J Ind Eng Int (2014) 10:60
DOI 10.1007/s40092-014-0060-z

ORIGINAL RESEARCH

Multi-site production planning in hybrid make-to-stock/make-to-order production environment

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Received: 26 May 2013 / Accepted: 18 April 2014 / Published online: 5 June 2014

Abstract Today competitive environment has enforced practitioners and researchers to pay great attention to issues enhancing both production and marketing competitiveness. To do so, it has been obligatory for the firms to consider production side activities while customer requirements are on the other side of competition. In this regard, hybrid make-to-stock (MTS)/make-to-order (MTO) production systems have revealed outstanding results. This paper addresses multi-site production planning of a hybrid manufacturing firm for the first time in the hybrid systems' body of literature. In this regard, a network of suppliers, manufacturers and customers is considered for which a mixed-integer mathematical model is proposed. Objective function of the proposed mathematical model seeks to maximize profitability of the manufacturing firm. Because of computational complexity of the developed mathematical model, a genetic algorithm is developed upon which numerical experiments are reported in order to show validity and applicability of the proposed model.

Keywords Multi-site production planning · Hybrid MTS/MTO · Make-to-stock · Make-to-order · Mathematical programming

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Introduction

Upon the level of product customization, production systems might be divided into two major categories including make-to-stock (MTS) and make-to-order (MTO). MTS production systems are mainly structured upon forecasts of demand mix and volumes. Therefore, these systems generally yield lower level of customization by processing standard products (Lee and Tang 1997). In contrary, production of an MTO product does not initiate unless an order is received. In other words, MTO production is triggered with receipt of an order. Higher level of customization is guaranteed in MTO production, while products are exposed to risk of obsolescence (Hendry and Kingsman 1989). In order to take advantages of two MTS and MTO production systems, hybrid MTS/MTO production systems have recently attracted academicians and practitioners. In a hybrid MTS/MTO production system, a segment of the production line is conducted upon demand forecasts (MTS segment) and the resulted unfinished work-in-process (WIP) inventory is completed through remainder of the line upon the received orders (van Donk 2001). The point which separates MTS and MTO parts of the production line is called customer order decoupling point (CODP). In other words, CODP is the point at which received orders enter the production value chain and are linked to unfinished WIPs. According to the concept of CODP, Fig. 1 shows different kinds of production systems.

So far, numerous research instances have been published in the field of hybrid MTS/MTO, which are applied for a single production facility. However, in today's production environments, firms ought to consider diverse market needs and supplier relationships in their production planning systems must be considered. Also they may have multiple factories which are linked to each other to produce a variety of products. Hence firms need to apply the system that considers these assumptions and competitiveness to attract customers. In this

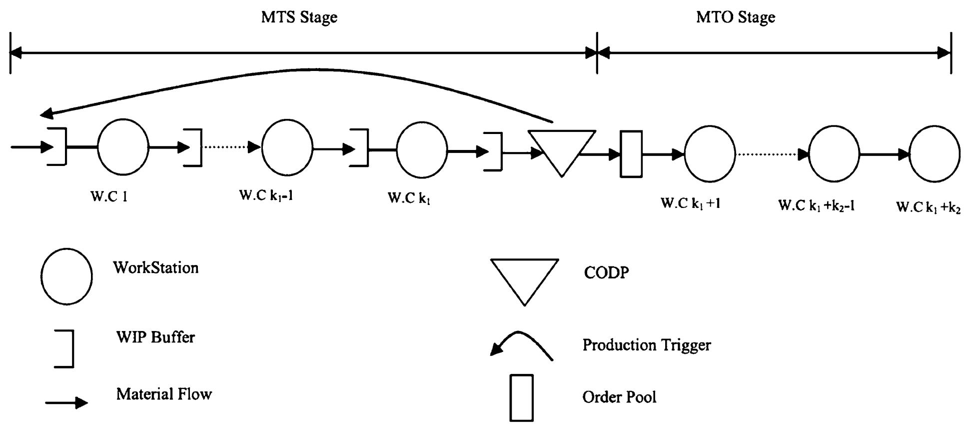

Fig. 1 A schematic of production line in a hybrid MTS/MTO system (Kalantari et al. 2011)

work we consider a multi-site firm which fulfills production of various products and each factory is linked to suppliers and products are held in central warehouse. To be responsible in this firm we apply hybrid MTS/MTO policy that produces parts of the specific products with MTS policy, then stores these products in the central warehouse while customer orders are received. The differentiation of our work is met through considering the multi-site production planning with customers and suppliers relationships. In addition, we assume that CODP point of the firm is not located within the factories, but it is located between the factories that make standard products and the factories of custom products. The considered system is elaborated more in "Proposed model". It is assumed that the considered firm is able to deliver three kinds of products; (a) standard products upon their forecasted demands (family of MTS products), (b) partially customized products by adding options to the standard products (family of MTS/MTO products), and (c) fully customized products (family of MTO products). In the proposed system, the forecasted demands of the MTS products are first satisfied, then it is evaluated whether to accept or reject the coming MTS/MTO and MTO orders with their relevant due dates.

Remainder of the paper is structured as follows. In the next section, we review related works on hybrid MTS/MTO production planning and multi-site production planning. "Proposed model" represents the proposed model of multi-site hybrid MTS/MTO system. In "Solution methodology" and "Numerical experiments", solution methodology and conducted experimental results are presented, respectively. Finally, "Conclusions and future research directions" provides conclusions and directions for the future research.

Literature review

The first academic work about the hybrid MTS/MTO systems was done by Williams (1984). He considered a single-stage system with probabilistic demands, and tackled the problem using queening theory. Adan and van der Wal (1998) considered a production facility which processed pure MTS and pure MTO products, for which system performance was studied when MTO products were added to the production line. Arreola-Risa and DeCroix (1998) addressed partitioning decision in a shop with both MTS and MTO products. They decided to deliver a product upon MTS policy or MTO policy with respect to their production costs. Other instances of such problem are found in Mu (2001) and Tsubone et al. (2002). Gupta and Benjafar (2004) introduced the concept of DD policy in order to take advantages of MTS and MTO policies to enhance flexibility and responsiveness. Soman et al. (2006) focused on the operational issues of the hybrid MTS/MTO production system by optimizing lot sizes of the MTS, MTO and MTS/MTO products. Their model was devoted to the scheduling problem of the hybrid production systems with the objective function of minimizing the total cost of holdings and setups. Jiang and Geunes (2006) considered due date setting problem which arose in the MTS/MTO production facilities, since it is one of the main issues related to the customer orders. In this regard, they adopted MTS policy for the fast-moving (standard) products and the MTO policy for the slow-moving (customized) products. Chang et al. (2003) developed a heuristic algorithm for job release in a wafer fabrication industry. In another different research field, Zarepour et al. (2009) developed a Fuzzy TOPSIS-Analytic Hierarchical Process (AHP) to determine partitioning of MTS, MTO and MTS/MTO products. However, the assumptions of this model are too complex and not applicable in the real-world environments. Kalantari et al. (2011) developed a novel decision support system that used the DD advantages in their production system in one factory in order to cope with the acceptance/rejection decision. Their developed model also tackled pricing and due date setting of the coming accepted orders. Kerkkanen (2007) applied his model in the steel rolling mill and claimed that in the other works researchers tend to go from the MTS strategy to the MTO strategy, but in this work, he went from MTO policy to MTS/MTO policy that led to large setup costs while being tractable in small size of products. Kober and Heineke (2012) studied a hybrid system with two families of products; MTS and MTO, from which former's demand was assumed constant and the latter's demand was uncertain. Also they defined the ratio of partitioning of customer orders in MTS and MTO families using a hybridization of Pareto-Law and Base-Surge. Zarepour et al. (2008), in another paper, focused on the threats and opportunities that influenced the firm and proposed a hybrid model of AHP and SWOT to partition the coming orders into MTS and MTO product families. Rafiei and Rabbani (2011) proposed a fuzzy ANP structure to locate the CODP of every family of coming orders. With respect to the multi-site production planning, Safei et al. (2010) considered production planning of a multi-site manufacturing firm using an integrated simulation-mathematical modeling approach to cope with the problem of production–distribution model found in Gnoni et al. (2003) and Lee and Kim (2002). Nikisha et al. (2012) proposed a multi-site multi-product model for the factories with assembly line production. They used a Lagrangian decomposition method to solve the considered problem. Georgios and Puigjaner (2009) developed a scheduling model for the multi-site production areas, and used mixed-integer linear programming model to solve this problem. The back orders are considered in this paper. Their developed model had too many constraints, leading to intractability for those organizations which adopted global production–distribution systems. Terrezas-Morano et al. (2011) proposed a multi-period multi-site production planning that considered sequence-dependent jobs with multiple markets and warehouses. They also applied Lagrangian decomposition method to cope with complexity of the developed model.

Proposed model

We construct a multi-site production planning model to determine manufacturing plan for a network of multiple firms. To be successful in today's competitive market, we applied a hybrid MTS/MTO strategy in our model. Also we considered suppliers, manufacturers and customers in our model to raise its adaptability in the real environments. The considered production system includes three families of products including MTS products, MTO products and MTS/MTO products. The reason for choosing product families for MTS/MTO products is that these products are usually classified into product families according to the similarities in their process routes or their semi-finished products in hybrid MTS/MTO production environments. Formation of product families facilitates production planning and control. The main characteristic of this model is considering different relationships between suppliers and customers through a network of multi-site production systems. Figure 2 depicts network structure of the proposed model and the relationships between factories and their suppliers as well as the customer markets.

We assume that our model consists of three factories processing MTS, MTO and MTS/MTO products, each of which has dedicated warehouses to keep raw materials and WIP inventories. Suppliers 1 and 2 supply raw materials to Factories 1, 2, and Supplier 3 supplies raw materials to Factory 3. Also the central warehouse in the considered production network is taken into account to store finished products. In our model, MTS products are made in Factory 1 and customers' demands are responded from the stocked products of Factory 1 in the central warehouse. Demands for MTS products are forecasted by the marketing department. To the best of our knowledge, it is the first paper which assigns the CODP of the MTS/MTO products in the warehouse of factory instead of any stages of the production line. In other words, customer orders are accomplished using the finished goods inventory of Factories 1 and 2 in the case of orders received from the customers (Fig. 2). Also we assume that MTO products are only processed in Factory 2. Moreover, two customer segments are considered. The developed model first satisfies demands of the MTS products, then evaluates market orders and accepts some of those with respect to their profitability and production capacity. It is noted that the proposed model have some similarities with the one presented in Kalantari et al. (2011). The constraints which model accepted amounts of orders in different periods are similar to the ones developed in Kalantari et al. (2011). However, the proposed model in this paper is completely distinct from that of Kalantari et al. (2011). Their developed model corresponded to a manufacturer producing MTS/MTO and MTO products with prioritized customers and orders, while our developed model include MTS, MTO, and MTS/MTO products in a three-echelon supply chain. Having following assumptions considered, a mixed-integer programming is developed as follows.

Assumptions

Here for simplifying the model and considering its characteristics, assumptions of the model are presented as follows.

- Planning horizon consists of T planning periods;
- The model consists of multi-site and hybrid MTS/MTO production system that maximizes responsiveness for needs of two markets that interact with them;

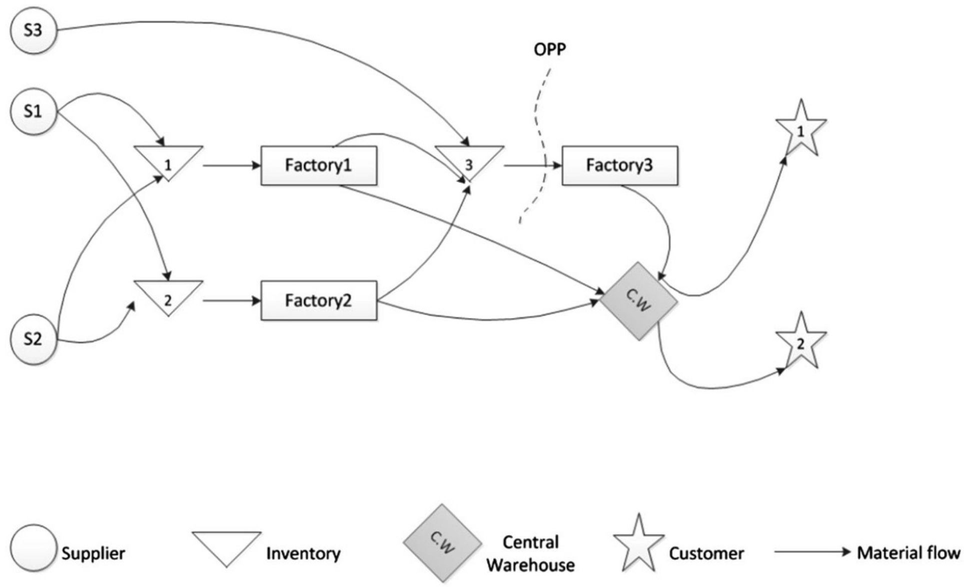

Fig. 2 The proposed structure of the model

- The distances among customers, factories and procurements are neglected in the network to simplify the model;
- This model includes three suppliers, three factories and two customer markets;
- Factories 1 and 2 make the MTS products and WIPs according to the forecasted demands, while Factory 3 completes MTS/MTO orders and accomplishes MTO orders in the case of order acceptance. Thus, Factory 3 aims to enhance competitiveness of the firm in order to have a higher level of responsiveness;
- Raw materials of Factories 1 and 2 are fed through Suppliers 1 and 2. Supplier 3 feeds Factory 3 to complete the orders;
- Two customer markets are considered, and every customer in each markets have the same priority to accept or reject their orders, since every customer could play an important role in the market;
- Purpose of the firm is firstly responding to the forecasted demands of MTS products, then accepting/rejecting orders to maximize the profitability according to the capacity of the factories;
- Each factory has various resources to produce products;
- Setup times between resources are not considered in this model;
- Holding cost of raw materials and final products are taken into account in the proposed model;
- Shortage is not allowed;
- Initial inventories are zero;
- Capacity of the resources consists of capacity in regular working time and capacity in working overtime.

Parameters and decision variables

The following notation will be used throughout the paper.

Indices

$i = \{1, 2, \ldots, I_1\}$	Index of MTS products
$i = \{I_1, \ldots, I_2\}$	Index of MTS/MTO products
$i = \{I_2, \ldots, I_3\}$	Index of MTO products
$j = \{1, 2, 3\}$	Index of factory
$s = \{1, 2, 3\}$	Index of supplier
$c = \{1, 2\}$	Index of customer
$r = \{1, 2, \ldots, R\}$	Index of row material
$m_j = \{1, 2, \ldots, M_j\}$	Index of resource (machine)

Parameters

h_{rjt}	The holding cost of raw material type r in factory j from period t to $t + 1$
h_{it}	The holding cost of product type i from period t to $t + 1$
CR_{ijmt}	The cost of producing a product i in factory j with resource m_j in period t in regular time
CO_{ijmt}	The cost of producing a product i in factory j with resource m_j in period t in overtime
PS_{ict}	The price of product i in market place c in period t
PR_{rst}	The price of raw material r via supplier s in period t
RR_{mjt}	The maximum capacity of resource m_j in factory j in period t in regular time (in machine hours)
RO_{mjt}	The maximum capacity of resource m_j in factory j in period t in overtime (in machine hours)

R_{ijm} The amount of resource m_j in factory j that is needed to produce a product i in period t in regular time (in machine hours)

O_{ijm} The amount of resource m in factory j that is needed to produce a product i in period t in overtime (in machine hours)

RMR_{ir} The amount of raw material r that is needed to make the product type i in period t

DD_{ict} Due date of the product type i which is related to customer c

D_{ict} Demand for MTS products type i in period t by customer c

WIP_{it} Demand for WIPs in the CODP point in period t

PRO_{ict} The amount of orders for MTO product i by customer c in period t

$PRSO_{ict}$ The amount of orders for MTS/MTO product i by customer c in period t

Variables

XO_{ijmt} The amount of produced product i in factory j and resource m_j in period t in overtime

XR_{ijmt} The amount of produced product i in factory j and resource m_j in period t in regular time

S_{ijct} Denoting the value of shipment of product i from factory j to central ware house and then to customer c in period t

RM_{jsrt} Denoting the value of raw material sales for factory j from supplier s in period t

IX_{it} Inventory level of product i at the end of period t

IR_{jrt} Inventory level of raw material r in the factory j at the end of period t

$APTSO_{it}$ The value of MTS/MTO product type i in period t which is accepted in previous periods and not completed

$APTO_{it}$ The value of MTO product type i in period t which is accepted in previous periods and not completed

IW_{it} Inventory level of WIPs of MTS/MTO products at the end of period t

y_{ict} 1, if order i by customer c is accepted in period t 0, otherwise

Mathematical model

Here the mathematical model of the proposed network structure is developed as follows:

$$\begin{aligned}\max & \sum_{i=1}^{I_3}\sum_{j=1}^{3}\sum_{c=1}^{2}\sum_{t=1}^{T}(S_{ijct}\times \mathrm{PS}_{ict}) \\ & - \sum_{i=1}^{I_3}\sum_{j=1}^{3}\sum_{m=1}^{M}\sum_{t=1}^{T}(\mathrm{CR}_{ijmt}\times \mathrm{XR}_{ijmt}+\mathrm{CO}_{ijmt}\times \mathrm{XO}_{ijmt}) \\ & - \sum_{s=1}^{3}\sum_{r=1}^{R}\sum_{j=1}^{3}\sum_{t=1}^{T}(\mathrm{PR}_{srt}\times \mathrm{RM}_{jsrt}) - \sum_{i=I_1}^{I_2}\sum_{t=1}^{T}\mathrm{IW}_{it}\times h_{it} \\ & - \sum_{i=1}^{I_3}\sum_{t=1}^{T}(\mathrm{IX}_{it}\times h_{it}) - \sum_{r=1}^{R}\sum_{j=1}^{3}\sum_{t=1}^{T}(\mathrm{IR}_{jrt}\times h_{jrt})\end{aligned} \tag{1}$$

$$\sum_{j=1}^{2}\sum_{m=1}^{M}(\mathrm{XO}_{ijmt}+\mathrm{XR}_{ijmt}+\mathrm{IX}_{i(t-1)}) \geq \sum_{c=1}^{2} D_{ict} \quad i=1,\ldots,I_1,\forall t \tag{2}$$

$$\sum_{j=1}^{2}\sum_{m=1}^{M}(\mathrm{XO}_{ijmt}+\mathrm{XR}_{ijmt}+\mathrm{IX}_{it}) \geq \mathrm{WIP}_{it} \quad i=\{I_1,\ldots,I_3\},\forall t \tag{3}$$

$$\sum_{i=1}^{I_3} R_{ijm}\times \mathrm{XR}_{ijmt} \leq \mathrm{RR}_{mjt} \quad \forall m_j,j,t \tag{4}$$

$$\sum_{i=1}^{I_3} O_{ijm}\times \mathrm{XO}_{ijmt} \leq \mathrm{RO}_{mjt} \quad \forall m_j,j,t \tag{5}$$

$$\begin{aligned}\mathrm{IX}_{it} = \mathrm{IX}_{i(t-1)} + \sum_{j=1}^{3}\sum_{m=1}^{M}(\mathrm{XO}_{ijmt}+\mathrm{XR}_{ijmt}) \\ - \sum_{c=1}^{2}\sum_{j=1}^{3} S_{ijct} \quad \forall t, \\ i=1,..,,I_1,I_2,..,I_3\end{aligned} \tag{6}$$

$$\begin{aligned}\mathrm{IW}_{it} = \mathrm{IW}_{i(t-1)} + \sum_{j=1}^{2}\sum_{m=1}^{M}(\mathrm{XO}_{ijmt}+\mathrm{XR}_{ijmt}) \\ - \sum_{m=1}^{M}(\mathrm{XO}_{i3mt}+\mathrm{XR}_{i3mt}) \\ i=I_1,..,I_2\end{aligned} \tag{7}$$

$$\mathrm{IX}_{i0} = 0 \quad \forall i \tag{8}$$

$$\begin{aligned}\mathrm{IR}_{rjt} = \mathrm{IR}_{rj(t-1)} + \sum_{s=1}^{4}\mathrm{RM}_{rjst} \\ - \sum_{i=1}^{I_3}\sum_{m=1}^{M}\mathrm{RMR}_{ir}\times(\mathrm{XO}_{ijmt}+\mathrm{XR}_{ijmt}) \quad \forall r,j,t\end{aligned} \tag{9}$$

$$\mathrm{IR}_{rj0} = 0 \quad \forall r,j \tag{10}$$

$$\sum_{j=1}^{2} S_{ijct} = D_{ict} \quad i=1,..,I_1,\forall c,t \tag{11}$$

$$\mathrm{IX}_{it} = \mathrm{IX}_{i(t-1)} + \sum_{m=1}^{M} (\mathrm{XO}_{i3mt} + \mathrm{XR}_{i3mt}) - \sum_{c=1}^{2} S_{i3ct} \quad i = I_1, .., I_2, \forall t \tag{12}$$

$$\mathrm{IW}_{i0} = 0 \quad i = I_1, .., I_2 \tag{13}$$

$$\sum_{s=1}^{4} \mathrm{RM}_{rjst} \geq \sum_{i=1}^{I_3} \sum_{m=1}^{M} (\mathrm{XO}_{ijmt} + \mathrm{XR}_{ijmt}) \times \mathrm{RMR}_{irjmt} - \mathrm{IR}_{rjt} \quad \forall r, j, t \tag{14}$$

$$\mathrm{APTSO}_{ict} = \mathrm{APTSO}_{ic(t-1)} + (\mathrm{PRSO}_{ict} \times y_{ict}) - \sum_{m=1}^{M} (\mathrm{XO}_{i3mt} \times O_{i3mt} + \mathrm{XR}_{i3mt} \times R_{i3mt}) \quad i = I_1, .., I_2, \forall c, t \tag{15}$$

$$\mathrm{APTSO}_{ic0} = 0 \quad i = I_1, .., I_2, \forall c \tag{16}$$

$$\mathrm{APTSO}_{icT} = 0 \quad i = I_1, .., I_2, \forall c \tag{17}$$

$$\mathrm{APTO}_{ict} = \mathrm{APTO}_{ic(t-1)} + (\mathrm{PRO}_{ict} \times y_{ict}) - \sum_{j=1}^{2} \sum_{m=1}^{M} (O_{ijmt} \times \mathrm{XO}_{ijmt} + R_{ijmt} \times \mathrm{XR}_{ijmt}) \quad i = I_2, .., I_3, \forall c, t \tag{18}$$

$$\mathrm{APTO}_{ic0} = 0 \quad i = I_2, .., I_3, \forall c, t \tag{19}$$

$$\mathrm{APTO}_{icT} = 0 \quad i = I_2, .., I_3, \forall c, t \tag{20}$$

$$t \times y_{ict} \leq \mathrm{DD}_{ict} \quad i = I_1, \ldots, I_3, \forall c, t \tag{21}$$

$$\begin{cases} S_{i3cx} = \mathrm{PRSO}_{ict} & \text{if;} \quad (y_{ict} = 1) \wedge \left(\sum_{t'=t}^{x} \sum_{m=1}^{M} (\mathrm{XO}_{i3mt'} + \mathrm{XR}_{i3mt'}) \geq \mathrm{PRSO}_{ict}\right) \\ S_{i3cx} = 0 & \text{otherwise} \end{cases} \quad i = I_1, .., I_2, \; \forall t, c, x \geq t \tag{22}$$

$$\begin{cases} \sum_{j=1}^{2} S_{ijcx} = \mathrm{PRO}_{ict} & \text{if;} \quad (y_{ict} = 1) \wedge \left(\sum_{t'=t}^{x} \sum_{j=1}^{2} \sum_{m=1}^{M} (\mathrm{XO}_{ijmt'} + \mathrm{XR}_{ijmt'}) \geq \mathrm{PRO}_{ict}\right. \\ S_{ijcx} = 0 & \text{otherwise} \end{cases} \quad i = I_2, .., I_3, \; \forall t, c, x \geq t \tag{23}$$

$$\begin{aligned} &\mathrm{XO}_{ijmt}, \mathrm{XR}_{ijmt}, S_{ijct} \geq 0, \text{Integer} \\ &x \geq 1, \text{Integer} \\ &\mathrm{APTO}_{it}, \mathrm{APTSO}_{it}, \mathrm{IR}_{rjt}, \mathrm{IX}_{it}, \mathrm{RM}_{rjst}, \mathrm{IW}_{it} \geq 0 \\ &y_{ict} \in \{0, 1\} \end{aligned} \tag{24}$$

Objective function of the developed model is represented in Eq. (1). It seeks to maximize profitability of the firm with respect to sale amount, and holding costs of raw materials, WIPs and finished products, as well as operational costs. Constraints (2) consider demands for the MTS product family, and describe that their demands are satisfied at the end of each period. Constraints (3) describe that predetermined demands for MTS/MTO products are satisfied at the end of each period. Constraints (4) and (5) explain that the assigned capacity to each factory is not greater than maximum capacity of the machines during that period. Constraints (6), (8) and (12) control levels of MTS, MTO and MTS/MTO product inventories in each factory. Constraints (7) and (13) control levels of WIP inventories of MTS/MTO products, while levels of raw materials in each factory are controlled through Constraints (9) and (10) with respect to every period. Constraints (11) describe that MTS product demands are delivered at the end of each period. Constraints (14) control the assigned amount of raw materials from suppliers at each period. Constraints (15), (16) and (17) control amount of MTS/MTO orders accepted in previous periods, but not yet completed. Constraints (18), (19) and (20) play the same role for the MTO product orders. It is noted that Constraints (15)–(20) are modeled upon the concepts introduced in Kalantari et al. (2011). Constraints (21) ensure adherence to the MTO product due dates, while Constraints (22) and (23) check capacity availability of MTS/MTO and MTO orders in each period in Factory 3, respectively, upon which orders are accepted and delivered to the customers in the relevant due dates. Finally, Constraints (24) define variables of the developed model.

Solution methodology

Because the developed model in "Proposed model" consists of nonlinear constraints, we applied genetic algorithm (GA) to solve our problem. GA is a metaheuristic algorithm which is constructed upon an iterative stochastic searching procedure towards better (near-optimal)

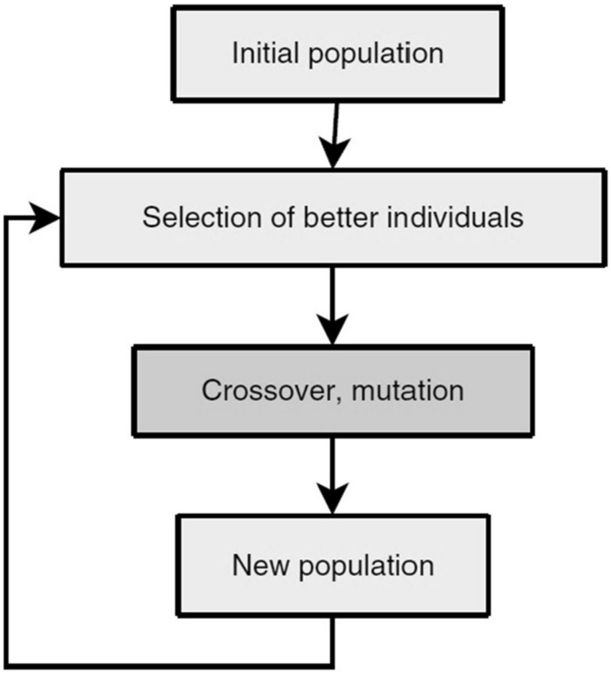

Fig. 3 General steps of the GAs

solutions. This algorithm represents more general approximate solution procedure applicable to a large variety of optimization problems (e.g., in Izadi and Kimiagari 2014; AriaNezhad et al. 2013; and Mariajayaprakash et al. 2013), since it is tailored to solve various optimization problems in diverse research fields. It has been shown that metaheuristics are able to tackle instances of problems that are believed to be hard in general, by exploring usually large solution search spaces of the instances. To do so, these algorithms attempt to reduce effective size of the space and by exploring the space efficiently. Metaheuristics aim at two main purposes; solving problems faster and solving problems of larger size. Moreover, they are simple to encode and flexible to be implemented on diverse categories of optimization problems.

GAs have been introduced by Holland in the 1970s upon the adaptive processes of natural systems. Traditionally, GAs are associated with the use of a binary representation but nowadays one can find GAs that use other types of representations. A GA usually applies a crossover operator to two solutions as well as a mutation operator that randomly modifies individual to promote diversity (Rawlins 1991). Figure 3 shows general steps of the GA.

In order to solve the developed model, we used Optimization Toolbox of MATLAB and applied GA. Upon conducted numerical results, following tunings are selected for the utilized optimization toolbox. Number of population size is considered 100, and creation function is considered constraint dependent. We assigned 0.8 for crossover fraction, and used Equation (24) for reproduction of the elite counts.

Table 1 Sizes of problem instances

Characteristics	Sizes
Number of periods	3
Number of MTS products	1
Number of MTO products	1
Number of MTS/MTO products	1
Number of factories	3
Suppliers	3
Customer markets	2
Number of resources in each factory	2
Type of raw materials	2

Table 2 Parameters of the uniform distributions upon which input data are generated

Parameter	Range	Parameter	Range
h_{rjt}	Uniform (1,3)	R_{ijm}	Uniform (1,3)
h_{it}	Uniform (1,3)	O_{ijm}	Uniform (1,4)
CR_{ijmt}	Uniform (1,5)	RMR_{ir}	Uniform (1,3)
CO_{ijmt}	Uniform (1,8)	DD_{ict}	Uniform (t,3)
PS_{ict}	Uniform (20,60)	D_{ict}	Uniform (20,40)
PR_{rjst}	Uniform (1,2)	WIP_{it}	Uniform (10,20)
RR_{mjt}	Uniform (100,170)	PRO_{ict}	Uniform (30,100)
RO_{mjt}	Uniform (10,45)	PRSO_{ict}	Uniform (10,20)

Table 3 The resulted objective value and CPU time for the considered problem

Problem sizes	Results
Number of integer variables	84
Number of continues variables	84
Number of constraints	138
Average objective function value	6,679
Average CPU time (min)	0.09

$$\text{Elite Counts} = 0.05 * \max(\min(10 * \text{ number of variables}, 100), 40) \tag{25}$$

Also, migration fraction is assumed 0.2 to make the crossover function scattered. The considered stopping criteria are iteration number and penalty function value.

Numerical experiments

In this section, a problem example is considered to show feasibility and applicability of the proposed mixed-integer

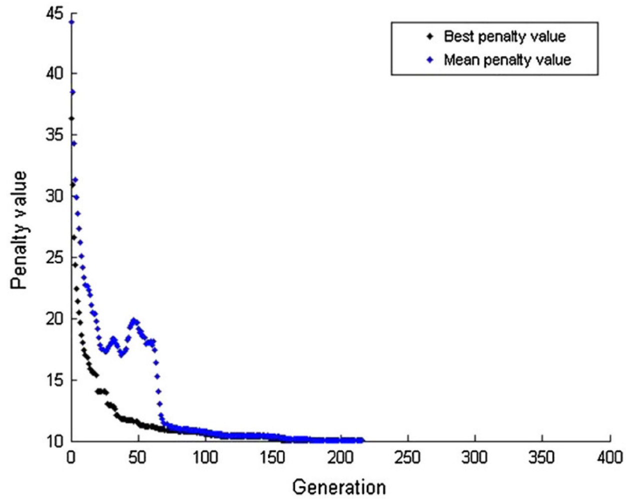

Fig. 4 Best fitness plot of the developed GA

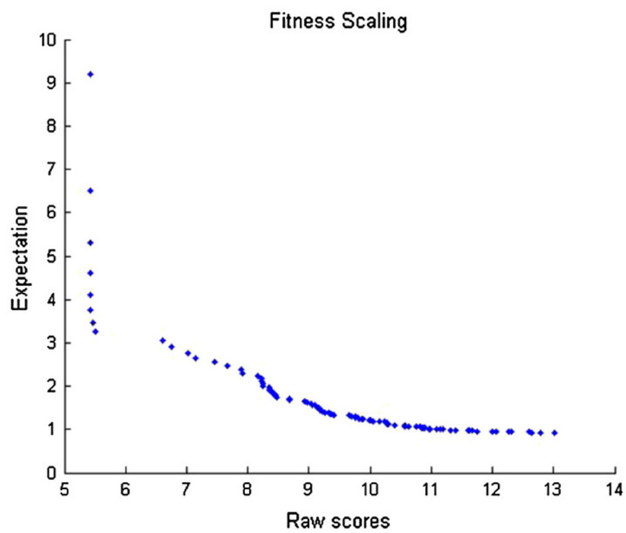

Fig. 5 Scaled fitness (expectation) of the best found solutions in the developed GA

programming model by means of the developed explained GA. Table 1 presents sizes of the input data for the considered problem instance. In this regard, input data of the problem instance are randomly generated. The programming model was implemented in GA Toolbox of MATLAB.

As mentioned earlier, input data of the problem instances are randomly generated upon uniform distributions whose parameters are listed in Table 2.

We generated the parameters based on Table 2, upon which variable matrices were fed to the GA Toolbox. Then the randomly generated problem is solved using the developed GA ten times whose results are shown in Table 3. Figure 4 compares the best found fitness values with the average ones throughout different generations. Moreover, Fig. 5 presents fitness scaling of the best found solutions of the developed GA. In this regard, fitness function of every solution is scaled, upon which its survival probability is calculated. In Fig. 5, “Raw score” represents fitness value of individual solutions, while scaled values are shown by “Expectation”. As it is shown, lower fitness value (raw score) and higher scaled value are obtained.

Conclusions and future research directions

Emerging trends of competitiveness in today’s business environment have attracted actors in different fields of industry and service. To this end, adherence to customer requirements plays an important role, which is attained for the product/service providers using order-based deliveries. In this regard, this paper proposed a mixed-integer programme for production planning of a multi-site production firm. The considered firm produces three kinds of products including MTS, MTO, and MTS/MTO. In the developed model, it was attempted to maximize profit of the manufacturer as well as determining production plan of such products, including acceptance/rejection decisions, order lot sizes and inventory-related issues. To tackle complexity of the proposed model, a GA was developed. Moreover, a problem set was considered to show feasibility and applicability of the proposed mathematical model and validate performance of the developed algorithm.

In order to continue the obtained results of this paper, two research directions are recommended. First, it is highly suggested to broaden scope of this paper to the entire sectors of the supply chain. In this regard determining customer order decoupling points might of considerable importance, since these points play strategic roles in the chain success. Also, it might be interesting to address scheduling problem which is closely related to the problem of this paper.

Acknowledgments The authors would like to acknowledge the financial support of University of Tehran for this research under grant number 8109002/1/07. Also, they are grateful to the reviewers for their valuable, constructive comments.

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