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Optimizing Production and Inventory Decisions for Mixed Make-to-order/Make-to-stock Ready-made Garment Industry

INVENTORY MANAGEMENT COURSE

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ABSTRACT

In this study, we use the MILP model to plan production in the garment industry. The scope of research and application model on this topic has been based on a case study in Egypt, and we will re-apply this analytical model to our own data to find out the influence between the factors and make an optimal production decision.

This model considers capacity decisions and financial planning for mixed manufacturing environments of make-to-order (MTO) and make-in-stock (MTS) to cope with changes in demand but can be predicted.

We will provide research results on the application of the MILP model in the analysis of MTS and MTO production. It clearly shows that production decisions are strongly influenced by cash availability and that this research model is quite sensitive to increases in fabric costs and inventory cost while overall net profit is not affected significantly by changes in inventory holding costs. Besides, the study using this MILP model again will help garment factories make reasonable decisions according to their production capacity and can adapt to changes. Seasonal demand can be predicted by making production and inventory decisions for MTO and MTS.

Keywords: MILP model, Make to order, make to stock, production planning, ready-made garment industry.

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CHAPTER 1 INTRODUCTION

1.1 System Description

Among the industries in the world, the RGM ready-made garment industry is one of the quite competitive industries [1], because of its specificity, it is ready-made garments. Coming up with the optimal plan for this knitting industry is a very challenging task, especially with MTO/MTS needs. In addition, the seasonality of demand in the garment industry is often short-lived, the production plan must immediately respond to the demand for production decisions. And respond to the rapid changes of the fashion market, of the time trend in the world. As a result, horizontal plans are often quite short, seasonal. Therefore, planning decisions such as production time, production quantity to meet demand must be made very carefully because it directly affects the cost and revenue of the factory.

In which, the price of raw materials, specifically fabric, is the most important factor that affects production costs and cash flow for production operations, especially make-to-order products. This issue was caused by some garment factories in Egypt experiencing due to a recent currency floatation. Some factories are troubled with financial turmoil due to payment delays and recurring operating cost pressures. The main challenge is the management of MTS and short-term production planning for MTS with limited resources and finance.

In the world, there are a number of research papers on production planning for the garment industry, but mainly for the MTS production system. The decision that poses problems for the MTO production system will be different from the MTS production system. For MTOs, the most important thing is to meet the demand on the day of delivery although quantities and times may be subject to change. Therefore, it requires a detailed production plan that can control the inflow and outflow production.

The order of this research is in the following sequences. The methodology of this research is reviewed in Section II. Furthermore, Section III shows a final process that wraps up and provides an experimental result of this research. Lastly, Section IV presents a conclusion and recommendation.

1.2 Problem Statement

A company in the textile industry that only manufactures MTO products has a serious financial deficit due to the impact of the rising price of fabric material. This leads us to plan for the MTO and MTS category of textiles and to monitor the factory's available cash flow throughout the planning process to make optimal decisions. The goal is to enable the plant management team to make realistic decisions based on cost versus projected revenue for orders (MTO) and production planning (MTS) for a given season.

1.3 Scope and Limitations

The MILP model developed in this research has the goal of maximizing achieved net profits by eliminating prospective cost elements from sales revenues. The importance of this research is coming from the engaging financial aspects, such as the cash flow, with the production planning of a hybrid MTO-MTS manufacturing system. Separating finances from production planning is no longer a viable option for a company to stay afloat.

We will discuss research on the use of MILP for analyzing MTS and MTO production models to help the management of garment factories to make rational decisions according to their production capacity and be able to adapt to predictable seasonal demand changes by how to make production decisions and inventory decisions for 2 types of goods MTO and MTS. This model also demonstrates that cash availability has a significant impact on production decisions, and this research model is sensitive to changes in fabric costs and sub-bids while total net profit is unaffected. Changes in inventory holding costs have a substantial impact.

CHAPTER 2 BACKGROUND AND LITERATURE REVIEW

2.1 Background

The ready-made garment is always hard to manage with its pattern changes constantly over time. Firms must learn how to come up with short term plans that could secure their profit but also satisfy customers' needs. Both types of products provide significant benefits to the business. Planning for mixed MTS/MTO demand types, on the other hand, might be challenging for the majority.

On-the-spot payment is not always guaranteed with made-to-order manufacture. Therefore, most organizations tend to focus on their make-to-stock product. This is fairly apparent in previous studies. In the literature, research in the field of production planning for either MTO or MTS production systems is addressed more frequently than that for both modes of demand within the same system. There are just a few publications that consider them all together, but they all emphasis on the textile sector.

2.2 Literature review

Several research papers on production planning in the garment industry have been published. This serves as a starting point for the field. Guo, et.al (2006) constructed a job shop scheduling (JSS) model for a mixed- and multi-product assembly apparel environment. The goal of their design is to reduce the overall cost of earliness and tardiness by determining when to begin production on each order and how to assign operations to machines. A genetic algorithm (GA) was used to solve the proposed model. Mok, et al. (2013) also implemented GA in combination with group technology to get automated work assignments, ensuring efficient resource usage and job completion.

Ohta, Hirota, and Rahim (2007) looked at a multi-production inventory policy comparison between MTO and MTS. The study used a queuing model, with the optimality condition determined by which products are made-to-order and which are in stock. They calculated the optimal level of base stock. The investigation of how planners should approach the combination MTO-MTS issue in the real world would put the finishing touches on this study.

Kaminsky and Kaya (2009) offered advice on when to utilize made-to-order and made-to-stock procedures in centralized and decentralized supply chains. They evaluated the advantages of employing each operation in different situations and how to run the whole system to keep expenses low. This is one of the first articles that analyze inventory decisions, scheduling, and lead time quotation in the context of a supply chain, as well as the influence of the supplier–manufacturer relationship on these systems. However, these were simplified models, and real-world systems have far more complicated attributes than these models can describe.

Beemsterboer, Land, and Teunter (2016) built a Markov Decision Process model to examine the benefits of hybrid planning techniques for both MTO and MTS. The system decides when MTO and MTS items should be manufactured, taking into account positive lead times for MTO products. The development of heuristic planning approaches for hybrid production systems in more complicated contexts, such as working station or machine configurations, was lacking in the study.

In 2011, Gunalay selected which scheduling policy to follow for MTO versus MTS items in a single facility. The overall cost, inventory holding, and order delay costs were evaluated between two distinct server scheduling policies, first in first out and cyclic service. There is no dominating approach for either production policy or product scheduling policy, according to the analytical and numerical examination.

Rafiei, Rabbani, and Kokabi, (2014), presented a mixed-integer program for a multi-site production firm's production planning. Their intention was to maximize the manufacturer's profit. It would be interesting to look at the scheduling issue, which is linked to the issue in their study.

A strong methodology has been given by Wong, et.al (2014) for optimizing medium-range production planning in a combined MTS–MTO business context. The given model included suppliers, processes, and consumers to assess their inconsistencies and to justify the suggested model by applying it to an industrial case. Their article concentrates on cost-related uncertainty rather than all potential future concerns. Adopting non-financial uncertainty into the model, such as manufacturing lead time or raw material supply lead time, would improve its use for academics and practitioners.

Under the hybrid strategy of MTO/MTS, Zhang et.al, 2015 provided a nonlinear integer programming model that co-optimizes multi-level inventory matching and order planning for steel plants. Their research also delivered an enhanced Particle Swarm Optimization (PSO) approach that can overcome the problem of local optimal limitation.

Rabbani et.al (2008) described a hybrid strategy to decide which items will be made-to-order and which will be kept in stock, based on a strategic technique of strengths and weaknesses, opportunities and threats (SWOT) analysis, and a fuzzy analytical hierarchy process (FAHP). Combining the two methodologies yielded quantifiable values for the SWOT criteria, resulting in an order partitioning choice. However, crucial restrictions such as the firm's capacity and time limit were not considered in the article.

The model suggested in this study is a MILP model with the goal of optimizing net profits by deducting possible cost factors from sales revenues.

The relevance of including financial variables, such as cash flow, into the production planning of a hybrid MTO-MTS manufacturing system underpins this research. Separating financing from production planning is no longer a viable option for sustaining a corporation.

CHAPTER 3 METHODOLOGY

3.1 Problem descriptions

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. Also, once fabric is ordered, the factory must provide enough cash to pay for it.

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.

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 Mathematical model formulation

3.2.1 Model assumption

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 products 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.

3.2.2 Model formulation

3.2.2.1 Index sets

Set	Index
T: set of time periods t	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
K: set of level fabrics	k

3.2.2.2 Input parameters

α^S_{fj}	Amount of fabric *f* used to make one unit of MTS product j	***m^2.fabric***
h^O_m	labor hours required to process one unit of MTO product m	***hrs/unit***
h^S_j	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 k1,2, 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	

3.2.2.3 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***

R^O	Regular time production quantity of MTO product *m* during period *t*	***unit***
R^S	Regular time production quantity of MTS product *j* during period *t*	***unit***
O^O	overtime production quantity of MTO product *m* during period *t*	***unit***
O^S	overtime production quantity of MTS product *j* during period *t*	***unit***
b_{ft}	Binary integer variables, b_{ft} *1* if fabric *f* is purchased for price level *k2,* in time period *t* and 0 for otherwise	
S_{mt}	Subcontracting amount of product *m* at time period *t*	***units***
ζ^O_{mt}	Binary integer variables, ζ^O *1;* if MTO product *m* is produced during period ***t,*** ζ^O *0 otherwise.*	
ζ^S	Binary integer variables, ζ^S *1;* if MTS product *j* is produced during period ***t,*** ζ^S *0 otherwise.*	

3.2.2.4 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.

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

$$
\begin{aligned}
Max.\ P = & \sum_{m\in M}\sum_{t\in T} p_m^O\, D_{mt} + \sum_{j\in J}\sum_{t\in T} p_j^S\, F_{jt} - \sum_{m\in M} R_m^{CO} \sum_{t\in T} R_{it}^O \\
& - \sum_{m\in M} O_m^{CO} \sum_{t\in T} O_{mt}^O - \sum_{j\in J} R_j^{CS} \sum_{t\in T} R_{jt}^S - \sum_{j\in J} O_j^{CS} \sum_{t\in T} O_{jt}^S \\
& - \sum_{t\in T}\sum_{f\in F} r_{fk}\, FQ_{fkt} - \sum_{m\in M}\sum_{t\in T} I_{mt}^{CO}\ I_{mt}^O - \sum_{j\in J}\sum_{t\in T} I_{jt}^{CS}\ I_{jt}^S \\
& - \sum_{t\in T}\sum_{f\in F} I_{ft}^{CF}\, IF_{ft} - \sum_{t\in T}\sum_{m\in M} Sb_{mt}^C\, S_{mt}
\end{aligned} \qquad (1)
$$

3.2.2.5 The constraints

$$IF_{ft=0} = IF_{in} \qquad \forall t \qquad (2)$$

$$
\begin{aligned}
& IF_{ft-1} + FQ_{fkt} - \textstyle\sum_{i\in I} \alpha_{fi}^O \left(R_{it}^O + O_{it}^O\right) \\
& - \sum_{j\in J} \alpha_{fj}^S \left(R_{jt}^S + O_{jt}^S\right) = IF_{ft}
\end{aligned} \qquad \forall f, \forall t \qquad (3)
$$

$$I_{jt=0}^S = I_{in}^S \qquad \forall t \qquad (4)$$

$$\left(R_{jt}^S + O_{jt}^S\right) + I_{jt-1}^S - I_{jt}^S = F_{jt} \qquad \forall j \in J, \forall t \qquad (5)$$

$$I_{mt-1} + R_{mt}^O + O_{mt}^O + S_{mt} = D_{mt} + I_{mt} \qquad \forall m\in M, \forall t \qquad (6)$$

$$\sum_{m\in M} h_m^O\, R_{mt}^O + \sum_{j\in J} h_j^S\ R_{jt}^S \le H_{max} \qquad \forall t \qquad (7)$$

$$\sum_{m\in M} h_m^O\, O_{mt}^O + \sum_{j\in J} h_j^S\ O_{jt}^S \le G_{max} \qquad \forall t \qquad (8)$$

$$\sum_{f\in F} w_f IF_{ft} \le W_{max} \qquad \forall t \qquad (9)$$

$$\sum_{m\in M} v_m^O\, I_{mt}^O + \sum_{j\in J} v_j^S\ I_{jt}^S \le V_{\max} \qquad \forall t \qquad (10)$$

$$FQ_{f1t} \le q_f\, b_{ft} \qquad \forall f, \forall t \qquad (11)$$

$$q_f(1-b_{ft}) \leq FQ_{f2t} \qquad \forall f, \forall t \qquad (12)$$

$$CH_t = C_0 \qquad \forall t = 1 \qquad (13)$$

$$CH_{t-1} + \sum_{m \epsilon M} p_m^o D_{mt} - \sum_{f \epsilon F} r_{fk} FQ_{fkt} - \sum_{m \epsilon M} (R_m^{CO} R_{mt}^O + O_m^{CO} O_{mt}^O) - \sum_{j \epsilon J} (R_j^{CS} R_{jt}^S + O_j^{CS} O_{jt}^S) - \sum_{m \epsilon M} Sb_{mt}^C S_{mt} = CH_t \qquad \forall t \in \{1,2,3,4\} \qquad (14)$$

$$CH_{t-1} + \sum_{m \epsilon M} p_m^o D_{mt} + \sum_{j \epsilon J} p_j^S F_{jt} - \sum_{f \epsilon F} r_{fk} FQ_{fkt} - \sum_{m \epsilon M} (R_m^{CO} R_{mt}^O + O_m^{CO} O_{mt}^O) - \sum_{j \epsilon J} (R_j^{CS} R_{jt}^S + O_j^{CS} O_{jt}^S) + \sum_{m \epsilon M} Sb_{mt}^C S_{mt} = CH_t \qquad \forall t \in \{5,6 \ldots 12\} \qquad (15)$$

$$CH_t \geq C^T \qquad t = 12 \qquad (16)$$

$$R_{mt}^O + O_{mt}^O \geq B_m^O \zeta_{it}^O \qquad \forall m, \forall t \qquad (17)$$

$$\zeta_{it}^O \geq \frac{1}{L} \sum_{m \in M} (R_{mt}^o + O_{mt}^o) \qquad \forall m, \forall t \qquad (18)$$

$$R_{jt}^S + O_{jt}^S \geq B_j^S \zeta_{jt}^S \qquad \forall j, \forall t \qquad (19)$$

$$\zeta_{jt}^S \geq \frac{1}{L} \sum_{j \in J} (R_{jt}^S + O_{jt}^S) \qquad \forall j, \forall t \qquad (20)$$

$$FQ_{fkt}, IF_{ft}, CH_t, I_{mt}^O, I_{jt}^S, R_{mt}^O, R_{jt}^S, O_{mt}^O, O \geq 0 \qquad (21)$$

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 $k2$ 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

3.3 Model in Cplex

We implement the model in Cplex and Runs the model with random generate. Before developing the formulation, we will first present the notation in Cplex:

k: the numberlevel pricing fabric
nmts: the number of type of MTS
nmto: the number of type of MTO
tf : the number of type of fabric
np: number period
rmts: range MTS
rmto: range MTO
rf: range type of fabric
rp: range period
rk: range level pricing fabric
ICF[rf][rp]: holding cost fabric taken from excel
ICO[rmto][rp]: holding cost MTO taken from excel
ICS[rmts][rp]: holding cost MTS taken from excel
IFA[rf]: inventory of each type of fabric at period 0
IS[rmts]: inventory of each type of MTS products at period 0
RCO[rmto]: regular time production cost per unit of each m MT0 products
RCS[rmts]: regular time production cost per unit of each j MTS products
OCO[rmto]: overtime production cost per unit of m product MTO
OCS[rmts]: overtime production cost per unit of j produce MTS

SBC[rmto][rp]: subcontracting cost for each m MTO product at each period
AFO[rf][rmto]:amount of fabric f to make one unit of MTO product m
AFS[rf][rmts]: amount of fabric f to make one unit of MTS product j
HO[rmto]: labor hour needed to process one unit of product m of MTO
HS[rmts]: labor hour needed to process one unit of product j of MTS
HMAX: maximum available regular production hours per period
GMAX: maximum available overtime production hour per period
WF[rf]: warehouse space needed per meter of each fabric f
WFMAX: maximum fabric warehouse capacity (m2)
VO[rmto]: storage space requirement per unit of finished MTO product m
VS[rmts]: storage space requirement per unit of finished MTS product j
VMAX50: maximum storage space for MTO and MTS
DM[rmto][rp]: demand based on confirmed orders MTO
FJ[rmts][rp]: forecasted demand MTS
PO[rmto]: selling price of one unit of MTO product m
PS[rmts]: selling price of one unit of MTS product j
RF[rf][rk]: purchase price r of fabric f at level k
QF[rf]: minimum of meters fabric to get discount (m2)
BO[rmto]:minimum batch size for production of MTO product m
BS[rmts]:minimum batch size for production of MTS product j
CO:initial cash available at the beginning of the planning horizon
CT: minimum final cash targeted at the end of the planning horizon
L : a large positive number
FQ[rf][rk][rp]: Area of fabric f ordered at price level k during period t (m2)
IA[rf][rp]: Area of fabric f kept in inventory by the end of period t (m2).
CH[rp]: Cash available by the end of period t
ILO[rmto][rp]: WIP Inventory level of MTO product m by the end of period t
ILS[rmts][rp]: WIP Inventory level of MTS product j by the end of period t
RO[rmto][rp]: Regular time production quantity of MTO product m during period t
RS[rmts][rp]: Regular time production quantity of MTS product j during period t
OP[rmto][rp]: overtime production quantity of MTO product m during period t
SP[rmts][rp]: overtime production quantity of MTS product j during period t
S[rmto][rp]: Subcontracting amount of product m at time period t
B[rf][rp]: if fabric f is purchase for price level k = 2, in time period t and = 0 otherwise.
F[rmto][rp]: =1 if MTO product m is produced during period t, and = 0 otherwise
F1[rmts][rp]: =1 if MTS product j is produced during period t, and = 0 otherwise
Next, we define constraints in Cplex:

```
c1 :forall (f in rf, t in rp: t == 0){ IA[f][t] == IFA[f];}
c2 :forall(f in rf, k in rk, t in rp){IA[f][0] + FQ[f][k][0] - sum(i in rmto)AFO[f][i]*(RO[i][0] + b
OP[i][0]) - sum(j in rmts)AFS[f][j] *(RS[j][0]+ SP[j][0]) == IA[f][0];
  if(t>0) IA[f][t-1] + FQ[f][k][t]
  - sum(i in rmto)AFO[f][i]*(RO[i][t] + OP[i][t])
  - sum(j in rmts)AFS[f][j] *(RS[j][t]+ SP[j][t]) == IA[f][t];}
c3 :forall (j in rmts, t in rp: t == 0){ILS[j][t] == IS[j];}
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c4 :forall(j in rmts, t in rp ){(RS[j][0] + SP[j][0]) - ILS[j][0] == FJ[j][0];
    if (t > 0  )(RS[j][t] + SP[j][t]) + ILS[j][t-1] - ILS[j][t] <= FJ[j][t];}
c5 :forall(m in rmto, t in rp){ ILO[m][0] + RO[m][0] + OP[m][0] + S[m][0] == DM[m][0] + ILO[m][0];
    if (t>0) ILO[m][t - 1] + RO[m][t] + OP[m][t] + S[m][t] == DM[m][t] + ILO[m][t];}
c6 :forall(t in rp){sum(m in rmto) HO[m]*RO[m][t] + sum(j in rmts) HS[j]*RS[j][t] <= HMAX;}
c7 :forall(t in rp){sum(m in rmto) HO[m]*OP[m][t] + sum(j in rmts) HS[j]*SP[j][t] <= GMAX;}
c8 :forall(t in rp: t>=1 &&t<=12){sum(f in rf) WF[f]*IA[f][t] <= WFMAX;}
c9 :forall(t in rp: t>=1 &&t<=12){sum(m in rmto) VO[m]*ILO[m][t] + sum(j in rmts) VS[j]* ILS[j][t] <=
VMAX;}
c10 :forall(f in rf, k in rk, t in rp: k == 1){FQ[f][k][t] <= QF[f]*B[f][t];}
c11 :forall(f in rf, k in rk, t in rp: k == 2 ){QF[f]*(1 - B[f][t]) <= FQ[f][k][t];}
c12 :forall(t in rp:t == 0){CH[t] == CO;}
c13 :forall(f in rf, k in rk, t in rp: t<=4 && t>=1){CH[t-1] + sum(m in rmto) PO[m] * DM[m][t] - sum(f in
rf) RF[f][k]*FQ[f][k][t]- sum(m in rmto)(RCO[m]*RO[m][t] + OCO[m]*OP[m][t])- sum(j in
rmts)(RCS[j]*RS[j][t] + OCS[j]*SP[j][t])- sum(m in rmto) SBC[m][t]*S[m][t] == CH[t];}
c14 :forall(f in rf, k in rk, t in rp: t >=5 && t<=12){CH[t-1] + sum(m in rmto) PO[m] * DM[m][t] + sum(j
in rmts) PS[j] * FJ[j][t] - sum(f in rf) RF[f][k]*FQ[f][k][t]- sum(m in rmto)(RCO[m]*RO[m][t] +
OCO[m]*OP[m][t])- sum(j in rmts)(RCS[j]*RS[j][t] + OCS[j]*SP[j][t])+ sum(m in rmto) SBC[m][t]*S[m][t]
== CH[t];}
c15 :forall(t in rp: t==12){         CH[t] >= CT;}
c16 :forall(m in rmto, t in rp){RO[m][t] + OP[m][t] >= BO[m]*F[m][t];}
c17 : forall(m in rmto, t in rp){F[m][t]  >= 1/L * sum(m in rmto)(RO[m][t] + OP[m][t]);}
c18 :forall(j in rmts, t in rp){RS[j][t] + SP[j][t] >= BS[j]*F1[j][t];}
c19 :forall(j in rmts, t in rp){F1[j][t] >= 1/L * sum(j in rmts)(RS[j][t] + SP[j][t]);}
forall(f in rf, k in rk, t in rp: 1 <= t <= 12)
    FQ[f][k][t] >= 0;
forall(f in rf, t in rp:  1 <= t <= 12)
    IA[f][t] >= 0;
forall(t in rp:  1 <= t <= 12)
    CH[t] >= 0;
forall(m in rmto, t in rp:  1 <= t <= 12)
    ILO[m][t] >= 0;
forall(j in rmts, t in rp:  t == 0)
    ILS[j][t] ==0;
forall(j in rmts, t in rp:  1 <= t <= 12)
    ILS[j][t] >= 0;
forall(m in rmto, t in rp:  1 <= t <= 12)
    RO[m][t] >= 0;
forall(j in rmts, t in rp:  1 <= t <= 12)
    RS[j][t] >=0;
forall(m in rmto, t in rp:  1 <= t <= 12)
    OP[m][t] >=0;
forall(j in rmts, t in rp:  1 <= t <= 12)
    SP[j][t] >=0
```

CHAPTER 4 RESULTS

4.1 Data Collection

The production capacity data obtained from the factory were as shown in table 1 for the regular, overtime and storage capacities. The regular hours are 48 hours per week and the over-time hours are 10 hours per week.

Table 1: Production capacity data for the base case

Capacities available per period	
Regular Capacity H_{max}	260 hrs
Overtime Capacity G_{max}	160 hrs
Storage capacity for Final products V_{max}	50 m^2
Storage capacity for fabrics W_{max}	40 m^2

In all the computational runs, a period is one week, and there are five 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 2 Followed by MTO and MTS input data in tables 8, 9, 10 and 11.

Table 2: Fabrics input parameters

Fabric input parameters	Fabric 1	Fabric 2	Fabric 3	Fabric 4	Fabric 5
$r_{fk=1}$	4	4	6	4	3
$r_{fk=2}$	5	6	7	6	5
w_f	0.004	0.004	0.004	0.004	0.004
q_f	30	40	100	100	50

Table 3: Inventory holding cost of fabric f during period t (EGP/m2/week)

	0	1	2	3	4	5	6	7	8	9	10	11	12
1	2.5	3	2.7	1.9	1.5	2.6	3	1.8	2.9	2.9	1.8	3	2.6
2	2	2.2	2.6	3	2.6	1.5	2.7	1.9	2.3	2.2	2.6	2.2	1.5
3	2	2.1	2.1	2.3	2.4	1.9	2.6	2.5	1.9	1.8	3	2.5	1.5
4	1.5	2.3	2.2	1.6	2.1	2.9	2.8	2.4	1.6	2.3	1.8	1.7	2
5	2.8	2.9	2.5	2.8	3	2.7	2.9	1.5	1.6	2.8	2.6	2.1	1.6

Table 4: Amount of fabric f used to make one unit of MTO product m (m2)

fabric f/	1	2	3	4	5	6	7	8	9	10
1	0.5	0.5	0.4	0.5	0.6	0.4	0.5	0.6	0.7	0.4
2	0.7	0.7	0.7	0.7	0.6	0.7	0.6	0.6	0.6	0.7
3	0.69	0.64	0.6	0.68	0.6	0.6	0.6	0.66	0.61	0.62
4	0.7	0.78	0.74	0.73	0.71	0.73	0.71	0.71	0.72	0.78
5	0.8	0.8	0.71	0.77	0.73	0.73	0.8	0.8	0.78	0.79

Table 5: Amount of fabric f used to make one unit of MTS product j (m2).

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	0.7	0.7	0.5	0.7	0.7	0.7	0.6	0.6	0.6	0.5	0.7	0.6	0.5	0.7	0.5
2	0.7	0.6	0.6	0.7	0.6	0.7	0.7	0.7	0.7	0.6	0.7	0.6	0.7	0.7	0.7
3	0.6	0.69	0.65	0.62	0.6	0.62	0.61	0.63	0.63	0.6	0.65	0.66	0.61	0.64	0.65
4	0.78	0.72	0.79	0.75	0.77	0.76	0.8	0.7	0.76	0.8	0.8	0.79	0.71	0.78	0.8
5	0.74	0.76	0.7	0.73	0.77	0.78	0.72	0.75	0.75	0.8	0.74	0.71	0.73	0.77	0.72

Table 6: Initial inventory values and initial cash value

Initial fabric inventory	Initial MTO/MTS inventory	C_0 (EGP)
0	0	200000

Table 7: Inventory holding cost per unit of MTO product m during period t (EGP/unit/week).

	0	1	2	3	4	5	6	7	8	9	10	11	12
1	3.20	3.40	3.30	3.50	3.50	3.80	3.00	3.00	3.00	3.10	3.90	3.50	3.30
2	3.80	3.90	3.10	3.80	3.60	3.10	3.50	3.40	3.00	3.60	3.00	3.60	4.00
3	3.70	3.20	3.80	3.70	3.70	3.00	3.20	4.00	3.60	3.40	3.20	3.10	3.40
4	3.50	3.30	3.40	3.80	3.90	3.30	4.00	3.80	3.00	3.50	3.30	3.20	3.50
5	3.50	3.70	3.50	3.60	3.20	3.60	3.80	3.80	3.80	3.30	4.00	3.60	3.40
6	4.00	3.00	4.00	3.20	3.30	3.10	3.50	3.20	3.50	3.30	3.90	4.00	3.90
7	3.30	3.40	3.50	3.10	4.00	3.10	4.00	3.00	3.50	3.40	3.00	3.60	3.80
8	3.10	3.70	3.70	3.40	3.30	4.00	3.90	3.40	3.00	3.60	3.30	4.00	3.80
9	4.00	3.10	3.60	3.90	4.00	3.10	3.50	3.20	3.90	3.70	3.50	3.30	3.40
10	3.90	3.10	3.60	4.00	3.40	3.60	3.90	3.30	4.00	3.40	3.50	3.70	3.70

Table 8: Labor hours required to process one unit of MTO product m (hr/unit).

MTO	1	2	3	4	5	6	7	8	9	10
Hours	0.067	0.067	0.050	0.083	0.067	0.067	0.050	0.067	0.067	0.050

Table 9: Labor hours required to process one unit of MTS product j (hr/unit).

MTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost	0.050	0.067	0.067	0.083	0.050	0.067	0.050	0.050	0.050	0.050	0.050	0.067	0.083	0.083	0.083

Table 10: Inventory holding cost per unit of MTS product during period t(EGP/unit/week).

	0	1	2	3	4	5	6	7	8	9	10	11	12
1	3.20	3.30	3.60	3.40	4.00	3.80	4.00	3.00	3.70	3.70	3.10	3.10	3.70
2	4.00	3.70	3.20	3.80	3.50	3.90	3.60	3.20	3.20	3.70	3.40	3.10	3.80
3	3.20	4.00	4.00	3.20	3.90	3.80	3.90	3.80	3.80	3.60	3.90	3.70	3.80
4	3.40	3.40	3.50	3.60	4.00	3.50	3.00	3.00	3.20	3.40	3.50	3.30	3.10
5	3.70	3.90	3.50	3.50	3.90	3.40	3.60	3.70	3.20	3.10	3.90	3.20	3.00
6	3.80	3.40	3.30	3.30	3.70	3.80	3.70	3.80	3.90	3.50	3.20	3.10	3.80
7	4.00	4.00	3.80	3.10	3.80	3.90	3.60	3.40	4.00	3.60	3.40	3.40	3.80
8	3.30	3.20	3.10	3.40	3.40	3.20	3.20	3.30	3.60	3.00	3.40	3.60	3.20
9	4.00	3.70	3.40	3.90	3.40	3.00	3.70	3.00	3.90	3.90	4.00	3.60	3.30
10	3.70	3.10	3.80	3.50	4.00	3.60	3.40	4.00	3.70	3.70	3.30	4.00	3.10
11	3.40	4.00	3.60	3.50	3.30	3.00	3.90	3.70	3.30	3.90	3.60	3.10	3.10
12	3.00	3.10	3.70	4.00	3.10	3.40	3.40	4.00	3.40	4.00	3.40	3.90	3.90
13	3.70	3.80	4.00	3.30	3.60	3.60	3.20	3.60	3.10	3.30	3.30	3.70	3.40
14	3.40	3.90	3.20	3.90	3.50	3.80	3.90	3.50	3.90	3.20	3.30	3.50	3.60
15	3.10	3.50	3.90	3.80	3.60	3.60	4.00	3.50	3.20	3.20	3.90	4.00	4.00

Table 11: Regular time production cost per unit of MTO product m (EGP/unit)

MTO	1	2	3	4	5	6	7	8	9	10
Cost	1.4	1	5.1	4.2	4.4	4.8	4.2	3.1	4.3	2.2

Table 12: Regular time production cost per unit of MTS product j (EGP/unit)

MTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost	3.1	4.6	2.7	4.7	2.6	4.1	2.7	3.1	4.7	5	1.1	1	4.9	1.9	5.2

Table 13: Storage space requirements per unit of finished MTO product m (m2/unit)

MTO	1	2	3	4	5	6	7	8	9	10
Space	0.03	0.01	0.02	0.07	0.07	0.09	0.03	0.08	0.05	0.05

Table 14: Storage space requirements per unit of finished MTS product j (m2/unit)

MTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Space	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05

Table 15: Base case MTO demands

MTO/t	0	1	2	3	4	5	6	7	8	9	10	11	12
1	0	257	255	275	269	278	251	254	304	298	275	258	249
2	0	203	256	232	204	231	202	209	249	200	200	220	220
3	0	260	243	270	244	249	230	272	204	255	271	272	257
4	0	268	217	213	264	254	228	225	220	205	271	288	200
5	0	200	304	246	235	247	258	217	278	246	237	221	222
6	0	256	228	227	260	259	210	302	263	208	213	249	250
7	0	191	253	224	229	212	230	197	287	294	209	265	268
8	0	247	298	204	224	223	227	278	284	253	244	248	221
9	0	197	262	298	263	204	274	281	216	267	242	216	216
10	0	241	264	238	263	282	250	224	200	279	235	233	226

Table 16: MTS forecasted demands

MTS/t	0	1	2	3	4	5	6	7	8	9	10	11	12
1	0	201	191	184	174	211	218	207	193	194	194	196	176
2	0	214	202	209	184	170	187	169	177	198	171	212	189
3	0	201	174	199	215	181	167	180	215	193	206	195	177
4	0	220	211	218	214	191	168	174	197	189	219	186	186
5	0	195	182	182	225	190	170	206	185	196	190	214	213
6	0	191	194	172	174	204	175	205	191	203	225	222	193
7	0	198	187	194	191	200	221	189	174	196	169	176	192
8	0	210	189	217	181	215	206	195	187	211	187	186	205
9	0	181	169	197	168	186	177	202	172	197	201	211	181
10	0	179	189	180	197	192	212	184	205	183	198	190	178
11	0	170	185	198	195	216	177	171	171	199	188	194	178
12	0	184	203	207	186	200	187	209	194	186	195	182	188
13	0	207	199	179	200	190	170	182	221	220	168	208	178
14	0	206	188	190	178	191	219	179	208	173	190	218	205
15	0	216	214	183	198	209	197	190	207	194	185	188	177

Table 17: Over- time production cost per unit of MTO product m (EGP/unit)

MTO/t	1	2	3	4	5	6	7	8	9	10
Cost	8.7	5.1	15.6	4.2	11.4	4.2	9	7.8	8.4	11.7

Table 18: Over- time production cost per unit of MTS product j (EGP/unit)

MTS/t	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Cost	8.7	8.1	3.6	11.7	12.6	15.6	5.4	5.4	10.8	6	10.8	4.5	6.6	15.3	12

Table 19: Subcontracting cost for MTO product i during time period t (EGP/unit)

MTO/t	0	1	2	3	4	5	6	7	8	9	10	11	12
1	0	29	30	27	29	29	30	26	30	30	28	26	27
2	0	25	26	28	27	30	30	27	26	26	29	25	26
3	0	28	26	26	30	30	30	28	29	27	25	28	27
4	0	26	25	26	26	26	28	27	28	27	29	28	25
5	0	25	29	28	25	28	30	25	29	25	29	30	27
6	0	27	29	26	26	29	30	27	28	26	29	30	30
7	0	26	28	27	30	28	26	29	28	29	30	29	30
8	0	30	29	25	25	28	26	28	25	28	28	28	28
9	0	30	25	30	26	29	27	28	28	27	27	26	27
10	0	30	28	30	26	29	29	29	28	29	30	25	28

Table 20: Selling price of one unit of MTO product m (EGP/unit)

MTO	1	2	3	4	5	6	7	8	9	10
Price	54	55	60	54	57	51	59	50	52	53

Table 20: Selling price of one unit of MTS product j (EGP/unit)

MTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Price	40	37	45	37	40	36	45	39	45	41	39	42	45	43	36

Table 21: Minimum batch size for production of MTO product m

MTO	1	2	3	4	5	6	7	8	9	10
Batch size	200	180	130	180	210	160	170	200	280	120

Table 21: Minimum batch size for production of MTS product j

MTS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Batch size	130	120	140	170	180	140	100	170	130	160	120	120	140	120	120

4.2 The data results discussion

The input data distribution was based on historical demand patterns . The results for the base case are presented in table 22, 23, 24, with an optimal integer objective of the profit ***689,375 EGP.*** Where the model decisions to produce in regular, overtime /subcontract or hold in inventory were seized on costs only.

Table 22: Base case optimal results MTO

MTO	Variables	1	2	3	4	5	6	7	8	9	10	11	12
MTO1	RO_{1t}	183	168	199	179	193	159	164	155	168	193	184	180
	OO_{1t}	90	94	81	87	84	82	87	88	85	90	89	84
	IO_{1t}	10	0	10	0	3	6	1	3	8	6	5	0
	$S1t$	6	7	7	7	0	8	0	7	3	10	1	1
MTO2	RO_{1t}	115	122	152	131	116	141	163	169	149	106	140	154
	OO_{1t}	89	83	83	80	87	92	85	93	85	88	82	86
	IO_{1t}	0	2	5	10	0	0	0	0	0	9	3	0
	$S1t$	3	4	10	8	4	6	1	3	7	6	2	5
MTO3	RO_{1t}	118	112	108	152	136	124	149	112	146	139	151	165
	OO_{1t}	81	80	84	89	92	89	82	88	94	92	87	93
	IO_{1t}	3	5	4	4	5	0	0	0	10	6	6	0
	$S1t$	4	4	0	6	0	6	4	7	7	3	6	8
MTO4	RO_{1t}	187	142	100	151	179	116	138	119	107	100	152	183
	OO_{1t}	88	94	80	93	91	86	81	80	91	94	81	93
	IO_{1t}	2	7	10	8	1	10	6	4	2	10	1	0
	$S1t$	5	2	10	8	9	7	2	0	9	8	1	5
MTO5	RO_{1t}	188	200	119	132	191	154	171	177	111	172	129	149
	OO_{1t}	81	90	84	81	95	81	95	93	80	93	95	93
	IO_{1t}	8	8	3	3	7	1	0	5	1	10	4	0
	$S1t$	6	1	8	1	9	9	8	8	6	8	10	5

MTO5	RO_{1t}	188	200	119	132	191	154	171	177	111	172	129	149
	OO_{1t}	81	90	84	81	95	81	95	93	80	93	95	93
	IO_{1t}	8	8	3	3	7	1	0	5	1	10	4	0
	S_{1t}	6	1	8	1	9	9	8	8	6	8	10	5
MTO6	RO_{1t}	172	144	197	108	140	149	142	193	152	124	180	183
	OO_{1t}	93	86	87	94	85	82	84	87	90	87	90	88
	IO_{1t}	2	4	9	5	3	3	8	3	7	4	0	0
	S_{1t}	8	7	1	0	2	1	7	0	8	3	8	1
MTO7	RO_{1t}	132	154	171	130	111	180	159	189	108	148	194	134
	OO_{1t}	90	92	89	93	81	85	95	82	89	85	95	90
	IO_{1t}	0	0	0	0	5	10	7	7	2	1	6	0
	S_{1t}	3	4	0	10	2	8	8	3	7	7	9	5
MTO8	RO_{1t}	109	192	191	100	171	135	123	117	137	119	118	134
	OO_{1t}	83	93	80	91	81	85	80	87	81	88	88	89
	IO_{1t}	3	7	10	3	7	4	7	8	0	5	0	0
	S_{1t}	4	1	2	6	6	0	0	1	3	9	0	4
MTO9	RO_{1t}	143	177	122	146	146	155	166	101	126	175	143	144
	OO_{1t}	91	84	80	91	81	94	80	82	82	80	94	83
	IO_{1t}	0	2	2	1	0	0	0	0	0	0	2	0
	S_{1t}	5	2	7	1	2	1	0	2	10	7	7	1
MTO10	RO_{1t}	177	196	165	151	108	139	127	174	190	117	164	178
	OO_{1t}	81	86	82	90	81	91	81	82	84	90	82	85
	IO_{1t}	0	3	3	1	0	9	8	4	3	0	3	0
	S_{1t}	1	3	0	7	0	3	0	0	0	10	0	4

Table 23: Base case optimal results MTS

MTS	Variables	1	2	3	4	5	6	7	8	9	10	11	12
MTS1	RO_{1t}	112	103	115	137	134	144	128	100	107	120	121	146
	OO_{1t}	64	64	62	68	74	75	61	71	71	70	70	73
	IO_{1t}	9	0	0	0	0	0	8	0	0	7	1	0
MTS2	RO_{1t}	112	108	104	127	112	150	150	133	126	130	101	128
	OO_{1t}	63	72	74	63	74	70	67	74	64	71	74	60
	IO_{1t}	1	0	0	0	1	6	7	2	10	7	6	0
MTS3	RO_{1t}	114	104	116	122	131	118	140	119	116	147	125	104
	OO_{1t}	71	70	70	71	72	72	67	66	61	73	71	71
	IO_{1t}	5	5	3	0	8	7	9	0	8	0	5	0
MTS4	RO_{1t}	144	134	138	125	109	122	135	133	107	122	118	128
	OO_{1t}	75	75	60	72	70	66	71	73	61	75	67	75
	IO_{1t}	9	8	0	0	0	0	0	9	5	1	10	0
MTS5	RO_{1t}	135	148	147	122	121	140	106	145	100	113	130	142
	OO_{1t}	71	70	73	69	75	71	65	64	74	62	73	67
	IO_{1t}	5	2	9	8	0	0	0	9	4	7	4	0
MTS6	RO_{1t}	122	104	139	106	142	112	113	144	125	128	122	105
	OO_{1t}	67	65	72	73	70	73	65	60	67	62	73	69
	IO_{1t}	10	2	3	1	1	1	7	4	7	8	10	0
MTS7	RO_{1t}	106	138	138	139	133	118	100	129	137	104	137	100
	OO_{1t}	74	62	65	66	61	62	61	66	68	61	61	70
	IO_{1t}	7	0	9	3	6	4	4	3	0	9	6	0
MTS8	RO_{1t}	106	107	146	148	131	110	135	131	134	105	125	146
	OO_{1t}	74	64	70	68	63	69	75	72	66	68	70	62
	IO_{1t}	0	3	10	0	0	0	0	2	7	1	4	0

MTS9	RO_{1t}	126	103	136	140	105	134	103	117	125	144	123	115
	OO_{1t}	72	60	61	61	61	61	71	69	63	67	60	67
	IO_{1t}	8	0	0	0	0	0	5	7	10	5	5	0
MT10	RO_{1t}	102	123	123	125	104	133	146	149	144	142	114	115
	OO_{1t}	71	69	72	67	75	63	65	66	70	63	75	64
	IO_{1t}	1	5	1	0	0	0	0	10	0	0	0	0
MTS11	RO_{1t}	149	111	143	140	122	119	138	129	100	140	117	142
	OO_{1t}	69	64	71	61	68	69	73	72	66	64	68	74
	IO_{1t}	0	4	1	9	1	0	0	0	7	2	9	2
MTS12	RO_{1t}	130	147	136	125	111	142	120	141	128	120	140	127
	OO_{1t}	69	64	73	68	75	68	65	70	61	67	71	71
	IO_{1t}	3	0	0	0	2	4	7	3	6	9	8	0
MTS13	RO_{1t}	100	138	149	109	115	127	144	142	118	145	140	105
	OO_{1t}	61	67	68	69	70	62	75	63	72	65	68	74
	IO_{1t}	10	5	4	0	0	0	5	8	7	8	4	0
MTS14	RO_{1t}	148	149	136	105	106	143	104	134	150	122	117	121
	OO_{1t}	65	64	63	74	66	60	60	63	67	75	60	69
	IO_{1t}	7	0	9	0	0	0	0	0	0	2	4	0
MTS15	RO_{1t}	106	116	102	101	123	103	144	140	125	122	108	123
	OO_{1t}	73	75	73	74	61	74	64	63	66	63	66	61
	IO_{1t}	3	7	6	4	10	0	0	0	0	7	1	0

Results for amounts of fabric purchased per period and their inventory levels are indicated in tables 24 and 25.

Table 24: Base case fabric purchasing amounts

	FQf2t											
	Periods											
Fabric	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
F1	6261.6	6380.4	6346.8	6367.2	6300	6501.6	6075.6	6176.4	6240	6117.6	6290.4	6482.4
F2	7115.36	7307.3	7288.68	7349.02	7252.98	7412.72	6977.32	7105.7	7205.1	7121.38	7210	7463.96
F3	6666.46	6848.14	6831.33	6889.07	6798.45	6945.86	6539.51	6660.24	6754.25	6677.61	6757.14	6996.24
F4	7963.8	8167.77	8143.2	8203.65	8099.91	8291.92	7795.32	7936.37	8042.45	7938.19	8057.92	8335.34
F5	7758.66	7959.9	7936.83	7997.37	7895.43	8079.42	7597.77	7735.8	7840.35	7741.23	7853.1	8124.96

Table 25: Base case fabric inventory levels

	IFft											
	Periods											
Fabric	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
F1	3120	3078.6	3264.6	3246.6	3244.8	3156.6	3144	3109.8	3120.6	3060	3173.4	3052.8
F2	2868.32	2834.16	2984.968	2995.664	2964.472	2904.888	2858.632	2850.456	2872.968	2848.048	2951.144	2822.064
F3	2688.4	2656.508	2797.208	2808.108	2777.924	2722.768	2678.3	2671.384	2692.888	2670.52	2767.112	2645.544
F4	4005.3	3956.68	4172.025	4180.54	4143.945	4055.675	3999.255	3982.355	4010.825	3968.77	4113.005	3937.05
F5	3903.9	3856.725	4065.51	4075.305	4038.015	3953.16	3896.265	3881.07	3909.51	3870.21	4010.73	3838.23

Table 25: The cash flow for base case

Period	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Cash	243972	259915	254252	259367	242283	250642	246333	245208	257300	260967	248407	262626

The cash flow per period for the base case is indicated in figure 1

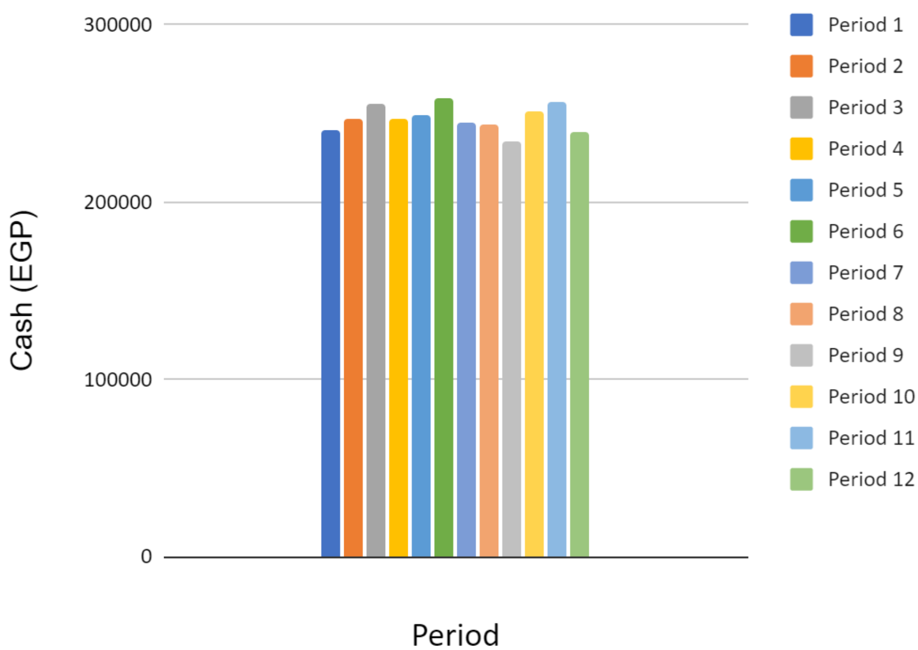

Figure 1: Cash flow for base case

4.3 Sensitivity Analysis

Changing influential parameters of the model are in charge of checking the reaction of the costs and revenues towards those changes. The parameters are tested that are subjected to changes or uncertainties: fabric price changeability and the inventory holding costs.

4.3.1 Impact of increasing fabric price on the profits.

Fabric price is one of the most important parameters of the system. Thus, changing these prices has considerable impacts on the revenues and inventory Table 26, for each percent increase in the fabric price, it shows revenues and inventory holding costs in reducing the process.

Table 26: Fabric price percentage increase vs. profits and fabric cost

Fabric price percent increase	Profits	Fabric cost
Base	689,375	1879822.07
10%	567,327	2001870.596
30%	203,261	2365936.352
40%	32,280	2536917.25
45%	-54,022	2623219.084

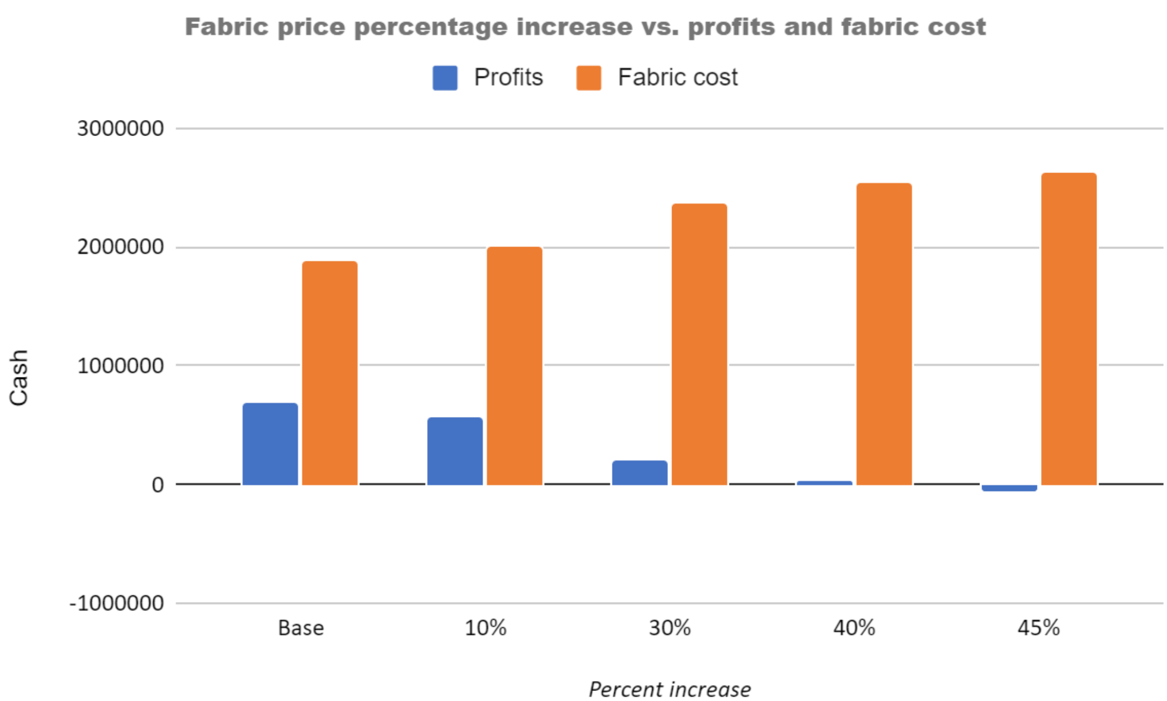

Figure 2: Fabric price percentage increase vs. revenues

Figure 2: Shows how profits were extremely sensitive to fabric price increases; a falling model is displayed in revenues for every percent rise, it will be impossible for the revenues to get a positive number as the fabric cost grew by around 45%. The increasing fabric cost was sensitive to the profits for using the large number of fabrics and their price

4.3.2 Impact of increasing the inventory holding cost on the revenues

Negative impacts of rising inventory holding costs for MTO, MTS, and textiles in Table 27. The MTS inventory cost has a much lower holding cost than the fabric, while the MTO inventory had the lowest one. This corresponds to the data regarding fabric quantities for MTO products. Both MTS and MTO products all require 3.5 meters of fabric for each type.

Table 27: 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	689375.1597	1621625	1418004	1424.5	1750	467257.2703
10%	655479.2938	1621625	1418004	1801.8	2006.15	500519.6862
20%	597280.33	1621625	1418004	2291.23	2297.23	557938.14
40%	494476.6922	1621625	1418004	2291.23	2297.23	660741.7778
60%	441099.377	1621625	1418004	2435.42	2345.12	713927.013

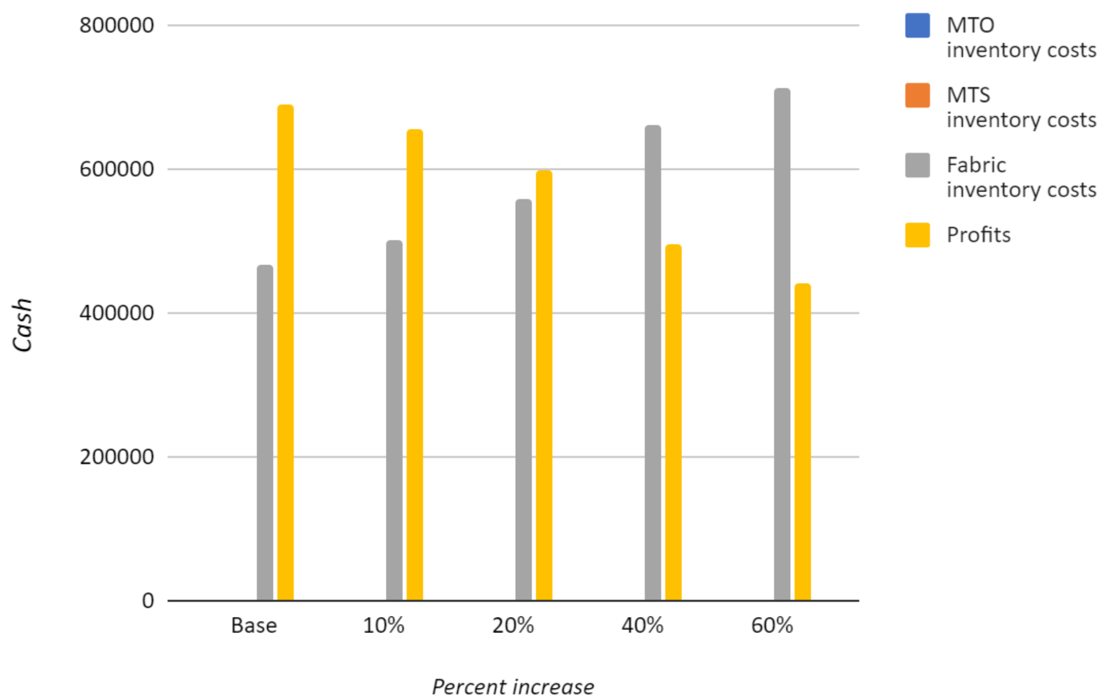

Figure 3: Profits and costs for inventory holding cost increase

As seen in table 27,, increasing the inventory holding cost by another 10% reduced earnings by another 5% - 6% percent. .As the cost of inventory keeping grew, the net profits did not really decline. Fabric inventory cost was sensitive to the rise in inventory holding costs due to the big number of them, but the MTS and MTO were not. This is because the MTS and MTO amount are produced in a row with a level of acceptable demand or would say pretty small against the capacity.

CHAPTER 5 CONCLUSION

5.1 Concluding remarks

For the readymade garment business, a MILP model for production and inventory planning of a combined MTO – MTS system is presented. The proposed model demonstrated that having an MTS production line in addition to the MTO production stream is an effective solution for overcoming financial disadvantages and the consequences of relying simply on MTO needs.

The created model assisted in making the best inventory and production decisions for various items in a mixed MTO-MTS product to get the best results. The critical decisions need to be taken into account that must be made as a result of the influence of production costs on revenue.

Income was considered at the end of each quarter and positive cash flow was generated at the end of each period in difficultís in the Garment Industry. As a result, there will be no budgetary constraints in the production process. The sales of the MTS and MTO goods provided cash inflow .The most important aspects need to be taken into account that impact the manufacturing process. The fabric required for manufacture, capacity constraints, and financial availability were all issues. For the planned items, MTO due dates and predicted demand were satisfied.

Fabric pricing was a critical parameter, and the model was quite sensitive to changes in it, which was understandable considering that the fabric price accounts for 90% of the garment material cost. The quantity of money available to create for MTS is limited, and this has an impact on the choice to accept orders. The findings assisted in making practical decisions that considerably improved a clothing business.

The model's effectiveness was notable for its simplicity and application to practical garment manufacture, since it took into account the most important inputs. It has also addressed the important and concrete decisions that had a substantial influence on the judgments taken.
The issue has been to find the best answer for a garment business's sustainability and growth by combining capacity and production planning decisions with financial considerations. As a result, a policy for garment manufacturing production and capacity planning was highlighted.

5.2 Insights on Future work:

1. For a better prediction, consider accounting for missed revenue and backlogging for MTO requests.
2. Merging MTO demands acceptance and rejection criteria.
3. Examining the effects of the interest rate on the cash flow and revenues for every specific loan might be part of future studies.
4. Including fabric purchase decisions in the model, such as supplier selection, supplier lead-time effect, and discount conditions from suppliers.

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