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A Simulation-Optimization Model for Capacity Coordination in Make to Stock/Make to Order Production Environments

Helia Yousefnejad[1], Masoud Rabbani*[1], Neda Manavizadeh[2]

1. School of Industrial Engineering, College of Engineering, University of Tehran, Tehran, Iran
2. Department of Industrial Engineering, Khatam University, Tehran, Iran

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Abstract
Capacity coordination, as the tactical level of hierarchical production planning in hybrid MTS/MTO systems, includes numerous important decisions. In this paper, two of these decisions i.e. finding the best strategy for the acceptance/rejection of incoming orders and determining orders' due dates – are investigated. Also a simulation model is proposed to evaluate the efficiency of the presented mixed integer model. Finally, an industrial case study is considered in a food processing plant to evaluate the proposed framework and conduct suitable sensitivity analysis.

Keywords
Production planning, Make to stock, Make to order, Order Acceptance, Simulation Optimization

* **Corresponding Author, Email:** mrabani@ut.ac.ir

Introduction

Production strategies are mainly categorized into pure Make to Stock (MTS) and pure Make to Order (MTO). Pure MTS systems are used for producing standard items, and their success completely depends on forecasts. The main issues in these systems are inventory management, lot size determination and demand anticipation. Competitive markets, changes of customers' tastes and increasing product variety caused pure MTS systems to considerably lose their efficiency (Hendry & Kingsman, 1989; Van Donk et al., 2001). Despite pure MTS, pure MTO systems are completely customer oriented. MTO products have a large variety according to customer orders. The main issues in these systems are to minimize average delivery time and average order lateness, and to have an effective capacity plan. It is also crucial to have a good strategy for order acceptance/rejection and to achieve a high due date adherence (Dellaert & Melo, 1996; Holweg & Pil, 2001). In recent years, a third production system called hybrid MTS/MTO has been introduced by academicians and practitioners to replace both pure MTS and pure MTO strategies. As illustrated by Halawa et al. (2017), shifting from a pure MTO strategy to a hybrid MTS/MTO production system remarkably improves the system robustness coping with demand volatility and also increases its responsiveness to customers. A hybrid production system introduces a concept called Customer Order Decoupling Point (CODP). Then, the first part of the production process is MTS-based (before CODP) and the remaining part of the process (after CODP) is MTO-based and produces finished goods according to customer specifications. The location of CODP for different types of products is shown in Figureure 1. For pure MTS and pure MTO products, CODP is located at the first and last station, respectively. For MTS/MTO products, CODP may be located in any of the stations depending on where we want to bring customers' desires and specifications in (Mu, 2001). In hybrid production systems, the manufacturer produces generic products and keeps the semi-finished inventory before the CODP (Hax & Meal, 1973; Rafiei & Rabbani, 2012). While an order is accepted by the company, the production process will be continued according to the customer desires.

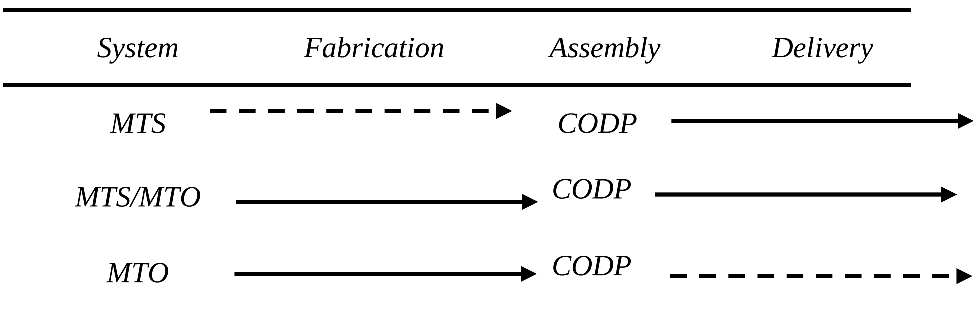

Figure 1. Production strategies; dotted lines show forecast-driven activities and solid lines show order-driven ones, (Easton & Moodie, 1999).

In order to tackle the complexity of hybrid production systems planning and control, Hax and Meal's well-known Hierarchical Production Planning (HPP) is used (Hax & Meal, 1973; Soman et al., 2004; Soman et al., 2006). HPP is formed in three decision making levels, consisting of strategic (long term), tactical (mid-term) and operational (short term) layers. In the first level, product families are formed and the location of CODP are determined for each of them (Van Donk et al., 2001; Zaerpour et al., 2009; Hemmati & Rabbani, 2010; Rafiei & Rabbani, 2011; Rabbani et al., 2014, Ghalehkhondabi & Suer, 2018). The tactical level, which corresponds to capacity coordination, addresses issues such as MTS lot size calculation, the acceptance or rejection determination policy for MTO and hybrid MTS/MTO orders, and the allocation of remaining capacity to the accepted orders (Soman et al., 2004; Rafiei & Rabbani, 2012). In the third level, short term decisions with more details are made including production scheduling and job sequencing (Soman et al., 2006).

In this paper, the second level of the HPP structure is investigated. The main assumptions are as follows:

1) Three different types of products are considered, including pure MTO, pure MTS and MTS/MTO.
2) It is assumed that product family formation is already done in the first level of the HPP (Soman et al., 2004). Also, the location of CODP and the production method for each product family is known.
3) A multistage food processing line is considered.
4) Overtime capacity is allowed in order to tackle capacity shortages.
5) In case of incoming orders, it is possible for the company to offer different combinations of price and delivery time to customers and to negotiate their acceptance/rejection.

The paper aims at presenting a new structure for order acceptance/rejection in a hybrid MTS/MTO context with pure MTS, MTS/MTO and pure MTO products. The proposed simulation- optimization model considers the real world uncertainties related to order arrivals and processing times, and also suggests a price-due date determination approach considering the ability to negotiate with customers over these two variables.

The paper is structured as follows. Section 2 is dedicated to review the related literature. In Section 3, the proposed simulation-mathematical model is elaborated in order to accept/reject incoming orders. Here, the due date and price of each accepted order will be determined. The case study is explained in Section 4 to evaluate the applicability of the developed model. In the end, some concluding remarks and future research directions are presented in Section 5.

Literature Review

Hybrid MTS/MTO production is still a new subject in production planning environment. Williams (1984) is one of the first researchers who studied combined MTS/MTO production systems. He tried to answer some questions including: which kind of products is better to make to stock? What orders (MTO) should be accepted? How the MTS batch sizes should be determined? What is the effect of producing MTO items on the inventory system? He used the queuing theory to minimize the sum of inventory holding costs and the stock-out and setup costs considering stochastic demand, multi-product and multi-machines. There are other researchers who tried to tackle the first question asked by Williams. In order to identify MTS and MTO products, Carr et al. (1993) presented an ABC classification. They have presented a production policy labeled as "No B/C policy", where the B and C items are considered as MTO items and A category items are produced based on forecast. They also used queuing theory to show that the "No B/C policy" results in lower costs than pure MTS strategy. As another research with the same purpose, Zaerpour et al. (2008) applied a fuzzy AHP-SWOT approach to MTS and MTO product partitioning problem. Adan and Vander Wal (1998) also defined another type of classification for MTS and MTO items. They categorized standard products to stock and specific products to order. Chang et al. (2003) developed a heuristic production activity control model to achieve the different production criteria for MTO and MTS in a hybrid production environment. An order release policy and a dispatching control plan have been presented to meet the order due dates and reduce the cycle time of MTO orders. This release plan guaranties that the order will be released at the most appropriate time and the dispatching control facilitates on-time delivery of orders. For MTS products, they developed a capacity planning method to fill the finished product buffer size to an appropriate level based on forecasts.

In recent years, many researchers presented decision making structures for the acceptance or rejection of the incoming orders as one of the important decisions at the tactical level (Gharehgozli et al., 2008; Ebadian et al., 2009; Kalantari et al., 2011; Manavizadeh et al., 2013). In one of these studies, Kalantari et al. (2011) proposed a decision support system for order acceptance/ rejection policies in a hybrid MTS/MTO environment, containing five steps. In the first step customers are prioritized using a fuzzy TOPSIS model. Then, undesirable orders are identified using a rough-cut capacity and rough-cut inventory check. After rejecting the undesirable orders, at the third level, a mixed-integer linear model is applied to price and due date determination of the remaining orders. In the next step a set of instructions are provided for the negotiation process with customers over price and delivery time of the received orders. In the end, it is the customer who has to decide on the acceptance or rejection of company's terms. If the suggestion is acceptable for the costumer, his order is considered as an accepted one. So, the final agreement depends on the question that if the firm's offer satisfies the customers or not.

Hemmati et al. (2010), too, presented a different framework for the acceptance of orders using an MTO production system. Similarly, Rafiei and Rabbani (2012) investigated tactical level decisions, considering an MTS/MTO production. Their proposed structure takes into account issues such as acceptance or rejection policy and due date determination for MTO and MTS/MTO orders, MTS lot size setting and capacity coordination. They also proposed a backward algorithm for the MTS lot-sizing problem. Manavizadeh et al. (2013) proposed a decision making structure for MTO or MTS/MTO orders acceptance/rejection, considering the problem of price and due determination using a mathematical programming model. Besides, bargaining is deemed possible for the consumers.

In one of the most recent papers, Rabbani et al. (2017) developed a multi-stage model to tackle the mid-term issues, including acceptance or rejection of incoming orders, MTS lot sizing and MTO due date determination by taking into account the ability to use overtime and outsourcing capacity. Their presented model also offers alternative items in order to increase firm’s service level.

Makui et al. (2016) determined the aggregate production planning of products with limited expiration date. They suggested a postponement strategy to cope with the uncertain conditions of these products considering three types of production including direct production (MTS), semi-finished production (MTS/MTO) and final assembly (MTO).

Without taking into account the due date, Ghalehkhondabi et al. (2017) considered CODP determination for each product family along with order pricing problem.

According to aforementioned studies, different methods have been proposed to facilitate making basic decisions of hybrid MTS/MTO systems. Most of these are qualitative studies, while the remaining research projects focused on presenting mathematical models. So still there is a lack of a mixed simulation-optimization model in order to check the validation and practicability of the presented models. It seems that applying a simulation model to these kinds of systems to test the proposed techniques and measure their efficiency by creating real world circumstances can be helpful.

Proposed model

This research adopts a simulation approach to the proposed production model in order to demonstrate its applicability and assess its performance. In this regard, a multi stage food processing company with a hybrid MTS/MTO production system is simulated by Arena 10.00 simulation software. The proposed production process has four steps: processing, granulating, packaging and case packing, as shown in Figureure 2.

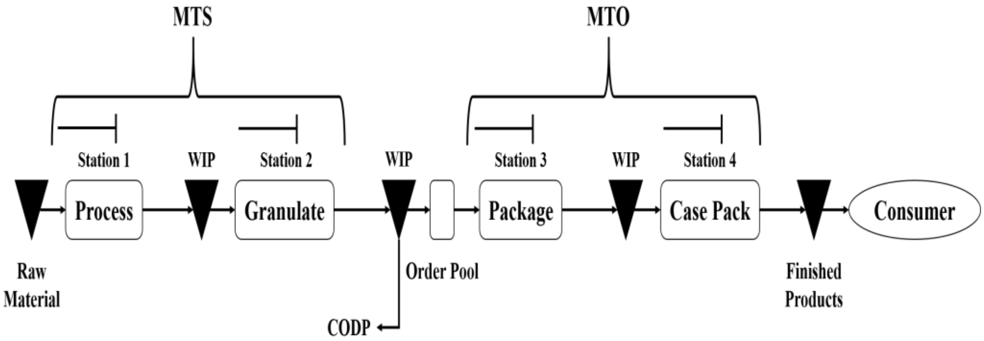

Figure 2. A typical food processing industry

There are some studies which show the compatibility of food industry with MTS/MTO production systems (VanDam et al., 1998; VanDonk, 2001). In a food industry, the packaging stage is considered as an MTO station because in this stage, finished goods are packaged based on the customer`s specifications. Each MTO or MTS/MTO order has a predetermined due date. Due to the risk of losing market share, precise delivery date is an important characteristic for food retailers, hence the firm aims to on-time order delivery. MTS demand is fulfilled from the stock. A sequence-dependent setup is needed when the production plan is changed from one item type to another. The changeover time between products of the same family is less and this is one of the benefits of forming product families.

The paper aims at answering the following questions:Which MTO or MTS/MTO orders should be accepted considering the necessity to make a balance among production capacity, proceeds from the sales and lateness costs? Inappropriate order acceptance policy leads to delay the accepted orders due to capacity shortage.

- How can the best lot size be determined for MTS products?
- How can we form different sets of price and delivery time to attract customers?

In this study, a simulation model is presented to tackle these questions. When an order arrives, the simulation process will be linked to a mathematical model in order to determine its price and due date. Then, the rest of the simulation process is run using the outputs of the mathematical model (Figure. 3).

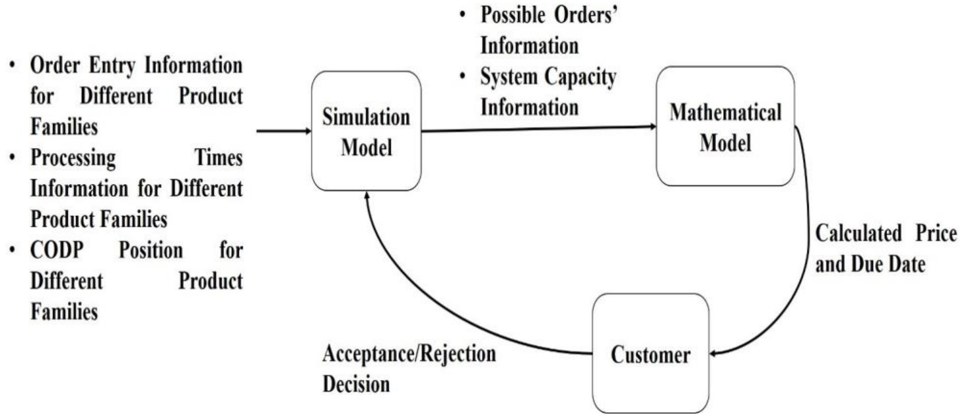

Figure 3. Proposed Simulation-Optimization approach

Simulation Model

In the intended company, MTO orders enter the job pool with a Poisson distribution so the time between entrances follows an exponential distribution. The entity which is moving through the production line is considered as a batch of product and the processing time of each entity on each station consists of both process and setup time. The intended case is a food processing industry in Iran, but due to business privacy issues it was not possible for the authors to present its real information, so the model is run using random data which are generated in Arena software during the simulation process according to determined random distributions. The distribution of the random variables of the model is determined during a six month data collection and analysis of the intended company's demand and process information. Despite the processing times of the MTS products, which are constant and already known, the MTO and MTS/MTO (after CODP) processing times are random variables and follow normal distribution.

In order to simulate the production process of this company, a simulation model is proposed (Figure. 4) using Arena 10.0 software. Arena is an effective tool to simulate the future performance of a system in order to identify opportunities for improvement. Using Arena the best possible way to run a business can be chosen by simulating any possible conFigureuration of the system and comparing their performance with the current situation.

In the presented model a food processing line with four stations is considered. The company produces pure MTS (MTS_1 and MTS_2), pure MTO (MTO_1 and MTO_2) and hybrid MTS/MTO (MTS/MTO_1 and MTS/MTO_2) products. It should be noted that MTS/MTO_1 and MTS/MTO_2 orders are produced using the WIP of MTS_1 and MTS_2 in CODP, respectively. Figureure 4 shows that when orders arrive, if they are negotiable, the negotiation process begins and the due date and price for each order is determined using the mixed integer model presented before. The model is solved using Lingo 8.0 software and the results are linked to the simulation model. After the negotiation, if the customer accepts the terms and if her order was a possible one for the company according to other, previously acceptedorders re, the order is loaded on the job pool with a pre-determined priority. To identify this priority a critical ratio (*CR*) already used by Soman et al. (2006) is applied. Orders with the smallest *CR* should be loaded first. This ratio for each MTO or MTS/MTO order **i** is defined as:

$$CR_i = \frac{DD_i - t_{now}}{remained\ \ work\ \ content}$$

In this model, one product batch is considered as the entity which is moving through the production line so the size of the incoming order should be a multiple of batch size. Here we consider that in a special case, the order size could be a half of the batch size. After producing each product batch, a setup time is required. In order to show this assumption in the Arena model, the MTS/MTO order should wait at CODP until enough number of MTS batches are ready for them. After running simulation for a constant time, the number of unfinished orders (back orders) is evaluated and will be used as a performance measure to compare different situations of the production process.

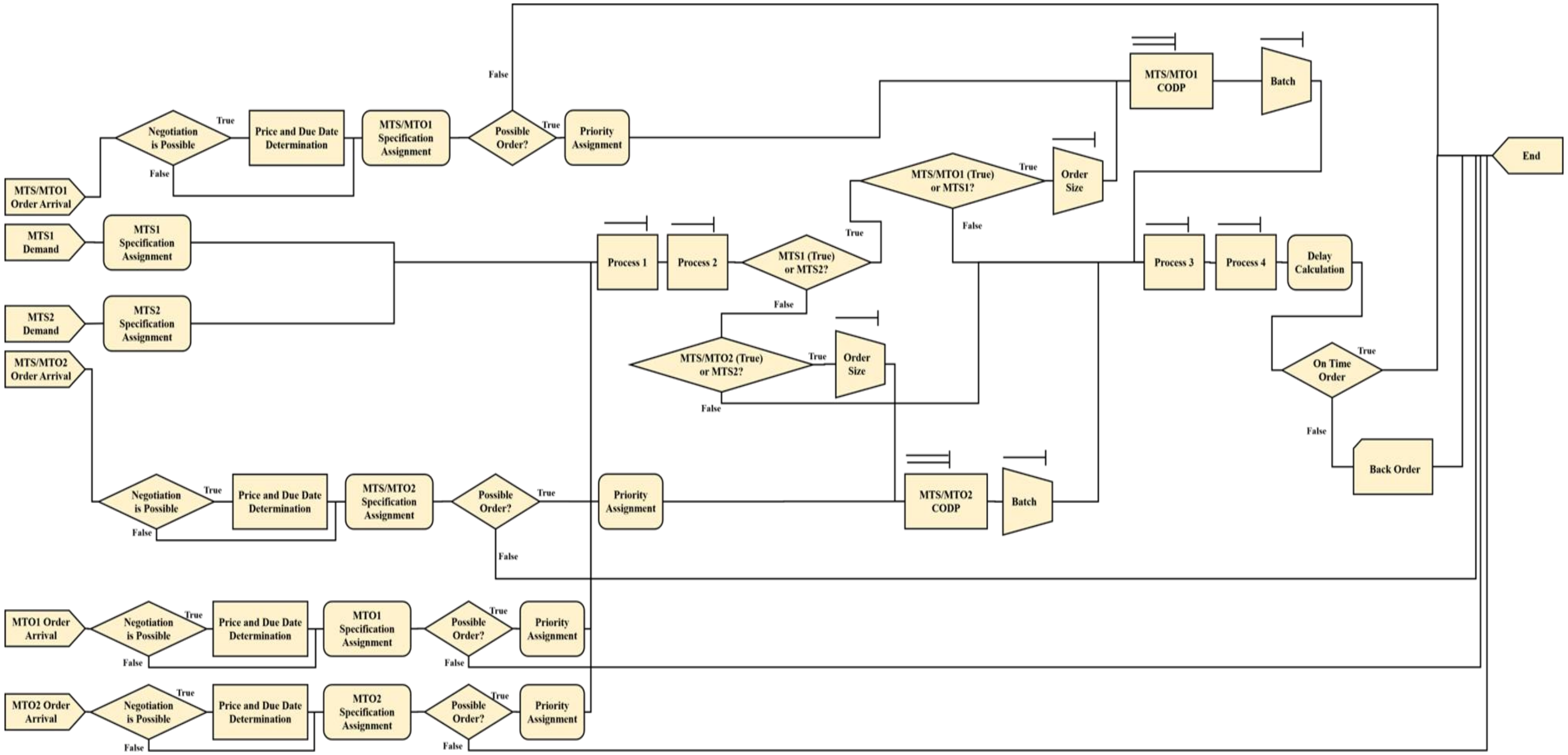

Figure 4. Arena simulation model

Price and due date determination

When an MTO or MTS/MTO order arrives, at first its desirability which depends on the company's criteria such as the customer's loyalty, the quantity of the order and the raw material availability should be evaluated. For desirable orders with negotiable due date, it depends on the negotiator and his expertise to find the best agreement for both the company and the consumer. In the case of our food processing company, it is possible for us to suggest different combinations of due date and price to the customers. This policy helps the company to accept more profitable orders according to its capacity. If there is an order with fixed due date which brings a considerable profit to the company, it is possible to use outsourcing or over timing to meet the order (Ebadian et al., 2009; Rafiei & Rabbani, 2012).

As mentioned before, one of the policies of a company is to offer alternative due dates with different prices to the customer. This policy not only provides the customer with more choices, but also helps the company to accept more incoming orders considering available capacity. In order to generate different prices for incoming orders due to their due dates, a mixed integer model is solved. Before presenting the model, its required inputs including order completion dates (OCDs) and also the earliest release date (ERD) of the order are computed using a backward method (Kingsman & Hendry, 2002):

$$
\begin{aligned}
&OCD_{i,\beta(i,n_i)} = d_i, \\
&OCD_{i,\beta(i,n_i-1)} = OCD_{i,\beta(i,n_i)} - T_{i,\beta(i,n_i)} - AW_p, \\
&\vdots \\
&OCD_{i,\beta(i,s)} = OCD_{i,\beta(i,s+1)} - T_{i,\beta(i,s+1)} - AW_p, \\
&\vdots \\
&LRD_i = OCD_{i,\beta(i,1)} - T_{i,\beta(i,1)} - AW_p, \\
&ERD_i = LRD_i - Queue\ Delay,
\end{aligned}
$$

where

$\mathbf{n_i}$	number of working stations order **i** should pass
$\boldsymbol{\beta_{(i,s)}}$	***s***th *working station for order* ***i***
$\mathbf{d_i}$	*order* ***i*** *due date*
$\mathbf{OCD_{i,\mu(i,r)}}$	*operation completion date of order* ***i*** *on resource*
$\mathbf{LRD_i}$	*latest release date of order* ***i***
Queue Delay	*required time for accepted orders waiting to be released*
$\mathbf{AW_p}$	*average waiting time on each station for a P priority order*
$\mathbf{T_{ir}}$	*required processing time of order* ***i*** *on resource* ***s***

After computing these parameters, the proposed mathematical model for determining the minimum price of an order with a specific due date is as follows:

Parameters

$\mathbf{cr_{ist}}$	cost of order **i** production on station **s** at time **t** in regular capacity
$\mathbf{Co_{ist}}$	cost of order **i** production on station **s** at time **t** in overtime capacity
$\mathbf{ct_i}$	cost of lateness of order **i** per unit time
$\mathbf{p_i}$	probability of order **i** to be accepted
$\mathbf{iw_{ist}}$	required time of order **i** waiting on station **s** with **ERD** at time **t**, ($\mathbf{iw_{ist}} = \mathbf{T_{is}}$)
$\mathbf{iwp_s}$	total required capacity remained from the previous planning period
$\mathbf{ow_{ist}}$	total required capacity for order **i** on station **s** with **OCD** at time **t**, ($\mathbf{ow_{ist}} = \mathbf{T_{is}}$)
$\mathbf{CR_{st}}$	regular capacity of station **s** at time **t**
$\boldsymbol{\alpha_{st}}$	fraction of station **s** capacity at period **t** allocated to future orders
$\mathbf{CO_{st}}$	overtime capacity of station **s** at time **t**
OS(i)	orders with definite due dates
M	a large number

Decision variables

$\mathbf{Y_{ist}}$	dedicated capacity of station **s** to order **i** at time **t**
$\mathbf{O_{ist}}$	dedicated over time capacity of station **s** to order **i** at time **t**
$\mathbf{LT_i}$	lateness of order **i**
$\mathbf{FT_i}$	order **i** completion date on the last station
$\mathbf{X_{it}}$	$\begin{cases} 1 & \textbf{\textit{if}}\ \ Y_{i,\beta(i,n_i)} > 0, \\ 0 & \textbf{\textit{otherwise}} \end{cases}$

The proposed mathematical model

$$Min\ z = \sum_{i \in O^s} \sum_{s=1}^{S} \sum_{t=1}^{T} \left[cr_{ist}(Y_{ist} - O_{ist}) + co_{ist} O_{ist} \right] + \sum_{i \notin OS(i)} ct_i LT_i \tag{1}$$

$s.t.$

$$\sum_{i \in O_s} (Y_{ist} - O_{ist}) \leq CR_{st}(1 - \alpha_{st}) \qquad \forall s, t \tag{2}$$

$$\sum_{i \in O_s} O_{ist} \leq CO_{st} \qquad \forall s, t \tag{3}$$

$$iwp_s + \sum_{i \in O_s} \sum_{t=1}^{T} iw_{ist}\ p_i \leq \sum_{i \in O_s} \sum_{t=1}^{T} Y_{ist} \qquad \forall s \tag{4}$$

$$\sum_{\substack{i \in OS(i) \\ i \in O_s}} \sum_{k=1}^{T} ow_{isk}\ p_i = \sum_{\substack{i \in OS(i) \\ i \in O_S}} \sum_{k=1}^{T} Y_{isk} \qquad \forall s, t \tag{5}$$

$$\sum_{k=1}^{T} iw_{isk}\ p_i \leq \sum_{t=1}^{T} Y_{isk} \qquad \forall s, i \in OS(i); i \in O_s; t \in (1, \ldots, d_i) \tag{6}$$

$$Y_{i,\beta(i,n_i),t} \leq MX_{it} \qquad \forall t, i \notin OS(i) \tag{7}$$

$$-FT_i + t \leq M(1 - X_{it}) \qquad \forall t, i \notin OS(i) \tag{8}$$

$$LT_i \geq (FT_i - d_i) \qquad \forall i \notin OS(i) \tag{9}$$

$$LT_i \leq (T - d_i) \qquad \forall i \notin OS(i) \tag{10}$$

$$\sum_{k=1}^{t} ow_{isk}\ p_i = \sum_{k=1}^{t+(T-d_i)} Y_{isk} \qquad \forall s, i \in OS(i); i \in O_s; t \in (1, \ldots, d_i) \tag{11}$$

$$Y_{ist}, O_{ist} > 0 \qquad \forall s, t, i \in O_s \tag{12}$$

$$LT_i, FT_i \geq 0\ ,\ X_{it} \in \{0,1\} \qquad \forall t, i \notin OS(i) \tag{13}$$

The presented model aims at minimizing the sum of production cost and lateness penalties. Constraints 2 and 3 show the capacity limitations in regular time and overtime. Constraint 4 represents that the total amount of workload on each resource during the planning horizon should not exceed the available amount of that resource. Constraints 5 and 6 are dedicated to orders which have definite delivery dates. Constraints 7-11 represent the calculation of lateness amount for orders which can be delayed. Constraints 12 and 13 are non-negativity constraints.

After determining the price of an incoming order, it will be conveyed to the customer and it is up to him to accept it or not. The output of the mathematical model is used as an input for the simulation model in order to achieve final results.

Computational results

The target of the designed simulation model is to measure the performance of the acceptance/rejection strategy which is recommended before. In order to correctly evaluate the model's applicability, it should be noted that having the most ontime delivered orders is the most important factor for the company. Delivering orders on the promised due date is a satisfying factor for the customers and guaranties their loyalty to the company and improves the market share of the industries as a result of this loyalty. Another important criterion is to satisfy the demand of routine (MTS) items. On the other hand, minimizing the work in process of each station is a key factor for the industry under study not only because of the costs of holding this inventory but also for a more important reason which is specific to a food industry, i.e. the limited shelf life of raw materials and work in process (Van Donk, 2001). In order to satisfy this factor, the average time in queue for each product family on each station should be minimized.

In this part, in each replication of simulation process, different percentages of incoming orders will be accepted using the mixed integer model which is represented before, and enter the job pool, then the impact of different acceptance percentages on each item's average waiting time in queue and ultimately on the percentage of on-time orders will be investigated. Also, in order to analyze the impact of the order arrival intensity on the service level, four different order arrival rates (i.e. 1.00, 1.50, 2.00 and 2.50 orders per day) with exponential inter-arrival time are used. As another analysis on the presented model, we want to answer the question of the effect of having a bottleneck station in the production line. Three different situations are compared to each other. The first situation is that the bottleneck is a station before CODP (here station 1), the second situation is that the bottleneck is exactly the station which is also CODP (here station 3) and in the last case bottleneck is located after CODP (here station 4). Tables 1, 2 and 3 show the data of processing time for each of these situations respectively.

Table 1. Each product families processing times for a batch of product when station 1 is defined as the CODP (in minutes)

	MTS		MTO		MTS/MTO	
	MTS_1	MTS_2	MTO_1	MTO_2	MTS/MTO_1	MTS/MTO_2
Station 1	180	170	Normal (180,30)	Normal (170,20)	180	170
Station 2	140	130	Normal (140,30)	Normal (130,20)	140	130
Station 3	120	130	Normal (120,40)	Normal (130,10)	Normal (120,30)	Normal (130,20)
Station 4	130	150	Normal (130,10)	Normal (150,20)	Normal (130,20)	Normal (150,40)

The results of having a bottleneck, with the largest processing time for each kind of products are shown in table 4, 5 and 6 respectively. As it is obvious

Table 2. Each product families processing times for a batch of product when station 3 is defined as the as the CODP (in minutes)

	MTS		MTO		MTS/MTO	
	MTS_1	MTS_2	MTO_1	MTO_2	MTS/MTO_1	MTS/MTO_2
Station 1	120	100	Normal (120,30)	Normal (100,20)	120	100
Station 2	140	130	Normal (140,30)	Normal (130,20)	140	130
Station 3	170	180	Normal (170,40)	Normal (180,10)	Normal (170,30)	Normal (180,20)
Station 4	130	150	Normal (130,10)	Normal (150,20)	Normal (130,20)	Normal (150,40)

Table 3. Each product families processing times for a batch of product when station 4 is defined as the CODP (in minutes)

	MTS		MTO		MTS/MTO	
	MTS_1	MTS_2	MTO_1	MTO_2	MTS/MTO_1	MTS/MTO_2
Station 1	120	100	Normal (120,30)	Normal (100,20)	120	100
Station 2	140	130	Normal (140,30)	Normal (130,20)	140	130
Station 3	120	130	Normal (120,40)	Normal (130,10)	Normal (120,30)	Normal (130,20)
Station 4	180	190	Normal (180,10)	Normal (190,20)	Normal (180,20)	Normal (190,40)

from the results, the sensitivity analysis shows that with the increase in the number of accepted orders, the average waiting time and average number of entities in queue will be increased. The ability to on-time responding to orders is also increased with the decrease in the number of accepted orders.

Also it could be shown that minimum back order occurs when the bottleneck is placed in a station before CODP. Finding the best location for the CODP is investigated by Olhager (2003) and from his paper it could be concluded that the bottleneck should be placed upstream the CODP in order to prevent the demand volatility and product variety to meet the bottleneck. Regarding to this policy, the bottleneck is a station that only works in a routine way and the fluctuations of order entry have no effect on it. The concluded results from Olhager`s paper are completely compatible with the results of our simulation process, which is presented in tables 4, 5 and 6.

Table 4. Simulation results when the bottleneck is located before CODP (station 1)

Number of replication / Criteria	1	2	3	4
Time between MTO order arrivals (day)	Exp (1.00)	Exp(1 .50)	Exp (2.00)	Exp (2.50)
Number of incoming orders	28	19	18	13
Number of accepted orders	26	18	15	13
Number of back orders	3.00	2.00	0.00	0.00
Ratio of delayed orders to the total number of MTO or MTS/MTO accepted orders	0.11	0.11	0.00	0.00
Average waiting time for each entity(min)	32.00	21.06	30.00	20.66
Average number in queue	9.06	5.68	7.30	6.44

Table 5. Simulation results when the bottleneck is located at CODP (station 3)

Number of replication Criteria	1	2	3	4
Time between MTO order arrivals (day)	Exp (1.00)	Exp(1.50)	Exp (2.00)	Exp (2.50)
Number of incoming orders	27	23	19	15
Number of accepted orders	22	18	15	12
Number of back orders	6.00	5.00	3.00	1.00
Ratio of delayed orders to the total number of MTO or MTS/MTO accepted orders	0.27	0.28	0.20	0.08
Average waiting time for each entity(min)	40.00	21.52	32.30	25.47
Average number in queue	11.23	6.42	7.66	7.89

Table 6. Simulation results when the bottleneck is located after CODP (station 4)

Number of replication Criteria	1	2	3	4
Time between MTO order arrivals (day)	Exp (1.00)	Exp(1 .50)	Exp (2.00)	Exp (2.50)
Number of incoming orders	29	20	17	12
Number of accepted orders	25	17	13	10
Number of back order	4.00	3.00	2.00	0.00
Ratio of delayed orders to the total number of MTO or MTS/MTO accepted orders	0.16	0.18	0.15	0.00
Average waiting time for each entity(min)	40.00	21.06	30.00	20.66
Average number in queue	11.06	5.68	7.30	6.44

Conclusion and future work

In this paper, issues of the tactical level of hierarchical production planning process in a hybrid MTS/MTO production system are investigated. A food processing industry with MTS, MTO and MTS/MTO products is considered as a case study. In order to find the best policy for acceptance or rejection of incoming MTO or MTS/MTO orders, a simulation model is proposed using Arena 10.0 software. In the presented model, due date and price of an order should be determined during a negotiation process. After that, the accepted orders are prioritized based on a critical ratio in order to increase the company’s ability to satisfy the pre-determined due dates. Beside the MTO orders, satisfying MTS demands is considered based on a forecast. Finally, some experimental results and sensitivity analysis are presented in order to make the model more understandable and applicable in real situations. As a suggestion for future research, the limited shelf life of raw material or finished products can be taken into account by using inventory control concepts. Also supplier issues such as comparing the quality, capacity, flexibility and price of each supplier and choosing the best one can be added to this research design. The ability to subcontract the incoming orders can be considered as a way of accepting more orders and responding to them in the best manner.

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