.

The new generation usually consists of a mixture of the mutated offspring and the parents that were selected based on their fitness values. This process of reproduction and selection maintained until a predetermined termination criterion is fulfilled. Fig. 1 summarizes the steps in genetic algorithms.

The strategies used in the proposed genetic algorithm are discussed next.

A. Chromosome Representation

The chromosome consists of $n + \sum_{i=1}^{n} K_i$ binary genes. The first n genes are for commercially available materials, the rest of the genes $\sum_{i=1}^{n} K_i$ are for the possible manufacturing processes for the commercially available materials.

Consider a product that have three commercially available materials for manufacturing and 2, 1, 3 possible manufacturing process for the first, the second, and the third available material respectively.

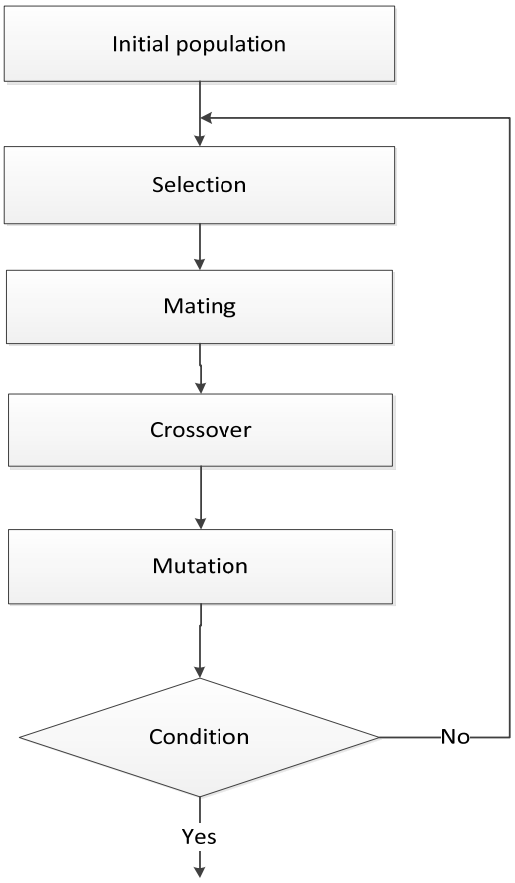


Fig. 1 A flow chart for genetic algorithm

One possible chromosome for such a scenario is given in Fig. 2 with 9 total number of genes from which two genes only have the value of 1 and the rest zeros. Genes numbers 1-3 representing the first, second, and third commercially available materials respectively. Genes numbers 4-5 represent the two available manufacturing process for the first material. Gene number 6 represents the available manufacturing process for the second material. Finally, genes numbers 7-8 represent the three available manufacturing processes for the third material.

0	0	1	0	0	0	0	1	0

Fig. 2 One possible chromosome for material and manufacturing process selection

It showed be noticed here that the gene carries two pieces of information: the values of the gene and the position of the gene. The value of the gene conveys the information whether the material or the manufacturing process is selected or not, 1 means it is selected and 0 means otherwise. The location of the gene corresponds to the specific material and specific manufacturing process used for the material. Encoding this chromosome gives the following information: the selected material is the third material and the selected manufacturing process is the second manufacturing process for the third material.

Open Science Index, Industrial and Manufacturing Engineering Vol:10, No:2, 2016 publications.waset.org/10003522/pdf

B. Fitness Function and Selection

The fitness values for the different chromosomes can be calculated using (3) which calculates the total manufacturing cost. The fitness values for all chromosomes (parents and offspring) in the generation are calculated and elitist selection strategy is employed to select the next generation individuals.

C. Mutation Operator and Reproduction

Since we used position-based chromosome representation schema, crossover operator will not be effective as the rate of infeasible chromosomes due to crossover will be very high and corrections needed for these chromosomes will be very expensive in terms of computation time. To explore the sample space adequately, heavy mutation rate for the parents will be used instead of crossover to reproduce. The mutation strategy will be as follows:

Begin

Select either 1 or 2 randomly.

- If 1 is selected,
- keep the material gene unchanged and record its position in $G_{ms} = i$and select a random number between 1 and K_i and record it in G_{mfs}.
  - Set genes numbers $n + \sum_{i=1}^{G_{ms}-1} K_i$ to $n + \sum_{i=1}^{G_{ms}} K_i$to zeros
  - Set genes number $n + G_{mfs} + \sum_{i=1}^{G_{ms}-1} K_i$ to 1
- If 2 is selected,
  - Set the genes numbers1: n to zero
  - Select a gene randomly by selecting a random number between 1 andnand set the gene value to 1. Record gene's position in $G_{ms} = i$and select a random number between 1 and K_i and record it in G_{mfs}.
  - Set genes numbers $n + \sum_{i=1}^{G_{ms}-1} K_i$ to $n + \sum_{i=1}^{G_{ms}} K_i$ to zeros
  - Set gene number $n + G_{mfs} + \sum_{i=1}^{G_{ms}-1} K_i$ to 1

End

This mutation strategy will guarantee that the offspring is feasible.

The crossover will be replaced by high level of mutation. In this GA, the offspring will be generated by mutating the best chromosome found in the generation $Pop - 1$ times, where Pop is the population size. The next generation consists of $Pop - 1$ offspring and the best chromosome from the previous generation.

V. Conclusion

A novel and reliable theoretical model based on a non-linear binary programming model is proposed to minimize the total cost of production by optimizing the selection of the manufacturing process along with the material used in the product under performance indices and availability constraints. The model selects the manufacturing material and the manufacturing process for the product simultaneously such that the total manufacturing cost is minimized under certain performance indices constraints. Due to the limitations in the number of pages that a manuscript can occupy in this journal, the experimentations to verify the validity of this model will be published separately in due course.

Acknowledgment

The author is grateful to the Applied Science Private University, Amman, Jordan, for the full financial support granted to this research

References

[1] M. F. Ashby, Multi-objective optimization in material design and selection, Acta mater. 48 (2000) 359-369

[2] Ashby, MF. 'Materials selection in mechanical design' Pergamon Press, Oxford, 1992

[3] M.F. Ashby and D. Cebon, Materials selection in mechanical design, Troisieme Conference Europeennesur les Materiaux et les ProcedesAvancesEuromat '93, Paris, June 8-10 1993

[4] Niu B, Olhoff N, Lund E, Cheng GD. Discrete material optimization of vibrating laminated composite plates for minimum sound radiation. Int J Solids Struct 2010; 47:2097–114.

[5] Xu ZS, Huang QB, Zhao ZG. Topology optimization of composite material plate with respect to sound radiation. Eng Anal Bound Elem 2011; 35:61–7.

[6] Zhang J, Chaisombat K, He S, Wang CH. Hybrid composite laminates reinforced with glass/carbon woven fabrics for lightweight load bearing structures. Mater Des 2012; 36:75–80.

[7] Dieter, G.E. Engineering design a material and processing approach. NY: McGraw-Hill; 1991

[8] Kasim M. Daws, Zouhair I. AL-Dawood, Sadiq H. AL-Kabi, Selection of Metal Casting Processes: A Fuzzy Approach, Jordan Journal of Mechanical and Industrial Engineering, Volume 2, Number 1, Mar. 2008, pp. 45 – 52.

[9] Esawi A., Ashby M., "The Development and Use of a Software Tool for Selecting Manufacturing Process at EarlyStages of Design". Conference on Integrated Design and Process Technology, Berlin, Germany, 1998.

[10] Karthik, S., Chung C.W, Ramani K. &Tomovic M. "Methodology for Metal-Casting Process Selection" Society of Automotive Engineers, Inc., 2002

[11] Yusheng Chen Saty and Gupta K, "A Web-Based Process/Material Advisory System ". ASME International Metal Engineering Proceedings, Orlando, Florida, 2000

[12] Holland, J. H. 1975. Adaptation in Natural and Artificial Systems. University of Michigan Press. (Second edition: MIT Press, 1992)

[13] Karthik S., Patwardhan H., Chung C., and Ramani K., "Rapid Application Development of Process Capability Supplier." Computer and Information in Engineering (CIE) Conference, Chicago, USA, 2003.

[14] Yusheng Chen Saty and Gupta K, "A Web-Based Process/ Material Advisory System ". ASME International Metal Engineering Proceedings, Orlando, Florida, 2000.

[15] Gursel, A. Suer, and Badurdeen, F. Capacitated lot sizing by using multi-chromosome crossover strategy, J Intell manuf, (2008) 19:273-282.