Computers & Industrial Engineering 113 (2017) 602–613

Contents lists available at ScienceDirect

Computers & Industrial Engineering

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

Multi-stage multi-product multi-period production planning with sequence-dependent setups in closed-loop supply chain

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ARTICLE INFO

Keywords:
Production planning
Closed-loop supply chain
Sequence dependent setup
Rolling horizon
Simulated annealing algorithm
Flow shop

ABSTRACT

This paper studies multi-stage multi-product multi-period capacitated production planning problem with sequence dependent setups in closed-loop supply chain. In this problem, manufacturing and remanufacturing of each product is regarded consequently, and in addition to the setup for changing products, a setup while changing the processes is needed. To formulate the problem, a mixed-integer programming (MIP) model is presented. Four MIP-based heuristic named non-permutation and permutation heuristics, using rolling horizon are utilized to solve this model. Moreover, a simulated annealing algorithm using a heuristic to provide initial solution is developed to solve the problem. To calibrate the parameters of the proposed simulated annealing algorithm, Taguchi method is applied. The numerical results indicate the efficiency of the proposed meta-heuristic algorithm against MIP-based heuristic algorithms.

1. Introduction

The management of return flows has been increasingly paid attention by researchers during last two decades. Contrary to traditional supply chain where the products flow from manufacturers to customers, in closed-loop supply chain, the manufacturers often collect the used products from the customers and reprocess them for a higher profit or reduce the negative environmental effects.

In published literature in the field of closed-loop supply chain, numerous studies have been made and a large number of models have been developed. Stindt and Sahamie (2014) classified the quantitative studies of closed-loop supply chain in four groups of network design, production planning, product returns management, and forecasting. In closed loop supply chain there are different options for recovery such as reuse, repair, remanufacturing, refurbishing, retrieval and recycling; in which remanufacturing that transforms the defective products into an as-good-as new condition is attractive in terms of environmental concerns, legislation and economics (Stindt & Sahamie, 2014). Ilgin and Gupta (2010) categorized the studies in the field of remanufacturing into six groups of forecasting, production planning and scheduling, capacity planning, inventory management, and uncertainty effect.

Production planning in hybrid systems which includes manufacturing and remanufacturing is an important issue in closed-loop supply chain, the purpose of which is the optimum usage of production resources to produce the products according to the demand in the planning horizon. In these problems, remanufacturing is used as well as manufacturing to satisfy demands.

Production planning has been paid attention by researchers since early twentieth century. It was first studied by Wagner and Whitin (1958); they solved a single-stage, single-product, multi-period uncapacitated production planning using a forward dynamic programming. Research in the field of production planning is vast and contains numerous topics; one of the most complex of them is lot sizing. Bahl, Ritzman, and Gupta (1987) classified the lot sizing problems into four categories according to the number of levels and resource capacity. Karimi, Fatemi Ghomi, and Wilson (2003) classified the lot sizing problems into the capacitated lot sizing problem (CLSP), the economic lot scheduling problem (ELSP), the discrete lot sizing and scheduling problem (DLSP), the continuous setup lot sizing problem (CSLP), the proportional lot sizing and scheduling problem (PLSP) and the general lot sizing and scheduling problem (GLSP), all of which are NP-hard in case of capacity constraint. Production planning or specifically lot sizing with remanufacturing is the focus of the current study.

Lot sizing in hybrid systems including manufacturing and remanufacturing is considered in many studies of closed-loop supply chain. First, Richter and Weber (2001) developed reverse Wagner-Whitin model for hybrid lot sizing problem, and proved that in the case of constant cost and demand, the optimal policy is starting remanufacturing before exchanging to manufacturing process. Yang, Golany, and Yu (2005) considered an uncapacitated problem with concave cost functions, and cited that even in the case of constant costs, the problem would be NP-hard. This problem is modelled as a network

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http://dx.doi.org/10.1016/j.cie.2017.09.040
Received 27 March 2016; Received in revised form 12 March 2017; Accepted 23 September 2017
Available online 25 September 2017
0360-8352/

flow type formulation, and a polynomial time heuristic has been utilized to solve it. Teunter et al. (2006) considered two schemes for setup cost: a common setup cost for manufacturing and remanufacturing for single production line; or different setup cost for dedicated lines. In case of common production line, an exact polynomial time dynamic programming algorithm is presented. For both cases, heuristic methods as extensions of Silver-Meal method, Least Unit Cost method, and Part Period Balancing method have been proposed. Li, Chen, and Cai (2006) studied a multi-product problem with demand substitution, in which a higher quality product can satisfy the demand of a lower quality one, in case of large amounts of returned products, a dynamic programming method has been proposed to obtain a near optimal solution. Pan, Tang, and Liu (2009) investigated the problem with disposal of returned products. This problem has been analysed under different scenarios and solved using dynamic programming algorithm. Pineyro and Viera (2010) and Zhang, Jiang, and Pan (2012) studied the problem with different demands for new and remanufactured products. Zhang, Liu, and Tu (2011) considered the startup cost in the first period among periods with positive production, Genetic algorithm is developed to solve the problem. Corominas, Lusa, and Olivella (2012) focused on overtime, lost demands and the variety of returned products. The proportion of returned products is a nonlinear function of their paid price. To solve the problem, the objective function and constraints have been linearized via piecewise functions. Chen and Abrishami (2014) assumed separate demand for new and remanufactured products and developed a Lagrangian decomposition based method to solve the problem. Li, Baki, Tian, and Chaouch (2014) developed a robust tabu search algorithm to solve the problem and evaluated it using 6480 benchmark instances. Baki, Chaouch, and Abdul-Kader (2014) proposed a new MIP formulation for the problem with better bound when integrality constraints are relaxed. They developed a dynamic programming based heuristic with some improvement schemes to solve the problem. Lee, Doh, and Lee (2015) studied a capacity and lot sizing problem and developed two linear programming relaxation based heuristics to solve it. Sifaleras and Konstantaras (2015) proposed general variable neighbourhood search (GVNS) algorithm to solve the problem. Parsopoulos, Konstantaras, and Skouri (2015) introduced some modification in the problem formulation and developed a modified differential evolution (DE) algorithm to solve the problem. Jing, Li, Wang, and Deng (2016) considered the problem with backorder and multiple factories to produce new products, remanufactured products, or both. They presented three models to consider different cases and proposed an approach based on self-adaptive genetic algorithm with population division (SAGA-PD) to solve the problem.

The existing uncertainties in closed-loop supply chain which are due to the amount and quality of returned products, the reprocessing time, effective yield and customer demand, incur the planning complexity (Stindt & Sahamie, 2014). Some of these uncertainties especially uncertain quantity and quality of returned products are considered in lot sizing with remanufacturing. Li, Li, and Saghafian (2013) considered the stochastic and price-sensitive amount and the uncertain quality of returned products. Kenne, Dejax, and Gharbi (2012) regarded two machines for manufacturing and remanufacturing with stochastic failures and repairs. Mukhopadhyay and Ma (2009) considered the uncertainty of demand and returned products' quality. Shi, Zhang, Sha, and Amin (2010), Wei, Li, and Cai (2011), Naeem, Dias, Tibrewal, Chang, and Tiwari (2013) and Hilger, Sahling, and Tempelmeier (2015) considered the uncertainty of the amount of returned products and demand. Dong, Lu, and Han (2011) focused on uncertainty of returned products' quality, the time of returning, and reprocessing time. They regarded inspection, recovery, and assembly operations for remanufacturing. Macedo, Alem, Santos, Junior, and Moreno (2016) considered the uncertain demand, return rate and setup cost due to quality of returned products. They used a two-stage stochastic programming model to deal with the uncertainties.

One of the most common complexities in lot sizing problems is setup time, which is usually associated with changing tools and cleaning machines. Sequence-dependent setup time is one of the most complex setups where the setup time of current product depends on the previous scheduled product. Sequence-dependent setup time in lot sizing problem for single machine has been considered by many researchers; Gupta and Magnusson (2005) developed a heuristic method to solve the lot sizing problem with sequence dependent setups and proposed a procedure to achieve a lower bound for the problem. Almada-Lobo, Klabjan, Antónia carravilla, and Oliveira (2007) proposed two linear mixed-integer programming (MIP) models for CLSP with sequence dependent setup time and cost, and developed a five-step heuristic approach to solve the problem. Kovács, Brown, and Tarim (2009) presented a new approach to model the CLSP with sequence dependent setup time; in which they introduced a binary variable to indicate whether a product is produced or not, and consider prespecified efficient sequences. Almada-Lobo and James (2010) proposed a neighbourhood search algorithm to solve the CLSP with sequence-dependent setup time. Menezes, Clark, and Almada-Lobo (2011) studied the problem with non-triangular setups and solved some examples using CPLEX software. James and Almada-Lobo (2011) considered the CLSP with sequence-dependent setup in systems with parallel machines. They proposed an iterative neighbourhood search heuristic based on MIP formulation to solve the problem.

The multi-stage production system with complex setups in lot sizing problem has been studied in recent years. Mohammadi, Fatemi Ghomi, Karimi, and Torabi (2010) proposed a multi-product, multi-period lot sizing problem with sequence dependent setups and setup carry-over in a flow shop. To formulate the problem, for each machine and each period, N (the number of products) setups are considered, and artificial setups from one product to the same one are permitted. They used a rolling-horizon and fix-and-relax heuristics to solve the problem. Mohammadi, Fatemi Ghomi, and Jafari (2011) proposed a genetic algorithm to solve the lot-sizing problem with sequence dependent setups in permutation flow shop. Ramezanian, Saidi-Mehrabad, and Teimoury (2013) considered a flow shop system and modelled the problem more efficiently than Mohammadi et al. (2010) and Mohammadi et al. (2011) using starting and completion time of production. They solved the problem using rolling horizon framework in permutation cases. Mohammadi (2010) and Mohammadi and Jafari (2011) considered the problem in flexible flow shops and developed MIP-based iterative approaches to solve the problem. Ramezanian and Saidi-Mehrabad (2013) considered the problem with uncertain processing times and demand and developed a hybrid simulated annealing (SA) algorithm to solve it. Ramezanian, Sanami, and Nikabadi (2016) studied the problem in flexible flow shop environment and used rolling horizon heuristic and particle swarm optimization algorithm (PSO) to solve the problem. Gómez Urrutia, Aggoune, and Dauzère-Pérès (2014) and Wolosewicz, Dauzère-Pérès, and Aggoune (2015) considered the job shop systems and assumed that schedule of processing products are predetermined. Although the sequence dependent setups have been considered in many lot sizing studies, none of them consider remanufacturing.

Considering the real characteristics such as multi-stage production system and complex setups like sequence dependent setup and setup carry-over makes the lot sizing problem more complex in terms of modelling and solving, but multi-stage production system with complex setups is not considered in the previous studies of closed loop supply chain. Therefore, the motivation for this study is developing a more comprehensive model considering the multi stage system with complex setups including sequence dependent setup and setup carry-over, and remanufacturing in order to implement in complicated industries such as auto car factory.

To the best knowledge of our literature review, the conducted studies of lot sizing in closed loop supply chain considered a single stage production system with simple setups. Therefore, the main contribution of the current study is considering a multi-stage lot sizing problem with sequence dependent setups and setup carry-over in closed loop supply