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Solving the integrated product mix-outsourcing problem using the Imperialist Competitive Algorithm

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ABSTRACT

The integrated product mix-outsourcing optimization is a major problem in manufacturing enterprise. Generally, heuristic or meta-heuristic solution approaches are used to optimize such problems. Heuristic approaches for these problems include Theory of Constraints (TOC) and Standard Accounting. Sometimes heuristic approaches are inefficient especially in large problems and instead, in these cases meta-heuristic algorithms have been applied extensively. In this paper a novel meta-heuristic algorithm "Imperialist Competitive Algorithm" (ICA) is applied to solve the integrated product mix-outsourcing optimization problem. Also, the results obtained from ICA are compared with the results of TOC and Standard Accounting approaches.

1. Introduction

Maximizing the enterprise profit and fully utilizing the limited production resources is a key optimization problem in the strategic planning of enterprises. Furthermore, another major difficulty is how to optimize the enterprise's production throughput within the determined product types (Wang, Sun, Si, & Yang, 2008). Aggregating the above two optimization concerns results in the product mix optimization problem which involves identification of the type and quantity of product to produce in order to make the most profit (Coman & Ronen, 2000). In the competitive market enterprises try to meet the market demand as much as possible. Although, this increases the sale revenue and profit, but in most cases, the enterprise resources produce the total demand are insufficient. Therefore, the enterprises tend to outsource part of the demand to external suppliers. Hence, the product mix and the outsourcing decisions have to be made simultaneously in many of the real world cases and can be referred to as the integrated product mix-outsourcing optimization problem.

Küttner (2004) stated that to solve the product mix problem and decide on the production volume for each product, the demand's forecast and the value of utilized resources should be considered. Lea and Fredendall (2002) demonstrated that the choice of product mix influences on the enterprise performance measures such as profit, work-in-progress (WIP), customer service, and manageability of the shop. To solve the product mix problem, there are two general approaches in the literature: heuristic and meta-heuristic algorithms.

One of the well-known heuristics is the Theory of Constraints (TOC) (Goldratt, 1987). The book by Eliyahu Goldratt "The Goal" explains that TOC is a management philosophy that focuses on constraints, which restrict the performance of an organization in achieving its goal (Goldratt & Cox, 2004). This Management philosophy originated from operation management (Watson, Blackstone, & Gardiner, 2007). Various applications of TOC are known to be product mix, logistics, scheduling, performance measurement, problem solving/thinking process, project management, market segmentation. Based on TOC, the throughput, due date, utilization, and other key performance measures of an enterprise can be controlled and optimized by controlling only the bottleneck resources in the enterprise (Goldratt, 1987). The TOC approach has been applied to solve the product mix problem by many researchers such as Goldratt (1990), Patterson (1992), Plenert (1993) and Lee and Plenert (1996). In most of previous studies related to the product mix problem, this problem has been extended either with increase in the number of constrained resources or products (Coman & Ronen, 2000). Balakrishnan (1999) claimed that when multiple constraints exist, the conventional TOC heuristic is not an appropriate solution method for product mix problem. They proposed that a linear-integer programming is a better tool than the TOC. Mabin (2001) showed that the TOC solution approach is improperly applied by Balakrishnan (1999) and argues that TOC and LP can be applied effectively in synergy. Plenert (1993) pro-

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vided an example where the TOC heuristic does not produce an optimal or even feasible solution. In cases with more than one bottleneck, identification of the dominant bottleneck becomes very difficult (Fredendall & Lea, 1997). Based on TOC approach the resource that has the maximum value of planned utilization is considered as the dominant bottleneck resource (Fredendall & Lea, 1997). Patterson (1992) and Goldratt (1990) tested the TOC heuristic by a test problem that its solution involves 100% utilization of bottleneck resource. In some other studies such as Plenert (1993) and Lee and Plenert (1996), the TOC approach has been applied and examined in instances that the bottleneck resource has not 100% utilization in the optimal solution. In other words, idle time is considered for the bottleneck resource during optimization. The main objective of TOC is to maximize the output that is obtained by determination and exploitation of the Critically Constrained Resource (CCR) (Onwubolu & Mutingi, 2001). However, the shortcoming of the above methods is that, in an attempt to make the TOC approach explicit, only small problem sizes can be solved to optimality within reasonable computation time (Onwubolu & Mutingi, 2001). Therefore, in addition to heuristic methods some meta-heuristics and intelligent search algorithms, such as Tabu search (TS) (Onwubolu, 2001), genetic algorithms (GA) (Onwubolu & Mutingi, 2001), hybrid Tabu-simulated annealing approach (Mishra, Tiwari, Shankar, & Chan, 2005), and other meta-heuristics algorithms are used to solve large-scale product mix optimization problem. Wang et al. (2008) developed an immune algorithm to solve the TOC product mix problem.

Outsourcing of production happens when an enterprise, instead of performing the entire production in-house, contracts with one or more external contractor to make part of the production outside (Sen & Zhu, 1996). In other words, the production outsourcing problem is the decision making problem of which products/parts should be produced in-house and which should be contracted out to be manufactured by one or more external suppliers (Küttner, 2004). Outsourcing is defined by Heshmati (2003) as the subcontracting relationship between firms, and the hiring of workers in non-traditional jobs. In practice, outsourcing is not only a "pure" make-or-buy decision, but also includes a shifting from internal production to external procurement (Lai, 2006). Outsourcing decision is always a de-integration decision, in which prior commitments to internal production should be ignored (Roodhooft & Warlop, 1999).

Generally, the top five reasons for outsourcing are: improvement of the company's focus, access to world-class capabilities, acceleration of benefits from re-engineering, risk sharing, and freeing the resources for other aims (Deavers, 1997).

The strategic goal for outsourcing decision-makers should be minimizing the total costs required to receive a given quantity and quality of outsourced products (Lai, 2006). An enterprise could benefit from competitive advantages (reliability, quality and cost) by contracting out the production of products (Perry, 1997). Sharpe (1997) mentioned that outsourcing lowers the adjustment costs of responding to economic changes. Adjustments are normally needed due to technological innovation, customer preference changes, and other changes in supply or demand. Glass and Saggi (2001) mentioned that outsourcing decreases the marginal production cost, increases profit, and creates greater incentives for innovation.

Efficient enterprises usually assign their own resources to those activities that are in the value chain and create more profit than competitors (Shank & Govindarajan, 1992). Other activities not enjoying such advantages are increasingly outsourced to external suppliers. It is expected that with outsourcing the production cost savings relative to internal production happens because outside suppliers benefit from smoother production schedules and centralization of expertise (Chalos, 1995; Roodhooft & Warlop, 1999).

De Kok (2000) considered outsourcing as a measure for assigning the capacity. The excessive capacity needs are not delayed but are instead outsourced. Thus, in the cases that market demands exceeds existing capacity, outsourcing may be a good way to achieve the benefits of cost saving and risk sharing.

In recent years, outsourcing has become an important strategy for many business enterprises. For a successful outsourcing decision, the benefit of cost savings is an important factor. Thus, the decision about outsourcing requires an accurate analysis of relevant costs (Lai, 2006). In his thesis, Lai (2006) develops a decision model which incorporates capacity expansions and outsourcing using a mathematical programming approach. In this work, the benefits of expanding resource capacities of various kinds or outsourcing simultaneously are evaluated. Gardiner and Blackstone (1991) solved a make-or-buy one-bottleneck-one-product problem using the bottleneck capacity for better decision making and integrated some capacity issues with financial issues. Their work was followed by Balakrishnan and Cheng (2005) who presented a method based on spreadsheet LP solver that generated better solutions for the outsourcing problem. Coman and Ronen (2000) also formulated a production mix- outsourcing problem as a LP problem. They examined three solution approaches: standard cost accounting, standard TOC, and their solution. In their results, they showed that the TOC solution was worse than their LP enhanced solution.

One of the shortcomings of TOC and Standard Accounting solution approaches is that these methods only consider the situations (constraints) present inside the enterprise. While in the product mix-outsourcing problem both internal and external constraints should be dealt with. Availability and cost of enterprise resources are examples for internal constraints and availability and cost of outsourcing resources are cases for external constraints. Thus, models for integrated product mix-outsourcing problem must consider both internal and external constraints simultaneously.

In the work at hand to solve large-scale integrated product mix-outsourcing problems a novel meta-heuristic is employed. This meta-heuristic is called Imperialist Colony Algorithm (ICA) that has recently been introduced by Atashpaz-Gargari and Lucas (2007) for dealing with different optimization tasks. The rest of this paper is organized as following: in Section 2 the integrated product mix-outsourcing problem is described and formulated as a LP model. In Section 3 the ICA algorithm is described in detail. Section 4 includes the simulation results. In this section results of applying the ICA algorithm and two other methods (TOC and Standard Accounting) are shown. Section 5 concludes the paper.

2. Problem statement

Here, we describe the linear programming (LP) formulation for the integrated product mix-outsourcing problem. In addition, an instance of this problem is given. Both formulation and instance are based on the work of Coman and Ronen (2000). The LP definition of product mix-outsourcing problem can be represented by:

$$\begin{aligned} & Max \sum_{i=1}^{n} X_i(OP_i - RM_i) \\ & s.t., \\ & \quad \sum_{i=1}^{n} a_{ij} X_i \leqslant b_j j \in \{1,2,\ldots,M\}, \\ & \quad X_i \leqslant D_i i \in \{1,2,\ldots,n\}. \end{aligned} \tag{1}$$

Where X_i is the decision variable that indicates the amount of production of product i in the enterprise, OP_i and RM_i are the outsourcing cost and the raw material cost, respectively. D_i indicates the demand of product i. The total capacity of resource j in the