

Benefits of Additional Make-to-Stock Channel with Price Control Characteristic to Make-to-Order Channel

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Abstract — In this paper we study the benefits for a manufacturer or supplier of having a secondary sales channel with price control in addition to its primary sales channel. Our definition of the primary sales channel is that a majority of company's total profit is from it, and that the company has make-to-order (MTO) production environment to meet this demand. On the other hand, our definition of the secondary channel is that the company is assumed to be able to create certain demands by reducing the price of standard products for the channel. Therefore, the secondary channel is supplied by make-to-stock (MTS) products as a manufacturer tries to make use of excess capacity after meeting the demand for the primary channel. We assume that the manufacturer can create just enough volume of demand from the secondary channel to match the excess production capacity. We call the primary channel MTO, and the secondary MTS. In other words, a manufacturer or supplier can increase revenues/profits and smooth the MTO productions by using the MTS channel through utilizing the excess capacity. However, developing MTS channel needs investments. In this paper, we try to find out in what operational characteristics a company can justify the investments for the benefits of developing the additional MTS channel to the existing MTO channel. We measure the quantitative benefits of the additional channel over various sets of operational characteristics and interpret the results. With a set of experiments, we investigate the effect of demand variability, capacity utilization, and holding and other production-related costs with a simple price-demand relationship. We have observed that benefits increase as demand variability increases, as capacity utilization decreases, and as capacity change costs. However, the holding does not seem to impact the benefits.

Keywords—*aggregate production planning, make-to-order, make-to-stock, channel management, price control*

1. Introduction

Market demand can be categorized into two types: one that asks specific functions of a product with a specific lead time of delivery and the other with general functions with instant lead time: Demand for custom products versus demand for standard products. Manufacturing

strategies that companies choose for these different types of market demand are called Make-To-Order (MTO) and Make-To-Stock (MTS) productions respectively. Cattani et al (2002) show an example of a messenger bag manufacturer who makes both custom type MTO products and standard MTS products. In the paper, the company currently has "flexible capacity" to make both MTO and MTS products. It considers outsourcing off-shore "efficient capacity" to make MTS products separately. They study a question of which way would be more profitable for the firm, and introduce "spackling" strategy in contrast to "focused" strategy where the former is building both types products with one flexible capacity, and the latter is building each type of products separately using both flexible and efficient capacities.

Under the spackling strategy, a company, using only one capacity, first makes custom MTO products as demanded each period, and then fills in, or spackles, the production schedules with standard MTS products, to restock inventory. This is because the order patterns for MTO products are bumpy yielding an undesirable production profile compared to smooth schedules that would allow for higher capacity utilization. Cattani et al (2002) suggest that sometimes, spackling strategy is more profitable depending on the trade-offs between cost savings the focus strategy offers via efficient production (reduced cost times units produced) versus lowered amortized fixed cost per unit when single capacity is better utilized. They claim that better capacity utilization arises as the fixed costs of flexible capacity are amortized over greater average volume under spackling.

This "spackling" strategy is the basic idea of this paper. The main question in this paper is how beneficial to have an additional secondary MTS channel when a manufacturer has its existing primary MTO market. If the benefits cannot be justified for cost savings from the focus strategy and costs for developing MTS channel, this strategy would not be very meaningful to the manufacturer. Since every company has a different set of operational characteristics, it is important to know for managers under what operational characteristics this strategy is most beneficial to them. We build a multi-

period dual channel model with a price-sensitive secondary MTS channel. Then, using simulations, we test out various sets of operational characteristics for the model and observe how certain operational characteristics affect the performance of the model. We have observed that benefits increase as demand variability increases, as capacity utilization decreases, and as capacity change cost increases. We could not substantiate the beneficial behaviour from holding cost.

Our definition of the primary sales channel is that a majority of company's total profit is from the primary channel, and that the company has make-to-order (MTO) production environment to meet this demand. On the other hand, our definition of the secondary channel is that the company is assumed to be able to create certain demands by reducing the price of the product or using more standard/general products for the channel. The secondary channel is supplied by make-to-stock (MTS) products as a manufacturer tries to make use of excess capacity after meeting the demand for the primary channel. We assume that the manufacturer can create just enough volume of demand from the secondary channel to match the excess production capacity.

There are a lot of possibilities of using dual production strategy using spackling. For example, a microprocessor manufacturer can mainly produce Pentium-like high performance processors while utilizing excess capacity by producing Celeron type of lower-end products. Another example can be applied to the service industry: We can think of a local paint contractors where they paint exterior of houses during peak season, summer, at a regular price and offer discounted prices for painting interior of factories during off-peak season, winter. More examples can be applied to the automobile industry, clothing industry, or PC manufacturing industry.

The structure of this paper is as follows: The next section reviews the existing literature. We, then, lay out the problem setup and mathematical formulation. Due to the complexity of the problem, we model a smaller scale problem with restricted conditions with contrived demand data so that we can solve the problem with Excel Solver and interpret the output meaningfully. An experimental design is described for measuring impact of certain operational characteristics. Results of the experiments are shown and discussed. Finally, we conclude the paper with possible future extensions.

2. Literature Review

The modeling approach we use for the problem is similar to traditional aggregate production planning (APP) problem. APP is a production smoothing and work force balancing problem for medium range planning. Objective

of APP is to minimize total costs meeting fluctuating demand: production change costs, inventory costs, and shortage costs. One of the classic works in this area is done by Holt et al, also known as HMMS, (1960) who solved the problem by LDR (Linear Decision Rule). Linear programming and simulation have been used as well by other researchers. Research in APP was very active from late 50's to 70's. For a comprehensive review in APP, we recommend reading Silver (1967)

There are other ways to smooth production levels than APP. Leith (1974) studies using advertising promotion to shift seasonal demand. Kamien and Li (1990) study subcontracting for production smoothing. Cattani et al (2002) use "spackling" to smooth MTO production of custom products with MTS of standard products. They study when spackling is better than producing MTO and MTS products separately. Cattani et al (2002) has a very similar view of the problem to this paper, but we looked at the actual benefits that can be found under various operational characteristics of the firms which can possibly use this strategy.

3. Problem Setup and Model Formulation

We study a multiple period, and single-stage supply chain problem. We allow inventory carry-overs from one period to the next for MTS channel only in our multiple-period problem. It is not needed for MTO because the demand needs to be met for the order taken. Therefore, no inventory would be available to be carried over. Backorders are only allowed for MTO channel because we have to meet the current period's unmet demand for the primary channel in the next period not to lose any sales that have a high profit margin. Since backordering incurs possible capacity change cost in the following period, we do not backlog for MTS demand as MTS demand has lower profit margin that will not justify the change-over cost. In our model, production rate changes incur capacity change cost in each period. Hence, the operational costs that are involved in the model are inventory holding costs and capacity change costs at the end of each period.

This problem can be mathematically represented by a network formulation with several side constraints. A network flow diagram of the model is shown in Figure 1 below: This diagram shows an example of network flow diagram for a three period problem ($n=3$). In Figure 1, Node Q represents production quantity. Node S represents supplied quantity for corresponding type of demand. At each period, there are two separate demand nodes: one for MTO (D_{t-MTO}) and the other for MTS channel (D_{t-MTS}). Although we modelled both MTO demand and MTS demand are dependent on the corresponding price, for the experiment in the next section, we assumed only the MTS demand is dependent on its MTS price.

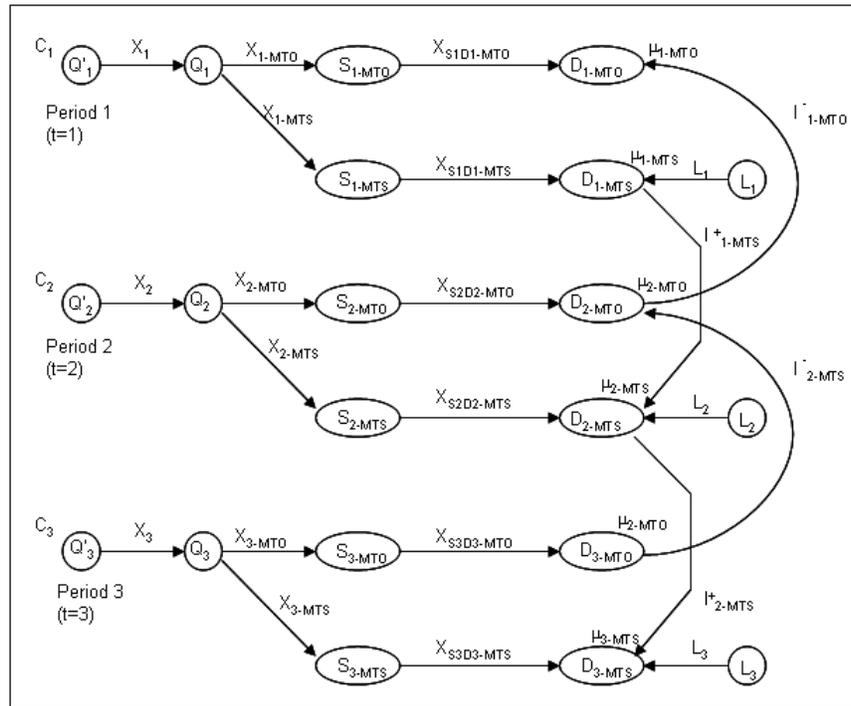


Figure 1. Network representation of the two-channel problem for three periods ($n=3$)

The model allows backorders (I_{t-MTO}^-) for MTO demands because a supplier would not want to lose any sales from MTO channel. Any excess capacity after meeting as much MTO demand as possible will be used to produce products for MTS channel. Here, the model allows lost sales (L_t) for MTS demand because a supplier would not want to produce any more just for MTS customers after MTO demands are met. If there are any excess inventory (I_{t-MTS}^+) after meeting MTS demand, then it will be carried over to the next period.

A general mathematical formulation is shown in (1)-(16). Although Figure 1 looks like a network flow diagram, because of the constraints (14) - (16) in the formulation, the model breaks the conditions of a pure network structure. These are added to the network model as side constraints because they are necessary for deciding whether to increase the production rate or not. The objective function of the formulation is presented in (1). The constraints are shown in (2)-(16) followed by definitions of the terms used.

Maximize profit:

$$Z = \left[P_{MTO} \cdot \sum_{t=1}^n \mu_{t-MTO} + P_{MTS} \cdot \sum_{t=1}^n \mu_{t-MTS} \right] - \left[\sum_{t=1}^n (X_t \cdot c_t) + P_{MTS} \cdot \sum_{t=1}^n L_{t-MTS} + \sum_{t=1}^{n-1} (I_{t-MTS}^+ \cdot h_t) + \sum_{t=1}^{n-1} (I_{t-MTO}^- \cdot \pi_t) \right] + \sum_{t=1}^{n-1} (X_t^{\Delta+} \cdot \lambda_t) + \sum_{t=1}^{n-1} (X_t^{\Delta-} \cdot \omega_t) + \sum_{t=1}^{n-1} (Y_t^+ \cdot F_t^+) + \sum_{t=1}^{n-1} (Y_t^- \cdot F_t^-) \quad (1)$$

Subject to:

$$X_t \leq C_t, t = 1, \dots, n \quad (2)$$

$$X_t = X_{t-MTO} + X_{t-MTS}, t = 1, \dots, n \quad (3)$$

$$X_{t-MTO} = X_{S_t D_{t-MTO}}, t = 1, \dots, n \quad (4)$$

$$X_{t-MTS} = X_{S_t D_{t-MTS}}, t = 1, \dots, n \quad (5)$$

$$\begin{cases} X_{S_t D_{t-MTO}} + I_{t-MTO}^- = \mu_{t-MTO}, t = 1 \\ X_{S_t D_{t-MTO}} + I_{t-MTO}^- - I_{t-1-MTO}^- = \mu_{t-MTO}, t = 2, \dots, n-1 \\ X_{S_t D_{t-MTO}} - I_{t-1-MTO}^- \geq \mu_{t-MTO}, t = n \end{cases} \quad (6)$$

$$\begin{cases} L_t + X_{S_t D_{t-MTS}} - I_{t-MTS}^+ = \mu_{t-MTS}, t = 1 \\ L_t + X_{S_t D_{t-MTS}} - I_{t-MTS}^+ + I_{t-1-MTS}^+ = \mu_{t-MTS}, t = 2, \dots, n-1 \\ L_t + X_{S_t D_{t-MTS}} + I_{t-1-MTS}^+ \geq \mu_{t-MTS}, t = n \end{cases} \quad (7)$$

$$\begin{cases} L_t + X_{S_t D_{t-MTS}} - I_{t-MTS}^+ + I_{t-1-MTS}^+ = \mu_{t-MTS}, t = 1 \\ L_t + X_{S_t D_{t-MTS}} - I_{t-MTS}^+ + I_{t-1-MTS}^+ = \mu_{t-MTS}, t = 2, \dots, n-1 \\ L_t + X_{S_t D_{t-MTS}} + I_{t-1-MTS}^+ \geq \mu_{t-MTS}, t = n \end{cases} \quad (8)$$

$$\begin{cases} L_t + X_{S_t D_{t-MTS}} - I_{t-MTS}^+ = \mu_{t-MTS}, t = 1 \\ L_t + X_{S_t D_{t-MTS}} - I_{t-MTS}^+ + I_{t-1-MTS}^+ = \mu_{t-MTS}, t = 2, \dots, n-1 \\ L_t + X_{S_t D_{t-MTS}} + I_{t-1-MTS}^+ \geq \mu_{t-MTS}, t = n \end{cases} \quad (9)$$

$$\begin{cases} L_t + X_{S_t D_{t-MTS}} - I_{t-MTS}^+ = \mu_{t-MTS}, t = 1 \\ L_t + X_{S_t D_{t-MTS}} - I_{t-MTS}^+ + I_{t-1-MTS}^+ = \mu_{t-MTS}, t = 2, \dots, n-1 \\ L_t + X_{S_t D_{t-MTS}} + I_{t-1-MTS}^+ \geq \mu_{t-MTS}, t = n \end{cases} \quad (10)$$

$$\begin{cases} L_t + X_{S_t D_{t-MTS}} - I_{t-MTS}^+ = \mu_{t-MTS}, t = 1 \\ L_t + X_{S_t D_{t-MTS}} - I_{t-MTS}^+ + I_{t-1-MTS}^+ = \mu_{t-MTS}, t = 2, \dots, n-1 \\ L_t + X_{S_t D_{t-MTS}} + I_{t-1-MTS}^+ \geq \mu_{t-MTS}, t = n \end{cases} \quad (11)$$

$$\mu_{t-MTO} = f(P_{MTO}) \quad (12)$$

$$\mu_{t-MTS} = g(P_{MTS}) \quad (13)$$

$$X_t + X_t^{\Delta+} - X_t^{\Delta-} = X_{t+1}, t = 1, \dots, n-1 \quad (14)$$

$$M \cdot Y_t^+ \geq X_t^{\Delta+} \quad (15)$$

$$M \cdot Y_t^- \geq X_t^{\Delta-} \quad (16)$$

$$Y_t^+, Y_t^- = \{0,1\} \quad (15)$$

$$t = 1, \dots, n-1 \quad (16)$$

Where:

(Decision variables)

X_t = planned quantity to be produced in period t

X_{t-MTO} = supplying quantity to meet MTO demand at period t

X_{t-MTS} = supplying quantity to meet MTS demand at period t

$X_{S_t D_{t-MTO}}$ = flow between a supply node (S_t) to a demand node (D_t) for MTO demand

$X_{S_t D_{t-MTS}}$ = flow between a supply node (S_t) to a demand node (D_t) for MTS demand

I_{t-MTS}^+ = excess inventory for MTS channel at the end of period t

I_{t-MTO}^- = backorder for MTO channel at end of period t

L_{t-MTS} = quantity of lost sale for MTS channel

μ_{t-MTO} = MTO demand at node D_{t-MTO} at t

μ_{t-MTS}	= MTS demand at node D_{t-MTS} a function of MTS-price
X_t^{A+}	= increase in production rate from $t-1$ to t
X_t^{A-}	= decrease in production rate from $t-1$ to t
Y_t^+	= 0/1 variable (1 if production rate is increased at period t , 0 if not)
Y_t^-	= 0/1 variable (1 if production rate is decreased at period t , 0 if not)
P_{MTO}	= price for MTO channel (fixed and decided by market)
P_{MTS}	= price for MTS channel (varies depends on μ_{t-MTS})

(Costs and other constants)

n	= number of time periods in planning horizon
C_t	= capacity in units of product in period t
c_t	= production or purchase variable cost per unit in period t
h_t	= holding cost per unit after meeting MTS demand from period t to $t+1$
π_t	= backorder cost per unit of MTO demand carried from period t to $t+1$
λ_t	= cost to increase the production rate by one unit from period $t-1$ to t
ω_t	= cost to decrease the production rate by one unit from period $t-1$ to t .
F_t^+	= fixed cost for increasing production rate at period t .
F_t^-	= fixed cost for decreasing production rate at period t .

The objective function in (1) is to maximize profits, which is the sum of its revenue from meeting MTO and MTS demands as much as possible, minus total costs which includes variable production cost, lost sales from not being able to meet MTS demand, inventory holding costs after meeting MTS demand, backorder costs for the unmet MTO demand, variable costs per unit produced for increasing or decreasing production rate at each period, and fixed costs for the decision to increase or decrease production rate at each period. The capacity constraints in (2) and (3) limit the total amounts to be supply for MTO and MTS channel in the each period by the capacity limit set for the period. Constraints (4) and (5) may not mean much now because they are written for expandability of the model according the network diagram shown in Figure 1. The next three constraints, (6)-(8), are flow balance equations at the MTO demand nodes for all the periods. Constraints (6) and (8) apply to the very first and last periods. By (7), the model makes sure that, in each period between the very first and last period, the MTO demand balances with supplied quantity for MTO and backordered amount from the previous period and to the next period. In similar way, constraints (9)-(11) represent flow balance equations at the MTS demand nodes. Expressions (9) and (11) are for the first and last periods. Constraint (10) imposes flow balance between MTS demand and amounts of lost sales, supplied quantity for MTS and carried-over quantities from the previous period and to the next period. Price-demand functional relationships are shown in (12) and (13): one for MTO channel and the other for MTS. Change in total production amounts from one period to the next is represented in (14). Expressions (15) and (16) set

zero-one variables for decisions to change production levels in each period.

Some of the above constraints are relaxed for the analysis in the remaining sections of the paper since we study a simplified model to reduce complexity in model behaviour. For example, the price-demand relationship for MTO channel (12) is not considered for our analysis. The demand from the primary channel is assumed to be stochastic whereas the demand from the secondary channel is assumed to be a linearly related to the price the company sets for the channel. The primary demand is satisfied by MTO manufacturing, and the secondary demand by MTS inventory.

The objective function of the formulation is to maximize the profit over entire planning horizon. As the profit is obtained by subtracting total costs (holding and capacity change costs) at the given period, the objective function becomes non-linear because the revenue from the MTS channel has non-linear term due to a price-demand relationship: i.e. the MTS revenue is a product of price and quantities sold while the quantities sold for MTS channel is a function of the price for the channel. The function describing the relationship between demands and prices will have a decreasing pattern as price goes up, and could be a straight line, concave, or convex curves depending on the industry in question. For example, if a linear relationship is assumed between MTS price and MTS demand for constraint (13), the revenue from MTS channel in the objective function will be quadratic as shown in (17) and (18) below:

$$\mu_{MTS} = g(P_{MTS}) = -a * P_{MTS} + b \quad (17)$$

$$\begin{aligned} R_{MTS} &= \mu_{MTS} * P_{MTS} = g(P_{MTS}) * P_{MTS} \\ &= (-a * P_{MTS} + b) * P_{MTS} \\ &= -a * P_{MTS}^2 + b * P_{MTS} \quad (18) \end{aligned}$$

(Where R : Revenue, P : Price, and μ : Demand)

The revenue is expressed by the square term of the MTS price which affects the objective function to be non-linear. This nonlinearity makes the model behaviour more difficult to predict. So, we have simplified the model and run a set of experiments to see the behaviour of the model to draw meaningful results. A simplified Excel Solver model and the experiment setups are explained in the next section.

4. Experimental Design

With Excel solver, we model a four period model with contrived demand data. The model we use for the experiment has a fixed price for MTO channel, P_{MTO} . In our experiments, for simplicity, we do not consider

production rate change cost and shortage costs unlike traditional APP. The only costs we are considering are inventory holding costs and capacity change cost. The holding costs are linearly proportional to the amount of end inventory in each period. The capacity change cost is a fixed charge cost. It may look somewhat similar to the fixed production rate change cost, but the difference is that it does not occur every time the production level changes except when production level goes over capacity limit. We call it “hard” capacity and explain it later in this section.

We use a linear decreasing function for the price-demand relationship in MTS channel. By this we are assuming that

we can somewhat control the MTS demand with P_{MTS} . P_{MTS} is set at each period and is a decision variable. The price-demand relationship for MTS channel we use for our experiment is shown in Figure 2 below. Additionally, we assume unconstrained production capacity with relevant capacity change costs and unconstrained holding capacity with relevant holding costs.

In observing the behaviour of the model, we use contrived data at current stage to avoid its complex interactions between capacity change costs and holding costs along with its nonlinear (quadratic in this case) profit function. When we used random generated demands, the results were not easy to interpret for the model behaviour.

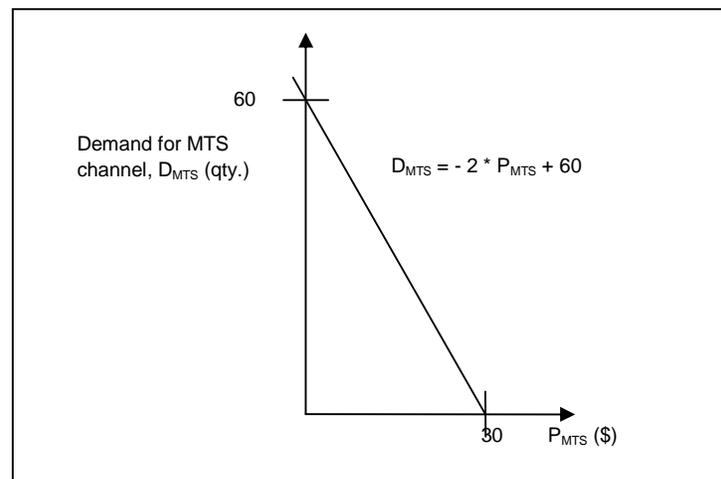


Figure 2. A linear price-demand relationship for MTS channel

We use 100 for an average demand per period for MTO channel. We make sure the sum of all four periods is always 400 for each experiment for fair comparison of profit improvements of different demand profiles. We use following three data series of demand profile:

- No demand variation: 100-100-100-100 → +/- 0% var.
- Low demand variation: 75-125-75-125 → +/- 25% var.
- High demand variation: 50-150-50-150 → +/- 50% var.

Our model is limited by the hard capacity constraint (similar to a fixed charge problem). As it is mentioned earlier, what we mean by a “hard” capacity is that when production level goes over the preset capacity limit, a capacity change cost incurs, and then the capacity level is set back to the original preset level in the next period. On the other hand, when it is a “soft” capacity, the capacity level is set to the production level every time the production level changes, while incurring fixed cost: then the capacity level is equal to the production level in each period. Soft capacity constraint case will be discussed in future extensions section. The preset hard capacity level

is set in a way the average target capacity utilization over the planning horizon can be kept at a desired level. For example, if one desires a capacity utilization level of 75% when the average demand per period is 100, then the capacity level is set to 133 per period ($100/133 = .75$). Figure 3 below is an example diagram of a production plan when it follows the demand exactly.

The model developed in this paper is expected to look for an optimal solution by assessing the following alternatives available in planning to meet fluctuating demands: The model

- Builds inventories during periods of slack MTO demand and sells them to MTS channel,
- Carries backorders for MTO customers or tolerates lost sales from MTS customers during periods of peak demands, and
- Varies production rate in case there is a spike in MTO demand stream.

What the model tries to do is graphically shown in Figure 4 below.

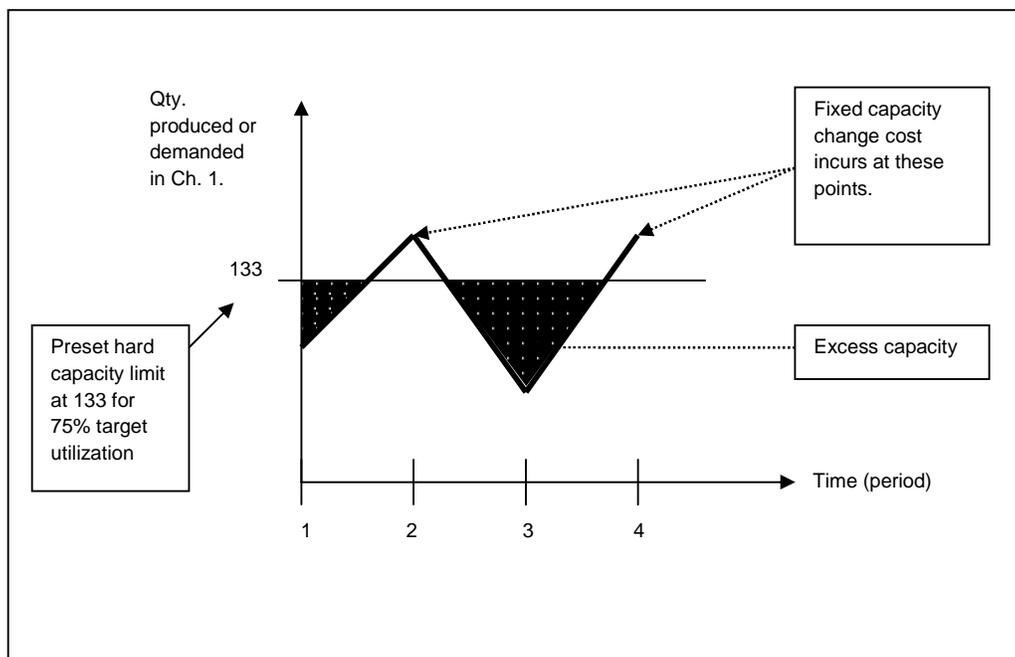


Figure 3. Example of a production plan with a hard capacity limit

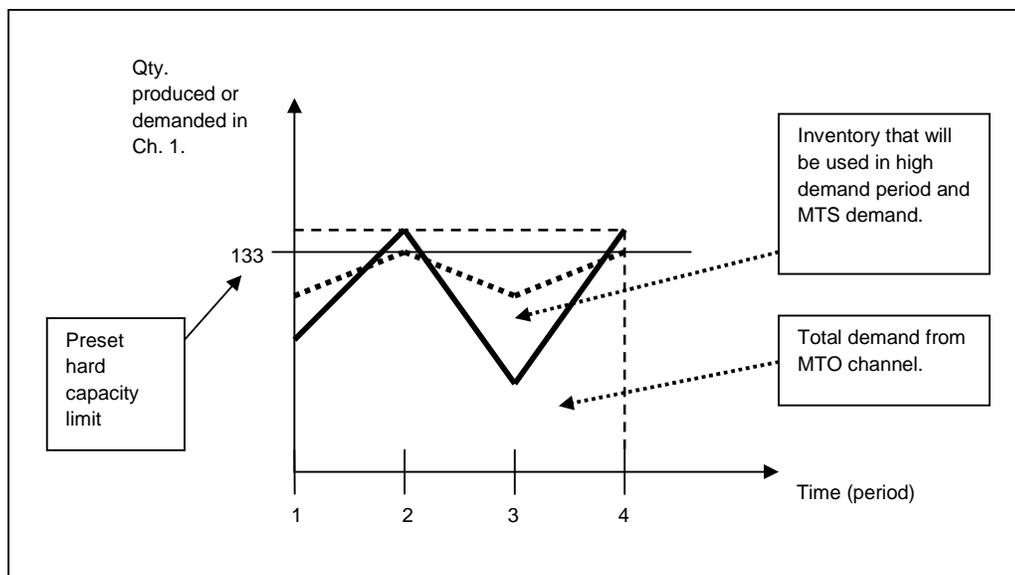


Figure 4. Example of a production plan illustrating performance measure
(When capacity change costs are infinite)

We build an experimental design to observe the behavior of the model in terms of profit increase by introducing MTS channel to an existing MTO channel with various factors. We use MTO price of \$40. The followings are the four factors we used for the design:

- Factor 1: Average capacity utilization (two levels)
→ Low (75%) and High (90%)
- Factor 2: Demand variances (three levels)
→ None (0%), Low (25%), and High (50%)
- Factor 2: Holding costs (three levels in percentage of P_{MTO}) → Low (0%), Medium (15%), and High (40%)

- Factor 3: Capacity change costs (four levels in percentage of maximum possible revenue from MTS channel) → 0%, 50%, 100%, and 400%

For the same setting of experiments as described above, we run two models (Model 1 and Model 2) and compared the profit increased. Model 1 is an optimization model with MTO channel only, and Model 2 is with both MTO and MTS channels.

5. Results and Discussions

The performance measure we use is the profit increase from Model 1 to Model 2. We define the “base case” when Model 1 has zero capacity change cost and zero holding cost. In the base case, the maximum profit we can get is \$16,000 reaping all the demand over four periods from MTO channel since the total demand of 400 is constant for each experiment when P_{MTO} is set to \$40. This profit amount is used as a base (100%) when we compare profits from other experiments because we know that \$16,000 is the maximum we can do without MTS

channel. The percentage improvement from the base case is the performance measure of the experiments. For example, when we add MTS channel to the base case, the maximum additional profit from MTS channel with the given price-demand relationship is found to be \$1,800 which is 11.25% of the base case profit. Thus, the maximum total profit from both MTO and MTS channels are summed up to \$17,800 (111.25%), an improvement of 11.25%. Profit improvements from Model 1 and Model 2 for three demand variations are shown in Table 1 and Table 2 below:

Table 1. Summary of profit improvements over capacity change costs and holding costs

Capacity change costs (% of max. rev. from Ch.2)	Holding costs (% of P_{MTO})		
	0%	15%	40%
0%	11.30%	11.30%	11.30%
50%	9.80%	11.10%	11.10%
100%	8.40%	8.87%	8.87%
400%	6.30%	5.77%	5.77%

(When capacity utilization of 90% and demand variation of 50%)

Table 2. Summary of profit improvements over demand variance and capacity utilization

Demand variance in MTO	Capacity Utilization	
	75%	90%
0%	11.25%	7.51%
25%	11.43%	8.46%
50%	11.54%	9.28%

Table 1 show that profit improvement decreases as capacity change costs increase. However, the profit improvement did not change over different levels of holding cost. This matches our intuition that when capacity change cost is high, it tends to offset the benefits from the revenue by MTS channel. Holding cost would not affect the profit improvement because we only hold MTS inventory, but not MTO inventory as explained earlier. MTS inventory is used after meeting MTO inventory and the demand for MTS is controlled with the price just enough to use up the excess capacity from MTO. Secondly, we observe that we can achieve, on average, higher profit improvements when capacity utilization is lower. It also matches with our intuition that

when we have more excess capacity, we can utilize it for more profits. Finally, profit improvements appear to increase as demand variance increases. It can be explained by as demand variance increases there are more opportunity to utilize excess capacity for MTS due to the fluctuation of MTO demand.

6. Conclusion and Future Extensions

We find that developing secondary MTS channel with standard products to utilize the excess capacity from primary MTO channel with customized or higher end products is beneficial for a manufacturer/supplier. From our experiments with various operational characteristics, a

company can achieve profit improvement from developing MTS channel. And the profit improvement increases as demand variability increases, capacity utilization decreases, and changeover cost decreases. The holding cost for MTS is found to be not affecting the profit improvement. Overall, in the worst case, when capacity utilization is high and demand variation is low (90% and 0% respectively), we found that we can still achieve 7.51% of profit improvement with Model 2 over Model 1 due to utilizing the excess capacity. It means that the minimum profit improvement possible due to the excess capacity is 7.51% with the given operational settings which are reasonable. This would provide a good benchmark for utilizing MTS channel for the excess capacity.

One of the possible extensions would be extending this study for a longer planning horizon to see more realistic scenarios: e.g. 12-24 periods. Another possible extension may be adding specific seasonality to MTO demand pattern to see how the benefits change for certain demand patterns. Lastly, although hard capacity constraint is used in this experiment, depending on the characteristics of certain industry, soft capacity constraint can be more realistic. Soft capacity constraint in which capacity limit is set to the level of the production level of each period (production level = capacity level) can be studied. Experiment with soft capacity constraint would be more challenging because it is more difficult to keep the capacity level as constant as possible due to demand variability. Since one of the goals of the project is production smoothing, it would be more difficult to see the smoothing effects with the soft capacity constraint.

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