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A modified particle swarm optimization for aggregate production planning



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ABSTRACT

Particle swarm optimization (PSO) originated from bird flocking models. It has become a popular research field with many successful applications. In this paper, we present a scheme of an aggregate production planning (APP) from a manufacturer of gardening equipment. It is formulated as an integer linear programming model and optimized by PSO. During the course of optimizing the problem, we discovered that PSO had limited ability and unsatisfactory performance, especially a large constrained integral APP problem with plenty of equality constraints. In order to enhance its performance and alleviate the deficiencies to the problem solving, a modified PSO (MPSO) is proposed, which introduces the idea of sub-particles, a particular coding principle, and a modified operation procedure of particles to the update rules to regulate the search processes for a particle swarm. In the computational study, some instances of the APP problems are experimented and analyzed to evaluate the performance of the MPSO with standard PSO (SPSO) and genetic algorithm (GA). The experimental results demonstrate that the MPSO variant provides particular qualities in the aspects of accuracy, reliability, and convergence speed than SPSO and GA.

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1. Introduction

Aggregate production planning (APP) is an important technique in Operations Management. Other essential approaches, such as master production scheduling (MPS), capacity requirements planning (CRP) and material requirements planning (MRP), are closely associated with it. APP is medium-term capacity planning which determines ideal levels of workforce, production, inventory, subcontracting, and backlog over a specific time horizon that ranges from 2 to 12, or even 18, months to satisfy fluctuating demand requirements with limited capacity and resource (Al-E-Hashem, Aryanezhad, & Sadjadi, 2012; Graves, 2002; Stevenson, 2009). As the name suggests, APP solves problems involving aggregate decisions. It determines aggregate capacity level in factories for a given amount of periods, while without determining the quantity of each individual stock-keeping unit will be produced. The level of details makes APP a useful tool for thinking about decisions with an intermediate time frame that is too early to determine production levels by stock-keeping unit and too late to arrange for additional capacity. The goal of APP is normally to meet forecasted fluctuating demand requirements during a specific period in cost-effective manner. Typical costs include the costs of production, inventory, subcontracting, backlog, payroll, hiring, layoff, regular-time, and overtime (Silva, Figueira, Lisboa, & Barman, 2006).

1.1. Literature on APP domain

Many APP models and solutions with various degree of sophistication have been introduced since early 1950. The pioneers of the field, Holt, Modigliani, and Simon (1955) and Holt, Modigliani, and Muth (1956), initially revealed the importance and obstacles of this domain, and focused on the resolution of the aggregate planning problem. They formalized and quantified an aggregate problem by using a quadratic approximation to the criterion function involving costs of inventory, overtime, and employment. They also calculated a generalized optimal solution of the problem in the form of a linear decision rule, commonly known as the LDR model. The proposed approach was applied to a paint factory to generate a production plan by using a quadratic approximation to the actual operational costs of the factory. Hanssmann and Hess (1960) developed a model based on the linear programming approach using a linear cost structure of decision variables. It focused on the resolution that minimizing the total cost of regular payroll and overtime, hiring and layoffs, inventory and shortages incurred

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during a given planning horizon. Lanzenauer and Haehling (1970) extended the model of Hanssmann and Hess (1960) to a multiproduct, multi-stage production system, in which optimal disaggregate decisions can be made under capacity constraints. Rakes, Franz, and James Wynne (1984) presented a chance-constrained goal programming approach to the problem. It is a special case of stochastic programming to production scheduling which incorporates probabilistic product demand. A sophisticated overview of earlier research is given in Nam and Logendran (1992). They compiled the research literature of APP that is consisted of 140 journal articles and 14 books from 17 journals, presenting a classification scheme and summarizing various existing techniques into a framework. The techniques of those researches range from simple graphical methods to more sophisticated search, switching-heuristic and other dynamic methods, can be broadly categorized into two types: those that guarantee an exact optimal solution and those that do not.

In recent decades, depending on more assumptions made and advanced modeling approaches invented, the APP problem has become quite complex and large scale. There is a trend in the research community to solve the large complex problems by using modern heuristic optimization techniques. This is mainly due to the time-consuming and unsuitability of classical techniques in many circumstances.

Paiva and Morabito (2009) proposed an optimization model to support decisions in the APP of sugar and ethanol milling companies. The model is a mixed integer programming formulation based on the industrial process selection and the production lot-sizing model. Also, in their APP real case study, the application of the model results in 12,306 variables, where 5796 are binary and 6902 constraints. Sillekens, Koberstein, and Suhl (2011) presented a mixed integer linear programming model for an APP problem of flow shop production lines in automotive industry. In contract to traditional approaches, the model considered discrete capacity adaptions which originated from technical characteristics of assembly lines, work regulations and shift planning. A solution framework containing different primal heuristics and preprocessing techniques is embedded into a decision support system. Zhang. Zhang, Xiao, and Kaku (2012) built a mixed integer linear programming model which characterize an APP problem with capacity expansion in a manufacturing system including multiple activity centers. They used a heuristic method based on capacity shifting with linear relaxation to solve the problem. Ramezanian, Rahmani, and Barzinpour (2012) considered multi-period, multi-product and multi-machine systems with setup decisions, developed a mixed integer linear programming model for general two-phase APP systems. Due to the NP-hard class of the APP model, they implemented a genetic algorithm and tabu search for solving the model.

In addition to the integer linear programming models of APP problems, more complicated models have also been proposed. Mirzapour Al-E-Hashem, Malekly, and Aryanezhad (2011) addressed a multi-site, multi-period, multi-product APP problem under uncertainty in supply chain, proposed a robust multiobjective mixed integer nonlinear programming model, considering two conflicting objectives simultaneously to deal with the problem. In their research, cost parameters and demand fluctuations are subject to uncertainty, then the problem can transform into a multi-objective linear one, and to be solved as a singleobjective mixed integer programming model applying the LP-metrics method. Adil Baykasoglu and Gocken (2010) presented a fuzzy multi-objective APP model and proposed a direct solution method based on ranking methods of fuzzy numbers and tabu search to solve the model. Sakalli, Baykoc, and Birgoren (2010) discussed an APP model with possibilities for a blending problem in a brass factory. Their possibilistic linear programming model is solved by fuzzy ranking concept relaxed by using 'Either or'

constraints. The approach successfully solved the multi-blend problem for brass casting and determines the optimum raw material purchasing policies.

1.2. Literature implemented PSO on various fields

Over the past decade, a number of computational swarm-based systems have been developed. Some of them become very popular optimization techniques in many domain researches soon afterwards. One is particle swarm optimization (Kennedy & Eberhart, 1995a), abbreviated as PSO. PSO originated from bird flocking models and has become an exciting new research field still in its infancy compared to other paradigms in artificial intelligence.

Baltas, Tsafarakis, Saridakis, and Matsatsinis (2013) introduced a PSO variant to a service design and diversification problem. They designed and implemented genetic algorithm and PSO to statedpreference data derived from conjoint consumer preferences for service attributes in a retail setting. Their method has valuable implications for managers aiming to improve how they design their services. Tsafarakis, Saridakis, Baltas, and Matsatsinis (2013) presented a new hybrid PSO approach to design an optimal industrial product line. The hybrid PSO searches for an optimal product line in a large design space which consists of discrete and continuous design variables. The approach illustrated through an application to a simulated dataset of industrial cranes. It also yielded important implications for strategic customer relationship and production management. Ramazanian and Modares (2011) introduced a multi-objective goal programming model for a multi-product multi-step multi-period APP problem in the cement industry. The model was reformulated as a single objective nonlinear programming model. It was solved by using the expanded objective function method and a proposed PSO variant whose inertia weight was set as a function. The simulation comparing with GA in the final showed that PSO gains satisfactory results than GA.

With many successful applications in various domain problems, PSO has shown that it is a considerably promising, efficient and robust technique for practical applications. For examples, PSO had been successfully applied to scheduling problems (Chen, 2011; Liao, Tseng, & Luarn, 2007), game theory problems (Lung & Dumitrescu, 2009; Pavlidis, Parsopoulos, & Vrhatis, 2005), optimization on continuously changing environments (Parsopoulos & Vrahatis, 2001), and detection of periodic orbits (Skokos, Parsopoulos, Patsis, & Vrahatis, 2005).

Although there are many applications implemented PSO on various fields, however, we seldom found it applying to the APP field. The reason may be attributed to that PSO was originally introduced for unconstrained and continuous optimization problems. Its operations imply the existence of unrestricted and continuous explorations in search space, which may have limited ability in dealing with constrained integral APP problems. Afterwards, during the process of optimizing APP problems, we did find that PSO gains limited ability and inefficiency in dealing with the problems, especially a large constrained integral APP problem with plenty of equality constraints. Therefore, in response to ease these shortcomings, we developed an effective modified mechanism for PSO, which introduced the concept of sub-particles, a particular coding principle, and a modified operation procedure of particles to the update rules to regulate the search processes for a particle swarm. And we found that the MPSO variant gains satisfactory performance in the aspects of accuracy, reliability, and convergence speed than SPSO and GA. Also, there are advantages of the MPSO to the APP problem solving than other approaches: (i) only a few parameters need to be adjusted; (ii) be able to speed up the convergence to the optimal solution; (iii) can be applied to optimize most of APP problems.

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