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Hybrid Make-to-Stock and Make-to-Order (MTS-MTO) Scheduling Model in Multi-Product Production System

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Abstract: In production process, scheduling is an important role in meeting the orders and reducing the cost. This process becomes more complicated when the factory produces various products. Scheduling model in the production process can be divided into two groups: make-to-stock (MTS) and make-to-order (MTO). General constraint in the MTS model is limited production capacity and inventory cost. This work aims to propose hybrid MTS-MTO model that can improve lead time and maintain low inventory. In this work, we propose three hybrid MTS-MTO scheduling models for the multi-product production system. In these models, we modify several scheduling algorithms that are used in computer system, such as shortest remaining time (SRT), shortest processing time (SPT), and Round Robin (RR). These models are hybrid (s, S)-first-come-first served (FCFS) model, hybrid modified (s, Q)-SPT model, and modified (s, Q)-SRT model. This model then is implemented into production simulation. In this simulation process, we compare the proposed models with the existing item-by-item based (s, S) model. Based on the simulation result, these proposed models perform better than the basic MTS model. The hybrid (s, Q)-modified SPT model performs as the best model in creating high completion ratio, low lead time, and low inventory ratio. In certain condition, our proposed model performs 344 percent in completion ratio, 19.8 percent in lead time, and 3 percent in inventory ratio compared with the existing model.

Keywords: Production planning, multi-product, make-to-stock, make-to-order, Round Robin, shortest processing time, shortest remaining time

1. Introduction

One common problem faced by manufacture companies that produce various products is determining which products should be produce and their quantity. They have limited resource in production capacity, inventory capacity, and capital. Meanwhile, there is uncertainty in incoming orders. Company cannot determine when the orders will arrive, the number of items, and quantity in each ordered item [1]. This condition is worse for companies that plan their production manually.

One popular method in regular product production is make-to-stock (MTS) policy [2,3]. For companies that implement the MTS policy, mistake in the production decision may cause some problems. Too low production in certain items may cause sales lost or delay in delivering orders [3]. Meanwhile, too high production in certain items may cause the increasing of the inventory cost [3]. Besides, over production also makes the capital converted into inventory for longer time and it can make lower liquidity. Quality of the products can also decline when the products are in the warehouse too long [3].

This condition does not occur in companies that implement make-to-order (MTO) policy. In MTO companies, inventory is assumed zero. Company will produce products only after the order arrives [2]. It makes MTO policy is better than MTS policy in minimizing inventory cost. In the other side, MTS policy is better in creating lower response time and waiting time rather than MTO policy [3]. MTS policy also has advantage in smoothing the production planning.

MTS policy is common in producing products for regular order [2]. Many companies implement MTS policy in their production system. There are many works related to this MTS model. Many of these works focus on comparing [1,2,4]

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or combining [3] the MTS policy and the MTO policy. Some of these works have declared that their proposed model is suit for multi-product environment [3,4].

Due to the limitation of both MTO and MTS model, hybrid MTS-MTO system is proposed. This model has been studied widely. Some studies implemented single-product scenario [5] while others implemented multi-product one [6,7]. In the multi-product manufacturing system, many studies classified the products into two groups: MTO based products and MTS based products [8,9]. Meanwhile, other studies did not discriminate these products strictly [10,11]. Some studies used single-stage manufacturing system [7] while others used multi-stage one [10]. The hybrid MTS-MTO system can be run in dedicated production facility or shared production facility [12].

Unfortunately, in those hybrid MTS-MTO studies, the interdependency problem of the incoming orders has not been investigated explicitly yet. Most hybrid MTS-MTO studies focused on which products should be produced, whether in MTS or MTO, and how these products should be produced. These decisions are mainly based on the demand volume and the customization level. Meanwhile, interdependency problem has not been concerned in developing the hybrid model. In many companies, interdependency among products is high. A single order may contain various products and this order can be delivered to the customer only if there is adequate quantity for all requested products in this order. The lack in one product may postpone the order delivery. This condition makes production planning in multi-product companies becomes more complicated.

This work aims to propose new model in hybrid MTS-MTO policy in multi-product production planning system to achieve high completion ratio, low lead time, and low inventory level. This new model also adopts and modifies Round Robin (RR), shortest processing time (SPT), and shortest remaining time (SRT) algorithms. RR is popular in computer (CPU and cloud) [13-16] and network [17-20] areas. This algorithm is widely used in computer and network areas due to the suit characteristic of these areas, where data or packet can be split into smaller chunks and in general, resources are not dedicated. Besides, penalty due to tardiness is not common in computer and network areas. This algorithm is usually used for scheduling or load balancing. Unfortunately, RR is not popular in production planning. In these works, there are several parallel machines in a manufacturing system.

Based on this explanation, there are contributions in this work. These contributions are as follows.

- The first contribution is involving the interdependency among products into the model and evaluating the relation between the interdependency and the model performance.
- The second contribution is adopting and modifying the job slicing technique in RR method into production planning model for regular multi product production environment.

The rest of the paper is structured as follows. Section 2 summarizes the related works in the hybrid MTS-MTO policy and scheduling algorithm in computer system. Section 3 explains the interdependency problem in multi-product production system. Section 4 describes the proposed model. Section 5 explains the simulation result and the discussion of this result. Section 6 resumes the conclusion.

2. Related Work

2.1 Hybrid Make-to-Stock/Make-to-Order Policy

In general, production system can be divided into two approaches: MTS and MTO [2,23]. There are several differences between these approaches. In the MTS system, customer demand is fulfilled by the available finished products in the inventory so that production runs to replenish the inventory [22]. In the MTO system, production runs to fulfil the customer demand [22]. Based on it, the MTS is also known as push system while the MTO is also known as pull system [22]. The MTS is better in high-capacity utilization, high availability, and short lead time while the MTO is better in flexibility and responsiveness due to high customized products and service [23]. MTS is a forecast based production model while the MTO is an order-based production model [11]. The inventory level in the MTS is high while the inventory level in the MTO is low [24]. The important key in the MTS is throughput while the important key in the MTO is delivery time [24].

The hybrid MTS-MTO model is a manufacturing model that combines both MTS and MTO models. This hybrid model is developed to take benefit of these two models [23]. Based on the production line usage, there are two approaches in this hybrid model: static (dedicated) approach and dynamic (shared) approach [12]. In the static approach, machines are split into two groups where the first group is dedicated for the MTS products and the second group is dedicated for the MTO products [12]. In the dynamic approach, production facility is switched between the MTS and the MTO products [12]. In the hybrid system, the MTO and MTS based production can run sequentially or parallelly between them [22].

Strict discrimination among products was found in several studies. Olhager discriminated products based on the coefficient of variation (CV) and ratio between production lead time and delivery lead time (P/D) [8]. The P/D indicates whether a product can be produced less than the customer desired delivery time. The MTS is chosen for products with low CV and the MTO is chosen for products with high CV. When the P/D is less than one, the MTO is preferred. Else, the MTS is preferred. Christopher and Towill used Pareto Law to discriminate products [9]. The MTS is chosen for products with high demand volume so that they are more predictable. The MTO is chosen for products with low and volatile demand. Youssef et al. discriminated products to be produced by using MTS or MTO based on the priority levels [7]. Soman et al. implemented a three-level discriminated hybrid MTS-MTO system [6].

Meanwhile, several studies did not discriminate products to be produced based on MTS or MTO strictly. Zhang et al. proposed hybrid MTS/assemble-to-order (ATO) production system [10]. In the first, manufacturer produces certain quantity of components for assembling the final products and certain number of final products by using MTS model. After demand arrives, manufacturer may need to assemble more final products to fulfil this order based the (ATO) model. Fiems et al. developed a shared two-stage hybrid model [11] where the item-by-item basis (s, S) policy is adopted in the MTS. The MTS mode is implemented when the inventory reaches or is below the s position and there are no backlogged orders. The MTO is implemented when the inventory reaches the S level. In this model, FCFS is used in the orders completion. Xiong et al. developed a switched hybrid model in the single-product production system [5]. In it, in the beginning or when the inventory is zero or very low and there is no order, the MTS is implemented. When there is incoming order, and the order quantity is higher than the inventory then the MTO is implemented to solve the quantity gap between the order quantity and the current quantity.

Based on review in literatures about hybrid MTS-MTO policy above, it is shown that most of studies focused on developing hybrid model based on the demand volume, demand volatility, and production. Meanwhile, the interdependency problem in the multi-product order has not been investigated explicitly and is not involved in the model development. The interdependency problem will be explained in section three.

2.2 Scheduling Algorithm in Computer System

Scheduling is also needed in computer system. In the computer system, scheduling means how to allocate resources (CPU, network, etc) to execute several jobs. Because scheduling in computer system is based on arrived jobs, it is similar with the MTO in manufacture system. But, in computer system, the jobs can be split into several packets and these packets can be executed or be transmitted before all packets in single jobs have been completed.

Round Robin (RR) is a popular scheduling algorithm. It is commonly used in the time-sharing system [15]. It is popular because its simplicity and fairness [15]. It is a pre-emptive version of the FCFS [16] which is common in manufacturing process [25,26]. It works by rotating the queue [15,20]. Each active task is divided into fixed time slice or time quantum [20]. Time quantum is time or slot that a server handles in one process. When the time quantum runs out, server will handle next active process [20]. Due to its circular queue, when the server finishes the process in the last task, the server goes to the first process. This process is formalized by using Equation (3) [20].

$$m_{i,k} = w_i(t - T_i) \tag{3}$$

Notations on the Equation 3 are known as:

$m_{i,k}$ = matrix for task i and block k
w_i = priority value for task i
t = current time
T_i = last time when the task i was served

One improvement in RR is weighted Round Robin (WRR). In general, basic RR assumes that all tasks in the system are equal [27] so they must get equal opportunity. In WRR, several tasks may have higher priority rather than others without pre-empting the lower priority tasks [27]. The weighting process can be static [28] or dynamic [29]. Based on this explanation, it is shown that RR algorithm can be implemented in the MTO as scheduling policy. Orders in manufacture are assumed as processes or jobs. Lot size is similar with time slice. Machine is similar with CPU or network.

Besides RR, several common scheduling algorithms in computer system are first come first served (FCFS), shortest job first (SJF), priority scheduling [30] and shortest remaining time (SRT) [31,32]. In the SJF, job which has minimum CPU time will be prioritized [30] so that SJF is similar with shortest processing time (SPT). Meanwhile, SRT is the pre-emptive derivative of the SJF [30].

3. Interdependency Problem

A multi-product manufacturing system often faces interdependency problem. An order contains several products. It can be delivered only if all requested products are ready. In it, some products may be fast moving goods while others are slow moving ones [3]. Some products may be already in the inventory while others may be not. The illustration is as follows. A company produces four products $\{g_1, g_2, g_3, g_4\}$. The stock of them is {10, 50, 30, 0} units. This company implements (s, S) policy based on item-by-item. In (s, S) policy, when the inventory reaches its minimum level (s) then factory will produce until its maximum level (S) is reached [33]. Meanwhile, it receives five orders. The detail of these orders is shown in Table 1. These orders are indexed based on the arrival time. They can be executed in several ways. By subtracting the order quantity with the remaining stock, quantity that should be produced is {495, 580, 20, 5}. Let assume that this company has 5 machines that produce 20 units per day each. Total production capacity will be 100 units per day. Total quantity that must be produced is 1,100 units. So, it needs 11 days. After 11 days, all orders can be executed, and the inventory is empty. In the beginning, minimum (s) and maximum (S) capacities are set static and equal. S is set four times bigger than the s. If s is 50 units, then S is 200 units. Based on the remaining stock and by implementing Equation

2, company should produce {190, 150, 170, 200} units. Based on this scenario, it will fail to fulfil the 2nd and the 5th orders because the requested products g_2 in order 2 and g_1 in order 5 exceed the S. In the end, the stock for g_3 and g_4 is too many.

Table 1 - Interdependency illustration

Order	Quantity (units)			
	g_1	g_2	g_3	g_4
1	30	0	0	0
2	35	500	20	5
3	100	20	5	0
4	50	100	20	0
5	300	0	5	0
Total	505	620	50	5

Now, let assume that S will be 500 units and the s will be 125 units. Based on this condition, this company can fulfil all orders absolutely because the S is still higher than or equal to the maximum requested quantity in each order. There are problems in this scenario, especially when it produces goods sequentially, for example $g_1 \rightarrow g_2 \rightarrow g_3 \rightarrow g_4$. Order 1 will be executed first because it contains g_1 only. Order 3 can be executed second and order 5 can be executed third. These three orders can be executed during the production of g_1 only because quantity of g_2 and g_3 in the inventory is enough. Order 2 and order 4 cannot be fulfilled although stock of g_1 and g_2 reaches maximum or S. Order 4 can be executed during the production process of g_3. In the end, order 2 can be executed during the production of g_4. This situation occurs due to interdependency problem. Besides, it also causes longer lead time.

This interdependency problem also becomes our motivation in this work. In this work, problem statement due to this interdependency problem is how we can reduce the lead time and maintain the quantity of the stock by modifying and improving this basic base stock model in multi-product production system.

4. Proposed Model

In this work, we combine the MTS model and the MTO model. We propose three hybrid MTS-MTO models. The first model is hybrid (s, S)-FCFS model. The second model is hybrid modified (s, Q)-SPT model. The third model is modified (s, Q)-SRT model. Similarity among these models is when there are any unexecuted orders, then the MTO model is implemented. Meanwhile, if there are not any unexecuted orders, the system implements basic or modified base stock model. It means that these models do not discriminate products. This decision is formalized by using Equation (1).

$$\forall m \in M, A_m = \begin{cases} make-to-order, n_{uo} > 0 \\ make-to-stock, n_{uo} = 0 \end{cases} \tag{1}$$

Notations on the Equation (1) are known as:

A_m = action taken for machine m
m = machine m
M = set of machines in the factory
n_{uo} = number of unexecuted orders

Before we explain further about our proposed models, there are several variables that are used in these models. Description of these variables is as follows.

o = certain order o
O = set of orders in the factory
o_{sel} = selected order
s_o = order status (0 = unexecuted; 1 = executed)
$t_{arr,o}$ = arrival time of order o
$t_{proc,o}$ = time needed to produce products in order o
$t_{rem,o}$ = remaining time needed to produce products in order o
p = certain product p
P = set of products produced in the factory
P_{o-sel} = set of products in the selected order
p_{sel} = selected product
q = quantity
$q_{p,o}$ = quantity of product p in order o

$q_{p,o\text{-}sel}$ = quantity of product p in selected order o
$q_{p,stock}$ = quantity of product p in the factory stock
$q_{p,prod}$ = quantity of product p that must be produced
$q_{p,min}$ = minimum in stock quantity of product p
$q_{p,max}$ = maximum in stock quantity of product p
$n(P_o)$ = number of products (product items) in order o
c_m = production capacity of machine m

In the first model, the system uses FCFS model for the MTO model and (s, S) model for the MTS model. When the system implements FCFS model, the quantity of products that are produced is determined based on the order. In the other side, when system implements (s, S) model, the system prioritizes product that the gap between the current stock and the minimum stock is the lowest. System will produce this product only if the gap is negative (the current stock is below the minimum stock). Then, the system produces this product until its maximum stock is achieved.

The FCFS model used in make-to-order policy is formalized in Equation (2) to Equation (4). Equation (2) is used to determine the selected order that will be executed. Equation (3) is used to determine the selected product that will be produced. Equation (4) is used to determine quantity of product that will be produced.

$$o_{sel} = o, o \in O \wedge s_o = 0 \wedge \min(t_{arr,o}) \tag{2}$$

$$p_{sel} = p, p \in P_{o\_sel} \wedge q_{p,o\_sel} > q_{p,stock} \tag{3}$$

$$q_{p,prod} = q_{p.o\_sel} - q_{p,stock} \tag{4}$$

Formalization of (s, S) model in this first proposed model is shown in Equation (5) and Equation (6). Equation (5) is used to determine the selected product that will be produced. Equation (6) is used to determine quantity of product that will be produced.

$$p_{sel} = p, p \in P \wedge q_{p,stock} < q_{p,\min} \wedge \min(q_{p,stock} - q_{p,\min}) \tag{5}$$

$$q_{p,prod} = q_{p,\max} - q_{p,stock} \tag{6}$$

The second model is also hybrid MTS-MTO model. The second model is combination between modified SPT model and modified (s, Q) model. The modified SPT is implemented when system runs MTO model and modified (s, Q) model is implemented when system runs MTS model. In this model, we modify the SPT model. In basic SPT, system will prioritize order with shorter processing time. In this work, we assume that all products are processed in the same processing time. So, order with less quantity will be prioritized. The SPT policy in this model is formalized by using Equation (7) to Equation (8). Equation (7) is used to determine the selected order in SPT policy. Equation (8) is used to determine production time for order o. In this SPT policy, Equation (5) is used to determine the selected product that will be produced. Meanwhile, Equation (6) is used to determine quantity of product that will be produced.

$$o_{sel} = o, o \in O \wedge s_o = 0 \wedge \min(t_{proc,o}) \tag{7}$$

$$t_{proc,o} = \sum_{p=1}^{n(P_o)} q_{p,o} \tag{8}$$

In the MTS model, we also modify the (s, S) model. In basic (s, S) model, system produces one product until it reaches maximum stock before it goes to another product. In this model, the system prioritizes product with the lowest gap between its current stock and its minimum stock, and if the gap is negative. This concept is similar with the first model. The difference is the produced quantity. In the second model, the produced quantity is equal to the machine capacity. So, system can produce another product before its current product reaches its maximum stock. This concept is adopted from the RR model so that production process is not dedicated for single product in certain length of time. The goal of this approach is to make balance stock among products and to reduce waiting time among products to be produced. In this modified (s, S) model, Equation (5) is used to determine product that will be produced. Meanwhile, Equation (9) is used to determine quantity of product that will be produced by machine m. In other word, this model can be seen as (s, Q) model.

$$q_{p,prod} = c_m \tag{9}$$

The third model is also the hybrid MTS-MTO model. The third model is the combination between the modified SRT model and the (s, Q) model. The modified SRT time is implemented when system runs MTO model and the modified (s, S) model is implemented when the system runs MTS model. The (s, Q) model used in the third model is same as it is used in the second model.

In this work, we modify the SRT model. The SRT model is widely used both in production process and in CPU process. In both environments, when system implements modified SRT model, job that the closest to the completion will be prioritized. In this work, we define the shortest remaining time order as order that the gap between the quantity of the ordered product and the current stock for the product is the smallest will become the shortest remaining time order. If the order can be fulfilled by the current stock, then the gap is equal to zero. So, the remaining time of this order is equal to zero too. Formalization of this modified SRT model is shown in Equation (10) to Equation (12).

$$o_{sel} = o, o \in O \wedge s_o = 0 \wedge \min(t_{rem,o}) \tag{10}$$

$$t_{rem,o} = \sum_{p=1}^{n(P_o)} \Delta(q_{p,o}, q_{p,stock}) \tag{11}$$

$$\Delta(q_{p,o}, q_{p,stock}) = \begin{cases} q_{p,o} - q_{p,stock}, q_{p,o} > q_{p,stock} \\ 0, q_{p,o} \le q_{p,stock} \end{cases} \tag{12}$$

5. Result and Discussion

These proposed models then are evaluated by implementing them into production process simulation application. This simulation application is developed by using PHP language and it is part of this work. In this simulation, user can set several adjusted variables. These variables are shown in Table 2.

Table 2 - Adjusted variables

Variable	Description
n_p	Number of products
n_{apo}	Average number of products in single order
f_m	Multiplication factor
n_m	Number of machines
n_d	Number of operational days
t_{ia}	Average inter-arrival time
r_o	Order ratio
f_{maxor}	Maximum order ratio multiplication factor
f_s	Stock multiplication factor
f_{maxs}	Maximum stock multiplication factor
f_{mins}	Minimum stock multiplication factor
f_c	Capacity multiplication factor

Based on these adjusted variables, several variables are set based on these adjusted variables. These variables are daily machine capacity (c) and maximum order ratio (r_{maxo}). Variable c is defined as production capacity of one machine in single day. Variable r_{maxo} is defined as maximum order quantity for a single product in an incoming order. These variables are formalized by using Equation (13) and Equation (14).

$$c = f_c . f_m \tag{13}$$

$$r_{maxo} = n_m . c . r_o . f_{maxor} \tag{14}$$

Before the simulation runs, variables related to the inventory are set. These variables include initial stock (s), minimum stock (s_{min}), and maximum stock (s_{max}). These variables are related to every product. These variables are formalized by using Equation (15) to Equation (17). In these equations, variable i is the product index. The initial stock is generated randomly.

$$s_i = rand(0,1) . f_m . f_s \tag{15}$$

$$s_{min,i} = f_m . f_{mins} \tag{16}$$

$$s_{max,i} = s_{min,i} . f_{maxs} \tag{17}$$

The overview of the simulation and the operational process is as follows. The manufacturing process is a single-stage production. The simulation runs from the day one until the operational day. During the simulation, orders arrive sequentially. The orders inter arrival time follows exponential distribution. The number of products in every order is generated randomly depends on n_{apo} and it represents the interdependency problem. The quantity in every ordered product in a single order is formalized by using Equation (18) and Equation (19). In these equations, j refers to the product index in an order and k is the order index. These orders then will be executed based on the available stock and the chosen method. Production process runs based on the current stock, backorder condition, and the chosen production method. The production rate of every machine (production facility) is assumed deterministic and constant. It produces good as its capacity and it is assumed that there is no defect product. The raw material is assumed unlimited so that it is always available every time the production runs. The manufacturer adopts shared manufacturing facility so that every product can be produced by using any machines and the system does not discriminate between the MTO based products and the MTS ones. Every machine is scheduled daily. Everyday, the sequencing process runs from the first machine to the last machine.

$$n_{q,j,k} = rand(0,1).n_m.c.r_o \tag{18}$$

$$n_{q,j,k} = \begin{cases} n_{q,j,k}, n_{q,j,k} \leq r_{maxo} \\ r_{maxo}, n_{q,j,k} > r_{maxo} \end{cases} \tag{19}$$

There are three observed variables in this simulation, and they will be used to evaluate performance. These variables include average lead time (t_l), completion ratio (r_c), and inventory ratio (r_i). Completion ratio is ratio between the number of executed orders and the number of total orders. Inventory ratio is ratio between total stock and total maximum stock when the simulation ends. Variable r_c is used to evaluate the capacity of the model to execute the incoming orders. Variable r_i is used to evaluate the efficiency of the stock or in other word is how the model keeps the stock low. The average lead time and completion ratio are related to company to perform fast response time [3]. Meanwhile, inventory ratio is related with ability of company to maintain low inventory [3].

In this simulation, there are five models that are implemented. The first and the second models are the existing MTS models that implements (s, S) model [33]. This (s, S) model runs based on item-by-item. The third, fourth, and fifth models are our proposed models. It means that we compare our proposed models with the existing models. There are two processes in every model: production process and order execution process. In the first model, FCFS method is used in the order execution process. In the second model, the earliest possible method is used in the order execution process. In the third model, hybrid (s, S)-FCFS model is used in the production process and FCFS model is used in the order execution process. In the fourth model, hybrid (s, Q)-modified SPT model is used in the production process and earliest possible method is used in the order execution process. In the fifth model, hybrid (s, Q)-modified SRT model is used in the production process and earliest possible method is used in the execution process.

In this simulation, we evaluate the performance of the models based on four adjusted variables, namely t_{ia}, r_o, f_{maxor}, and f_s. While simulation runs to evaluate one of these adjusted variables, other adjusted variables are set at their default value. The value of the adjusted variables is adopted from a medium size sock manufacturer in Bandung, Indonesia. This company sells products around the country through its distributors. Products that are ordered by a distributor may be different in the number of product items and the quantity. Their default value is shown in Table 3.

Table 3 - Adjusted variables default value

Variable	Default Value
n_p	10 units
n_{apo}	3 units
f_m	50
n_m	50 units
n_d	200 days
t_{ia}	5 days
r_o	1.5
f_{maxor}	5
f_s	2
f_{maxs}	5
f_{mins}	2
f_c	2

The first simulation is evaluating relationship between inter arrival time and the observed variables. The inter arrival time ranges from 2 to 10 days with one day interval. The result is shown in Fig. 1.

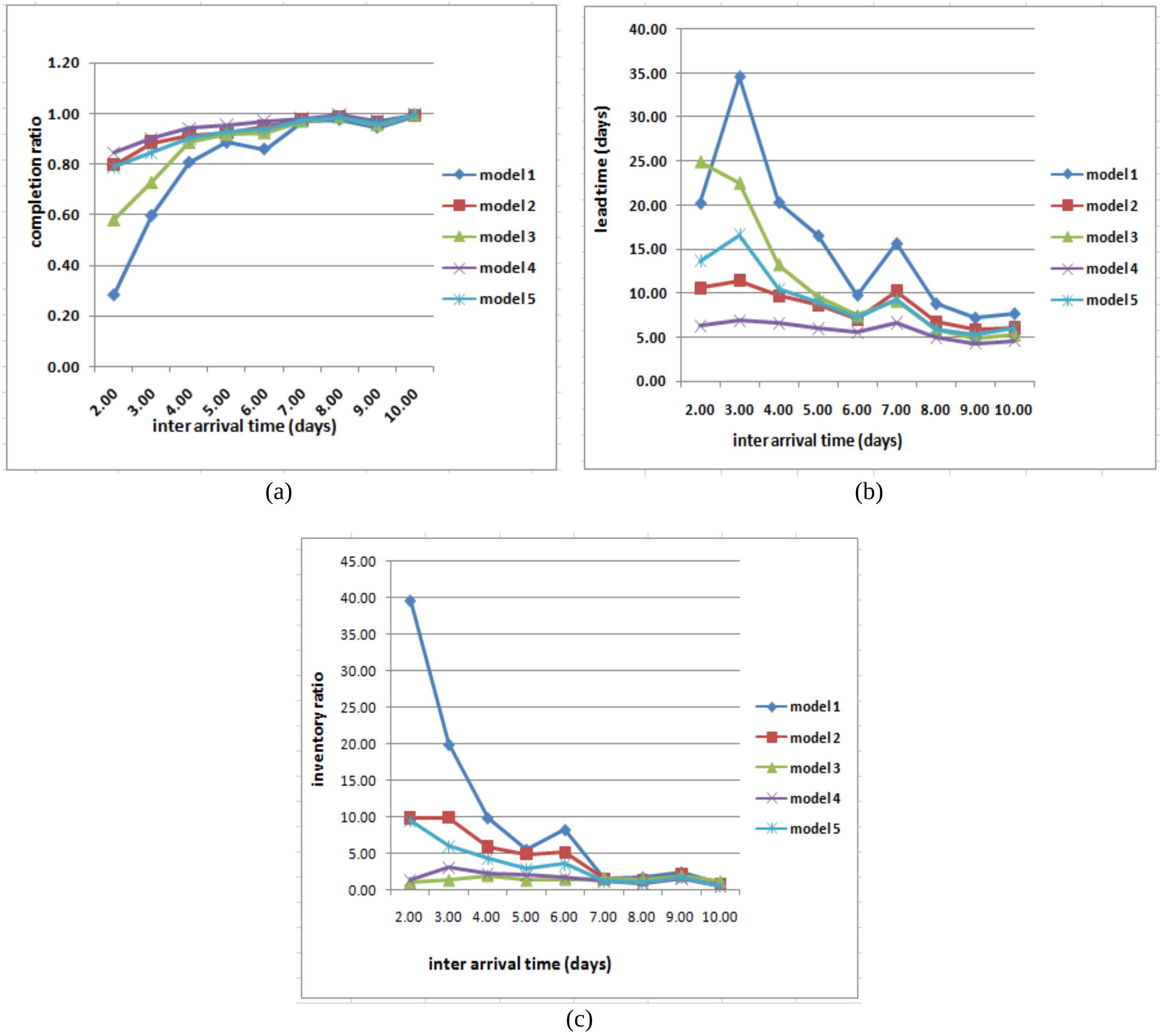


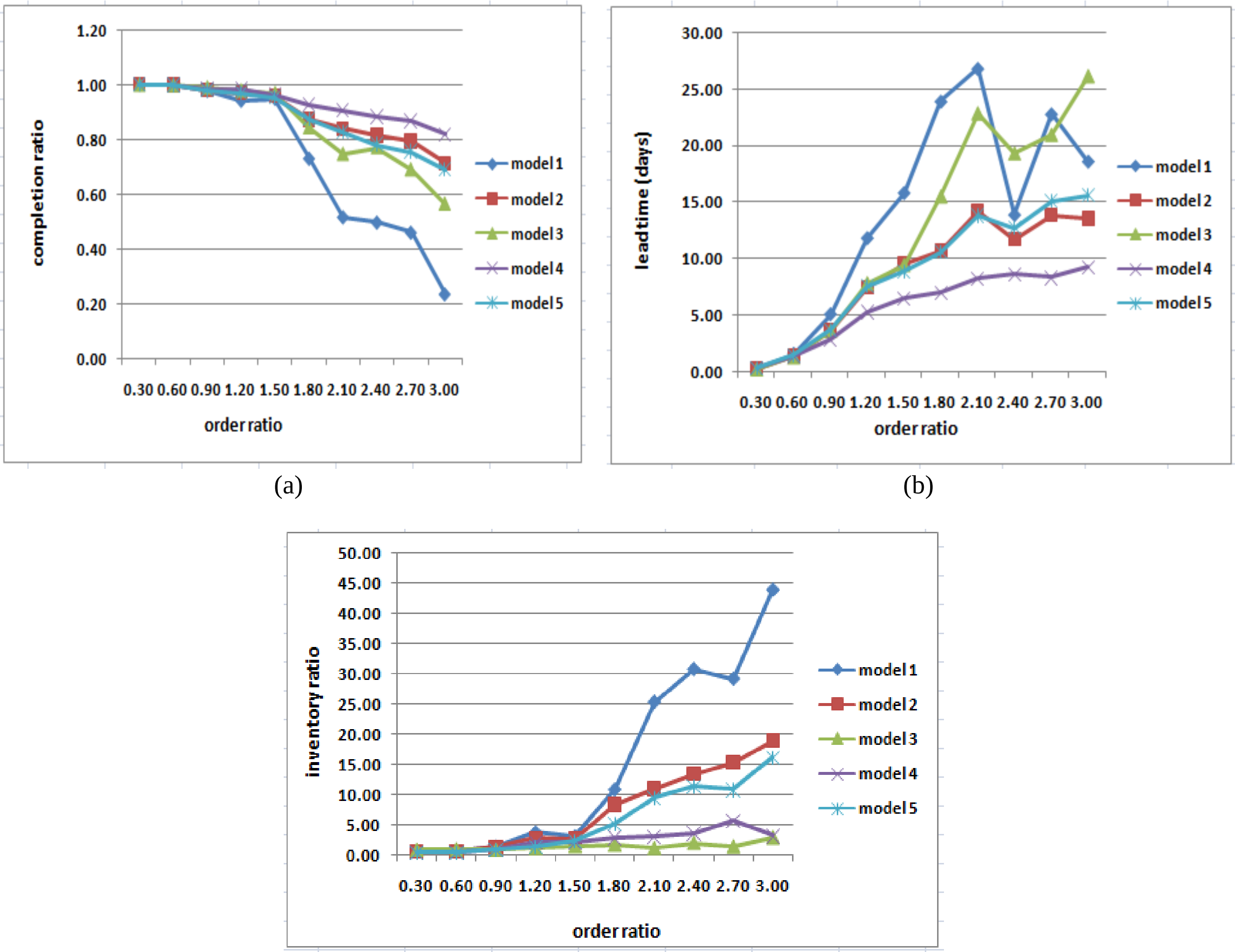
Fig. 1- Simulation result based on variation in inter arrival time: (a) completion ratio; (b) lead time; (c) inventory ratio

Evaluation of the first simulation is as follows. Fig. 1a shows that the increasing of the inter arrival times makes the completion ratio increase too. When the inter arrival time is low, the fourth model performs the best in completion ratio is 296% than the first model. The completion ratio of the fourth model is still higher than 80% whether the inter arrival time is low or high. Meanwhile, when the inter arrival time is high, all models perform high completion ratio with almost 100%.

Fig. 1b shows that the increasing of the inter arrival time makes the lead time decrease. When the inter arrival time is low, the lead time of the first model and the third model is high. Meanwhile, the lead time of the second model and the fifth model is moderate. The lead time of the fourth model is low. The lead time of the fourth model can be 19.8% of the first model when the inter arrival time is low. It goes to 59% when the inter arrival time is high. In every inter arrival time, the fourth model performs as the best model in maintaining low lead time.

Fig. 1c shows that the increasing of the inter arrival time makes the inventory ratio decrease. This condition occurs for the first, second, and the fifth model. Meanwhile, the inventory ratio tends to stable in low value for the third and the fourth model. When the inter arrival time is low, the inventory ratio of the fourth model is only 3% of the first model and it goes to 59% when the inter arrival time is high.

The second simulation is evaluating relation between order ratio and the observed variables. The order ratio ranges from 0.3 to 3 and the interval is 0.3. The result is shown in Fig. 2.



(c)

Fig. 2 - Simulation result based on variation in order ratio: (a) completion ratio; (b) lead time; (c) inventory ratio

Evaluation of the second simulation is as follows. Fig. 2a shows that the increasing of the order ratio makes the completion ratio decrease. In the beginning, the order ratio of all models is 1. It means that all orders can be completed. Meanwhile, during the increasing of the order ratio, its capacity decreases. When the order ratio is high, the completion ratio of the first model is the lowest. In the other side, the completion ratio of the fourth model is the highest. The completion ratio the fourth model is 344% than the first model when the order ratio is high.

Fig. 2b shows that the increasing of the order ratio makes the lead time increase. When the order ratio is low, the lead time of all models is less than one day. When the order ratio is high, the fourth model produces the lowest lead time. Its value is still less than ten days. Meanwhile, the first and the third models produce the highest lead time. The second and the fifth models produce moderate lead time.

Fig. 2c shows that the increasing of the order ratio makes the inventory ratio increase. When the order ratio is low, the inventory ratio of all models is less than 1. It means that the total stock is less than the total maximum stock. In the other side, when the order ratio is high, the inventory ratio of the first model is the highest which its value is almost 45. In the other side, the inventory ratio of the third and the fourth models is the lowest which its value is less than 5. When the order ratio is high, the inventory ratio of the fourth model is only 7.3% of the first model.

The third simulation is evaluating relation between maximum order multiplication factor and the observed variables. The maximum order multiplication factor ranges from 1 to 10 with 1 interval. The result is shown in Fig. 3.

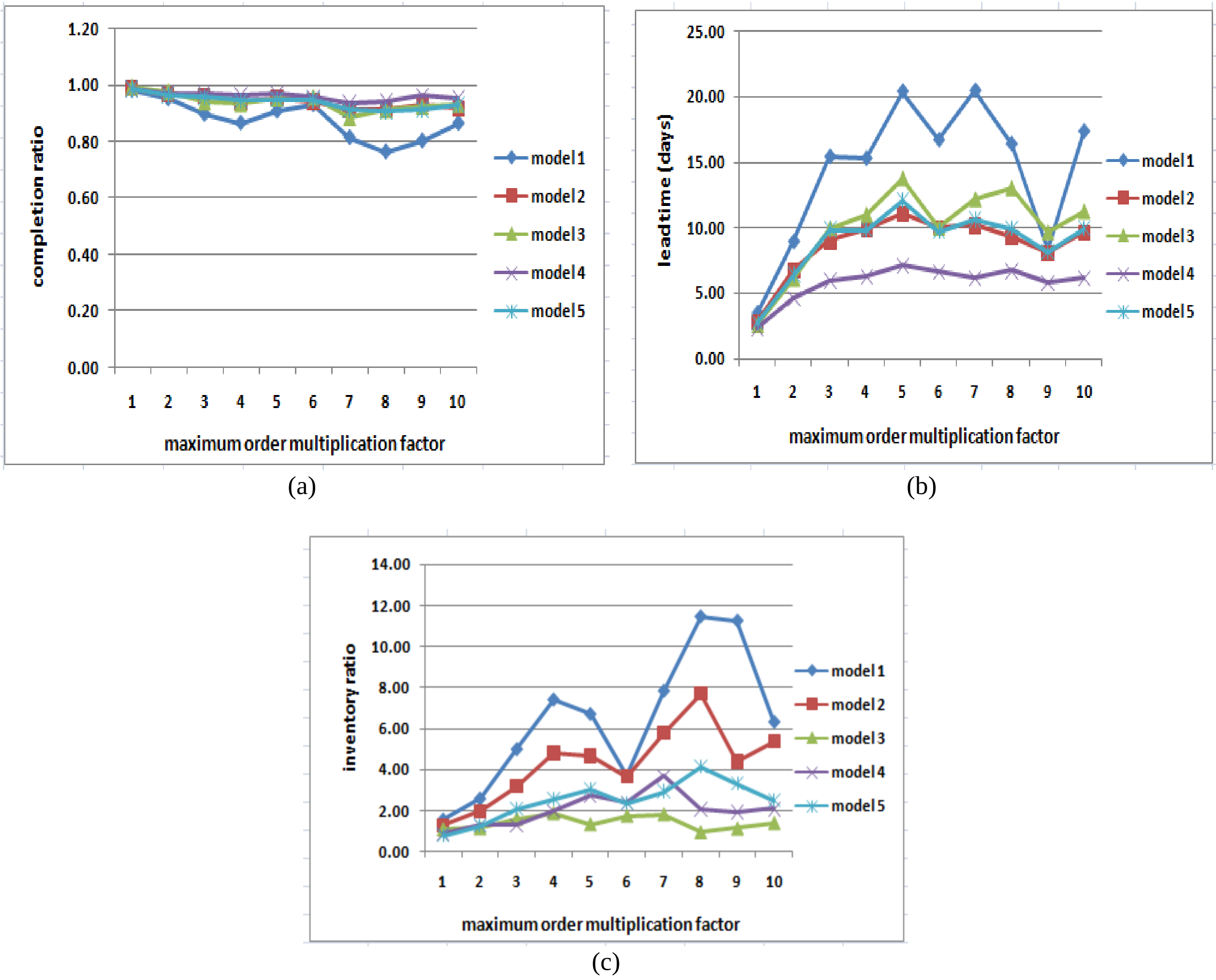


Fig. 3 - Simulation result based on variation in maximum order multiplication factor: (a) completion ratio; (b) lead time; (c) inventory ratio

Fig. 3a shows that the increasing of the maximum order multiplication factor does not affect the completion ratio. The completion ratio tends to fluctuate. Most of the completion ratio is higher than 0.8. Especially for the first model, its completion ratio tends to be lower than other ones. Fig. 3b shows that the increasing of the maximum order multiplication factor makes the lead time increase, especially when the adjusted variable is low. Then, the lead time tends to stable with fluctuation. Comparing among models, the fourth model produces the lowest lead time while the first model produces the highest lead time, especially when the maximum order multiplication factor is high. When this adjusted variable is high, the lead time of the fourth model is only 35% of the first model. Fig. 3c shows that there are several responses in inventory ratio due to the increasing of the maximum order multiplication factor. The inventory ratio of the third model is stable with small fluctuation. The third model also produces the lowest inventory ratio which its value is lower than 2 in any maximum order multiplication ratio. The inventory ratio of the first and the second models tends to increase with high fluctuation. The first model produces the highest inventory ratio, especially when the maximum order multiplication factor is high. The inventory ratio of the fourth and the fifth models tends to increase with small inclination.

The fourth simulation is evaluating relation between maximum stock multiplication factor and the observed variables. Higher stock multiplication factor means wider gap between minimum stock and maximum stock. It means that this simulation is used to evaluate the relation between the gap width with the observed variables. The maximum stock multiplication factor ranges from 1 to 10 with 1 interval. The result is shown in Fig. 4.

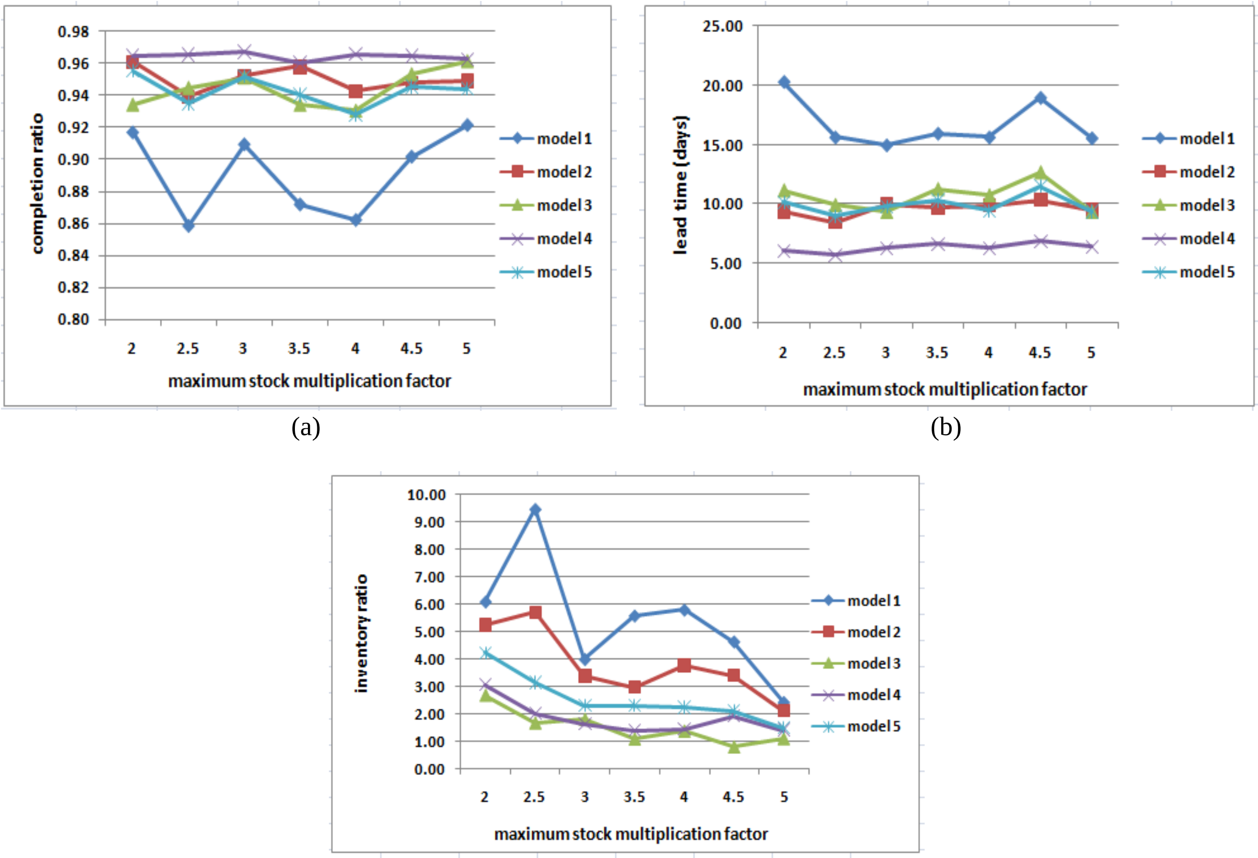


Fig. 4 - Simulation result based on variation in maximum stock multiplication factor: (a) completion ratio; (b) lead time; (c) inventory ratio

Fig. 4a shows that the increasing of the maximum stock multiplication factor does not affect the completion ratio. The completion ratio tends to fluctuate. The fourth model produces the highest completion ratio. The first model produces the lowest completion ratio.

Fig. 4b shows that the increasing of the maximum stock multiplication factor does not affect the lead time. The lead time tends to fluctuate. The lead time of the first model is the highest. Meanwhile, the lead time of the fourth model is the lowest. The lead times of the second, third, and fifth models are in the middle between the first model and the fourth model. The lead time of the fourth model is near to 5 days while the lead time first model is 15 to 20 days. Fig. 4c shows that the increasing of the maximum stock multiplication factor makes the inventory ratio decrease.

Fig. 4c shows that the increasing of the maximum stock multiplication factor makes the inventory ratio decrease. The inventory ratio of the third model is the lowest while the first model is the highest. The inventory ratio of the fourth model is a little bit higher than the third model.

6. Conclusion

This work shows that the production planning process that implements hybrid model (combination between MTS and MTO) performs better than the pure item-by-item based MTS model in the multi-product production system where there is interdependency among products in every order. Our proposed models (the third, fourth, and fifth model) perform better than the existing (s, S) models (the first and second models). The fourth model performs as the best model among other models. This model is consistent in producing high completion ratio, low lead time, and low inventory ratio. These conditions are proven in our four testing scenarios: inter-arrival time, order ratio, maximum order multiplication factor, and maximum stock multiplication factor. Although the third and the fifth models perform less than the fourth one, they are still better than the first and the second models. In certain conditions, our proposed model performs 344 percent in completion ratio, 19.8 percent in lead time, and 3 percent in inventory ratio rather than the existing model. The main factor due to our proposed models is prioritizing production for the completing orders when there are waiting orders and maintaining healthy stock when there are not any waiting orders. Splitting strategy that is adopted from Round Robin scheduling algorithm becomes the secondary factor in making our proposed models (the fourth and fifth models) are better than other models. This job slicing strategy makes the stock among products is more balance.

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