Mass Customization Decision Models to Improve Inventory and Production Plans

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Abstract

To meet what exactly customer demands efficiently, firms are engaging in ever more mass customization strategies. By approaching mass customization, they try to benefit from mass production economy of scale and satisfy customers with customized products at the same time.

In customization, a number of value adding activities is delayed by the time more accurate information about customer demand is received. The main shortfall of customization is prolonging delivery lead time. To improve the performance of customization strategies, this paper introduces four modified customization models (i.e. mass customization). Models are developed to delay forecasting, finishing and shipment operations. Buyer's waiting time and the mismatch between shipment quantity and real demand quantity are defined as the performance criteria for the mass customization models.

Developed mass customization models indicate considerable improvement in performance criteria, and provide important contribution to the implementation of mass customization strategy.

Keywords: Mass Customization, supply chain modeling, inventory planning

1. Introduction

Mass Customisation is defined as making product to meet customer's needs with near mass production efficiency (Pine, 1999; Jiao and Tseng, 2004). The introduction of the first theories of mass customisation dates back to the late 1980s. The application of mass customisation has been widely expanded since then. This mainly is because of increasing demand for the product personalisation as well as the advanced production and information technologies (Da Silveira et al., 2001). In mass customization strategy, some value adding activities in a supply chain are customized based on the customer order or more accurate information from the customer demand. This leads to reduction or elimination of risk, and uncertainties of production and carrying inventory (Zinn and Bowersox 1988).

The literature review has indicated that it is widely required to study techniques which maintain or enhance application of mass customization strategies (Piller, 2007). Alongside with other aspects of mass customisation, modelling different elements of it including mass production and customisation has become an imperative (Rudberg and Wikner, 2004). In view of that, this paper endeavors to model different levels of mass customization, and improve the performance of the employed mass customization strategies. It focuses on the customized packaging, labeling and shipment operations. Two performance criteria for the applied mass-customization strategies are considered: the buyer's waiting time and the mismatch between the real demand and the amount shipped to the customer. Clearly, by customizing some operations, there is a higher chance to provide customer with what it demands. On the other hand, the delivery lead time which is called buyer's waiting time in this paper will increase.

By distancing from pure customization model, this study develops modified mass customization models. Models include delayed forecasting and a mixture of delayed forecasting and customized finishing (packaging and labeling) and shipment operations. Developing the modified mass customization models is the main contribution of this paper.

The models are developed based on a case study in clothing industry - in a men's underwear and sock producer. The men's underwear and sock firm which is called company Alpha later on, makes its products based upon limited predetermined designs and production processes. Changes in design or material happen rarely. Even the color mix is fixed. Market share for the company has been stable for years. Therefore, the main focus point in company Alpha is maintaining the reputation by providing the right quality as expected from the brand. Beside quality, price should also be competitive for men's underwear. Products in this firm are distributed through wholesalers (which are called *buyers* later in this paper) which update information of the consumer market frequently. Wholesalers send their orders to the firm almost regularly. Changes in demand usually happen to the packaging, labeling and quantity of the orders. As the main alteration in orders is happened to the last stages of the production process and quantity of shipment, the firm considers the application of packaging and labeling (i.e. finishing) and shipment customization. In next section, this study starts with modeling no- customization and full-customization situation. Then it tries to improve the initial models to the mass-customization models. The outcome performance of the mass customization models is measured in terms of the buyer’s waiting time and the mismatch with buyer’s order using a numerical example based on the data collected from the case study.

2. Problem description and the Models

This study focuses on last stages of the production process of the company Alpha and the shipment of the product to the buyer's site. The last stage of the production process includes packaging and labeling which can be customized based upon the buyer’s order. The slight customization means the packaging and labeling can vary for different orders, although the operations and their time are almost similar. Later on, packaging and labeling operations are called "finishing stage". Customization of the finishing operations and shipment is considered by the models introduced in this study. The main incentive to pursue the mass customization strategy is matching supply and demand in a fluctuating market.

The mass customization problem is analyzed by two basic models and four modified models. Two basic models include "early finishing" (no customization) and customized finishing. In early finishing, customization does not happen. Products are packaged and labeled according to the forecast much prior to receiving customer order. Quite the opposite, in full customization, product is not prepared and shipped before receiving customer order. Advantages and drawbacks of each approach have been discussed earlier. Focusing on the mass customization approach, this study tries to overcome its main shortfall which is long delivery lead time. To do this, four mass customization models are developed to improve the performance of the initial models. The assumptions largely reflect the real-life situation of the case study described earlier. Simplifying assumptions are applied if necessary.

2.1 General assumptions

To consider the finishing operations time in the models, parameters θ and τ are defined as follows:

θ : Finishing time for each unit of product (hour/unit)

τ : Time available in each period for finishing operation (e.g. 8 hours when a period is assumed as one working day)

Thus, total number of products which can be produced (finished) in each period is $\frac{\tau}{\theta}$.

Products are delivered to the buyer in one shipment. Shipment time is shown by Lr and is defined as:

Lr : Transport lead-time – time (duration) of shipping products to the buyer's site (hour)

Finishing operations and shipment are considered in a planning horizon *T*. Each period is indicated by index *t*. Hence, $t \in T$. In the current case study, each period *t* refers to "one day".

Buyer’s demand is received by direct order, and also is forecasted by the company Alpha. They are notated as:

Dr_t : Real demand (order received) in period *t*

Df_t : Forecasted demand for period *t*

AP(*t*): Advanced planned production for the forecasted demand of period *t*.

When a buyer places its order in period *t*, the target is meeting buyer's demand as quick as possible. This is mainly because of the volatile final consumer market and its impact on the company Alpha buyers. Thus, buyers have no accurate plan when exactly they need the order they place in period *t*. Roughly, they just need it for very near future. In that respect, the company Alpha has two main options. Finishing and shipping products based on the demand prediction or delaying those operations by the time it receives buyer’s order in each period.

In the first approach, delivery is done in advance, so the buyer is satisfied about the time it receives the product. However, as shipment is done based on the prediction, it may be not exactly what they want in terms of quantity they need and in terms of customization in packaging and labeling. In the second approach, the buyer will exactly receive what it orders but with a time lag – which is usually lengthy.

In view of that, two variables of the models which show customer waiting time and difference between the delivery quantity and the real demand are defined as follow.

BWT Buyer's waiting time (hours): the time between customer order and product delivery (see Figure 1).

ε_t (Error): the difference between real demand (buyer’s order) in period *t* and product units prepared to meet that demand (of period *t*) based on the forecast for period *t*.

Df_t or Dr_t *Delivery*

BWT

τ

t-2 *t-1* *t* *t+1* *t+2* *t+3*

T

Figure 1. Time elements of the customization models.

Other key variables of the model are related to inventory, and defined as follows:

I(t)- Inventory: Number of items available in final product stock at the end of period *t*.

ATS(t)-Available-to-Ship: Number of items available in final product stock for shipment to the buyer's site during period *t*.

P(t) – Production in period *t*.

PC(t) – Production Capacity in period *t*.

S(t)- Shipment: Number of items shipped to the buyer's site in period *t*.

Note: ATS (t)= I(t-1) + P(t) – S(t)

DD (t) - Dissatisfied Demand: Buyer's order in period *t*, which is not shipped.

CDD (t) - Cumulative Dissatisfied Demand: Total buyer's orders by period *t* (including period *t*), which has not been shipped yet.

$$CDD(t) = \sum_{i=1}^{t} DD(i)$$

2.2 Advanced production planning model (no customization)

In advanced production planning model, decision about the packaging operations is made based on the outputs of the demand forecasting system. Master planning and scheduling department generates and updates demand forecast information regularly. Based on the forecast data, regardless to the real order of the buyer in period t, packaging operations are planned in advance. Production rate in period t for this model is indicated by $AP(t)$:

$AP(t)$ – Advanced production plan for period t.

At the end of period t, the available stock to ship (*ATS*) is reviewed. If it is enough to meet the real demand in period t – i.e. $D(t)$, the shipment is done at the amount of $D(t)$. Otherwise, the $ATS(t)$, is shipped. Hence, the shipment and in period t, and inventory at the end of period t are calculated as:

$$S(t)= \text{Min}\ \{ATS(t);D(t)\}$$

$$I(t)= \text{Max}\{ATS(t)-D(t);0\}$$

where

$$ATS(t)= \text{Max}\{I(t-1)+AP(t)-AB(t-1);0\}$$

Note: $I(t-1)*AB(t-1) = 0$

Backlog is also calculated as:

$B(t)$= Max $\{D(t)\text{-}ATS(t);0\}$

$$AB(t)=\sum_{i=1}^{t} B(i)$$

2.3 Full customization model

In this model, products are not packed or shipped before receiving the buyer's order. Once the company Alpha receives the buyer's order, packaging operation starts. Output of the packaging stage is shown by $PP(t)$ and is equal to the buyer's order for period t plus all backlog orders (as far as the production capacity permits). The same amount is shipped to the buyer. Production rate, shipment amount, available to ship, and inventory is calculated as follows:

$PP(t)$: Delayed production in period t. (1)

$PC(t)$: Production capacity in period t. (2)

$PP(t)$ = Min$\{D(t)+ AB(t\text{-}1); PC(t)\}$ (3)

$S(t)$= Min $\{ATS(t);D(t)\}$ (4)

$I(t)$= Max$\{ATS(t)\text{-}D(t);0\}$ (5)

where

$ATS(t)$= Max$\{I(t\text{-}1)+PP(t)\text{-}AB(t\text{-}1);0\}$ (6)

Lemma 1: In customization model, with assumption that $I(0)$=0, then

$I(t) = 0;\ \forall t \in \tau$

Proof:

Considering t=1, $ATS(t)$= Max{PP(1);0} and PP(1) = Min{D(1); PC(1)}, thus, $ATS(1) \leq PP(1)$ and $PP(1) \leq D(1)$. Hence, considering that I(1)= Max{ATS(1)-D(1);0}, I(1)=0. Based upon this, it is similarly proven that $I(t) = 0$ for t=2,3,…,n.

Backlog is also calculated as:

$B(t)$= Max {$D(t)$-$ATS(t)$;0}

$$AB(t)=\sum_{i=1}^{t} B(i)$$

The procedure of the customization model is illustrated in Figure 2.

2.4 Modified models

Two basic models discussed earlier have problems in managing inventory, backlogs and changes in production rate. The advanced production planning model suffers from very high inventory level. This is due to the forecast oriented production plan which mainly follows the historical trend of demand. On the other hand, the customization model, delays any decision about the production plan by the time it receives the real demand. Although in theory this system enjoys the zero inventory, however, it confronts high backlogs and late deliveries. The customization model also changes the production rate very frequently to cope with real demand. This is not desirable for many production systems and may cause serious problems in manufacturing systems which lacks high flexibility.

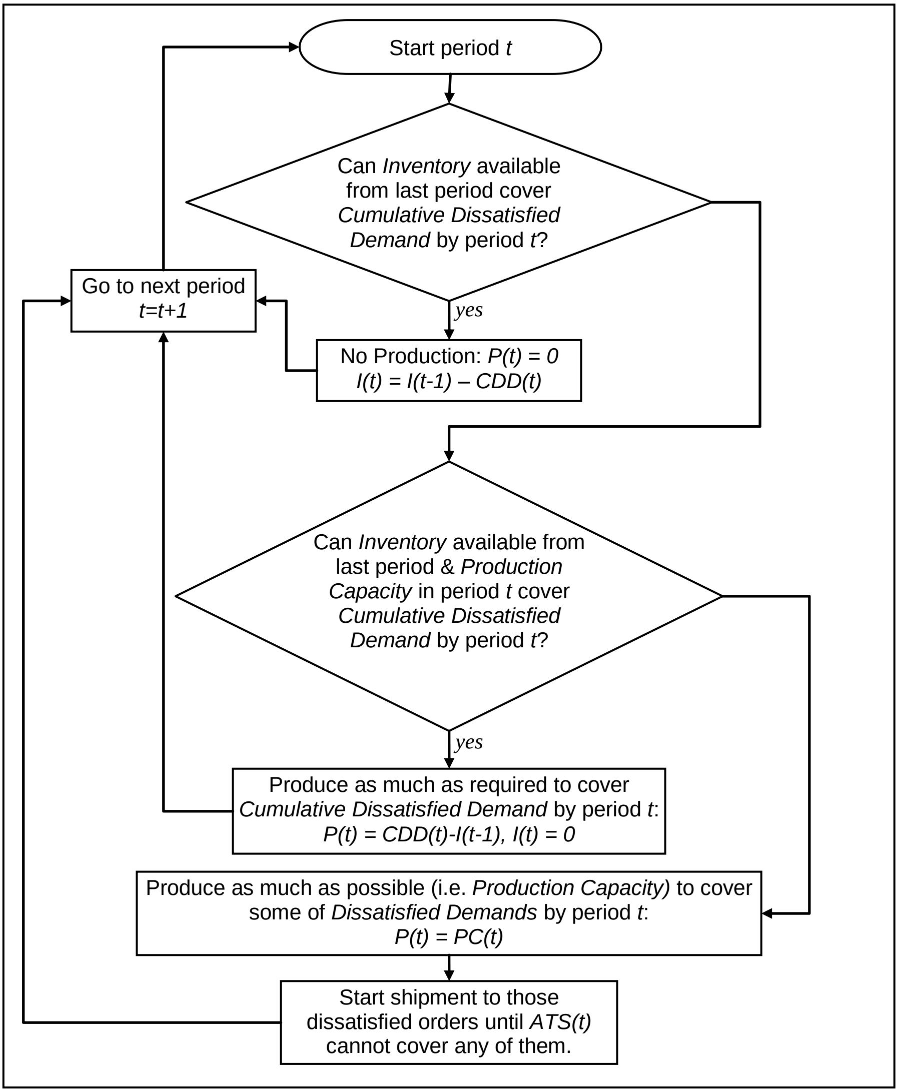

Figure 2. The procedure of the customization model.

Two modified models have been developed in this study to overcome shortfalls of the advanced production planning and customization models. The modified models try to improve the high inventory level, backlogs and changes in production plan. The first modified model focuses on improving advanced production planning model. They try to reduce very high inventory level of advanced production planning, while change index and backlogs should be kept as low as possible.

The second modified model focuses on improving customization model. They try to reduce very high backlog of customization, while change index and inventory should be kept as low as possible.

Details of the modified models are explained in the following sub-sections.

2.4.1 Modified Advanced Production Planning: delayed alteration

The first modified model keeps the advanced production planning model as a basis. Then, accepting frequent changes in production plan to a certain degree, they try to make the production plan closer to the real demand. In the modified advanced production planning model, the decision about the production rate of next periods is made at specific periods (same as advanced production planning), but minor changes in production rate is acceptable during those planned periods. In this due, this model is call delayed alteration. The alteration in advanced production plan is indicated by $MP(t)$ and are defined as:

$MP(t)$ – modified production index: the amount which is added/deducted from the planned production rate ($AP(t)$) to make it closer to the real demand in period t.

The avoid high alteration in production plan, the modified advanced production planning model put a limit on $MP(t)$, and let the $AP(t)$ to change ±100a%. Considering other factors of the model (i.e. $S(t)$, $ATS(t)$, $I(t)$, $B(t)$, $AB(t)$, etc.) as calculated as before, the production rate in each period is defined as:

$MAP(t)$: Modified Advanced Production Plan, which is calculated as:

$$MAP(t)= \begin{cases} \text{Max}\{AB(t\text{-}1)+D(t)\text{-}I(t\text{-}1),\ (1\text{-}a)AP(t)\} & \text{If } AP(t) > AB(t\text{-}1)+D(t)\text{-}I(t\text{-}1) \\ \text{Min}\{AB(t\text{-}1)+D(t)\text{-}I(t\text{-}1),\ (1+a)AP(t),\ PC(t)\} & \text{If } AP(t) < AB(t\text{-}1)+D(t)\text{-}I(t\text{-}1) \\ AP(t) & \text{If } AP(t) = AB(t\text{-}1)+D(t)\text{-}I(t\text{-}1) \end{cases} \quad (7)$$

Figure 3 illustrates the structure of the modified advanced production planning model.

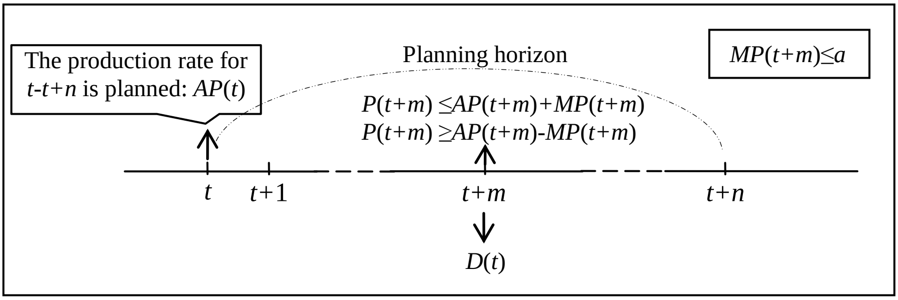

Figure 3. Structure of the modified advanced production planning model.

To examine the model capability, different "*a*"s should be tested to find the best level for inventory, backlogs and change index. Whilst, $AP(t) > AB(t-1)+D(t)-I(t-1)$, build up of inventory in period t happens:

$$I(t) = AP(t) + I(t-1) - AB(t-1) - D(t) \quad (8)$$

To moderate that inventory build up, the $AP(t)$ is reduced to $MAP(t)$ where

$$MAP(t) = \mathrm{Max}\{AB(t-1)+D(t)-I(t-1),\ (1-a)AP(t)\} \quad (9)$$

Hence, the higher the a, the less inventory is built up in period t. However, the higher the a, the higher the change index occurs.

Whilst, $AP(t) < AB(t-1)+D(t)-I(t-1)$, backlog in period t happens:

$$B(t) = AB(t-1) + D(t) - I(t-1) - AP(t) \quad (10)$$

To moderate that backlog, the $AP(t)$ is increased to $MAP(t)$ where

$$MAP(t) = \mathrm{Min}\{AB(t-1) + D(t) - I(t-1),\ (1+a)AP(t),\ PC(t)\} \quad (11)$$

Thus, the higher the *a*, the less backlog is built up in period *t*. However, the higher the *a*, the higher the change index occurs.

More analysis on the modified production planning model and its sensitivity to "*a*" will be provided in a case study discussion later.

2.4.2 Modified customization

The second modified model keeps the customization model discussed earlier as a base. Then, distancing from very extreme changes in production plan of the customization model, the modified customization model (mass customization) tries to moderate the alterations in production plan (i.e. change index). Moreover, due to fluctuations in demand and limited production capacity, the customization model faces considerable backlogs.

In the modified customization model, the decision about the production rate of each period is made at the beginning of that period (same as customization model), however to reduce the change index, a bound is placed on alterations in production rate.

Similar to the modified production planning model, the bound on alteration is notated by *a*. Accordingly, the modified customization model will indicate the production rate of period *t* same as *PP*(*t*) if it is not more/less than +/— 100*a%* of *PP*(*t*-1). Otherwise the production plan will just increase or decrease by *a%*, when *PP*(*t*) increases or decreases respectively.

$$MPP(t)=\begin{cases} PP(t) & \text{If } PP(t) \le (1+a)MPP(t\text{-}1) \\ & OR\ PP(t) \ge (1\text{-}\ a)MPP(t\text{-}1) \\ (1+a)MPP(t\text{-}1) & PP(t) > (1+a)MPP(t\text{-}1) \\ (1\text{-}\ a)MPP(t\text{-}1) & PP(t) < (1\text{-}\ a)MPP(t\text{-}1) \end{cases} \tag{12}$$

Where $MPP(t)$ is defined as "Modified customized Production".

Figure 4 illustrates the structure of the modified customized.

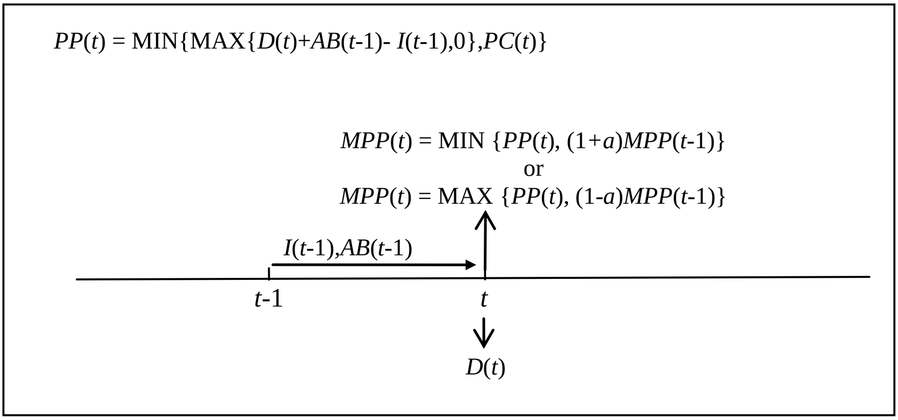

Figure 4. Structure of the modified customization model.

To examine the model capability, different "*a*"s should be tested to find the level of inventory, backlogs and change index. In customization model, the delayed production - $PP(t)$, follows the demand in period t and the accumulative backlogs by period t. As proven by Lemma 1, the inventory level in this model is zero. By moderating $PP(t)$, and make it closer to $PP(t$-

1) – or make the $MPP(t)$ closer to $MPP(t-1)$ in the modified customization model, rather than to $D(t)+AB(t-1)-I(t-1)$, the inventory is not zero anymore, and is calculated as:

$$I(t) = MPP(t) + I(t-1) - AB(t-1) - D(t) \tag{13}$$

Considering the amount of $MMP(t)$ in Equation (12), the higher the a, the more flexibility is provided to $MPP(t)$ to be closer to the $MPP(t-1)$ - or to the original $PP(t)$. So, it can be implied that the more the a, the less inventory is held.

The backlog in the modified customization model is calculated as:

$$B(t) = AB(t-1) + D(t) - I(t-1) - MPP(t) \tag{14}$$

By definition, it is also clear that the higher the a, the higher the change index occurs.

More analysis on the modified customization model and its sensitivity to "a" will be provided in a case study discussion later.

3. Findings: Computational Results

In this section, models developed earlier are applied in the case study of clothing industry – as explained in section 1.

The data for hundred periods has been applied for customization model, advanced production planning model and the modified models. All models have been run with the available demand date, and the modified customization models have been run for different values of a. For modified production planning model, a = 0.1, 0.2, 0.3, 0.4, 0.5, and 0.6, and for modified customization model, a = 0.1, 0.2, 0.3, 0.4, and 0.5 have been tested. The production capacity is 1300 unit per period.

As discussed earlier, modified models try to moderate advance production planning and customization models. Figure 5 illustrates the impact of different values of a on modified models. As show by Figure 5, the less a value, the less alterations happen in production plan. This shows the improvement in the change index value. On the other hand, modified customization models (mass customization) with high a value, gives more flexibility to production plan to change more frequently. Accordingly, the behavior of the models tends to the customization model.

Figure 6 and Table 1 compare the change, inventory and buyer's waiting time indices for all initial and modified mass customization models.

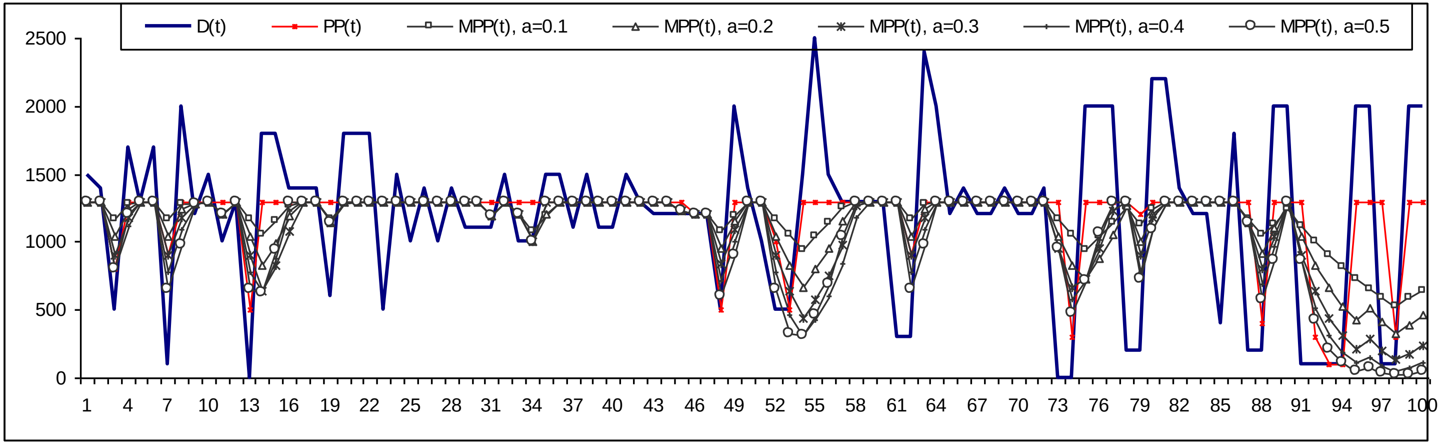

Figure 5. Demand fluctuation and the behavior of customization and modified customization models against that.

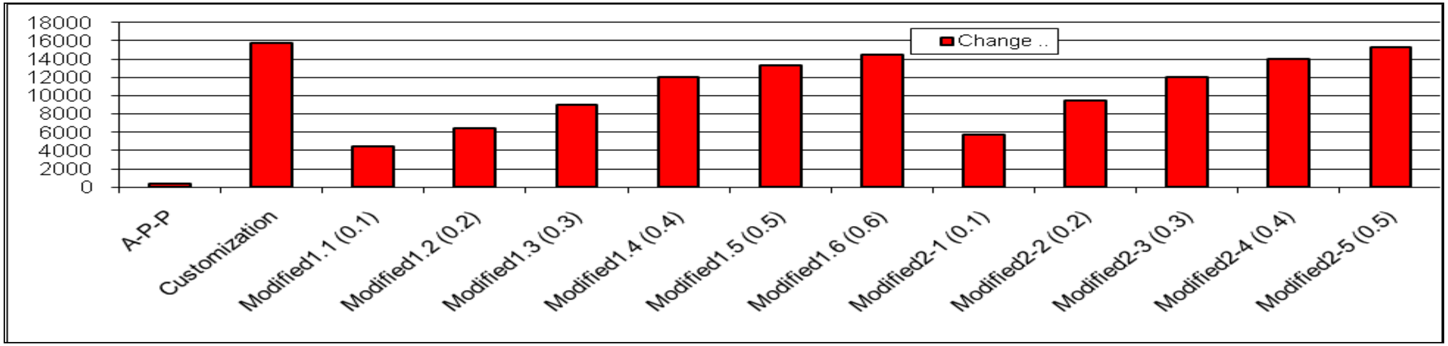

Figure 6. Changes in production plan from one period to another one (change index)

Table 1. Average of inventory in hand and buyer's waiting time.

	Change Index	MI(t)	MB(t)
A-P-P	400	100850	1550
Customization	15800	0	70900
Modified 1.1 (0.1)	4426	36809	21662
Modified 1.2 (0.2)	6484	24132	36432
Modified 1.3 (0.3)	9002	13207	49054
Modified 1.4 (0.4)	12024	8488	57502
Modified 1.5 (0.5)	13320	4680	62640
Modified 1.6 (0.6)	14456	2648	67520
Modified 2-1 (0.1)	5751	18431	42098
Modified 2-2 (0.2)	9474	1270	102870
Modified 2-3 (0.3)	12055	295	110828
Modified 2-4 (0.4)	14002	0	113826
Modified 2-5 (0.5)	15234	0	114453

4. Conclusion

To improve the performance of production and shipment customization strategies, this study has introduced some modified models for customization (mass customization models). First modified models work based on the delayed forecasting. Decision about finishing and shipment of the products are delayed but not by the time customer order is received. In these models, this is the forecasting which delayed to a later time, when more accurate information of the demand is available. Although this delay in forecasting and planning may cause delay in delivery, but more accurate production plan is generated. In the second group of modified customization models, in addition to the delayed forecasting, the real demand after receiving the customer order is also considered. The production and shipment plan is modified according to the buyer's order. In these models, buyer's waiting time is higher than the first group of modified models, however, the error term is considerably low.

In future studies, applying more efficient forecasting methods can be studied. Moreover, other performance criteria can be considered.

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