Computers and Operations Research 91 (2018) 21–36

Contents lists available at ScienceDirect

Computers and Operations Research

journal homepage: www.elsevier.com/locate/cor

A bi-objective aggregate production planning problem with learning effect and machine deterioration: Modeling and solution

Esmaeil Mehdizadeh[a], Seyed Taghi Akhavan Niaki[b,*], Mojtaba Hemati[a]

[a] Faculty of Industrial and Mechanical Engineering, Qazvin Branch, Islamic Azad University, Qazvin, Iran
[b] Sharif University of Technology, P.O. Box 11155-9414 Azadi Ave, Tehran 1458889694, Iran

ARTICLE INFO

Article history:
Received 16 November 2015
Revised 30 October 2017
Accepted 1 November 2017

Keywords:
Aggregate production planning
Bi-objective optimization
Subpopulation genetic algorithm
Learning effect
Machine deterioration

ABSTRACT

The learning effects of the workers and machine deterioration in an aggregate production planning (APP) problem have not been taken into account in the literature yet. These factors affect the performance of any real-world production system and require attention. In this paper, a bi-objective optimization model is developed for an APP problem with labor learning effect and machine deterioration. The first objective of this model maximizes the profit by improving learning and reducing the failure cost of the system. The second objective function minimizes the costs associated with repairs and deterioration, which depend on the failure rate of the machines in the production periods. The aim of this article is to obtain appropriate levels of production rates in regular and overtimes, inventory and shortage levels, workers' hiring and firing levels, and the quantities of the products that are subcontracted. To demonstrate the validity of the proposed mathematical formulation, the multi-objective model is converted into a single-objective model using the fuzzy goal programming method, based on which computational experiments are performed on a set of random small-sized instances solved by the LINGO software. As the problem is shown NP-hard, a subpopulation genetic algorithm (SPGA) is proposed to solve large-size problems. In addition, two other meta-heuristics called weighted sum multi-objective genetic algorithm (WMOGA) and non-dominated sorting genetic algorithm II (NSGA-II) are utilized to solve a set of benchmark problems, in order to validate the results obtained and to assess the performance of the SPGA. For tuning the parameters, the Taguchi method is proposed in order to obtain high-quality solutions. Finally, the performances of the proposed algorithms are statistically compared together. The computational results show that SPGA compared to the other algorithms has a better performance in terms of some multi-objective optimization criteria.

1. Introduction

Aggregate production planning (APP) is an operational activity that provides an aggregate plan for production processes over a medium time range. The aim of APP is to set overall output levels in order to face with fluctuating or uncertain demands as well as to provide supply. It presents the optimal production quantity and production time of goods, parts, materials and other resources to minimize the total operational cost of the organization. In APP, the number of items to be outsourced, the amount of overtime labor, the numbers of workers to be hired and fired in each period, and the inventory level to be held in stock and to be backlogged for each period are determined. The primary required inputs for APP consists of information regarding the resources and the available facilities, demand forecast for the planning period, and cost of different alternatives and resources. The costs involve inventory holding, ordering, and production cost through various production alternatives such as subcontracting, backorders, and overtime. Organizational policies considering the utility of the above alternatives are also necessary.

The workers' learning, as well as machine deterioration, has a significant impact on how an aggregated production is planned. These factors affect the performance of any real-world production system and require attention. However, they have not been taken into account in the available models presented in the literature yet. That is why a bi-objective APP model is proposed in this paper to simultaneously consider the effects of labor learning and machine deterioration.

2. Literature review

As a technical level planning, APP attempts to determine the optimal quantity of production, inventory level, workforce, and etc., in each period with regard to some constraints to satisfy uncer-

* Corresponding author.
E-mail addresses: Emehdi@qiau.ac.ir (E. Mehdizadeh), Niaki@Sharif.edu (S.T.A. Niaki).

https://doi.org/10.1016/j.cor.2017.11.001

tain demands of all products (Mirzapour Al-e-Hashem et al., 2011). Based on the number of the objective functions considered in the models proposed in the literature, the APP models can be classified into two categories: (1) single objective function problems and (2) multi-objective function problems. A common objective function in the APP models is the minimization of the total cost of the system. In addition, maximization of service level, minimization of the changing of the workforce level, minimization of the risk, maximization of the profit, maximization of the customer satisfaction is other objective functions considered in the literature.

Over the last decades, numerous single-objective APP models have been studied in the literature, where various models have been developed to solve the APP problem. In a survey of models and methodologies for APP presented by Nam and Ogendar (1992), some researchers such as Bitran et al. (1982), Axsater (1986), and Ari and Axsater (1988) employed the hierarchical production planning (HPP) approach. Some other researchers such as Masud and Hwang (1980) and Tabucanon and Majumdar (1989) used a multi-criteria decision-making (MCDM) approach. Moreover, Techawiboonwong and Yenradee (2003) presented an APP for multiple product-types where the worker resource could be transferred to the production lines. They proposed a mathematical model in spreadsheet format, where the actual data were used to test and validate the results obtained using the proposed model. Hossain et al. (2016) used a GA approach for solving a real-world multi-product, multi-period aggregate production planning (APP) problem.

Hung and Hu (1998) solved an APP problem involving multiple products, multiple resources, multiple periods, setup times, and setup costs. If a particular product was to be manufactured in a specific period, then they assumed that each required machine should be set up for that product exactly once during the period. They formulated such production planning problem with setup decisions into the framework of a mixed-integer programming (MIP) problem. They proposed a heuristic algorithm to obtain near-optimum solutions. This algorithm iterates between linear programming solution phases and setup decision computations to solve the difficult MIP problem at hand.

While all the above-mentioned research discussed a single objective APP model which tried to minimize the total cost, other objective functions can also be considered in APP models. In other words, multiple objective functions that conflict each other can be considered in a practical APP model (Wang and Liang, 2004). Wang and Liang (2005) proposed a multi-objective APP model including three objective functions of minimizing the total costs, minimizing the carrying and back ordering costs, and minimizing the changing workforce level in a fuzzy environment. Leung and Chan (2009) developed a multi-objective APP model which attempts to maximize the profit, minimize the repairing costs, and maximize machine utilization regarding different operational constraints. Mirzapour Al-e-Hashem et al. (2012) addressed a multi-objective mixed-integer nonlinear programming model to deal with an APP considering two conflicting objectives as well as the uncertain nature of the supply chain. Sadeghi et al. (2013) implemented a goal programming approach to solve a three-objective optimization problem developed for an APP. Their objectives included minimizing the total costs, minimizing carrying and back ordering costs, and minimizing the rate of changes in workforce level simultaneously. Entezaminia et al. (2016) proposed a multi-objective multi-period multi-product multi-site APP model in a green supply chain considering a reverse logistic (RL) network. In the model, minimizing the total losses and maximizing the total environmental scores of the products were the two objective functions. They demonstrated the trade-off between the conflicting objective functions by a set of Pareto-optimal solutions as generated by the LP-metrics method.

Based on the complexity involved in an APP problem that is usually modeled by a nonlinear mixed-integer programming model and due to NP-hardness of APP, using an exact or a hard-computing method is time–consuming, especially when the problem size increases (Fahimnia et al., 2006; Jiang et al., 2008; Partovi and Seifbarghy 2015). As such, some algorithms such as the hybrid algorithms proposed by Ganesh and Punniyamoorthy (2005) and Mohan Kumar and NoorulHaq (2005) and the Tabu search algorithm suggested by Baykasogluy (2006) and Pradenas and Pe∼nailillo (2004) were implemented to solve APP. Ramezanian et al. (2012) presented a two-stage APP model with the goal of reducing the cost. They utilized a Tabu search and a genetic algorithm to solve their proposed mixed integer linear problem. Mirzapour Al-e-hashem et al. (2013) used a stochastic programming approach to solve a multi-period multi-product multi-site APP problem in a green supply chain for a medium-term planning horizon under the assumption of demand uncertainty. Their proposed model was a nonlinear mixed integer programming that was converted into a linear programming by employing some theoretical and numerical techniques. Wang and Yeh (2014) utilized a modified particle swarm optimization (MPSO) algorithm to solve an APP problem. This algorithm introduces the idea of sub-particles, a particular coding principle, and a modified operation procedure of particles to update rules in order to regulate the search processes for a particle swarm. They evaluated the performance of their MPSO with the ones of a standard PSO (SPSO) and a genetic algorithm (GA). Silva and Marines (2014) proposed a fuzzy goal programming model (FGP) for a real APP problem with a Brazilian sugar and ethanol milling company that takes into account uncertainty involved in APP. Mehdizadeh and Atashi-Abkenar (2014) developed a mixed integer linear programming (MILP) model for an integrated APP problem in a closed-loop supply chain with preventive maintenance. They implemented a genetic algorithm (GA), harmony search (HS) and vibration damping optimization (VDO) algorithm for solving the problem. Chakrabortty et al. (2015) investigated the use of a particle swarm optimization (PSO) for an APP based on the potential environment. They offered a multi-product multi-period APP problem formulated as an integer linear programming. Modarres and Izadpanahi (2016) developed a robust optimization approach for an APP by focusing on energy saving to consider energy planning, demand, and production capacity simultaneously. That is why a meta-heuristic algorithm is proposed in the current paper to solve the APP problem with workers' learning effect and machine deterioration.

Among the meta-heuristics proposed to solve multi-objective APP problems, one can refer to the widely used Pareto-based non-dominated sorting genetic algorithm called NSGA-II, which is an extended version of the genetic algorithm (GA) proposed by Deb et al. (2002). This algorithm can be used in different scopes of operational management. In addition, the harmony search algorithm (HSA), as a music-inspired algorithm, is simple in concept and has just a few parameters. It is easy to be implemented and has been successfully applied to different problems including the mechanical structure design (Lee and Geem, 2004), pipe network optimization (Geem et al., 2002), and inventory models (Taleizadeh et al., 2011). Ramyar et al. (2017) presented a multi-objective model for a multi-product, multi-site APP problem of a supply chain. They utilized a Pareto-based multi-objective harmony search algorithm (MOHSA) to solve it. To demonstrate the performance of the presented algorithm, they used NSGA-II and NRGA to solve the problem as well.

A review of the literature on APP reveals that the learning effect of the workers has not been considered in the presented models yet. In addition, machine deterioration has not been taken into account. These factors affect the performance of any real-world pro-