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DYNAMIC STRUCTURE OF ORDER PENETRATION POINT IN HYBRID PRODUCTION SYSTEMS

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ABSTRACT

The dynamism of hybrid make-to-stock (MTS) /make-to-order (MTO) production systems has attracted the practitioners and academicians' attention all over the world because of the potential to benefit from both pure MTS and pure MTO advantages. On the other hand, order penetration point (OPP) has an essential role in hybrid manufacturing environments. Our aim is to explore such systems through covering some influential factors that have not been considered so far. Hence, a system dynamics (SD) model is created considering three different series of workstations (MTS, MTO, and MTS/MTO) in a manufacturing firm with a continuous production line. Furthermore, this paper considers the impacts of some significant, exogenous variables such as different outlays including operating expenses, holding costs, and the company's net profit.

Keywords: Production planning; Make to stock/Make to order; System dynamics; Capacity coordination; Order penetration point.

1. INTRODUCTION

Having known as an effective tool, production planning is becoming much more noteworthy, helping establishments to respond various market situations in a flexible manner. Competitive advantages belong to those companies which respond to orders rapidly and can deliver more customized goods. However, the obligation to have a high variety of products and instantaneous response times, places inconsistent demands on the production system [1,2,3]. Therefore, choosing an appropriate production system/approach is the most significant activity between other crucial decisions in a manufacturing company.

Categorized based on the capability to increase responsiveness or customization, figure 1 displays that various production policies from pure MTS to pure MTO exist with different levels of responsiveness and customization [4]. The key divergence among MTS and MTO is the timing of the receipt of the customer order compared with the final assembly of the finished product. Although in an MTO system the customer order is received before assembly of the

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final product, in an MTS environment, the product is assembled in anticipation of future orders and stored in the finished goods inventory [5].

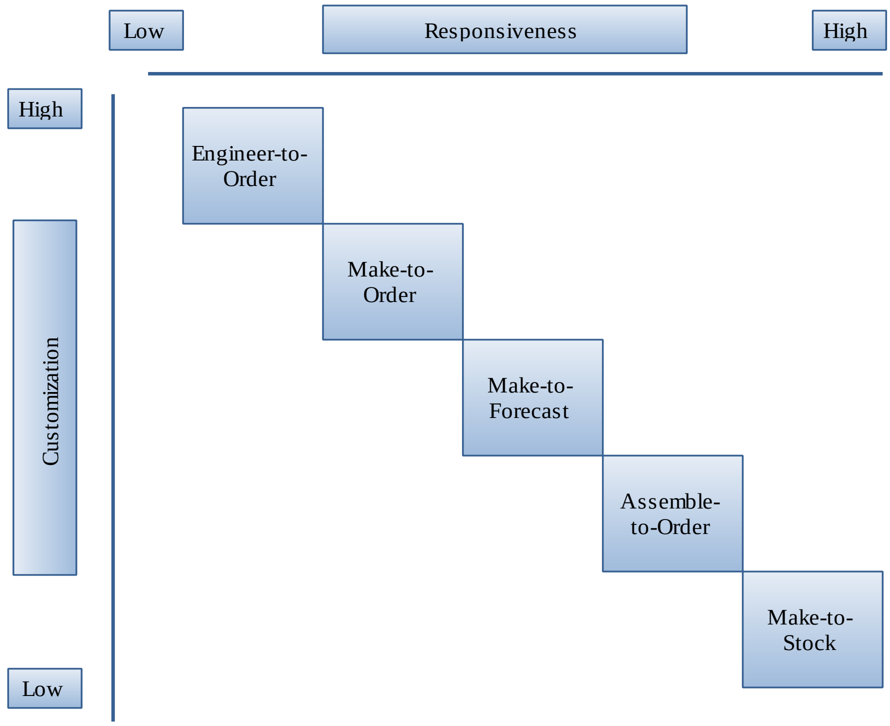

Figure 1: Production strategies to meet customization/responsiveness *[4]*

During the last two decades, a remarkable percentage of the researches in the field of production planning were aimed at the requirements of MTS companies [6]. At the present time, the choice among MTS or MTO system for a manufacturing establishment is a strategic one. Analyzing various working circumstances, firms are trying to make the best decision for being competitive in the global economy. Determining size, variety, and location of finished inventories, the company's logistics management has an important role in a pure MTS system. In such environments, computing a precise prediction of customer demand before production planning is considered as the main challenge. Furthermore, as demand is met from finished stock, products cannot be customized; this, will make MTS systems less attractive for highly competitive industries.

Therefore, manufacturing systems need to gain the benefits of both MTS and MTO systems in order to produce standardized products as well as customized ones [7]. While this seems to be impossible, the hybrid MTS/MT brings the two ends of a spectrum together by maintaining semi-finished goods at some stocking points. This, will increase the responsiveness since the delay will only be the time required for finalizing the MTO products. In an MTS system, future demand prediction is the only factor for releasing raw materials. As forecasts always have some sort of uncertainties, either redundant inventories or unforeseen stock outs will occur. On the other hand, production release occurs after receiving orders in an MTO system. With this regard, an appropriate combination of the two above-mentioned systems will rebound to attaining the advantages of both systems (i.e., lower inventory as well as shorter lead-time).

2. LITERATURE REVIEW

In spite of their attractiveness for practitioners and researchers, few articles exist in the literature, which address hybrid MTS/MTO systems in many aspects of the situations. Dealing with numerous questions for MTO products, Williams [8] was the first one studied a hybrid MTS/MTO, representing a single stage, stochastic demand, systems. He investigated relations among capacities and demands with the intention of answering several questions for hybrid systems. Solving a non-linear programming problem, Rajagopalan [9] presented a heuristic approach, specifying hybrid portioning and batch sizes for MTS products. Considering decomposition of products, Bemelmans [10] pondered the condition as a capacitated production planning problem, minimizing inventory holding costs as well as stock-out costs as major performance indicators. Li [11] explored the impression of customer comportment and market on MTO/MTS partitioning. He supposed a single product system with stochastic demands and maximized profit by means of stochastic optimization. Nguyen [12] addressed a hybrid MTS/MTO condition as a mixed queuing network and used the heavy traffic limit hypothesis in developing the process of finding estimates of fill rates and average inventory levels. Among various approaches applicable for hybrid production systems, hierarchical production planning (HPP) facilitates deciding through assorted decision levels with divergent characteristics [13]. Soman et, al. [14] defined three decision levels of HPP: strategic, tactical, and operational. In the strategic level, product family formation and OPP locating decisions are made. In the tactical level, capacity coordination as well as pricing and due date decisions are made. In the last level, order sequence and lot size determination decisions are planned. Addressing capacity coordination for hybrid production systems, Rafiei & Rabbani [15] considered three product types and developed a structure for determining order acceptance/rejection, due dates, and MTS products' lot sizes. proposing a structure consists of both mid-term and short-term production planning levels, Rafiei, et al. [16] addressed the second and third levels of HPP for hybrid MTS/MTO production systems.

Developing an inclusive dynamic model by means of SD approach, Georgiadis & Michaloudi [17] surveyed responsiveness in hybrid manufacturing systems integrating the advantages of multiple disciplines. Using a SD approach, an inventory and production system were modeled by Poles [18] for remanufacturing items with the intention of investigating process' dynamics as well as evaluating system improvement policies. He considered backorder, lead times, inventory coverage, and integrated remanufacturing/production capacity and demonstrated the remanufacturing procedure. A case study was propounded by means of developing a dynamic model and the simulation results were evaluated according to some performance measures.

3. PROBLEM DESCRIPTION AND MODELLING

Consider a set of three different workstations affecting performance of a manufacturing company. An increase in the overall capacity of the company will provide the company accept more customer orders. The company's order acceptance is a somewhat influential factor that will rebound to an increase in the net profit. On the other hand, the company will be convinced to increase the overall production, which will eventually leads to capacity increase. Each of the four factors mentioned in the central loop are affected by some other causes. For example, the overall production capacity is affected by overall capacity before Order Penetration Point (OPP) and after OPP. The utilization of capacity is profoundly dependent on the received customer orders and it is shown in practice that orders are not arriving continuously [19].

On the other hand, the customer suggests a specific time for the products delivery, which is known as desired delivery lead-time. Another effective concept to the mentioned factor is the actual delivery lead-time. If the ratio between actual and desired delivery lead-time (which is called “AD ratio”) is bigger than one, orders will be rejected for MTO and MTS/MTO products or customers will give up their purchase in MTS products. Hence, the company would accept incoming orders based on the available orders and the AD ratio. On the other hand, delivery and manufacturing lead-times depend on the total backlog (TB) and planned backlog (PB), in which the TB is influenced by planned and unplanned backlogs. From this point of view, there are two factors affecting the net profit: Label Price and Penalty.

On the other hand, customers giving orders typically quote a due date and a deadline and may penalize the manufacturer for late deliveries. This, rebounds to reduced revenue and even loss customers for the manufacturer [20]. Therefore, the penalty is defined as the product of AD ratio and unit delay penalty. The overall production will also affect the available production capacity, which will rebound to a decrease in the actual delivery lead-time, entailing the company accept more customer orders. The available production capacity will increase the shipment rate, proliferating demand Responses towards the total demand. The total demand effects the customer order and then, rebounds to unplanned backlog growth, affecting the total backlog. The dynamic model of the mentioned descriptions has been depicted in Figure 2.
As mentioned in the previous section, three types of workstations are taken into account in the propounded model. The total expected demand is divided into these three types, which are dependent on specific proportions for each. Hence, the production lot-sizes for each type will be specified. Note that these quantities are before the OPPs. Then, the available production capacity is affected by before OPP production items.

Thereafter, the production quantities after OPP are calculated based on the available capacity and the total demand (considered as overall demand of all three types that the customers states after OPP). The explained cause and effect relationships will finally affect the central loop and its elements such as overall production and overall capacity. It might appear, at the first glance, that when demand is greater than the capacity, the firm should expand capacity in order to be able to increase its response rate [21]. There are various characteristics for MTS, MTO, and MTS/MTO production systems. As we combined these three types into segregate workstations and placed it in a single company, their different aspects sometimes oppositely affect the parameters of manufacturing systems.

4. MODEL DESCRIPTION AND FORMULATION

As mentioned before, three types of demands including MTS, MTO, and MTS/MTO demands are studies in this research, which are considered respectively as following:

10+RANDOM UNIFORM(0,2,0)*SIN(1*(Time)) (1)

RANDOM NORMAL(3,9 ,6 ,2 ,0)+2*SIN(0.3*(Time)) (2)

RANDOM NORMAL(2.5, 9 ,5 , 3 , 0)+2.5*SIN(2*(Time)) (3)

Having the highest average in quantity**,** Figure indicates that the MTS demand (through time) has the least fluctuation in comparison with the two other ones and therefore, is more predictable. On the other hand, demand fluctuation in MTO and MTS/MTO demands are more than that of MTS. Hence, they are less predictable with lower average quantities in contrast with MTS demand. The total demand forecast is calculated through sum of the MTS, MTO, and MTS/MTO demands. Then, the capacity share of each workstation is determined through equations (4) to (6). Figure shows the capacity shares of each demand type workstations.

On the other hand, MTS production is dependent on holding cost. If inventory holding cost is high, the system should reduce its MTS production and, consequently, higher holding costs lead to less MTS production until the company decides not to produce such products any more.

$$\text{Capacity Share of MTS Workstations} = \mathit{Integral}((\mathit{MTS}\ \text{Demand} / \text{Total Demand}) - \text{Capacity Share of MTS Workstations})dt \quad (4)$$

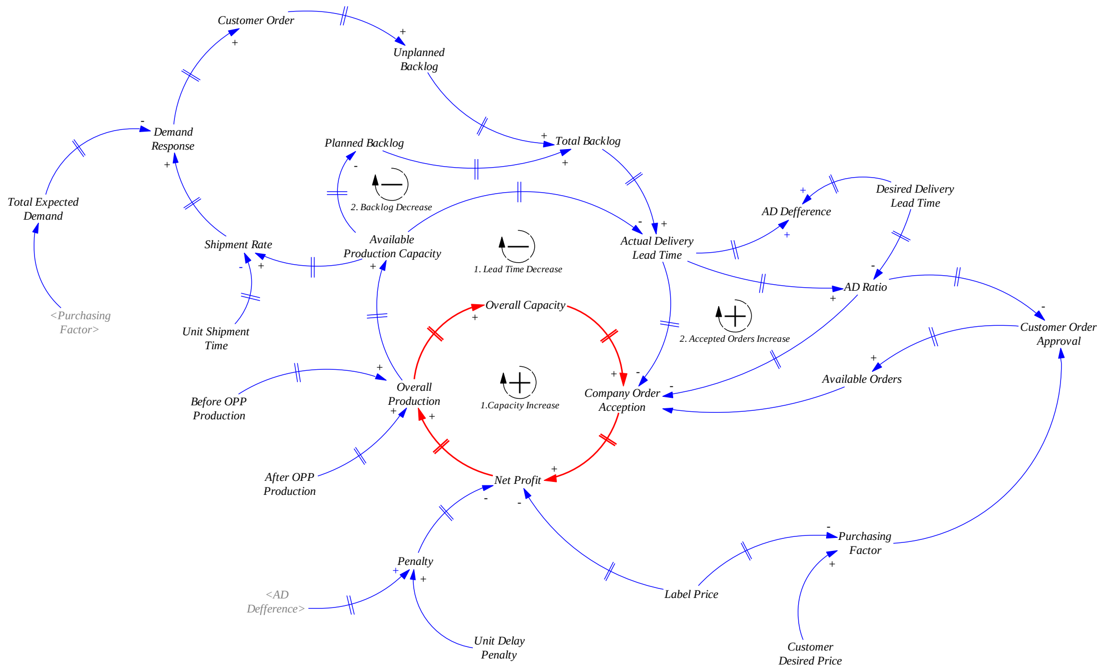

Figure 2: Dynamic Structure of OPP

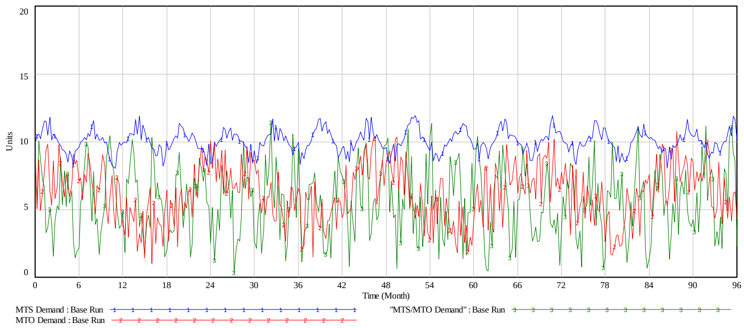

Figure 3: Demands for MTS, MTO, and MTS/MTO Products

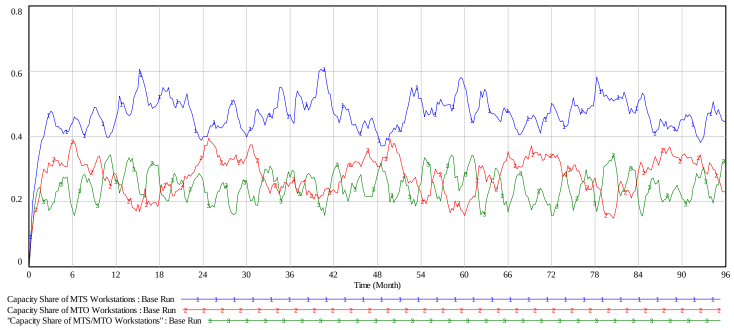

Figure 4: Capacity share of different Workstations

$$\text{Capacity Share of MTO Workstations} = \mathit{Integral}((\mathit{MTO}\ \text{Demand / Total Demand}) - \text{Capacity Share of MTO Workstations})dt \quad (5)$$

$$\text{Capacity Share of MTS/MTO Workstations} = \mathit{Integral}((\mathit{MTS} / \mathit{MTO}\ \text{Demand / Total Demand}) - \text{Capacity Share of MTS/MTO Workstations})dt \quad (6)$$

Therefore, as mentioned before, the firm is projected to restrict using inventory under such situations, and the MTS production will lead to zero. This is expressed in the model for calculating MTS production by means of the following formulas:

$$\text{KH Ratio} = \text{Capacity Cost Difference / Holding Cost Per Unit} \quad (7)$$

We first need to define the "Capacity Cost Difference" in order to reach to the estimation of "KH Ratio", which is determined through the following equation:

$$\text{Capacity Cost Difference} = \text{ABS(Cost of Adding a Unit of Capacity} - \text{Return from Selling a Unit of Capacity)} \quad (8)$$

In which "Cost of Adding a Unit of Capacity" is assumed to have normal distribution, using the following parameters:

$$\text{Cost of Adding a Unit of Capacity} = \text{RANDOM NORMAL(30, 70 , 45 , 20 , 7)} \quad (9)$$

Moreover, "Return from Selling a Unit of Capacity" is estimated using the following formula:

$$\text{Return from Selling a Unit of Capacity} = \text{SMOOTH(Net Profit / Available Production Capacity, 2)} \quad (10)$$

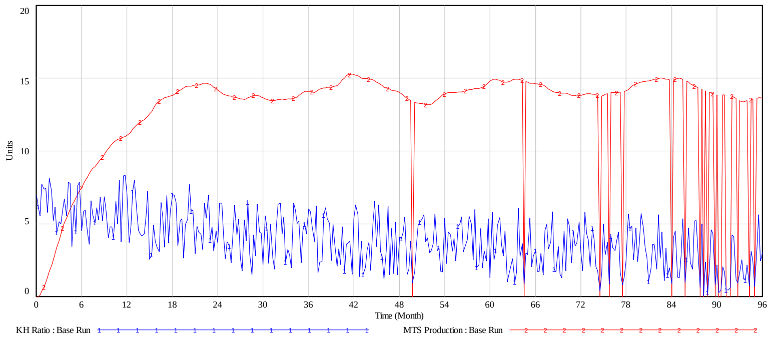

Figure 5: Simulation Results for MTS Production in Base Run

The holding cost is assumed to be constant with 7.5 $ per unit of capacity. Accordingly, the MTS production is estimated through equation 11. The equation exemplifies that when the “KH Ratio” is less than one (because of higher holding costs), the MTS Production will lead to zero and the company terminates responding to MTS demands. Figure shows the outcome of simulation for the MTS production when the holding cost is not so high. It is concluded that some demands are being rejected in the periods where the capacity cost difference was less than the specified holding cost.

$$\begin{aligned}&\text{MTS Production} = \text{IF THEN ELSE(KH Ratio<1, 0 ,}\\&\text{MTS Production Coefficient*SMOOTH(Capacity Share of MTS Workstations, 6))}\end{aligned}\tag{11}$$

The MTO production is also estimated based on its pre requisite capacity and the processing time, which is displayed in equation (12).

$$\begin{aligned}&\text{IF THEN ELSE(MTO Order Acceptance by Company<MTO Required Capacity ,}\\&\text{IF THEN ELSE(Total Processing Time Per Unit<MTO Delivery Lead Time,}\\&\text{UB*SMOOTH(Capacity Share of MTO Workstations, 3) , 0) ,}\\&\text{LB*SMOOTH(Capacity Share of MTO Workstations, 3))}\end{aligned}\tag{12}$$

To model the MTO production, the structure shown in Figure 6 is developed. The required capacities for MTS, MTO, and MTS/MTO demands are determined through the following equations:

$$\begin{aligned}&\text{MTS Required Capacity} = \mathit{Integral}(\text{MTS Expected Demand}\\&-\text{MTS Required Capacity})dt\end{aligned}\tag{13}$$

$$\begin{aligned}&\text{MTO Required Capacity} = \mathit{Integral}(\text{MTO Expected Demand}\\&-\text{MTO Required Capacity})dt\end{aligned}\tag{14}$$

$$\begin{aligned}&\text{MTS/MTO Required Capacity} = \mathit{Integral}(\text{MTS/MTO Expected Demand} -\\&\text{MTS/MTO Required Capacity})dt\end{aligned}\tag{15}$$

In which the expected demands are calculated using SMOOTH function, e.g. for the one related to MTS, it is indicated as following:

$$\text{MTS Expected Demand} = \text{SMOOTH(MTS Demand, 10)}\tag{16}$$

Furthermore, total processing time is expected to be constant during the planning horizon of the study. The MTS/MTO Production is also structured through the equation (17). Figure 6 expresses the behavior of MTO and MTS/MTO production in the developed model:

IF THEN ELSE("MTS/MTO Order Acceptance by Company"<"MTS/MTO Required Capacity",
UB*SMOOTH("Capacity Share of MTS/MTO Workstations", 10) ,
LB*SMOOTH("Capacity Share of MTS/MTO Workstations", 10)) (17)

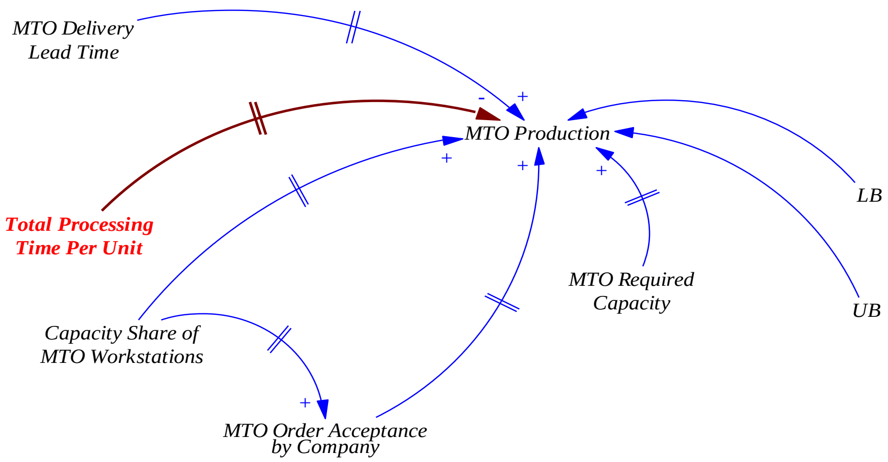

Figure 6: The structure of “MTO Production” in the model

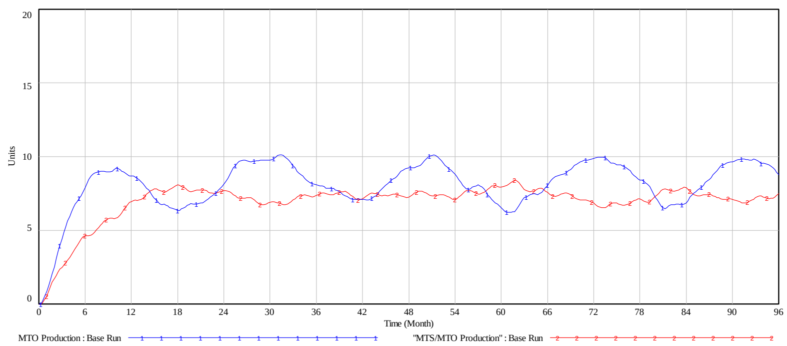

Figure 7: Simulation results for MTO and MTS/MTO Production in Base Run

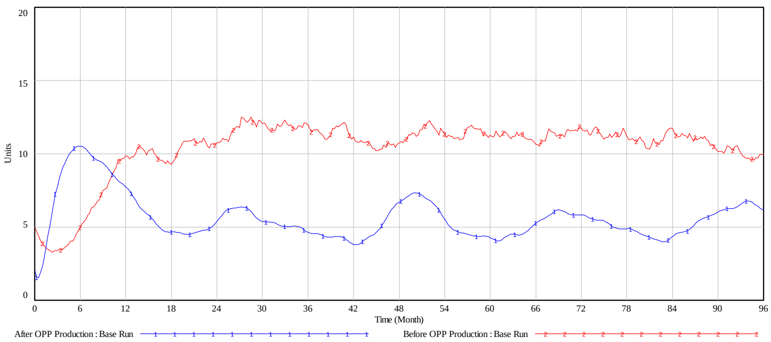

Figure 8: Simulation results for before and after OPP production in the developed model

Then, before and after OPP productions are premeditated respectively through workstations' production and total required capacity, using exponential delay according to equations (18) and (19). Figure 7 and 8 demonstrate the simulation result for these two variables. The required capacities for each type of production in the base run are also depicted in Figure 9.

$$\text{Before OPP Production} = \text{SMOOTHI(Workstations Production , 4 , 5)} \tag{18}$$

$$\text{After OPP Production} = \text{MAX(SMOOTHI(Total Required Capacity} - \text{Available Production Capacity , 4 , 2), 0)} \tag{19}$$

Considering products' price, penalties for delivery lateness and calculating net profit are some of the most significant modules in our developed model, which has not been studied so far in the previous studies. In the base run, a label price has been defined for the products through the following equation:

$$\text{Label Price} = \text{(1+Expected Margin)*Operating Expenses} \tag{20}$$

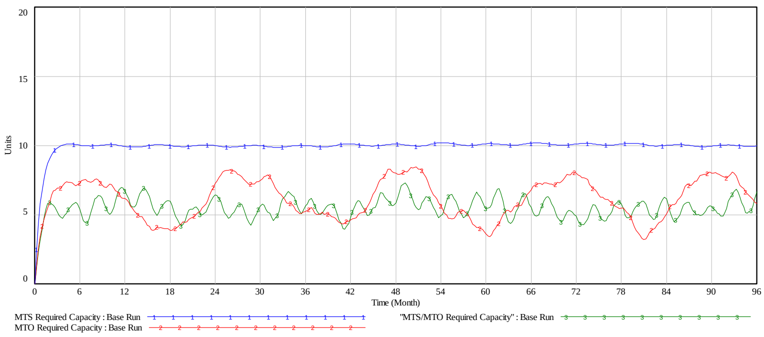

Figure 9: Simulation results for MTS, MTO, and MTS/MTO capacities in the Base Run

The expected margin is supposed to be constant during the planning horizon. However, operating expenses are the sum of holding cost per unit and fixed operating costs, which is normally distributed with the following parameters:

$$\text{Fixed Operating Cost} = \text{RANDOM UNIFORM(20, 50 , 6)} \tag{21}$$

On the other hand, penalties are determined through multiplication of the differences between actual delivery lead-time, desired delivery lead-time, and the unit delay penalty, which is supposed to be constant (30$). Consequently, equation (22) determines penalty and finally, the net profit is estimated through equation (23), based on the total order acceptations. Figure 10 indicates penalties and label prices for the base run and net profits are demonstrated in Figure .

$$\text{Penalty} = \text{IF THEN ELSE(AD Difference>0, AD Difference*Unit Delay Penalty , 0)} \tag{22}$$

$$\text{Net Profit} = \mathit{Integral}\text{((Label Price} - \text{Penalty)*Company Order Acceptance} - \text{Net Profit)}\,dt \tag{23}$$

Delivery lead times are another important factors considered in the developed model, which are based on order fulfillment rate, calculated through equation (24):

$$\text{Order Fulfillment Rate} = \text{SMOOTHI(Total Expected Demand*Shipment Rate , 5 , 6)/100} \tag{24}$$

The total expected demand is calculated based on MTS, MTO, and MTS/MTO expected demands, and the purchasing factor, using the following formula:

$$\begin{aligned}&\text{Total Expected Demand} = \mathit{Integral}(\text{IF THEN ELSE(Purchasing Factor>0,}\\&\text{SMOOTHI(MTS Expected Demand+MTO Expected Demand+}\\&\text{"MTS/MTO Expected Demand" , 3 , 6) , DELAY1(MTS Expected Demand+}\\&\text{MTO Expected Demand+"MTS/MTO Expected Demand", 5))} - \text{Total Expected Demand})\,dt\end{aligned} \tag{25}$$

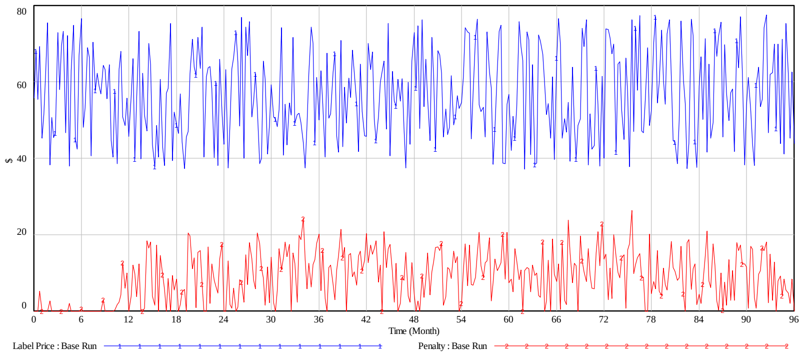

Figure 10: Simulation results for label price and penalty in the base run

5. CONCLUSION

The application of hybrid MTS/MTO production environments is becoming more and more dominating because of its flexibility against different demand situations. Despite lots of papers working in the field of MTS/MTO, literature survey of this paper shows that there is a need to dedicate research works to development of models and procedures for investigation of capacity coordination dynamics in hybrid manufacturing establishments. Hence, this paper proposed a system dynamics model for a hybrid MTS/MTO production environment with three different series of workstations (MTS, MTO, and MTS/MTO).

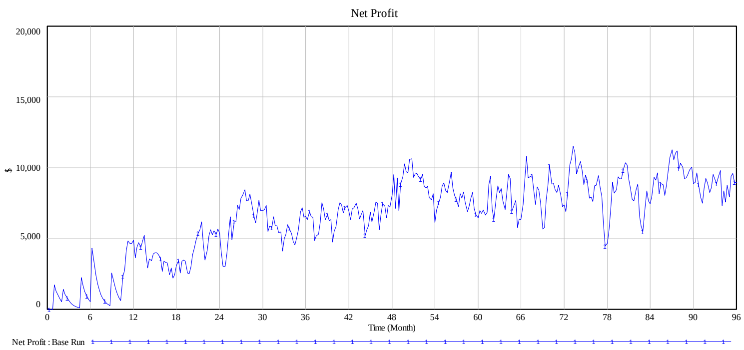

Figure 11: Simulation result for net profit in the base run

The key contribution and significance of this study is threefold. First, unlike most studies considering only a hybrid workstation that responds to all demand types, this paper defined three different workstations for responding to MTS, MTO, and MTS/MTO demands separately. This feature enables establishments to handle demand uncertainties and fluctuations in customer orders independently. Second, this is the first study that investigates the impacts of pricing and profit maximization in hybrid MTS/MTO production environments. Third, with reference to the functional and contextual analysis of hybrid systems, the dynamism of such systems has been explored considering the most influential factors in the proposed SD model. Finally, the system's performance was assessed by analyzing reactions of the propounded model under different conditions such as demand uncertainty, variable operating expenses, and pricing. The sensitivity analysis confirms the logical behavior of our developed model and, therefore, verifies its superiority in contrast with the previous study, since it considers factors that are more influential to explore dynamism in hybrid manufacturing environments.

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