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# Optimized production and inventory decisions for a mixed make-to-order/make-to-stock ready-made garment manufacturer

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SCHOOL OF SCIENCES AND ENGINEERING

# Optimized production and inventory decisions for a mixed make-to-order/make-to-stock ready-made garment manufacturer

By

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Under the supervision of

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# ABSTRACT

The American University in Cairo

Optimized production and inventory decisions for a mixed make-to-order/make-to-stock ready-made garment manufacturer

Aya M. Elmehany Youssef
Supervisor: Dr. Tamer F. Abdelmaguid

In this thesis, a production and inventory planning model for mixed make-to-order (MTO) make-to-stock (MTS) production system in garment industry. Where the dominant production is typically for the Make-to-order production and the make-to-stock production is penetrating the mainstream production (MTO) as a way of enhancing the revenues and maintaining a positive cash flow, that are often degraded due to either seasonality of demands or production planning challenges. The model considers capacity planning for the mixed environment when there are predictable fluctuating demands. Due to the nature of the clothing business, it is challenging for a garment manufacturer to cope with seasonal changes while having the best capacity utilization.

The literature acknowledges production planning in the garment industry. While a little focus was for capacity planning for seasonal fluctuating demands. Mathematical programming for capacity planning in a mixed MTO and MTS garment-manufacturing environment is a viable approach that can provide effective management decisions that can help the garment industry to strive in today's competitive pace.

The proposed model considers distributing the available capacity between MTO and MTS production and the implications of the costs and revenues for different capacity distribution. Decisions made on the production amounts, inventory levels and generated revenues are attained. The model was verified and validated by applying it to a local ready- made garment factory. The results ensured the validity of the proposed model. When analysis was made to the parameters that influence the decisions, it was found that distributing the capacity between MTO and MTS with different percentages had significant impact on the revenues and costs.

The model was very sensitive to the increases in the fabric price and subcontracting costs while the overall net profits were not significantly affected by the changes in the inventory holding cost. Last, this work is useful in helping garment manufacturers adapt rapidly to seasonal changes by deploying their capacity effectively in favor of their projected seasonal plans.

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# Chapter 1
# Introduction

## 1.1 Background

The readymade garment industry is considered as a one of the very competitive industries in the world, Guo, et.al (2006). Its supply chain is dynamic and complex due to the

disparity along the chain. Garment manufacturing is a substantial sector within the textile supply chain. Apparel industry has two sides of productions. One is the artistic part (high fashion industry) which is highly perishable and subjected to seasonality. The other is the ready-made garments, which is a very competitive market. Clothing is very profitable especially if it is well planned for.

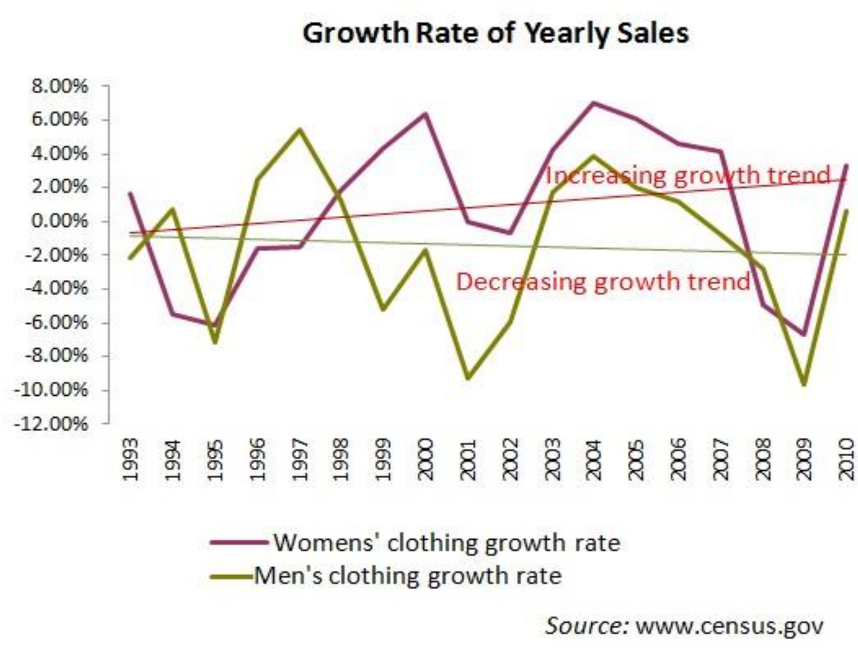


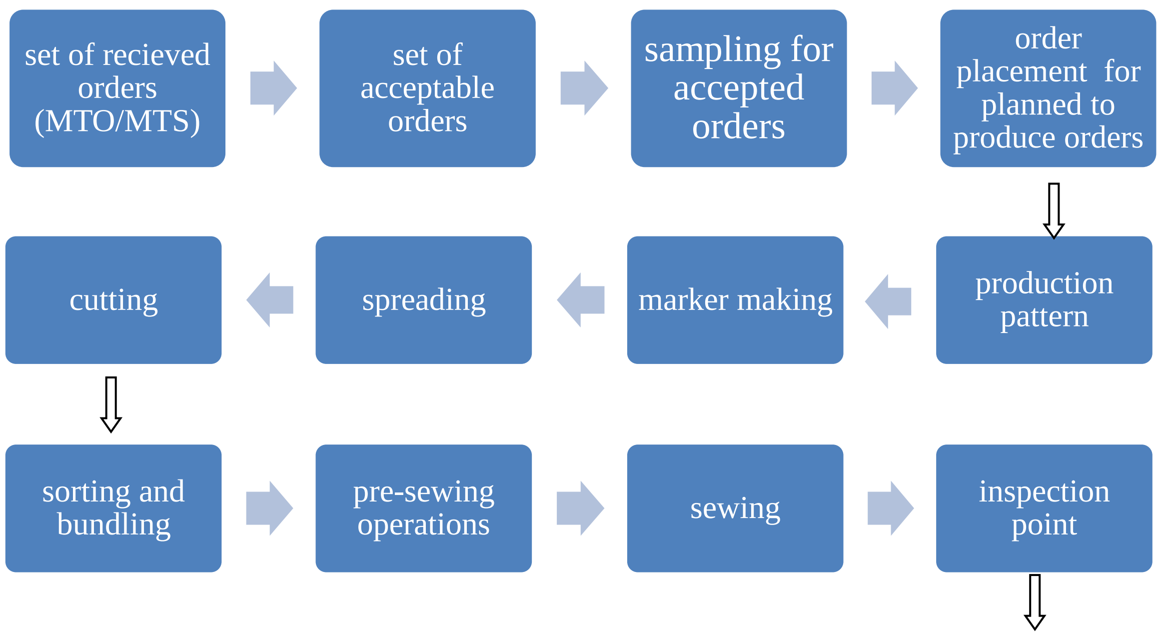

**Figure 1: Clothing growth rate**

Planning of the ready-made garment production involves many considerations such as timings of the fabrics supply and designing efficient production schedules that meet promised delivery dates. The ability to control the inputs and outputs of the apparel production process is a very challenging production management task, especially when there is variability in the demand types; whether it's made to order or made to stock; and amounts. The garment manufacturing is considered labor intensive due to the large number of manual operations.

Garments produced to fashion are subjected to high variety of taste, which implies more frequent garments to be available in stock prior to season and preferably an end of season clearance. Seasonality of the garment industry enforces having shorter-term production plans that tackles prominent production decisions, which is quite challenging to a management team. Managerial decisions must be expeditious in response to the accelerated market.

Often there are products produced to order and garments produced to stock. An effective management of both types of production types within limited resources of a garment factory is very crucial. Production managers are striving to meet orders due dates and at the same time achieve their production plan targets for selected seasonal products, that enable their firm to cope with the fierce competitive market.

Production of garment undergoes a series of processes. Figure 2 shows that the input to the process is the fabric and the output is the desired garment product. In many cases both types of production systems are tied up to the same process. The typical bottleneck in a garment production process is the sewing stage/ stitching. As it is considered the longest processing stage among garment-manufacturing stages, and that is why the industry is characterized by being labor intensive. Shorter time on the sewing requires highly skilled workers and therefore very high costs. It also needs attention to the quality of the stitched piece of garment before proceeding to the next operational stage, due to the difficulty of repairing any uncovered defects after an item being sewed. However, workers operating at the cutting stage are the most expensive. Typically, the minimum batch size of a garment ranges from 50 to 100 units.



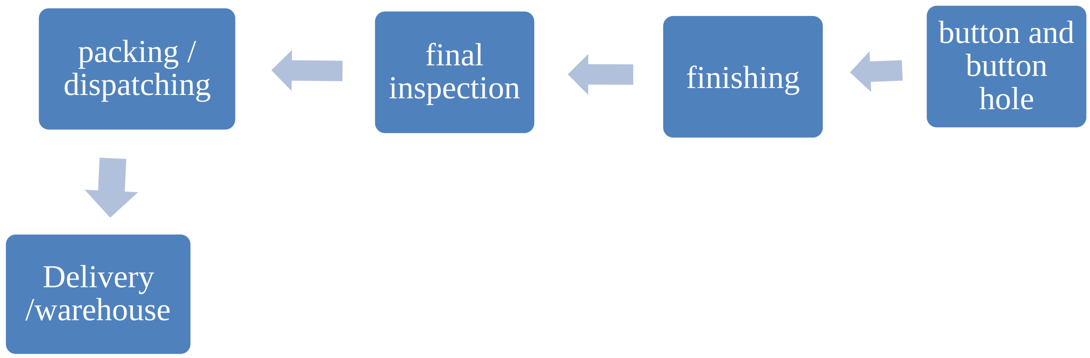



**Figure 2: Garment production processes**

- **Design/ Sketch**

The design or the sketch of the garment is the primary step in garment manufacturing. The sketch includes the features of the pattern to be produced.

- **Pattern Design**

Each component of the garment has its own pattern. That pattern is sketched on a hard paper with the exact dimensions. Seam allowance, trimming allowance, ease allowance, pleats and any special designs are all included in the pattern dimensions.

- **Sample Making**

The pattern is placed over the fabric, which is cut into the pattern form, and then the garment is sewed and assembled.

- **Production Pattern**

After the customer approves the sample pattern, production of the pattern starts. Sometimes different patterns that include any modifications required or suggested by the customer are produced.

- **Marker Making**

All required sizes of the same model and same fabric are detailed into its pattern design. Pattern details mean arranging pieces of the same garment in a way so as to minimize the fabric consumption and waste.

- **Spreading**

It is the process prior to fabric cutting directly where the fabrics desired to be cut is placed over each other in layers. The height of all the whole layers should not exceed the cutting scissor knife length.

- **Fabric Cutting**

The marker paper of the desired pattern is pinned over the fabric layer as accurately as possible. The straight knife cutting scissor is then used to cut out the fabric into the required garment pieces. This part of the process needs highly skilled labors for its accuracy.

- **Sorting/ Bundling**

Every component of the garment is sorted together in stack form according to their color and size of their respective style.

- **sewing (garments assembly)**

Sewing is the process of assembling garment components using different types of sewing with different rates.

- **Inspection**

At the inspection point, the sewed garments are carefully inspected to identify defects that may have occurred in preceding stages. Some defects such as wrong measurements can be corrected by sending it back to the respective stage. If it cannot be corrected it is regarded as second degree garment or scrap.

- **Pressing**

In this stage, the pressing machine is used if pressing is needed for specific garments like shirts collars and cuffs.

- **Finishing**

Finishing stage includes adding buttons if necessary. Afterwards each garment is inspected to make sure there are no defects. Then it is clean then it is ironed and folded to the required packing size.

- **Final Inspection**

It includes checking the fine garment details such as buttons, zippers, labeling, ironing and cleaning.

- **Packing and dispatching.**

  Products are packed after the final inspection. Packing may be sorted according to colors or size and then bundled in to boxes. The packaged garments are either placed at the warehouse or delivered to the customer.

As garment production is considered a fuzzy manufacturing environment, production and capacity planning in such an environment is very challenging particularly for stages with manual operations. Manufacturers are always trying to meet new trends and therefore the planning horizon is often short.

There are important decisions that have to be taken cautiously as they have direct impact on the costs and revenues. Decisions like determining optimal production times and quantities to meet due dates for MTO products. Moreover, having an updated seasonal plan for new seasonal products so as to preserve a competitive edge while at the same time minimizing the production costs to achieve target profits.

### 1.2 Problem description

Egypt ready-made garment manufacturing is a very promising industry. However,

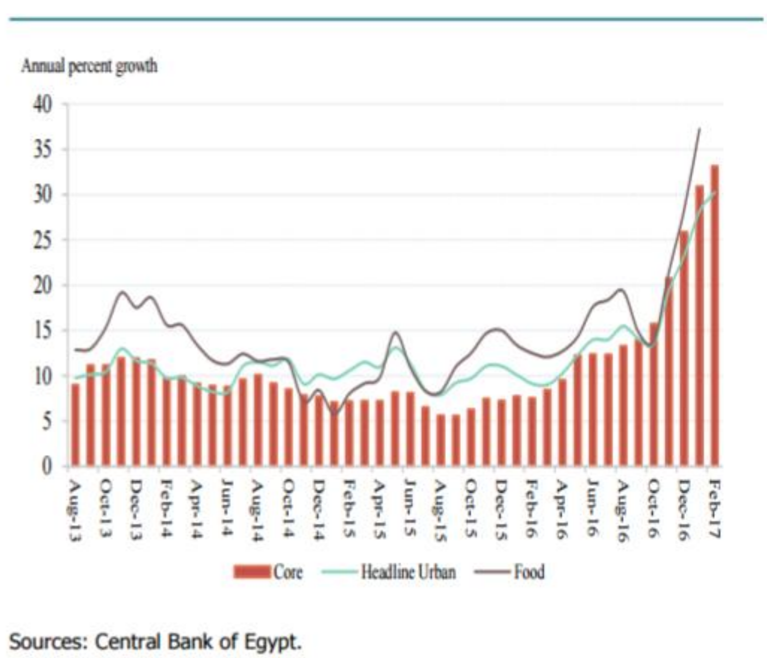



**Figure 3: Inflation rate in egypt past 5 years**

http://www.egyptindependent.com

Egyptian manufacturers were greatly affected by the economical stagnation the past few

years, as shown in the data in figure 3 according to the central bank of Egypt. Factories that depend solely on the local market have been greatly affected from the egyptian pound flotation, for fabric prices have notably increased. Fabrics required for large orders, can be supplied on installments along the production plan of the order. However, consecutive rises in the fabric prices encounter remarkable drawbacks in the cash flow that disables a smooth production to meet up with the upstream orders. The shorter the planning, the less risky the management will be subjected to the fluctuating fabric prices.

This work is motivated by the drawbacks in the net profits experienced by some of the ready-made garment factories. Factories that were affected by several and sequential financial strikes, resulting from continuous payment delays along with pressuring periodical operational costs. All have led to unpredictable financial disturbances.

The main challenge would be in the complexity of managing both production types within a short planning horizon with limited resources. Challenges like meeting orders due date, ability to produce forecasted demand within the season and succeed in generating a regular cash that permits smooth production flow.

Ready-made garment industry in Egypt is very promising if managed properly; the growing size of the population is an excellent asset that entails wide and varying marketing chances. Figure 4 shows the increasing trend of the population which consequently means increasing market opportunities.

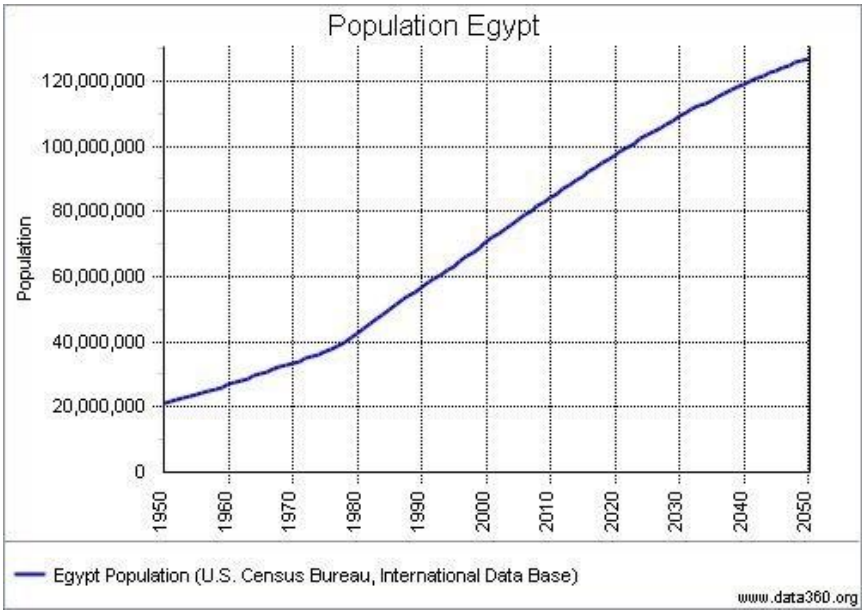



**Figure 4: Egypt population**

http://www.data360.org

Typically, ready-made garment industry in Egypt is managed by experience. Relying its decisions on a scientific yet practical ground engaged with experience is an important matter that allows it to cope with global developments in the field. Thereby, the beginning of the plan implementation was initiated from a deterministic model just to have a hand on the most frequent problem to tackle them together and then there would be further improvements that would consider the uncertainty of different aspects. At that point, the model would expand to a more sophisticated phase.

### 1.3 Thesis Outline

The rest of this thesis is organized as follows. Chapter 2 is a review of the literature addressing the thesis topic. Chapter 3 is a presentation and explanation of the developed model. The model validation and verification is highlighted in chapter 4 followed by the computational results and analysis in chapter 5. Closing with the conclusions obtained from the work and further recommendations for future work in chapter 6.

Three appendices are provided at the end of the thesis that present the input data and results for multiple MTO – MTS products.

# Chapter 2

# Literature Review

Make to order production does not always guarantee an on spot payment. It just ensures that there will be a cash inflow during a future period, which cannot be the only reliable source of revenue for sustaining a garment manufacturing facility. Therefore, firms plan to produce for stock. Although there are trade-offs for both modes of production, planning a made to order or made to stock only manufacturing environment is easier than planning both types of production in the same environment. This is very clear throughout the relevant literature. Research in the production-planning field for either MTO or MTS production systems is addressed quite often in literature than that with both modes of production within the same system. Limited number of papers that do consider them together focused on the Textile industry.

This chapter introduces a review of the aforementioned topic. It is divided into three primary areas related to the research at hand: the first deals with production planning in the garment industry, the second part focuses on production planning related to MTO environments and the third part deals with garment production planning for MTO and MTS production policies.

## 2.1 Production planning in the garment industry

Several research papers covered in production planning in the apparel industry. Wong and Chan (2001) proposed a heuristic framework that included master production scheduling (MPS) for an apparel factory. Its target was to minimize the total cost whether the demands were completed before or after their due dates and to minimize the pre-sewing operations completion time.

Mok (2011) stated that the apparel manufacturing environment is a fuzzy environment and hence an effective production planning for such an environment would be difficult. Therefore, he suggested an intelligent production algorithm for the garment manufacturing environment where he applied fuzzy set theory, genetic algorithms (GA) and multi-objective genetic algorithms (MOGA).

Guo, et.al (2006) used a job shop scheduling (JSS) model for a mixed- and multi-product assembly apparel environment to meet demands. The proposed model was solved by applying GA. The objective of the proposed model is to minimize the total penalties of earliness and tardiness by deciding orders' production starting time and the way of assigning different operations to operators.

Chen, et.al. (2012) developed a grouping genetic algorithm (GGA) for assembly line balancing problem (ALBP) particularly for sewing operations in the garment industry. Mok, et.al. (2013) used also GA in conjunction with group technology to obtain automatic job allocations that ensures an effective utilization of resources and jobs completion.

Ünal, Tunali and Güners (2009) research also suggested a heuristic algorithm for the line balancing problem in the apparel industry and tested its validity by using various line configurations through simulation.

Choy, et.al. (2011) combined genetic algorithm with an optimization model in a hybrid scheduling decision support model (SDSM) that solved the scheduling problem in a made to order work place. The model considered job tardiness and process variations to achieve a high productivity level.

## 2.2 Production Planning in MTO production systems

Often the production planning reported in literature is devoted to make-to-stock (MTS) production systems. The decision-making problems for make-to-order (MTO) production systems differ from that of MTS. In MTO, delivery dates are crucial, although the demands are uncertain in quantities and times; hence, it requires smart detailed production plans that enable full control of the production inflow and outflow.

Yeh, (2000) presented an approach for planning multi-product levels that uses a bill of material and data routing in organizing production data to accommodate customer orders specifications. This in turn enables them to negotiate order adjustments that might include allowing for changes in delivery schedules. Due to different constraints, the system is able to fulfill only some of them and the rest are rejected. Under this condition, MTO companies have to accept an optimal combination of the arriving orders so that their profit and share in the competitive market increase. The main criteria to select this optimal combination in such environments are short delivery times and high quality. Therefore, companies that produce according to MTO systems, are not able to predict the arrival time of orders and have to deliver the arriving orders quickly. Such companies need a decision-making structure which helps them manage the arriving orders to meet these main criteria.

Ebadian, et.al (2008) introduced a decision making structure for the order entry stage for a MTO system. The decisions were based on two factors. One was the price; the other was the delivery time whether fixed or flexible (if it could be negotiated). The mathematical model adopted was mixed integer programming. The structure made the decision on the arriving orders based on certain factors; determining the rejected undesired orders and computing the prices and delivery times of the accepted orders bounded by some constraints. The main challenge of such a MTO program was to process directly the arriving orders that are only profitable and feasible to the system.

Acceptance and rejection of orders in made to order systems is a challenging task therefore a decision making structure to improve the decision quality at the order entry stage would be vital.

Gharehgozli, Rabbani, zaerpour and Razmi (2008) introduced a decision structure to manage arriving orders but they divided the structure into two main phases. The first phase was designed to arrange orders according to order times, material arrival, and due dates. The second phase was decided upon orders using a hybrid methodology that combines analytical hierarchy process (AHP) with technique for order performance by similarity to ideal solution (TOPSIS).

Hemmati, Ebadian and Nahvi (2012) also created a decision making model to manage arriving orders, but they first divided them according to order priority. High or low priority depends on the order characteristics and TOPSIS. Orders were divided according to their due dates, material requirements and availability. Then a rough cut capacity plan for the orders was used to check which order would be feasible for the system.

Ebadian, Rabbani, Jolai and torabi (2009) proposed a hierarchical production planning structure in MTO companies that consisted of three decision levels: order entry, order release and order sequencing. Their target was to meet due dates by improving delivery date performance using a smooth production schedule. The last two levels were validated through numerical trials and simulation. The aim of the proposed hierarchy is to manage arriving orders using certain decisions per level, so as to have shorter, reliable delivery dates.

Soman, Donk and Gaalman (2004) developed a hierarchical planning system to decide which products to make- to- stock and which to make- to- order in the food industry. The authors considered capacity restrictions and varying set-up time between different products where the decision plan related to food. In the same fashion, Rajagopalan, (2002) developed a nonlinear integer programming model to decide which orders to make to stock and which to make to order, their inventory levels and selecting a production policy for the made to stock items. Rajagopalan (2002) put a penalty constraint to the lead time for MTO items and stated that he could have made MTO demands function in the lead time of each item in the demand. One of the aspects he considered in his model was the fractional lot sizes, re-order points and continuous distribution which forced model approximations. However, various aspects of the model presented here, such as the cost expression, fractional lot sizes and reorder points, and continuous-demand distributions, may be poor approximations in such scenarios.

### 2.3 Mixed MTO and MTS production systems

Wang and Rosenshine (1983) selected a heuristic rule for given orders, where some are with due dates (made- to -order) and others are not (made to stock). Their objective was to schedule the orders so that the mean flow time was minimal while satisfying their due dates. There were two types of conflicts that appeared to them, the first was related to the job timings; the other was with or without due dates.

Kaminsky and Kaya (2009) provided a decision guidance on when to use made to order or made to stock approaches in centralized and decentralized supply chains. They analyzed the benefit of using each system depending on specific circumstances, and how to operate the overall system in order to minimize the costs. Kamisky and Kaya also quoted due date per customer at arrival time. All that was explored analytically, inventory, scheduling, lead time decisions but in the context of supply chains where they elaborated on the effect of the supplier-manufacturer relationships in such system.

Rafiei, Rabbani and Kokabi (2014) addressed production planning of a multi-site hybrid made-to-stock/ made-to-order manufacturing firm. They developed a mathematical model that seeks to maximize manufacturing firm's profits.

Carr and Duenyas (2000) addressed the problem of modeling complex admission control and sequencing of different product segments. This was done by developing a M/M/1 queueing model to help the firm take former decisions into account when deciding which type of product to produce next and the annual quantities for MTS products. One of the major gaps which should be taken into consideration was the setup cost for different products. This would influence the production sequence and how decisions were made to accept an order, hence that point needed more elaboration.

Zhang, Zheng, Fang and Zhang (2015) proposed a mixed integer non-linear programming model aimed at solving the multi-level inventory matching problem. They focused on order planning for a hybrid MTO and MTS production planning strategies, as applied to the steel production environment. Multiple objectives were considered, such as penalty cost of earliness and tardiness, production costs, inventory matching cost, and order cancelation penalty. The infeasibility and inventory re-matching were treated through a proposed improved particle swarm optimization method.

Beemsterboer, Land and Teunter (2016) examined the advantages of hybrid planning approaches for both MTO and MTS by developing a Markov Decision process model. The system determines when to manufacture MTO and when to produce MTS products, while considering positive lead time for MTO products.

Morikawa, Takahashi and Hirotani (2014) investigated different policies for MTS production at a multi-stage serial system in traditionally MTO production environment. Their primary objective was to minimize the average orders' lateness with less MTS inventory. The performances of these policies were tested using simulation experiments. The semi-finished products were considered the MTS items and restrictions applied according to specifications and amounts. The criteria for selection were based on different rules “Buffer selection”, “matching acceptance” and ”MTS replenishment rules”.

Zhang, et.al. (2013) analyzed the performance measures of a hybrid MTS-MTO system for the same product using an analytical model. The dynamic switch between MTO-MTS was operated through a multi-server queuing model.

Günalay (2011) used two scheduling strategies (first in first out and cyclic service) to decide which scheduling policy to use for MTO versus MTS products in a single facility. The decision for both policies was based on the total cost, inventory and order delay cost.

Rafiei and Rabbani (2011) developed a mixed integer linear programming model to decide order partitioning, and to determine order penetration point location for a hybrid MTO/MTS delivery strategy.

Soman, Donk and Gaalman (2004) proposed a method for successful integration of the combined MTO and MTS but focused on the food industry. In 2007 they tackled the combined MTO/MTS situations by identifying possible analytical decisions for short-term batch-scheduling using heuristics. The updated approach was adopted when the researchers found the hierarchical frame work suggested by them in (2004) was generic and lacked analytical decision aids.

Ohta, Hirota, & Rahim, (2007) analyzed a multi-production inventory policy for MTO versus MTS. The analysis was based on a queuing model where the optimality condition was based on which product is made-to-order and which is to stock. They computed the optimal base-stock level.

Zaerpour, Rabbani, Gharehgozli, and Tavakkoli-Moghaddam (2008) presented a hybrid approach to decide which item will be made- to-order and which to stock using a strategic method strengths and weaknesses, and the opportunities and threats (SWOT) analysis and a fuzzy analytical hierarchy process (FAHP). Combining both methods reached a decision for orders partitioning by producing quantitative values for the SWOT factors. However the novel approach did not consider important constraints such as the firm's capacity and due date.

Hadj, Delft and Dallery (2004) used two different scheduling rules for combined MTO and MTS manufacturing system. MTS policy went under FIFO scheduling whilst MTO was considered of low volume and went under priority rule policy. Optimum solutions for each system were developed analytically and numerically.

Van Donk (2001) indicated that managers in the food industry found difficulty in deciding which products to make to order and which to stock. Van Donk developed a framework that helped make such decisions. Taking into consideration the market characteristics and the production process. The developed framework was based on the concept of the general decoupling point which was adapted to the specifications of the food industry.

Arreola-risa (1998) also used an analytical way to study the optimality conditions for MTO versus MTS for multiple products. The production times were general random variables, and the demands have different arrival rates and are independent Poisson processes. Khakdaman, et.al. (2015) developed a robust model for hybrid MTO/MTS multi-product firm. They incorporated suppliers, processes and customers in the presented model so as to examine their uncertainties, and validated their proposed model by applying it to an industrial case. Eltawil and K.W. (2011) proposed a hierarchal frame work for production planning for a hybrid MTO and MTS production in the textile industry at the tactical level.

**2.4 Existing techniques in the literature and research gap**

1. Production and capacity planning for a mix of multi-period, multi-product demands (MTO and MTS) in a ready-made garment-manufacturing environment, is still a ripe yet challenging area.
2. Engaging a financial aspect; cash flow; as a constraint with production, inventory and capacity aspects in a model, was not adequately addressed.

In the apparel industry, most of the research has focused on applying heuristic and hierarchy techniques to help the decision maker achieve the production goals. It is apparent that production planning in a combined MTO and MTS garment manufacturing environment was not tackled enough in literature. Considering capacity utilization with financial aspects were not jointly addressed. Thus targeting certain or near optimal production and capacity plan for a mix of MTO and MTS demands, is still an open question.

## 2.5 Thesis objectives

The objective of this work is to help the management team in a garment factory have practical insights on the decisions to take based on the costs versus the expected revenues for arriving orders (MTO) versus planned production (MTS) for a season.

The presented model in this study is devoted to medium size factories which have limited resources, and cannot afford more expenses to improve their productivity. At the same time, they cannot adopt sophisticated techniques used by large companies nor can they deal easily with complicated heuristics. Yet, they still need to maximize their revenues as far as possible, while considering their capacity constraints and meeting their production targets. The unique problem facing such garment factories is not well addressed in the literature, which is production and capacity planning for a mix of MTO and MTS production while considering influential parameters that governs the garment production. This research is mainly concerned with the decisions taken at the aggregate planning level. The following chapter; chapter 3; introduces a Mixed-integer linear programming (MILP) model that is formulated to take into account the important aspects that influences the decisions at that level of planning and provides an optimum production plan for the addressed problem.

# Chapter 3

## The Proposed MTO/MTS Production Planning Model

### 3.1 Problem description

Management of MTO and MTS production together in a readymade garment factory is a challenging problem. Particularly if the planning horizon is short, due to the nature of the industry, and if one of the systems was the only applicable kind of production. Various garments require different number of labor hours and amount of fabric per garment and the factory has limited capacity and financial resources finances. Also, once fabric is ordered, the factory must provide the enough cash to pay for it.

The fabric is acquired from two main sources; a retailer or a wholesaler. The retailer price is 10-15% above the wholesale price. In order to purchase from a wholesaler the amount purchased should not be less than 30 meters of fabric of the same type.

The amount of products decided for the MTS production, determines whether its fabrics will be purchased from a retailer or a wholesaler. Past data showed that the MTS fabrics were bought from a retailer without any discounts, due to the small quantities and in other season was due to the occurrence of a variety of MTS products with limited amounts per product.

Fabrics for MTO garments are purchased only if the order is received, while for the MTS case, fabrics are purchased based on the cash availability and production capacity. Therefore, it is essential to identify the time, and amount of fabric purchased while observing the cash availability. Smooth production requires that fabric supply is guaranteed before the beginning of production of the perspective product/order.

The management team aims at having a production plan for the factory that considers a successful operation of seasonal MTO and MTS production simultaneously, within the available resources. To achieve an optimum plan, major trade-offs from the interaction of both production types and their implications on the cash and revenue at the end of the season have to be considered. Trade-offs such as, capacity allocation for both production types during different seasons, producing an order in an early period and storing it or producing it in a latter period, and considering overtime or maybe subcontracting sometimes to be able to meet-up with the orders due dates.

Moreover, what if the forecasts for MTS are high and the MTO demands are low, would the cash available at the beginning of the season and the cash generated from the MTO along the planning horizon be sufficient to produce targeted stocks and still generate a profit?

Since fabric comprises a high percent of a garment cost, the amount of products decided for MTS production determines whether its fabrics will be purchased from a retailer or a wholesaler.

Fabrics for MTO garments are purchased only if the order is received, while for the MTS case, fabrics are purchased based on the cash availability and production capacity. Therefore, it is essential to identify the time, and amount of fabric to order while observing the cash availability.

Planning the production and delivery of garments under the fore-mentioned trade-offs, while considering the cash flow during the planning horizon was a challenging problem. Therefore, decisions need to be made to deal with these trade-offs. Such as the amount of fabric supplied and its ordering time, inventory levels (fabrics inventory, the work in process inventory, finished garment inventory), regular and overtime production quantities, periodical cash availability and the optimum amount of MTS production along with different MTO amounts.

The objective of the developed model is to maximize the net profits for various garments required for either MTO/MTS customer, while maintaining a positive cash flow throughout the planning horizon.

The proposed model is a deterministic model that is developed for a mix of MTO and MTS production within the limited resources. The model maximizes the net revenues resulting from the MTO and MTS sales along the planning horizon. It also provides an optimal production plan that deals with frequent production scenarios.

The main difference between MTO and MTS in the model is that the MTS products are produced and stocked along the planning horizon to meet the forecasted amounts, and no sales occur in the first four periods for the MTS.

### 3.2 Model Assumptions

1. Fabrics arrive on time.
2. The cost of other materials/subassemblies required for producing the garment (threads, buttons, zippers…) are included in the fabric cost.

3. Service wear products are produced based on MTO policy while children wear products are produced on a MTS policy.
4. MTO are confirmed orders at the beginning of the season.
5. Overtime is allowed for MTO and MTS production.
6. Initial inventory for material is zero for both product in categories.
7. The production capacity is known and fixed.
8. Subcontracting is allowed for MTO products only.
9. The planning horizon is 1 season, equivalent to 12 weeks.
10. Production cost includes labor cost and maintenance cost.
11. Once an order is delivered its cash is received.
12. No down-payment for MTO items.
13. Safety stock is not considered for neither MTO fabrics nor MTS products.
14. There is no minimum batch size required for subcontracted products.

## 3.3 Model formulation

### 3.3.1 Index sets

| **Set** | **index** |
|---|---|
| ***T:*** set of time periods | ***t*** |
| ***M:*** set of made to order (MTO) products | ***m*** |
| ***J****:* set of made to stock (MTS) products | ***j*** |
| ***F*** *:* set of fabric types | ***f*** |

### 3.3.2 Input parameters

| Symbol | Interpretation | Units |
|---|---|---|
| $I_{ft}^{CF}$ | Inventory holding cost of fabric *f* during period t | ***EGP/m²/week*** |
| $I_{mt}^{CO}$ | Inventory holding cost per unit of MTO product *m* during period *t*. | ***EGP/unit/week*** |
| $I_{jt}^{CS}$ | Inventory holding cost per unit of MTS product *during* period *t*. | ***EGP/unit/week*** |
| $IF_{f0}$ | Inventory of fabric *f* at time period *t=0* | $m^2$ |
| $I_{in}^{S}$ | Inventory of MTS product *j* at time period *t=0* | ***unit*** |
| $R_{m}^{CO}$ | Regular time production cost per unit of MTO product *m*. | ***EGP/unit*** |
| $R_{j}^{CS}$ | Regular time production cost per unit of MTS product *j*. | ***EGP/unit*** |
| $O_{m}^{CO}$ | Over- time production cost per unit of MTO product *m*. | ***EGP/unit*** |
| $O_{j}^{CS}$ | Over- time production cost per unit of MTS product *j*. | ***EGP/unit*** |
| $Sb_{mt}^{C}$ | Subcontracting cost for MTO product *i* during time period *t*. | ***EGP/unit*** |
| $\alpha_{fm}^{O}$ | Amount of fabric *f* used to make one unit of MTO product *m*. | $m^2$***.fabric*** |
| $\alpha_{fj}^{S}$ | Amount of fabric *f* used to make one unit of MTS product *j* | $m^2$***.fabric*** |
| $h_{m}^{O}$ | labor hours required to process one unit of MTO product *m*. | ***hrs/unit*** |
| $h_{j}^{S}$ | labor hours needed to produce one unit of MTS product *j*. | ***hrs/unit*** |
| $H_{max}$ | Maximum available regular production hours. | ***Hrs*** |
| $G_{max}$ | Maximum allowed overtime production hours. | ***Hrs*** |
| $w_f$ | Warehouse space needed *per square meter of* fabric *f* | $m^2/ m^2$ ***of fabric*** |
| $W_{max}$ | Maximum fabric warehouse capacity for fabrics | $m^2$ |

| | | |
|---|---|---|
| $v_m^O$ | Storage space requirements per unit of finished MTO product *m* | ***m²/unit*** |
| $v_j^S$ | Storage space requirements per unit of finished MTS product *j* | ***m²/unit*** |
| $V_{max}$ | Maximum storage capacity for MTO and MTS final products | $m^2$ |
| $D_{mt}$ | Confirmed orders at the beginning of the planning horizon | ***units*** |
| $F_{jt}$ | Forecasted demand for MTS product *j* during period *t* | ***units*** |
| $p_m^O$ | Selling price of one unit of MTO product *m* | ***EGP/unit*** |
| $p_j^S$ | Selling price for one unit of MTS product *j* | ***EGP/unit*** |
| $r_{fk}$ | Purchase price r of fabric f at level k, where k=1,2, indicating the two pricing levels. | ***EGP/*** $m^2$ |
| $q_f$ | Minimum meters of fabric so that the discount is offered/ can purchase from a wholesaler. | $m^2$ |
| $B_m^O$ | Minimum batch size for production of MTO product *m* | ***Units*** |
| $B_j^S$ | Minimum batch size for production of MTS product *j* | ***Units*** |
| $C_0$ | Initial cash available at the beginning of the planning horizon | ***EGP*** |
| $C^T$ | Minimum final cash targeted at the end of the planning horizon | ***EGP*** |
| $L$ | A Large positive number | |

### 3.3.3 Decision variables

| | | |
|---|---|---|
| $FQ_{fkt}$ | Quantity of fabric *f* ordered at price level *k* during period *t* | $m^2$ |
| $IF_{ft}$ | Inventory of fabric *f* by the end of period *t* | $m^2$ |
| $CH_t$ | Cash available by the end of period *t* | ***EGP*** |
| $I_{mt}^O$ | *WIP* Inventory level of MTO product *m* by the end of period *t* | ***unit*** |
| $I_{jt}^S$ | *WIP* Inventory level of MTS product *j* by the end of period *t* | ***unit*** |

| | | |
|---|---|---|
| $\boldsymbol{R^{O}_{mt}}$ | Regular time production quantity of MTO product *m* during period *t* | ***unit*** |
| $\boldsymbol{R^{S}_{jt}}$ | Regular time production quantity of MTS product *j* during period *t* | ***unit*** |
| $\boldsymbol{O^{O}_{mt}}$ | overtime production quantity of MTO product *m* during period *t* | ***unit*** |
| $\boldsymbol{O^{S}_{jt}}$ | overtime production quantity of MTS product *j* during period *t* | ***unit*** |
| $\boldsymbol{b_{ft}}$ | Binary integer variables, $\boldsymbol{b_{ft}}=1$ if fabric *f* is purchased for price level $k=2$, in time period *t*. | |
| $\boldsymbol{S_{mt}}$ | Subcontracting amount of product *m* at time period *t* | ***units*** |
| $\boldsymbol{\zeta^{O}_{mt}}$ | Binary integer variables, $\boldsymbol{\zeta^{O}_{mt}}=1$; if MTO product *m* is produced during period *t*, $\boldsymbol{\zeta^{O}_{mt}}=0$ *otherwise.* | |
| $\boldsymbol{\zeta^{S}_{jt}}$ | Binary integer variables, $\boldsymbol{\zeta^{S}_{jt}}=1$; if MTS product *j* is produced during period *t*, $\boldsymbol{\zeta^{S}_{jt}}=0$ *otherwise.* | |

### 3.3.4 The objective function

The objective function aims at maximizing the firm's total profits *'P'* which is the net value achieved from subtracting potential cost elements from sales revenues.

**Maximize Profit: P = Total Revenues – Total Costs.**

The Total Revenues = the total sales value at the end of the planning horizon for made to order products *m* and made to stock products *j*.

***The revenues are expressed mathematically as*:**

$$Revenues = \sum_{m\in M}\sum_{t\in T} p^{O}_{m}\ D_{mt} + \sum_{j\epsilon J}\sum_{t\epsilon T} p^{S}_{j}\ F_{j}$$

The total production costs are the sum of the regular costs, overtime costs, fabric costs, inventory holding cost for fabrics, work in process and final products over the planning horizon T and the setup cost.

Therefore, the **objective function** is expressed as follows:

$$P = \sum_{m\in M}\sum_{t\epsilon T} p_m^O\ D_{mt} + \sum_{j\epsilon\ J}\sum_{t\epsilon\ T} p_j^S\ F_j - \sum_{m\in M} R_m^{CO}\sum_{t\epsilon T} R_{it}^O - \sum_{m\in M} O_m^{CO}\sum_{t\epsilon T} O_{it}^O$$

$$-\sum_{j\in J} R_j^{CS}\sum_{t\epsilon T} R_{jt}^S - \sum_{j\in J} O_j^{CS}\sum_{t\epsilon T} O_{jt}^S - \sum_{t\epsilon T}\sum_{f\in F} r_{fk}\ FQ_{fkt}$$

$$-\sum_{m\in M}\sum_{t\epsilon T} I_{mt}^{CO}\ I_{mt}^O - \sum_{j\in J}\sum_{t\epsilon T} I_{jt}^{CS}\ I_{jt}^S - \sum_{t\epsilon T}\sum_{f\in F} I_{ft}^{CF}\ IF_{ft}$$

$$-\sum_{t\epsilon T}\sum_{i\epsilon I} Sb_{it}^C\ S_{it} \qquad (1)$$

**3.3.5 Constraints**

Initial fabric inventory is indicated by constraint (1) while constraint (2) represents the material balance constraints for MTO and MTS products. Initial inventory for MTS production is represented by equation (3). Equation (4) indicates inventory balance equation for meeting MTS forecast. Constraint (5) indicates MTO demand satisfaction constraint.

Equations (6) and (7) are for the capacity constraints for regular and overtime products respectively. Fabrics storage capacity constraint is denoted by equation (8). The storage capacity for MTO and MTS final products is illustrated by equation (9). Equations (10) and (11) are developed for the quantity discount on fabric purchase. where *k* represents the two price levels, *k* =1 means that no discount is offered for a quantity less than $q_f$ , as illustrated by equation (10), while *k=2* means that the amount purchased is greater than $q_f$ and therefore the discount is offered, equation (11). Equation (12) represents the initial cash at the beginning of the planning horizon.

The cash balance for the first four periods of the planning horizon is presented by equation (13). Equation (14) indicates the cash balance from period 5 to the end of the planning horizon, where the MTS sales take place with the MTO sales. The final cash at the end of the planning horizon should be greater than or equal an amount $C^T$, as denoted by equation (15).

Equations (16) and (17) satisfy the minimum batch production for MTO production. MTS minimum batch production is presented by equations (18) and (19) is for non-negativity constraints.

$$IF_{ft=0} = IF_{in} \qquad \forall t \qquad (1)$$

$$IF_{ft-1} + FQ_{fkt} - \sum_{i\epsilon I} \alpha_{fi}^{O} \left(R_{it}^{O} + O_{it}^{O}\right) - \sum_{j\epsilon J} \alpha_{fj}^{S} \left(R_{jt}^{S} + O_{jt}^{S}\right) = IF_{ft}, \qquad \forall f, \forall t \qquad (2)$$

$$I_{jt=0}^{S} = I_{in}^{S} \qquad \forall t \qquad (3)$$

$$\left(R_{jt}^{S} + O_{jt}^{S}\right) + I_{jt-1}^{S} - I_{jt}^{S} = F_{jt}, \qquad \forall j \epsilon J, \forall t \qquad (4)$$

$$I_{mt-1} + R_{mt}^{O} + O_{mt}^{O} + S_{mt} = D_{mt} + I_{mt} \qquad \forall m\epsilon M, \qquad \forall t \qquad (5)$$

$$\sum_{m\epsilon M} h_m^{O} R_{mt}^{O} + \sum_{j\epsilon J} h_j^{S} R_{jt}^{S} \leq H_{max}, \qquad \forall t \qquad (6)$$

$$\sum_{m\epsilon M} h_m^{O} O_{mt}^{O} + \sum_{j\epsilon J} h_j^{S} O_{jt}^{S} \leq G_{max}, \qquad \forall t, \qquad (7)$$

$$\sum_{f\epsilon F} w_f IF_{ft} \leq W_{max}, \quad \forall t \qquad (8)$$

$$\sum_{m\epsilon M} v_m^{O} I_{mt}^{O} + \sum_{j\epsilon J} v_j^{S} I_{jt}^{S} \leq V_{max}, \qquad \forall t \qquad (9)$$

$$FQ_{f1t} \leq q_f b_{ft} \qquad \forall f, \forall t \qquad (10)$$

$$q_f\left(1 - b_{ft}\right) \leq FQ_{f2t}, \qquad \forall f, \forall t \qquad (11)$$

$$CH_t = C_0, \qquad \forall t = 1 \qquad (12)$$

$$CH_{t-1} + \sum_{m\epsilon M} \sum_{t\epsilon T} p_m^{O} D_{mt} - \sum_{t\epsilon T} \sum_{f\epsilon F} r_{fk} FQ_{fkt} - \sum \sum_{m\epsilon M} \left(R_m^{CO} R_{mt}^{O} + O_m^{CO} O_{mt}^{O}\right)$$

$$-\sum_{j\epsilon J}\sum(R_j^{CS}\,R_{jt}^S + O_j^{CS}O_{jt}^S\,) \;= CH_t\,,\;\; forall\; t\;\epsilon t_1\;\;, where\;\; t_1$$

$$= \{\,1, 2, 3, 4\} \qquad (13)$$

$$CH_{t-1} + \sum_{m\epsilon M}\sum_{t\epsilon T} p_m^O D_{mt} + \sum_{j\epsilon J} p_j^S\,F_{jt}$$

$$-\sum_{t\epsilon T}\sum_{f\epsilon F} r_{fk}\;\; FQ_{fkt} - \sum_{m\in M}(\,R_m^{CO}R_{mt}^O + O_m^{CO}O_{mt}^O\,)$$

$$-\sum_{s\epsilon S}\sum_{j\epsilon J}(R_j^{CS}\,R_{jt}^S + O_j^{CS}O_{jt}^S\,) = CH_t\,,\;\; for\; t\;\epsilon\; t_2\;,\;\; where\; t_2$$

$$= 5, 6 \ldots .12. \qquad (14)$$

$$CH_t \geq\; C^T, \qquad \forall t = 12 \qquad (15)$$

$$R_{mt}^O + O_{mt}^O\;\; \geq B_m^O\zeta_{it}^O\;\;\; ;\;\; \forall m\,, \forall t \qquad (16)$$

$$\zeta_{it}^O \geq \frac{1}{L}\sum_{m\in M}(R_{mt}^o + O_{mt}^o)\;\; \forall m\,, \forall t \qquad (17)$$

$$R_{jt}^S + O_{jt}^S\;\; \geq B_j^S\zeta_{jt}^S\;\;\; ;\qquad \forall j, \forall t \qquad (18)$$

$$\zeta_{jt}^S \geq \frac{1}{L}\sum_{j\in J}(R_{jt}^S + O_{jt}^S)\;\;\; \forall j, \forall t \qquad (19)$$

$$FQ_{fkt}, IF_{ft}, CH_t\,, I_{mt}^O\,, I_{jt}^S\,, R_{mt}^O\,, R_{jt}^S, O_{mt}^O\,, O_{jt}^S, S_{mt}\;\; \geq 0 \qquad (20)$$

## 3.4 Model Characterization

The size of the MILP model developed in the previous section can be determined from the cardinality of the sets used in the model as detailed in table 3. Likewise, the total number of integer variables, binary variables in addition to the number of constraints can be figured out precedently as shown in table 4.

**Table 1: Size of the model components**

| **Model Component** | **Number** |
|---|---|
| **Variables** | |
| $FQ_{fkt}$ | \|F\|\|K\|\|T\| |
| $IF_{ft}$ | \|F\|\|T\| |
| $I^{O}_{mt}$ | \|M\|\|T\| |
| $I^{S}_{jt}$ | \|J\|\|T\| |
| $R^{O}_{mt}$ | \|M\|\|T\| |
| $R^{S}_{jt}$ | \|J\|\|T\| |
| $O^{O}_{mt}$ | \|I\|\|T\| |
| $O^{S}_{jt}$ | \|J\|\|T\| |
| $S_{mt}$ | \|M\|\|T\| |
| $CH_{t}$ | \|T\| |
| $b_{ft}$ *(binary variable)* | \|F\|\|T\| |
| $\zeta^{O}_{mt}$ *(binary variable)* | \|M\|\|T\| |
| $\zeta^{S}_{jt}$ *(binary variable)* | \|J\|\|T\| |
| **Constraints** | |

| | |
|---|---|
| *Fabric inventory constraints for MTO and MTS products* | \|F\|\|T\| |
| *Material balance for MTO production* | \|M\|\|T\| |
| *Material balance for MTS production* | \|J\|\|T\| |
| *Regular production capacity* | \|T\| |
| *Overtime production capacity* | \|T\| |
| *Fabrics storage capacity* | \|T\| |
| *MTO and MTS products storage capacity* | \|T\| |
| *No Quantity discount on fabric purchased offered* | \|F\|\|T\| |
| *Quantity discount on fabric purchased offered* | \|F\|\|T\| |
| *Initial cash* | \|T\| |
| *Cash balance constraint when no sales for MTS happens* | \|T\| |
| *Cash balance for the rest of the planning horizon* | \|T\| |
| *Minimum batch constraint for MTO* | \|M\|\|T\| |
| *Minimum batch constraint for MTS* | \|J\|\|T\| |

**Table 2: Size of the total number of variables and constraints**

| **Model component** | **Size** |
|---|---|
| Total number of non-negative integer variables | T+ FKT+ FT + 4MT+ 4JT |
| Total number of binary variables | 3FT+ MT+JT+4T |
| Total number of constraints | 3FT+ 2MT+ 2JT+ 7T |

Given that for the current model, the planning horizon $T$ is 12 periods, the number of fabric types $F$ used is only four types and the price levels $k$ are two levels, then the size of the model is controlled by the number of MTO and MTS products. Accordingly, for different number of MTO and MTS products, the problem size can be determined before hand as laid out in table 5, and the time taken by CPLEX to converge to an optimal integer solution.

**Table 3: Problem size for different number of MTO/MTS products**

| MTO, MTS | Computational time | Number of constraints | Number of binary variables | Number of integer variables |
|---|---|---|---|---|
| 2, 4 | 00:00:08:54 | 1531 | 120 | 414 |
| 4, 8 | 00:00:10:46 | 1589 | 192 | 686 |
| 8, 16 | 00:00:01:47 | 2945 | 336 | 1178 |
| 16, 32 | 00:00:10:46 | 6233 | 624 | 2162 |
| 32, 64 | 00:00:21:89 | 15113 | 1200 | 4130 |
| 64, 128 | 00:05:43:47 | 42089 | 2352 | 8066 |

The problem with different sizes was solved on a server with the following specifications: AMD opteron ™ processor 6174 2.2GHz (2 processors), 128 GB (RAM) - system type: 64-bit operating system, X 64-based processor.

Since the model size can be anticipated from the cardinality of the variables and constraints, figure 2 depicts the pattern of the problem size when the number of products increases, leading to an increase in the number of the variables and constraints.

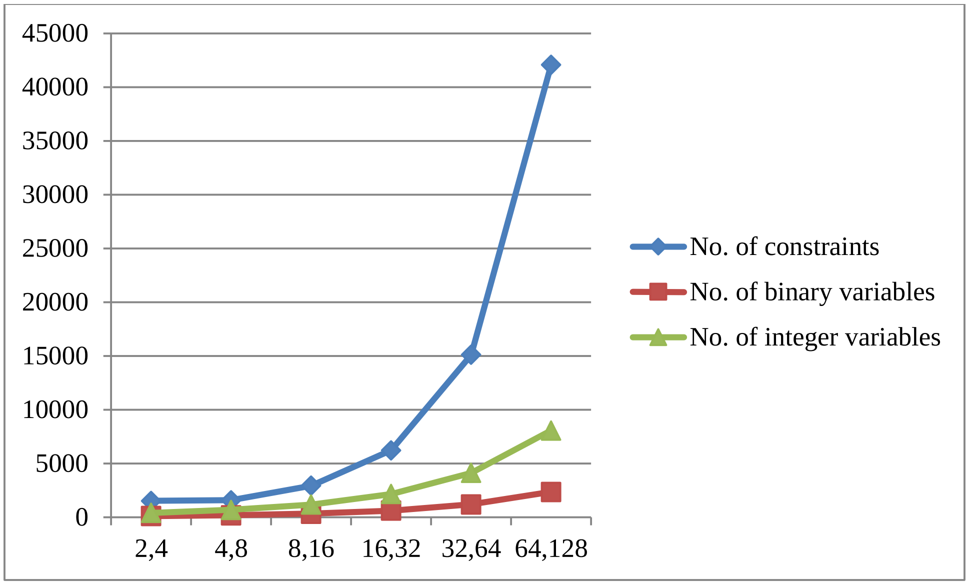



**Figure 5: Problem size vs. model characteristics**

The Model was solved using the optimization solver IBM® ILOG® CPLEX® Optimization Studio V12.7.1. It uses mathematical and constraint programming. The Optimization Programming Language (OPL) built-in tools for tuning and conflict detection enabled a rapid and accurate deploying of the model for its high performance solver. CPLEX can choose the best algorithm from the multiple algorithms provided for various kinds of models [1]. Computational experiments for different number of MTO and MTS products were examined. Inputs and Outputs for multiple of products are given in Appendix A and B.

# Chapter 4

## Model verification and validation

This chapter describes the computational working plan in order to verify and validate the proposed mathematical model. The first section of the chapter involves the verification phase where a base case was examined in order to verify the model and ensure the correctness of the solver output. The second section of the chapter is concerned with the validation stage for the model and it included three cases. The first case is considered to be the essential case as it used actual data and its output was compared with the output from a real life case. The second case was implemented to make sure that the quantity discount constraint is working correctly and the third case was carried out to examine the model performance for an extreme situation.

### 4.1 Model verification

An important aspect of the verification procedure was to confirm that the model was encoded properly before applying different cases. Using CPLEX optimization studio V12.7.1, exporting the model to an LP file is a way to log exactly how it is read and ensure that the model is generated correctly.

#### The base case

The model was tested using the data for an industrial case, which is treated as the base case for the computational experiments. The plant and input data are presented in the following section followed by the results and discussion of the base case output.

**Case study description**

This research considers a traditional Garment manufacturing facility. The Firm manufactures different types of garments. The factory used to produce only make-to-order production for the last five decades. Although make-to-order production guarantee its market, but it often encountered stressing operational schedules so as to meet the due dates. In the recent years, the factory faced many problems due to either inability to meet due dates or difficulty in receiving orders' cash promptly after its delivery. Consequently, many obstacles were raised due to the unavailability of sufficient cash for future scheduled orders. Therefore, the number of received orders was diminished, which caused a recognizable unutilized capacity. To overcome such obstacles, the management team sought of establishing a brand for children wear, which will be the MTS production stream, unlike the MTO products, which are service wear. The start-up cash for the make-to-stock production was relevantly small for the new production stream. Make-to-stock production type differed than those for make-to-order, the make-to-order was service wear and required experienced workers for its complicated technical operations, while the make-to stock is often children wear and was technically much simpler. The attempt was taken by trying only two products (MTS) per season. From the historical data for the past two years, the sales made by the selected MTS products; although the production was not as big as MTO; have built rapid cash inflow within its season. In addition it has received remarkable high demands, hence, the planner need to have smarter decisions for managing the MTO and MTS together within the available capacity and finances of the firm.

The proposed model was applied to AMDC Company; it is one of the leading companies in readymade garments in Egypt specialized in service wear garments in particular. The company was established in the early 1980s producing different service garments to different governmental sectors. All of the company production until 2014 was only based on MTO strategy, and recently they considered producing to stock as part of their production plan in order to enhance their revenues. Since the facility included the mixture of both production types therefore it was a suitable application for the proposed model.

Based on historical demands for MTO, there were two main products, which were highly demanded; which are the suits (MTOprod1) and the two-piece overalls (MTOprod2). In the computational work, those were the products considered for MTO along with the seasonal products for MTS. The production capacity data obtained from the factory were as shown in table 6 for the regular, overtime and storage capacities. The regular hours are 48 hours per week and the over-time hours are 12 hours per week.

**Table 4: Production capacity data for the base case**

| **Capacities available per period** | |
|---|---|
| Regular Capacity $H_{max}$ | 1300 hrs |
| Overtime Capacity $G_{max}$ | 330 hrs |
| Storage capacity for Final products $V_{max}$ | 900 $m^2$ |
| Storage capacity for fabrics $W_{max}$ | 100 $m^2$ |

In all the computational runs, a period is one week, and there are four common types of fabrics that are used for MTO or MTS production. Therefore, those are the only ones considered. Fabric input parameters are given in table 7 Followed by MTO and MTS input data in tables 8, 9, 10 and 11.

**Table 5: Fabrics input parameters**

| Fabric input parameters | Fabric 1 | Fabric 2 | Fabric 3 | Fabric 4 |
|---|---|---|---|---|
| $r_{fk=1}$ | 36 | 28 | 39 | 40 |
| $r_{fk=2}$ | 30 | 23 | 33 | 25 |
| $I_{ft}^{CF}$ | 0.14 | 0.11 | 0.15 | 0.15 |
| $\alpha_{fm}^{O}$ | 3 | 3 | | |
| $\alpha_{fj}^{S}$ | 0 | 1 | 0.75 | 1 |
| $w_f$ | 0.004 | 0.004 | 0.004 | 0.004 |
| $q_f$ | 30 | 40 | 100 | 100 |

**Table 6: Initial inventory values and initial cash value**

| *Initial fabric inventory* | *Initial MTO/MTS inventory* | *$C_0$ (EGP)* |
|---|---|---|
| *0* | *0* | *132000* |

**Table 7: MTO and MTS input data**

| *Input parameter* | *MTO1* | *MTO2* | *MTS1* | *MTS2* | *MTS3* | *MTS4* |
|---|---|---|---|---|---|---|
| $I_{mt}^{CO}$ | *0.18* | *0.19* | | | | |
| $I_{jt}^{CS}$ | | | *0.46* | *0.17* | *0.19* | *0.23* |
| $R_{m}^{CO}$ | *90* | *45* | | | | |
| $R_{j}^{CS}$ | | | *45* | *30* | *30* | *30* |
| $O_{m}^{CO}$ | *135* | *67* | | | | |
| $O_{j}^{CS}$ | | | *67* | *45* | *45* | *45* |
| $Sb_{mt}^{C}$ | *140* | *75* | | | | |
| $h_{m}^{O}$ | *1.3* | *1.3* | | | | |
| $h_{j}^{S}$ | | | *1.3* | *1.2* | *1* | *1.1* |
| $v_{m}^{O}$ | *0.4* | *0.4* | | | | |
| $v_{j}^{S}$ | | | *0.25* | *0.25* | *0.23* | *0.2* |
| $p_{m}^{O}$ | *170* | *110* | | | | |
| $p_{j}^{S}$ | | | *200* | *90* | *90* | *100* |
| $B_{m}^{O}$ | *50* | *50* | | | | |
| $B_{j}^{S}$ | | | *50* | *50* | *50* | *50* |

**Table 8: Base case MTO demands**

| Period / Product | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MTO 1 | | | 520 | 1100 | | 2500 | | | | | | 1000 |
| MTO 2 | | 515 | | | | | 2600 | | | | | 2000 |

**Table 9: MTS forecasted demands**

| Periods / Products | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MTS 1 | | | | | 400 | 250 | 250 | | | 500 | | |
| MTS 2 | | | 600 | 400 | 200 | | | | | | | |
| MTS 3 | | | 200 | 500 | 600 | | | | | | | |
| MTS 4 | | 500 | 405 | 133 | | | | | | | | |

**Table 10: Base case optimal results**

| products | variables | amount | period |
|---|---|---|---|
| **MTO 1** | $R^O_{1t}$ | 1000, 215, 806, 1000, 99, 1000, 1000 | 1, 2, 3, 4, 6, 8, 12 |
| | $O^O_{1t}$ | 0 | |
| | $I^O_{1t}$ | 1000, 695, 1501, 1, 1, 100, 100 | 1, 2, 3, 4, 5, 6, 7 |
| | $S_{1t}$ | 0 | |
| **MTO 2** | $R^O_{2t}$ | 785, 206, 401, 1000, 500, 500, 1000 | 2, 5, 6, 7, 9, 10, 11 |
| | $O^O_{2t}$ | 0 | |
| | $I^O_{2t}$ | 785, 270, 476, 877, 500, 1000, 2000 | 2, 3-4, 5, 6, 9, 10, 11 |
| | $S_{2t}$ | 723 | 7 |
| **MTS 1** | $R^S_{1t}$ | 400, 500, 500 | 5, 6, 10 |
| | $O^S_{1t}$ | 0 | |
| | $I^S_{1t}$ | 250 | 6 |
| **MTS 2** | $R^S_{2t}$ | 1 | 3, 5 |
| | $O^S_{2t}$ | 205, 194, 199, 217, 108, 275 | 3, 4, 5, 6, 7, 8 |
| | $I^S_{2t}$ | 206, 117, 25 | 3, 6, 7 |
| **MTS 3** | $R^S_{3t}$ | 251, 511 | 3, 5 |
| | $O^S_{3t}$ | 220, 29, 89, 200 | 1, 3, 5, 7 |
| | $I^S_{3t}$ | 20, 20 | 1, 2 |
| **MTS 4** | $R^S_{4t}$ | 0 | |
| | $O^S_{4t}$ | 100, 300, 50, 88 | 1, 2, 3, 4 |
| | $I^S_{4t}$ | 100, 50 | 1, 3 |

The input data distribution was based on historical demand patterns while for the MTS was mainly desired to be produced in the first quarter of the planning horizon. The results for the base case are presented in table 12 with an optimal integer objective of 153226 EGP. Where the model decisions to produce in regular, overtime /subcontract or hold in inventory were seized on costs only.

Results for amounts of fabric purchased per period and their inventory levels are indicated in tables 13 and 14.

**Table 11: Base case fabric purchasing amounts and their inventory levels**

| | $FQ_{f2t}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Periods | | | | | | | | | | | |
| Fabric | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| F1 | 4159 | 0 | 0 | 0 | 0 | 17 | 3000 | 0 | 1500 | 1500 | 3000 | 0 |
| F2 | 9360 | 0 | 0 | 0 | 0 | 0 | 0 | 3000 | 0 | 0 | 0 | 3000 |
| F3 | 1800 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1000 | 0 | 0 |
| F4 | 1313 | 0 | 0 | 0 | 650 | 217 | 258 | 275 | 0 | 0 | 0 | 0 |

**Table 12: Base case fabric inventory levels**

| | $IF_{ft}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Periods | | | | | | | | | | | |
| Fabric | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
| F1 | 4159 | 1804 | 1804 | 1804 | 1186 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F2 | 6360 | 5715 | 3297 | 297 | 297 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F3 | 1800 | 1800 | 1800 | 1800 | 1000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| F4 | 1048 | 748 | 282 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

The cash flow per period for the base case is indicated in figure 3

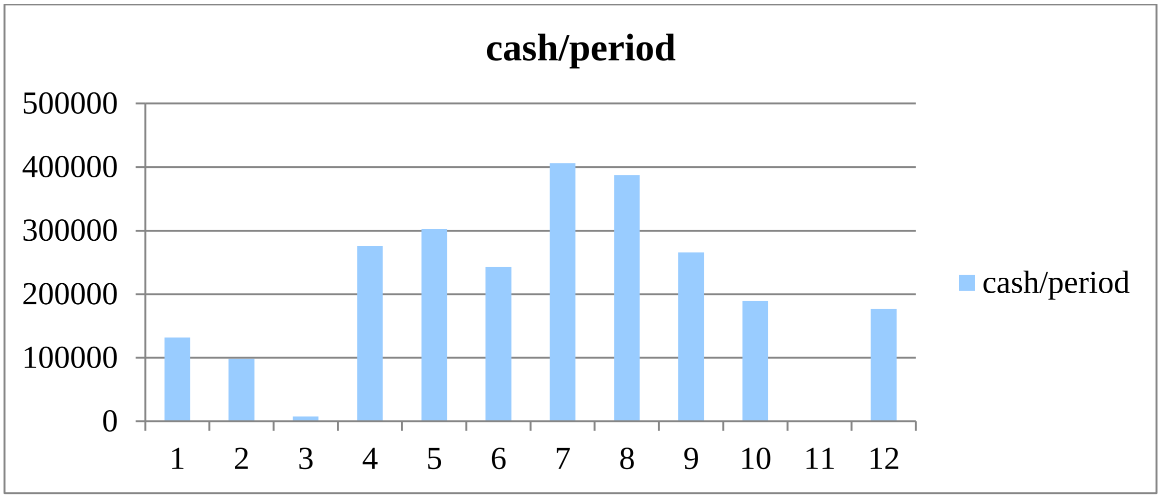



**Figure 6: cash flow for base case**

Table 16, indicates the periods where MTO and MTS production occurs and satisfying a minimum batch production.

**Table 13: Production plan for MTO and MTS produced during period t**

| Periods / Products | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MTO 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 1 |
| MTO 2 | 0 | 1 | 0 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 |

| Periods / Products | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MTS 1 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 0 |
| MTS 2 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| MTS 3 | 1 | 0 | 1 | 0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| MTS 4 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

## 4.2 Model Validation

Model validation was performed in order to validate the solver output solutions and evaluate expected outcomes from real and extreme scenarios that help at highlighting the limitations of the underlying model. The test cases indicated in table 17 were used for that purpose. They impart the objectives mentioned in the second column of the table and their expected gains.

**Table 14: Cases considered for model validation**

| Case | Objective of the case | Expected solve output |
|---|---|---|
| 1. Limited MTO and considerable space capacity. | The objective of the case is to show that depending solely on the MTO; especially when the arriving orders diminish; was in efficient. | Zeroes in most periods and small revenue is realized. Actual data was used for this case. |
| 2. No quantity discount for fabric purchased for MTS products. | To ensure that the fabric quantity discount equations are working correctly. | Fabrics required for MTS products will be purchased at price level $r_{f1}$ and the amounts will be decided for their perspective periods for the decision variable $FQ_{f1t}$ . |
| 3. Case where the model chooses mainly MTO/MTS. | To show how the MTS is profitable provided that there is enough money, that can funds its production and its market is guaranteed. | Higher inventory costs and lower revenues. |

**Case 1: Limited MTO and considerable space capacity**

The first case in the validation is the case when the factory used to produce only MTO products. The table below represents actual demands from historical data and their output solution.

**Table 15: Validation - Case 1**

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Demand** | MTO 1 | 0 | 0 | 0 | 80 | 0 | 0 | 0 | 0 | 0 | 666 | 0 | 0 |
| | MTO 2 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 800 | 0 |
| **products** | **variables** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| **MTO 1** | $R_{1t}^{O}$ | 746 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | $O_{1t}^{O}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | $I_{1t}^{O}$ | 746 | 746 | 746 | 666 | 666 | 666 | 666 | 666 | 666 | 0 | 0 | 0 |
| | $S_{1t}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **MTO 2** | $R_{2t}^{O}$ | 254 | 196 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 137 | 0 |
| | $O_{2t}^{O}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 213 | 0 |
| | $I_{2t}^{O}$ | 254 | 450 | 450 | 450 | 450 | 450 | 450 | 450 | 450 | 450 | 0 | 0 |
| | $S_{2t}$ | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

Results displayed for case 1; table 18; confirmed the results from the factory that there was an obvious large capacity not in-use as indicated by the zeroes for many periods and although the model solution moves towards maximizing the revenues, there were barely any revenues realized which support the attempt of initiating a MTS production stream.

**Case 2: No quantity discount for fabric purchased for MTS products.**

Fabric quantity discount constrained was confirmed as shown in the solution for the 64, 128 MTO, MTS products and the 32, 64 as well, as tabulated in table 19 and table 20 respectively. The decision for purchasing fabric quantity at different price levels is binded to the cash availability, fabric storage capacity and demands due dates.

**Table 16: fabric order quantity ($FQ_{fkt}$) solution for 64,128 MTO, MTS**

| **$FQ_{f1t}$** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 30 | 0 | 0 | 0 |
| 0 | 40 | 40 | 14 | 0 | 40 | 0 | 40 | 0 | 0 | 40 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 100 |
| 0 | 100 | 100 | 100 | 100 | 0 | 0 | 0 | 1 | 0 | 1 | 100 |
| **$FQ_{f2t}$** | | | | | | | | | | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| 509756 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 378814 | 442 | 26 | 0 | 0 | 9 | 0 | 754 | 106891 | 0 | 7 | 128288 |
| 75208 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 226 |
| 47501 | 1158 | 0 | 11 | 5871 | 0 | 1459 | 46751 | 0 | 0 | 0 | 94 |

**Table 17: fabric order quantity ($FQ_{fkt}$) solution for 32, 64 MTO, MTS**

| **$FQ_{f1t}$** | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 2 | 0 | 100 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 100 |
| **$FQ_{f2t}$** | | | | | | | | | | | |
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| 296956 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1260 | 0 | 0 |
| 65636 | 57720 | 18152 | 5485 | 35945 | 52033 | 65575 | 0 | 0 | 0 | 0 | 0 |
| 20000 | 0 | 0 | 0 | 0 | 0 | 0 | 6122 | 2 | 0 | 0 | 8000 |
| 46450 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 |

**Case 3: Case where the model chooses mainly MTO/MTS.**

In order to enable the model to choose whether to produce MTO or MTS, constraint number (5) was relaxed, thereby MTS was produced in the remaining capacity resulting in high inventory levels as shown in table 10, which impacted the revenues; 1,345 EGP. That is due to the limited initial cash and capacity constraints. Table 21, shows the increasing inventory levels for the four MTS products and the cash flow in that case was as illustrated in figure 4, the differences between the initial cash and the cash available by the end of the planning horizon was 3,757 EGP which is considered very low profit that cannot accommodate a following season production plan.

**Table 18: MTS inventory levels when eqn. (5) is relaxed.**

| Periods | MTS1 | MTS2 | MTS3 | MTS4 |
|---|---|---|---|---|
| 1 | 0 | 0 | 200 | 0 |
| 2 | 0 | 0 | 200 | 400 |
| 3 | 0 | 0 | 500 | 400 |
| 4 | 0 | 0 | 500 | 538 |
| 5 | 400 | 200 | 1100 | 538 |
| 6 | 650 | 300 | 1100 | 538 |
| 7 | 654 | 500 | 1300 | 538 |
| 8 | 654 | 800 | 1300 | 538 |
| 9 | 654 | 800 | 1300 | 538 |
| 10 | 1154 | 800 | 1300 | 538 |
| 11 | 1154 | 800 | 1300 | 538 |
| 12 | 1154 | 800 | 1300 | 538 |

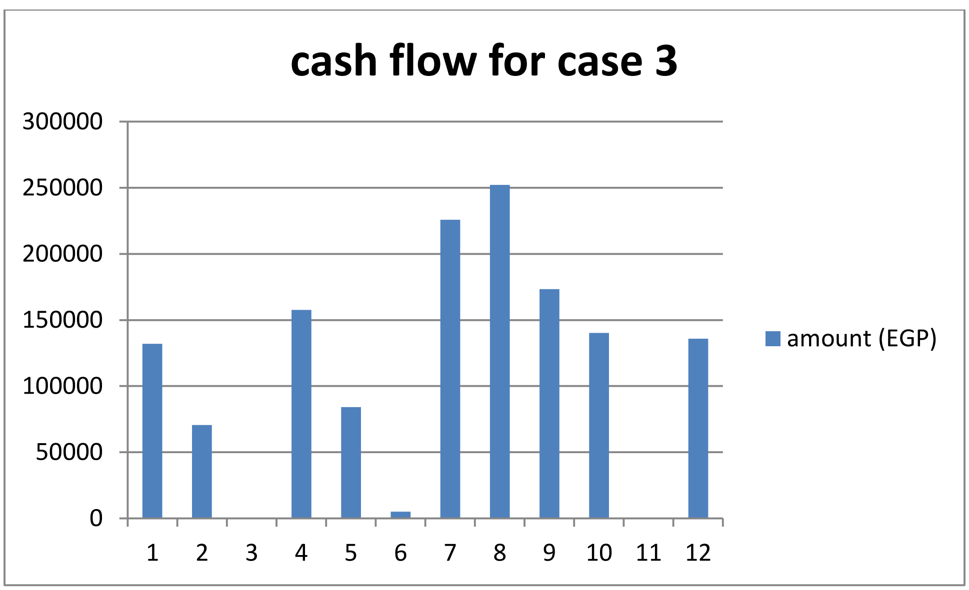



**Figure 7: cash flow/period for case 3**

# Chapter 5

# Computational Results and Sensitivity Analysis

The model behavior was tested by changing influential parameters and checking the response of the costs and revenues towards those changes. The chosen parameters were the parameters that were known in the industry to be subjected to changes or uncertainties.

The parameters, in which their values were changed and tested, are the percent of capacity occupied by MTO and MTS alternatively, fabric price changeability, the inventory holding costs and finally the subcontracting cost.

## 5.1 Impact of changing percent occupied by MTO and MTS on the revenues.

Since for the base case, the percent of capacity occupied by MTO was 70 % and 30% for the MTS production, then it was important to investigate the model sensitivity towards varying percentages, when distributed alternatively between MTO and MTS. Table 23. shows the different percentages tested and the corresponding gained revenues.

**Table 19: Capacity distributed between MTO, MTS, and their projected revenues**

| Percent of capacity occupied by MTO/MTS production | | net profits | MTO Rev. | MTS Rev. |
|---|---|---|---|---|
| MTO | MTS | | | |
| 70 | 30 | 153,227 | 1,433,100 | 559,000 |
| 60 | 40 | 294,263 | 1,240,000 | 793,000 |
| 50 | 50 | 478,107 | 1,030,000 | 1,200,000 |
| 40 | 60 | 509,472 | 827,000 | 1,240,000 |

Increasing the percent of capacity for MTS, the total revenues showed an increasing pattern while the MTO revenue falls back as shown in figure 4. Although the revenues attained in the graph makes sense, but that is not very accurate if the forecasted demands were not fully sold as planned. On the other hand, the MTO shows a higher revenue contribution when it occupied 40% of the capacity in contrary to the MTS when it occupied 40% of the capacity. Moreover, analyzing the 70-30 percent alternatively between MTO and MTS, when the former (MTO) occupied the higher percent, significant revenues were depicted unlike the MTS, the model has reported infeasibility. That was due to several things, the MTS production volumes are mainly restricted to the cash availability, in which the MTO revenues contributes in it but on the other hand the MTO production and fabric costs are also much higher.

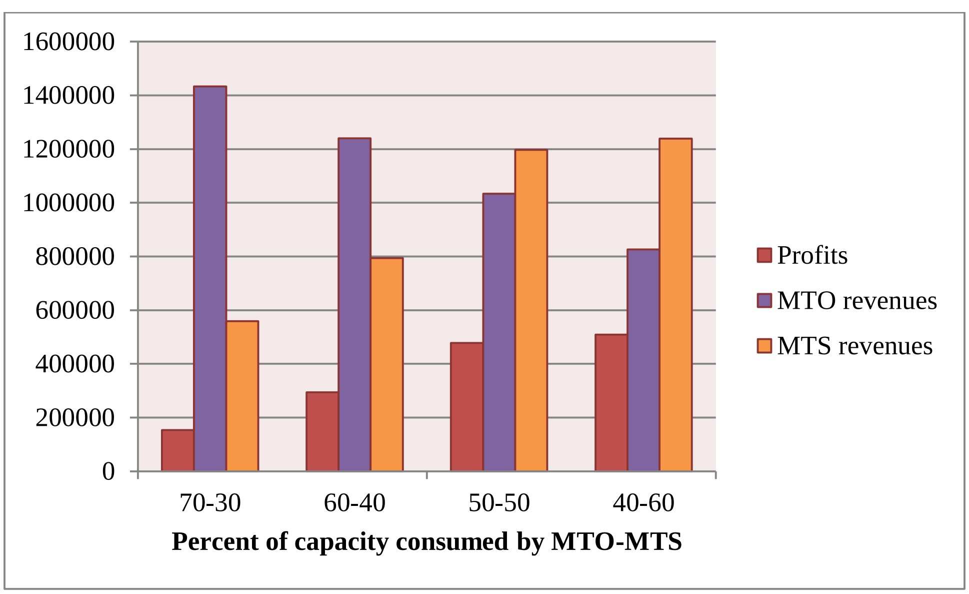



**Figure 8: Percent of capacity consumed by MTO-MTS vs. revenues**

The closer the percentage between the MTO and MTS capacity, while giving the MTO the higher percent, the more the revenues acquired.

Therefore, the most suitable percentages division would be 60-40 or 50-50 for allocating capacity to MTO- MTS respectively.

### 5.2 Impact of distributing capacity between MTO and MTS on the costs.

The results for the costs encountered from MTO & MTS production during regular, overtime and subcontracting show how the costs are sensitive to different production volumes for MTO and MTS as shown in table 24.

**Table 20: Production costs (EGP) vs. percentage of capacity**

| MTO % | MTS % | MTO Production cost | MTS Production cost | Subcontracting cost | Total costs |
|---|---|---|---|---|---|
| 70 | 30 | 658440 | 1.88E+05 | 54225 | 1838618 |
| 60 | 40 | 564363 | 2.49E+05 | 73050 | 1739645 |
| 50 | 50 | 452229 | 3.69E+05 | 88425 | 1752849 |
| 40 | 60 | 350631 | 3.77E+05 | 82125 | 1555890 |

Figure 9 exhibits how the MTO production costs are high even if it occupies smaller percent of the capacity. The subcontracting cost for the 50-50 and 40-60 percent were apparently close with a difference of 7% and the total costs for the same percentages were nearly the same. While when the MTS amounts exceeded that for the MTO; the 40-60 case; the total costs indeed decreased. However, when the MTS costs for the 40-60 and 50-50 case were compared, the difference in their costs will be just 0.2%.

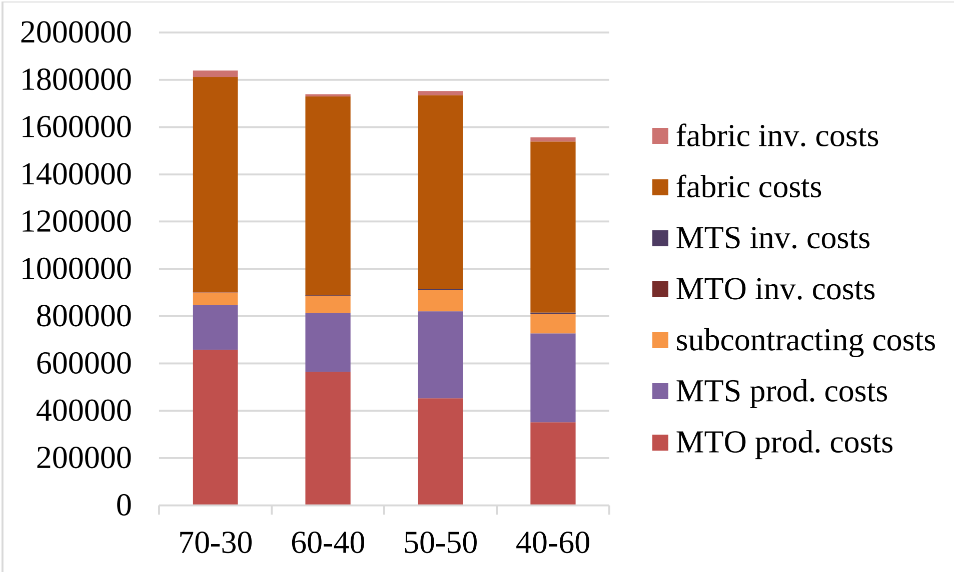



**Figure 9: percentage of capacity consumed vs. costs**

### 5.3 Impact of changing percent of capacity between MTO and MTS on the inventory holding costs.

MTS, as the term implies, has higher inventory costs than that for MTO, table 25. As the percent of capacity allocated for MTS increase the MTS inventory holding cost increases notably as shown from the results in figure 5, except for the 70-30 %, the MTO had a higher inventory, because it comprises higher percentage and there is enough storage area to store finished MTO products to meet its due date.

**Table 21: Percentage of capacity distributed between MTO and MTS vs. Inv. holding cost**

| MTO % | MTS % | MTO Inv. cost | MTS Inv. cost |
|---|---|---|---|
| 70 | 30 | 1785 | 216 |
| 60 | 40 | 1207 | 1433 |
| 50 | 50 | 1664 | 2237 |
| 40 | 60 | 648 | 4949 |

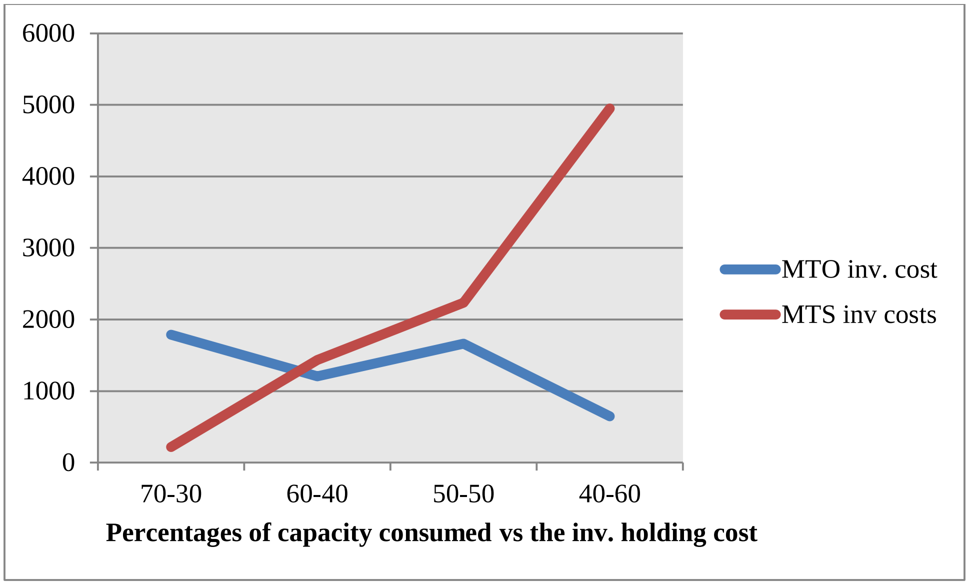



**Figure 10: Percentage of capacity distributed between MTO and MTS vs. inventory holding cost**

### 5.4 Impact of increasing fabric price on the profits.

Fabric price is a substantial parameter of the model**.** Thus measuring its implications on the revenues and inventory cost was vital. Table 26, demonstrates the revenues and inventory holding costs obtained for every percent increase in the fabric price.

**Table 22: Fabric price percentage increase vs. profits and fabric inventory cost**

| Fabric price percent increase | Profits | Fabric inventory cost |
|---|---|---|
| Base | 153,226 | 26,921 |
| 5% | 100,095 | 30,863 |
| 10% | 61,509 | 36,353 |
| 15% | 9,025 | 39,298 |
| 20% | -45,082 | 41,453 |
| 25% | -94,189 | 42,481 |

The profits were very sensitive to the fabric price increase as shown in figure 6; it showed a decreasing pattern for every percent increase in the fabric price, which almost decayed, and no revenues were realized when it increased by a percent more than 15 %. On the contrary, to the fabric inventory cost that moved in an increasing fashion; which was expected; as it is purchased and stored for the sake of the objective function optimality.

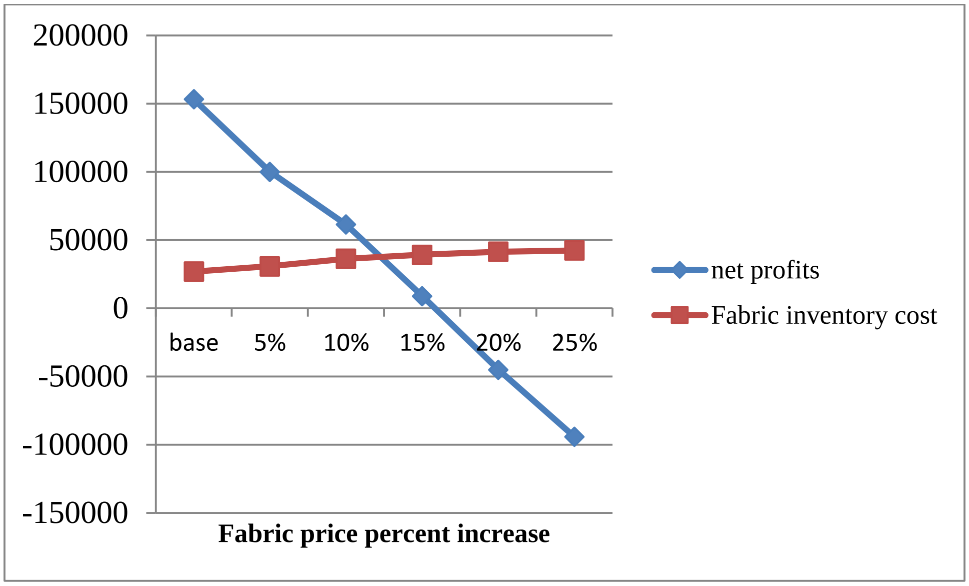



**Figure 11: Fabric price percentage increase vs. revenues**

### 5.5 Impact of increasing the inventory holding cost on the revenues.

Table 27, shows the impact of increasing the inventory holding cost for MTO, MTS and fabrics on their costs and the revenues. The fabric inventory cost showed the higher holding cost then the MTO and the least was the MTS inventory. That is consistent with the data for fabric amounts for the MTO products. Since one garment of a MTO product consumes 3 meters of fabrics unlike the MTS items, one garment of it never reach this number. Given that the MTO production to MTS production is 70 to 30, then the amounts purchased for MTO will be much higher.

**Table 23: Profits and costs for inventory holding cost increase**

| Percent increase | Profits | MTO revenues | MTS revenues | MTO inventory costs | MTS inventory costs | Fabric inventory costs |
|---|---|---|---|---|---|---|
| Base | 153226 | 1433100 | 558800 | 1785 | 216 | 26921 |
| 10% | 129047 | 1433100 | 558800 | 23511 | 996 | 33369 |
| 15% | 126466 | 1433100 | 558800 | 25684 | 1426 | 27222 |
| 20% | 121670 | 1433100 | 558800 | 27971 | 1673 | 21826 |
| 25% | 118418 | 1433100 | 558800 | 30654 | 1788 | 21294 |

Increasing the inventory holding cost by 10%, had a significant effect on the profits as it decreased by 16%, while further increases in the inventory holding cost has decreased the revenues in a range of 2 - 4% as indicated in table 22.

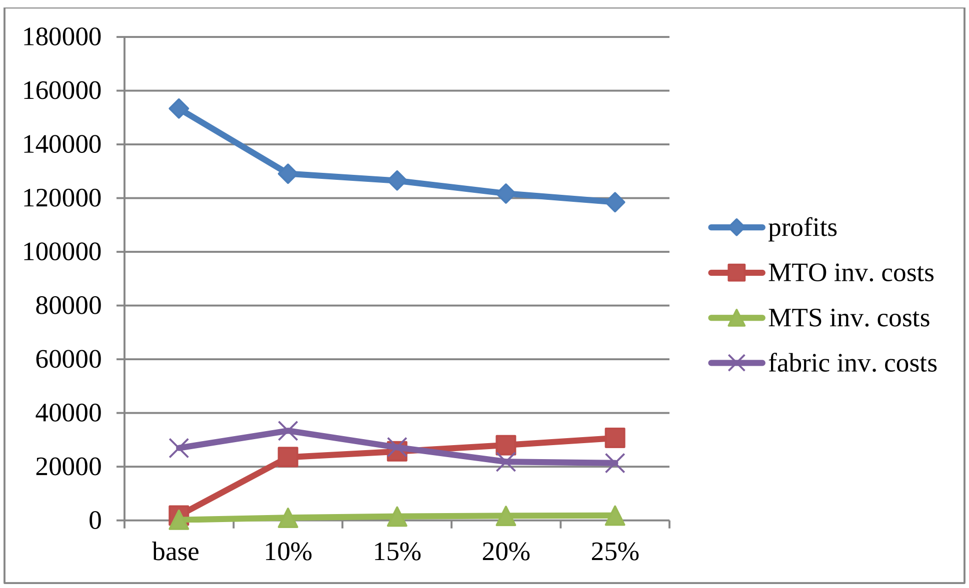



**Figure 12: net profits vs. change in inventory holding cost**

The net profits decreased as the inventory holding cost increased. The MTO inventory cost and fabric inventory cost were both sensitive to the increase in the inventory holding cost while the MTS weren't significantly affected by that increase and that is because here the MTS constituted only 30% of the capacity.

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### 5.6 Impact of increasing subcontracting cost on the profits.

The model considers subcontracting for the MTO products; hence, testing its impact on the revenues and related MTO production costs was meaningful. Table 28 displays the outputs for the revenues, MTO production costs, overtime costs, subcontracting costs and MTO inventory costs that are merged for every 5 percent increase in the subcontracting cost.

**Table 24: Revenues and costs vs. subcontracting cost percentage increase**

| Percentage increase in the subcont-racting cost | Profits | MTO Production cost | Overtime production cost for MTO and MTS | Subcontra-cting cost | MTO inventory cost |
|---|---|---|---|---|---|
| **Base** | 153226 | 658440 | 1.02E+05 | 54225 | 1785 |
| **5%** | 148377 | 662058 | 1.06E+05 | 52182 | 1786 |
| **10%** | 142118 | 660892 | 1.06E+05 | 54858 | 1841 |
| **15%** | 135593 | 660915 | 1.06E+05 | 57448 | 1843 |

When the subcontracting cost increase the revenues decreased by around 4% for every percent increase in the subcontracting cost. The MTO production cost was not significantly affected by that increase; it was just elevated on an average of 0.2% and the overtime production cost has remained almost unchanged. The inventory cost for MTO increased by around 3% when the subcontracting cost increased from 5% to 10%.

Therefore, the revenues were sensitive to the changes in the subcontracting cost for the percentages from 5 to 15 %, as presented in figure 13. A trial was made to test the changes if the subcontracting cost increased by 20% but the solver took a long time to solve (more than a day) to provide an optimum solution. So it was not included and for a practical reason that this percent increase was considered an extreme and typically, the subcontracting cost was not raised beyond the 10%, that is why the percentages tested were enough.

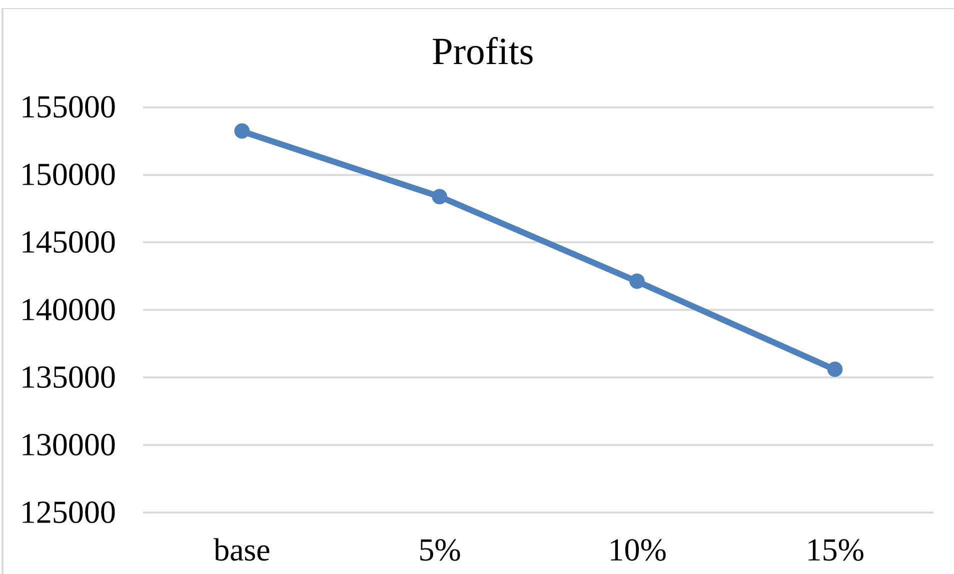


**Figure 13: profits vs. subcontracting cost**

# Chapter 6

# Conclusions and Future work

## 6.1 Concluding remarks

An MILP model for production and inventory planning of mixed MTO – MTS system for a readymade garment industry, is proposed. The developed model showed the successful approach of having a MTS production along with the MTO production stream, as a new way for overcoming financial drawbacks and the repercussions of depending solely on the MTO demands.

The optimum results attained from the developed model helped at making the right decisions regarding the inventory and production for different products for a mixed MTO-MTS products. The model considered the vital decisions encountered from the impact of the production costs on the revenues.

The challenge faced at such environment was to guarantee the generation of a significant revenue by the end of the season and positive cash flow at the end of each period. Thus, a steady production process will take place without financial shortages. Cash inflow was generated from the sales made by the MTS and the MTO items. The production plan considered the main factors that influence the production process. The factors were the fabric needed for production, the capacity limitations and the cash availability.

MTO due dates and forecasted demands were met for the planned products. Using the spare capacity to produce to stock had a significant contribution in the revenues and maintaining financial stability.

The model was very sensitive to the changes in the percentages of capacity allocation for MTO and MTS to different cost parameters, while distributing the capacity 60 to 40 percent for MTO/ MTS products respectively proved to be the best option. For the given MTO demands and target MTS, the tests on the percentage of MTS to be produced out of the desired target production, has proved to present a positive cash towards the end of each period and a significant revenue was realized.

Fabric price was a crucial parameter and the model was very sensitive to its changes, which was anticipated, as the fabric price comprises 90% of the garment material cost. Cash availability restricts the amounts to produce for MTS and affects the decision for accepted orders. The results obtained helped at giving a practical guiding decisions that improve a garment business significantly.

The effectiveness of the model was distinct in its simplicity and applicability to real life garment production, as it considered the prominent inputs of the garment production process. It has also tackled the vital and tangible decisions that happened to be of significant impact on the decisions made.

The challenge has lied in having an optimum solution from merging the capacity and production planning decisions with the finances in order to help a garment business to sustain and grow. Therefore, a policy for production and capacity planning in garment manufacturing was featured.

### 6.2 Insights on Future work:

1. Consider accounting for lost sales for a better forecast and consider backlogging for MTO demands.
2. Merging an acceptance - rejection criteria for MTO demands.
3. Future work may also include examining the implications of the interest rate for any given loan to the cash flow and the revenues.
4. Adding to the model procurement decisions related to the fabric that may include supplier selection, supplier lead-time effect, and supplier terms of discounts.

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# Appendix A: The inputs for multiples of MTO – MTS products

For multiple of products, Table A1 indicates the input capacities for 64 MTO and 128 MTS products. The distribution of the demands over the periods were distributed arbitrarily.

**Table A1: Input capacities for the 64, 128 MTO - MTS products**

| **Capacities available per period** | |
|---|---|
| Regular Capacity $H_{max}$ | 41600 |
| Overtime Capacity $G_{max}$ | 10560 |
| Storage capacity for Final products $V_{max}$ | 12000 |
| Storage capacity for fabrics $W_{max}$ | 2400 |

Table A2 represents the input costs used for the 64 MTO and 128 MTS products.

**Table A2: Input parameters for 64-128 MTO - MTS**

| *Input parameter* | *MTO* | *MTS* |
|---|---|---|
| $I_{mt}^{CO}$ | 0.18 | - |
| $I_{jt}^{CS}$ | - | 0.17 |
| $R_{m}^{CO}$ | 50 | - |
| $R_{j}^{CS}$ | - | 30 |
| $O_{m}^{CO}$ | 75 | - |
| $O_{j}^{CS}$ | - | 45 |
| $Sb_{mt}^{C}$ | 75 | - |
| $h_{m}^{O}$ | 1.3 | |
| $h_{j}^{S}$ | - | 1 |
| $v_{m}^{O}$ | 0.4 | - |
| $v_{j}^{S}$ | - | 0.2 |
| $B_{m}^{O}$ | 50 | - |
| $B_{j}^{S}$ | - | 50 |

**Table A3: Input price for 64 - 128 MTO - MTS**

| MTO product | Price (EGP) | MTS product | Price (EGP) |
|---|---|---|---|
| MTO product 1 | 170 | MTS product 1 | 200 |
| MTO product 2 | 110 | MTS product 2 | 90 |
| MTO product 3 | 90 | MTS product 3 | 90 |
| MTO product 4 | 90 | MTS product 4 | 100 |
| MTO product 5 | 80 | MTS product 5 | 60 |
| MTO product 6 | 80 | MTS product 6 | 70 |
| MTO product 7 | 170 | MTS product 7 | 80 |
| MTO product 8 | 110 | MTS product 8 | 90 |
| MTO product 9 | 90 | MTS product 9 | 100 |
| MTO product 10 | 90 | MTS product 10 | 90 |
| MTO product 11 | 80 | MTS product 11 | 90 |
| MTO product 12 | 80 | MTS product 12 | 100 |
| MTO product 13 | 170 | MTS product 13 | 60 |
| MTO product 14 | 110 | MTS product 14 | 70 |
| MTO product 15 | 90 | MTS product 15 | 80 |
| MTO product 16 | 90 | MTS product 16 | 90 |
| MTO product 17 | 80 | MTS product 17 | 200 |
| MTO product 18 | 80 | MTS product 18 | 90 |
| MTO product 19 | 170 | MTS product 19 | 90 |
| MTO product 20 | 110 | MTS product 20 | 100 |
| MTO product 21 | 90 | MTS product 21 | 60 |
| MTO product 22 | 90 | MTS product 22 | 70 |
| MTO product 23 | 80 | MTS product 23 | 80 |
| MTO product 24 | 80 | MTS product 24 | 90 |
| MTO product 25 | 170 | MTS product 25 | 100 |
| MTO product 26 | 110 | MTS product 26 | 90 |
| MTO product 27 | 90 | MTS product 27 | 90 |
| MTO product 28 | 90 | MTS product 28 | 100 |
| MTO product 29 | 80 | MTS product 29 | 60 |
| MTO product 30 | 80 | MTS product 30 | 70 |
| MTO product 31 | 170 | MTS product 31 | 80 |
| MTO product 32 | 110 | MTS product 32 | 90 |
| MTO product 33 | 90 | MTS product 33 | 200 |
| MTO product 34 | 90 | MTS product 34 | 90 |
| MTO product 35 | 80 | MTS product 35 | 90 |
| MTO product 36 | 80 | MTS product 36 | 100 |
| MTO product 37 | 170 | MTS product 37 | 60 |

| | | | |
|---|---|---|---|
| MTO product 38 | 110 | MTS product 38 | 70 |
| MTO product 39 | 90 | MTS product 39 | 80 |
| MTO product 40 | 90 | MTS product 40 | 90 |
| MTO product 41 | 80 | MTS product 41 | 100 |
| MTO product 42 | 80 | MTS product 42 | 90 |
| MTO product 43 | 170 | MTS product 43 | 90 |
| MTO product 44 | 110 | MTS product 44 | 100 |
| MTO product 45 | 90 | MTS product 45 | 60 |
| MTO product 46 | 90 | MTS product 46 | 70 |
| MTO product 47 | 80 | MTS product 47 | 80 |
| MTO product 48 | 80 | MTS product 48 | 90 |
| MTO product 49 | 170 | MTS product 49 | 200 |
| MTO product 50 | 110 | MTS product 50 | 90 |
| MTO product 51 | 90 | MTS product 51 | 90 |
| MTO product 52 | 90 | MTS product 52 | 100 |
| MTO product 53 | 80 | MTS product 53 | 60 |
| MTO product 54 | 80 | MTS product 54 | 70 |
| MTO product 55 | 170 | MTS product 55 | 80 |
| MTO product 56 | 110 | MTS product 56 | 90 |
| MTO product 57 | 90 | MTS product 57 | 100 |
| MTO product 58 | 90 | MTS product 58 | 90 |
| MTO product 59 | 80 | MTS product 59 | 90 |
| MTO product 60 | 80 | MTS product 60 | 100 |
| MTO product 61 | 170 | MTS product 61 | 60 |
| MTO product 62 | 110 | MTS product 62 | 70 |
| MTO product 63 | 90 | MTS product 63 | 80 |
| MTO product 64 | 90 | MTS product 64 | 90 |
| | | MTS product 65 | 200 |
| | | MTS product 66 | 90 |
| | | MTS product 67 | 90 |
| | | MTS product 68 | 100 |
| | | MTS product 69 | 60 |
| | | MTS product 70 | 70 |
| | | MTS product 71 | 80 |
| | | MTS product 72 | 90 |
| | | MTS product 73 | 100 |
| | | MTS product 74 | 90 |
| | | MTS product 75 | 90 |
| | | MTS product 76 | 100 |
| | | MTS product 77 | 60 |
| | | MTS product 78 | 70 |

| | | | |
|---|---|---|---|
| | | MTS product 79 | 80 |
| | | MTS product 80 | 90 |
| | | MTS product 81 | 200 |
| | | MTS product 82 | 90 |
| | | MTS product 83 | 90 |
| | | MTS product 84 | 100 |
| | | MTS product 85 | 60 |
| | | MTS product 86 | 70 |
| | | MTS product 87 | 80 |
| | | MTS product 88 | 90 |
| | | MTS product 89 | 100 |
| | | MTS product 90 | 90 |
| | | MTS product 91 | 90 |
| | | MTS product 92 | 100 |
| | | MTS product 93 | 60 |
| | | MTS product 94 | 70 |
| | | MTS product 95 | 80 |
| | | MTS product 96 | 90 |
| | | MTS product 97 | 200 |
| | | MTS product 98 | 90 |
| | | MTS product 99 | 90 |
| | | MTS product 100 | 100 |
| | | MTS product 101 | 60 |
| | | MTS product 102 | 70 |
| | | MTS product 103 | 80 |
| | | MTS product 104 | 90 |
| | | MTS product 105 | 100 |
| | | MTS product 106 | 90 |
| | | MTS product 107 | 90 |
| | | MTS product 108 | 100 |
| | | MTS product 109 | 60 |
| | | MTS product 110 | 70 |
| | | MTS product 111 | 80 |
| | | MTS product 112 | 90 |
| | | MTS product 113 | 200 |
| | | MTS product 114 | 90 |
| | | MTS product 115 | 90 |
| | | MTS product 116 | 100 |
| | | MTS product 117 | 60 |
| | | MTS product 118 | 70 |
| | | MTS product 119 | 80 |

| | | | |
|---|---|---|---|
| | | MTS product 120 | 90 |
| | | MTS product 121 | 100 |
| | | MTS product 122 | 90 |
| | | MTS product 123 | 90 |
| | | MTS product 124 | 100 |
| | | MTS product 125 | 60 |
| | | MTS product 126 | 70 |
| | | MTS product 127 | 80 |
| | | MTS product 128 | 90 |

## Appendix B: The outputs for multiple of multiple MTO – MTS products

This appendix includes the outputs for 64 MTO products and 128 MTS products.

**Table B1: Fabric inventory for multiple MTO – MTS products**

| Periods | Fabric 1 | Fabric 2 | Fabric 3 | Fabric 4 |
|---|---|---|---|---|
| **1** | 492917 | 311314 | 67742 | 36277 |
| **2** | 436256 | 303177 | 57342 | 20725 |
| **3** | 436256 | 223560 | 53942 | 5992 |
| **4** | 330191 | 223574 | 48432 | 3303 |
| **5** | 306290 | 137660 | 43808 | 7242 |
| **6** | 253610 | 100218 | 29614 | 1808 |
| **7** | 245936 | 0 | 27814 | 0 |
| **8** | 149993 | 644 | 20612 | 40751 |
| **9** | 142169 | 50367 | 17712 | 26252 |
| **10** | 89813 | 32223 | 7712 | 13002 |
| **11** | 89600 | 863 | 0 | 3537 |
| **12** | 599 | 129151 | 0 | 0 |

**Table B2: MTO optimum production and inventory plan**

| Demand, period (t) | MTO product | Regular | | Overtime | | subcontracting | | Inventory | |
|---|---|---|---|---|---|---|---|---|---|
| | | t | amount | t | amount | t | amount | t | amount |
| 5000,1 | **1** | 1 | 5000 | | | | | | |
| 5000,2 | **2** | | | | | 2 | 5000 | | |
| 5000,3 | **3** | 3 | 5000 | | | | | | |
| 5000,4 | **4** | 4 | 5000 | | | | | | |
| 5000,5 | **5** | 5 | 5000 | | | | | | |
| 5000,6 | **6** | 4, 6 | 3855, 1093 | 6 | 52 | | | 4, 5 | 3855, 3855 |
| 5000,7 | **7** | 6, 7 | 266, 4734 | | | | | 6 | 266 |
| 5000,8 | **8** | 6, 8 | 381, 3151 | 8 | 1468 | | | 6, 7 | 381, 381 |
| 5000,9 | **9** | | | 7 | 5022 | | | 7-8, 9-11 | 5022, 22 |
| 5000,10 | **10** | 10 | 5000 | | | | | | |
| 5000,11 | **11** | 9, 11 | 65, 4375 | 10 | 582 | | | 9, 10, 11-12 | 65, 647, 22 |
| 5000,12 | **12** | 12 | 8231 | | | | | 12 | 3231 |
| 5000,1 | **13** | | | 1 | 5000 | | | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 5000,2 | **14** | | | 2 | 5000 | | | | |
| 5000,3 | **15** | 2,3 | 2818, 138 | 3 | 2044 | | | 2 | 2818 |
| 5000,4 | **16** | 4 | 521 | 4 | 4479 | | | | |
| 5000,5 | **17** | 5 | 5000 | | | | | | |
| 5000,6 | **18** | 5, 6 | 4917, 33 | 6 | 50 | | | 5 | 4917 |
| 5000,7 | **19** | 7 | 5000 | | | | | | |
| 5000,8 | **20** | 8 | 5000 | | | | | | |
| 3000,9 | **21** | 6, 7, 9 | 2733, 260, 51 | | | | | 6,7-8, 9-12 | 2733, 2993, 44 |
| 3000,10 | **22** | 9, 10 | 17, 2932 | 9 | 51 | | | 9 | 68 |
| 3000,11 | **23** | 9, 11 | 2940, 60 | | | | | 9, 10 | 2940 |
| 3000,12 | **24** | 11, 12 | 14, 2936 | 11 | 57 | | | 11, 12 | 71, 7 |
| 3000,1 | **25** | 1 | 3000 | | | | | | |
| 3000,2 | **26** | 1 | 2998 | 1 | 2 | | | 1 | 3000 |
| 3000,3 | **27** | 3 | 3000 | | | | | | |
| 3000,4 | **28** | 4 | 3000 | | | | | | |
| 3000,5 | **29** | 5 | 3000 | | | | | | |
| 3000,6 | **30** | 5 | 3000 | | | | | 5 | 3000 |
| 2500,7 | **31** | 2, 7 | 55, 2391 | 5 | 54 | | | 2-4, 5-6 | 55, 109 |
| 2500,8 | **32** | 7 | 2500 | | | 8 | 1 | 9 | 2500 |
| 2500,9 | **33** | 7 | 2499 | | | 9 | 1 | 10 | 2500 |
| 2500,10 | **34** | 9 | 2500 | | | | | | |
| 2500,11 | **35** | | | 10 | 2500 | | | | |
| 2500,12 | **36** | 12 | 2500 | | | | | | |
| 2500,1 | **37** | 1 | 2500 | | | | | | |
| 2500,2 | **38** | 1 | 2500 | | | | | 1 | 2500 |
| 2500,3 | **39** | 3 | 379 | | | 2 | 2121 | 2 | 2121 |
| 2500,4 | **40** | 4 | 2500 | | | | | | |
| 7000,5 | **41** | 5 | 670 | 5 | 6330 | | | | |
| 7000,6 | **42** | 6 | 7001 | | | | | 6,7…. 12 | 1 |
| 7000,7 | **43** | 7 | 6999 | | | 5 | 1 | 5,6 | 1 |
| 7000,8 | **44** | 8 | 7000 | | | | | | |
| 7000,9 | **45** | 9 | 7000 | | | | | | |
| 7000,10 | **46** | 10 | 7000 | | | | | | |
| 7000,11 | **47** | 6, 8 | 6999, 50 | | | | | 6-7, 8-10,11-12 | 6999,70 49,49 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 7000,12 | **48** | 12 | 7000 | | | | | | |
| 7000,1 | **49** | | 0 | | | 1 | 7001 | 1 …12 | 1 |
| 7000,2 | **50** | 2 | 7000 | | | | | | |
| 9000,3 | **51** | 3 | 9000 | | | | | | |
| 9000,4 | **52** | 4 | 9000 | | | | | | |
| 9000,5 | **53** | 5 | 8584 | | | 5 | 416 | | |
| 9000,6 | **54** | 5, 6 | 1, 2417 | 5, 6 | 49, 6533 | | | 5 | 50 |
| 9000,7 | **55** | 7 | 9000 | | | | | | |
| 9000,8 | **56** | 8 | 8942 | 7 | 58 | | | 7 | 58 |
| 9000,9 | **57** | 9 | 9000 | | | | | | |
| 9000,10 | **58** | 8, 9, 10 | 6430, 50, 2520 | | | | | 8, 9 | 6430, 6480 |
| 9000,11 | **59** | 10, 11 | 2966, 6034 | | | | | 10 | 2966 |
| 9000,12 | **60** | 12 | 9000 | | | | | | |
| 7000,1 | **61** | 1 | 7000 | | | | | | |
| 7000,2 | **62** | 1, 2 | 112, 6887 | 1 | 1 | | | 1 | 113 |
| 7000,3 | **63** | 3 | 6999 | 3 | 1 | | | | |
| 7000,4 | **64** | 4 | 7000 | | | | | | |

**Table B3: MTS production plan for multiple of products**

| Forecast, period | MTO product | Regular | | Overtime | | Inventory | |
|---|---|---|---|---|---|---|---|
| | | period | amount | period | amount | period | amount |
| 1000, 4 | **1** | 2,4 | 712,288 | | 0 | 2,3 | 712, 712 |
| 1000, 4 | **2** | 2 | 1000 | | 0 | 2, 3 | 1000, 1000 |
| 1000, 4 | **3** | | 0 | 4 | 1000 | | 0 |
| 1000, 4 | **4** | 3 | 1000 | | 0 | 3 | 1000 |
| 1000, 4 | **5** | 1,4 | 833,167 | | 0 | 2,3,4 | 833, 833, 833 |
| 1000, 4 | **6** | 2 | 1,000 | | 0 | 2, 3 | 1000, 1000 |
| 1000, 4 | **7** | | | 4 | 1000 | | 0 |
| 1000, 4 | **8** | | | 3 | 1000 | 3 | 1000, 1000 |
| 600, 1 | **9** | 1 | 600 | | 0 | | 0 |
| 600, 1 | **10** | 1 | 600 | | 0 | | 0 |
| 600, 1 | **11** | 1 | 600 | | 0 | | 0 |
| 600, 1 | **12** | | 0 | 1 | 600 | | 0 |
| 600, 1 | **13** | 1 | 244 | 1 | 356 | | 0 |
| 600, 1 | **14** | 1 | 600 | | 0 | | 0 |
| 600, 1 | **15** | 1 | 600 | | 0 | | 0 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 600, 1 | **16** | | 0 | | 0 | | 0 |
| 2000,3 | **17** | | 0 | 10 | 2000 | 10, 11 | 2000, 2000 |
| 2000,3 | **18** | 12 | 2000 | | 0 | | 0 |
| 2000,3 | **19** | 10 | 2000 | | 0 | 10,11 | 2000, 2000 |
| 2000,3 | **20** | | 0 | 11 | 2197 | 11, 12 | 2197, 197 |
| 2000,3 | **21** | | 0 | 8 | 2000 | 8,9..12 | 2000 |
| 2000,3 | **22** | 11 | 2000 | | 0 | 11 | 2000 |
| 2000,3 | **23** | | 0 | | 0 | | 0 |
| 2000,3 | **24** | 11 | 2000 | | 0 | 11 | 2000 |
| 900,3 | **25** | 2 | 900 | | 0 | 2 | 900 |
| 900,3 | **26** | | 0 | 3 | 900 | | 0 |
| 900,3 | **27** | | 0 | 3 | 900 | | 0 |
| 900,3 | **28** | | 0 | 3 | 900 | | 0 |
| 900,3 | **29** | 2 | 900 | | 0 | 2 | 900 |
| 900,3 | **30** | | 0 | 3 | 900 | | 0 |
| 900,3 | **31** | 2 | 900 | | 0 | 2 | 900 |
| 900,3 | **32** | 3 | 900 | | 0 | | 0 |
| 700,2 | **33** | | 0 | 1 | 700 | 1 | 700 |
| 700,2 | **34** | | 0 | 1 | 700 | 1 | 700 |
| 700,2 | **35** | 2 | 700 | | 0 | | 0 |
| 700,2 | **36** | | 0 | | 700 | 1 | 700 |
| 700,2 | **37** | 2 | 700 | | 0 | | 0 |
| 700,2 | **38** | 2 | 700 | | 0 | | 0 |
| 700,2 | **39** | 1 | 700 | | 0 | 1 | 700 |
| 700,2 | **40** | 2 | 700 | | 0 | | 0 |
| 1500, 10 | **41** | 6, 8 | 1499, 50 | | 0 | 6-7, 8-9, 10-12 | 1499, 1549, 49 |
| 1500, 10 | **42** | | 0 | 8 | 1500 | 8,9 | 1500, 1500 |
| 1500, 10 | **43** | 10 | 1500 | 10 | 1500 | | 0 |
| 1500, 10 | **44** | | 0 | | 0 | 8,9 | 1500, 1500 |
| 1500, 10 | **45** | | 0 | | 0 | | 0 |
| 1500, 10 | **46** | 8 | 1500 | | 0 | 8,9 | 1500, 1500 |
| 1500, 10 | **47** | 9 | 1500 | | 0 | 9 | 1500 |
| 1500, 10 | **48** | 9 | 1500 | | 0 | 9 | 1500 |
| 700,3 | **49** | 2 | 700 | | 0 | 2 | 700 |
| 700,4 | **50** | 2 | 700 | | 0 | 2 | 700 |
| 700,5 | **51** | 2 | 700 | | 0 | 2 | 700 |
| 700,6 | **52** | 2 | 700 | | 0 | 2 | 700 |
| 700,7 | **53** | 3 | 700 | | 0 | | 0 |
| 700,8 | **54** | 2 | 700 | | 0 | 2 | 700 |
| 700,9 | **55** | 1 | 700 | | 0 | 1,2 | 700,700 |
| 700,10 | **56** | 1 | 700 | | 0 | 1,2 | 700,700 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1100, 6 | **57** | 6 | 1100 | | 0 | | 0 |
| 1100, 6 | **58** | 2 | 1100 | | 0 | 2,3..5 | 1100 |
| 1100, 6 | **59** | 2 | 1100 | | 0 | 2,3..5 | 1100 |
| 1100, 6 | **60** | 1 | 674 | 2 | 426 | 1, 2-5 | 674, 1100 |
| 1100, 6 | **61** | 6 | 1100 | | 0 | | 0 |
| 1100, 6 | **62** | 1 | 1100 | | 0 | 1,2..5 | 1100 |
| 1100, 6 | **63** | | 0 | 2, 5 | 212, 888 | 2-4,5 | 212, 1100 |
| 1100, 6 | **64** | 5 | 66 | 6 | 1034 | 5 | 66 |
| 1500, 10 | **65** | 10 | 1500 | | 0 | | 0 |
| 1500, 10 | **66** | 10 | 1500 | | 0 | | 0 |
| 1500, 10 | **67** | 10 | 1500 | | 0 | | 0 |
| 1500, 10 | **68** | | 0 | 10 | 1500 | | 0 |
| 1500, 10 | **69** | 6, 8 | 1498, 51 | | 0 | 6-7,8-9,10-12 | 1498, 1549, 49 |
| 1500, 10 | **70** | 10 | 1500 | | 0 | | 0 |
| 1500, 10 | **71** | 9 | 1500 | | 0 | 9 | 1500 |
| 1500, 10 | **72** | 10 | 1500 | | 0 | | 0 |
| 1000, 3 | **73** | 1 | 1000 | | 0 | 1,2 | 1000, 1000 |
| 1000, 3 | **74** | 3 | 1000 | | 0 | | 0 |
| 1000, 3 | **75** | | 0 | 3 | 1000 | | 0 |
| 1000, 3 | **76** | 3 | 1000 | | 0 | | 0 |
| 1000, 3 | **77** | 2 | 1000 | | 0 | 2 | 1000 |
| 1000, 3 | **78** | 3 | 1000 | | 0 | | 0 |
| 1000, 3 | **79** | 2 | 1000 | | 0 | 2 | 1000 |
| 1000, 3 | **80** | 1 | 1000 | | 0 | 1,2 | 1000, 1000 |
| 1000, 4 | **81** | 3 | 1000 | | 0 | 3 | 1000 |
| 1000, 4 | **82** | 3 | 1000 | | 0 | 3 | 1000 |
| 1000, 4 | **83** | 2 | 1000 | | 0 | 2, 3 | 1000, 1000 |
| 1000, 4 | **84** | 1 | 1000 | | 0 | 1,2,3 | 1000, 1000, 1000 |
| 1000, 4 | **85** | 4 | 1000 | | 0 | | 0 |
| 1000, 4 | **86** | | 0 | 1 | 1000 | 1, 2, 3 | 1000, 1000, 1000 |
| 1000, 4 | **87** | | 0 | 3 | 1000 | 3 | 1000 |
| 1000, 4 | **88** | | 0 | 2 | 1000 | 2, 3 | 1000, 1000 |
| 1300, 5 | **89** | 5 | 1300 | | 0 | | 0 |
| 1300, 5 | **90** | | | 2 | 1300 | 2, 3, 4 | 1300, 1300, 1300 |
| 1300, 5 | **91** | 2 | 1300 | | 0 | 2, 3, 4 | 1300, 1300, 1300 |
| 1300, 5 | **92** | 2 | 1300 | | 0 | 2, 3, 4 | 1300, 1300, 1300 |
| 1300, 5 | **93** | 2, 5 | 288, 1010 | 5 | 2 | 2, 3, 5 | 288, 288, 288 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1300, 5 | **94** | 3 | 1300 | | 0 | 3,4 | 1300, 1300 |
| 1300, 5 | **95** | | 0 | 3 | 1300 | 3,4 | 1300, 1300 |
| 1300, 5 | **96** | | 0 | 5 | 1300 | | 0 |
| 1300, 6 | **97** | | 0 | 4 | 1300 | 4, 5 | 1300, 1300 |
| 1300, 6 | **98** | | 0 | 4 | 1300 | 4, 5 | 1300, 1300 |
| 1300, 6 | **99** | 5 | 1000 | | 0 | | |
| 1300, 6 | **100** | 5 | 1000 | | 0 | | |
| 1300, 6 | **101** | 5 | 1000 | | 0 | | |
| 1300, 6 | **102** | 5 | 1000 | | 0 | | |
| 1300, 6 | **103** | 5 | 1000 | | 0 | | |
| 1300, 6 | **104** | | 0 | 2 | 1000 | 2,3…5 | 1000 |
| 900, 7 | **105** | | 0 | 6 | 900 | 6 | 900 |
| 900, 7 | **106** | | 0 | 7 | 900 | | 0 |
| 900, 7 | **107** | | 0 | 7 | 900 | | 0 |
| 900, 7 | **108** | 3, 7 | 783, 117 | | 0 | 3,4…6 | 783 |
| 900, 7 | **109** | 7 | 900 | | 0 | | 0 |
| 900, 7 | **110** | | 0 | 7 | 900 | | 0 |
| 900, 7 | **111** | | 0 | 7 | 900 | | 0 |
| 900, 7 | **112** | 6 | 900 | | 0 | 6 | 900 |
| 2000, 12 | **113** | 11 | 2019 | | 0 | 11, 12 | 2019, 19 |
| 2000, 11 | **114** | 10 | 2000 | | 0 | 10 | 2000 |
| 2000, 10 | **115** | 10 | 2000 | | 0 | | 0 |
| 2000, 11 | **116** | 9 | 2000 | | 0 | 9, 10 | 2000, 2000 |
| 2000, 12 | **117** | 12 | 163 | 11 | 1837 | 11 | 1837 |
| 2000, 11 | **118** | 9 | 2000 | | 0 | 9, 10 | 2000, 2000 |
| 2000, 12 | **119** | 12 | 308 | 11 | 1692 | 11 | 1692 |
| 2000, 11 | **120** | | 0 | 11 | 2000 | | 0 |
| 1500,9 | **121** | | 0 | 8 | 1500 | 8 | 1500 |
| 1500,9 | **122** | | 0 | 9 | 1500 | | 0 |
| 1500,9 | **123** | | 0 | 9 | 1500 | | 0 |
| 1500,9 | **124** | | 0 | 9 | 1500 | | 0 |
| 1500,9 | **125** | 9 | 1500 | | 0 | | 0 |
| 1500,9 | **126** | 9 | 1500 | | 0 | | 0 |
| 1500,9 | **127** | 9 | 1500 | | 0 | | 0 |
| 1500,9 | **128** | | 0 | 8 | 1500 | 8 | 1500 |

# Appendix C: Fabric inventory and quantity purchased for the 32 – 64 MTO – MTS

**Table C1: fabric inventory for 32-64 MTO - MTS**

| $IF_{ft}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| 287599 | 244456 | 233956 | 160471 | 145381 | 103849 | 100762 | 43306 | 22960 | 24250 | 250 | 250 |
| 1151 | 39494 | 24544 | 21029 | 1369 | 17849 | 1686 | 0 | 0 | 0 | 0 | 0 |
| 17600 | 11600 | 4400 | 4400 | 0 | 2 | 2 | 5898 | 0 | 0 | 0 | 0 |
| 43150 | 37200 | 24350 | 23350 | 22250 | 19050 | 19050 | 18796 | 18540 | 2000 | 0 | |

**Table C2: Fabric purchased at price level k=1**

| $FQ_{f1t}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 30 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | | | |
| 0 | 0 | 0 | 0 | 0 | 2 | 0 | 100 | 100 | 0 | 0 | 0 |
| 0 | 0 | 0 | 0 | 0 | 100 | 0 | 0 | 0 | 0 | 0 | 100 |

**Table C3: Fabric purchased at price level k=2**

| $FQ_{f2t}$ | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** |
| 296956 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1260 | 0 | 0 |
| 65636 | 57720 | 18152 | 5485 | 35945 | 52033 | 65575 | 0 | 0 | 0 | 0 | 0 |
| 20000 | 0 | 0 | 0 | 0 | 0 | 0 | 6122 | 2 | 0 | 0 | 8000 |
| 46450 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 100 |