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Simulation-based Optimized Production Policy for Hybrid MTS/MTO Glass Tube Manufacturing Systems

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Simulation-based Optimized Production Policy for Hybrid MTS/MTO Glass Tube Manufacturing Systems

BY

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Abstract

Glass Tube is one of the main components for fluorescent lamps as it contains all the other components to generate light. Glass tube industry faces a decline in demand in Egypt. This is attributed to two factors: currency floating and new lighting technologies. In response, glass tube manufacturers decided to diversify their products. This required the integration of Make-to-Stock (MTS), which is used usually for glass tube manufacturing, and Make-to-Order (MTO) which is used to fulfill demands for diversified products. In this thesis, Production policy is proposed to plan for MTS & MTO production. This policy determines when to produce broken glass (cullet), MTS product or MTO product. Priority is given to Cullet which is used as raw material in glass making. The second choice is to produce MTS product, and excess capacity is used to produce MTO products. Once MTO order is fulfilled, the choice is made to either produce cullet or MTS product. The policy defines two levels for cullet inventory and MTS product inventory. If cullet inventory reaches the lower level, cullet will be produced until the inventory level reaches higher level. If the cullet reaches the higher level or the level is decreasing towards lower level, products will be produced. The type of product is determined according to the inventory level of MTS product. If the MTS inventory level is lower than high inventory level, MTS product will be produced. Once it reaches high inventory level, MTO product will be produced. A simulation model is developed to simulate glass tube production. The model is divided into three interconnected modules: production, order fulfillment and decision. The model was verified and validated through different cases. Based on the simulation model, an optimization algorithm is applied to select optimum parameters for proposed policy with the objective of minimizing total costs. The proposed production policy proved its effectiveness in reducing total cost in glass tube manufacturing. Sensitivity analysis was performed to show the effect of raw material prices and energy price on the solutions obtained by optimization algorithm. Increase in raw material prices has effect on production parameters; however, it has no effect policy parameters. Increase in energy prices has effect on production parameters and policy parameters.

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Chapter One
Introduction

1.1 Background

This thesis considers a hybrid Make-To-Stock (MTS) and Make-To-Order (MTO) production in glass tube manufacturing systems. Hybrid systems allow for better utilization for available equipment which leads to cost reduction. Hybrid systems provide the flexibility to produce different products using available capacity. Production planning for hybrid systems requires a lot of effort in order to maximize the benefit from using hybrid system and ensuring steady production operations.

Production planning for hybrid systems problem was motivated by a situation at Al – Araby group which is a main producer for fluorescent lamps in Egypt. It has two factories that are complementing each other: the glass tube factory and the lamps factory. The glass tube factory converts the raw material into glass tubes which will be used further as a component in the production of fluorescent lamps at the lamps factory. Glass tubes are to be assembled with different components to make lamps. Production at glass tube is continuous without stoppage, and lamps production is a discrete.

1.1.1 Glass Tube Manufacturing

Glass basic manufacturing processes starts with receiving of raw materials and storing them in warehouses. Raw materials are divided into natural material such as silica sand, and synthetic material such as soda ash and glass cullet. This step is followed by mixing the raw material to get homogeneous blend of raw materials to get uniform properties of glass tube. By a screw machine, raw materials mixture is fed to the furnace to be melted till it becomes liquid. The furnace works continuously without any stoppage except for preventive maintenance. Preventive maintenance for the furnace occurs for three weeks each year. Melting process is done using four natural gas burners, which work sequentially.

Glass tube formation starts by the flow of molten glass over the sleeve which is hollow rotating cylinder. At the same time, air is blown to form the shape of tube. The dimensions of glass tube are determined by the rotation speed of the sleeve, the amount of air blown, the glass pull rate and the amount of glass flown in the sleeve. After forming the straight glass tube, tubes are cut into the required lengths along a conveyor. The conveyor allows the glass liquid to cool down and becomes solid. Several machines are set along the conveyor: a cutting machine, glazing machine and cullet removal machine. At the end of the conveyor, packaging is done manually by two workers where are stacked in a group of 90 tubes. Handling and packaging produce a lot of defects. After that, glass tubes are stored as shown in Fig. 1.1.

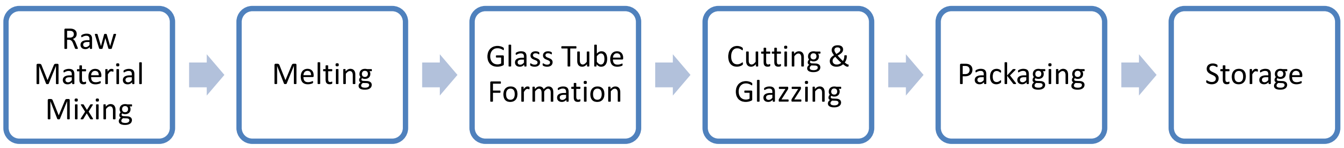

Figure 1.1: Glass Tube Manufacturing Process

1.1.3 Glass Tube Market

Glass tube industry faces a huge problem as a result of decrease in demand. New lighting technology has emerged which attracted a lot of the demand of lighting business such as LED technology. Besides, the government is leading a campaign to reduce the energy used in lighting. According to the annual report of the ministry of electricity and renewable energy year 2014-2015, the ministry made a contract, dated 8/4/2015, with the Arab Organization for Industrialization to supply 3.9 million high efficient street lighting [1]. The ministry also issued a contract to supply 13 million LED lamps for residential use.

Al-Araby glass factory was built with predefined capacity to meet local glass tube demand at that time when there was no LED technology. In the past, Al-Araby glass factory was producing a constant quantity of glass tubes (Make-To-Stock) which is used by Al-Araby lamps factory. That results into higher unused capacity. After new market shift towards LED technology, the demand for glass tubes has decreased. Therefore, the management decides to accept Make-To-Order (MTO) product demand.

1.1.4 Economic Environment Changes

The Egyptian government embarked an economic reform program as a result of severe problem of short-aging of hard currency. With the assistance of the International Monetary Fund

(IMF), the Egyptian government formulated the reform program, and in return the government receives $12 billion to promote the economy [2]. According to Egyptian Ministry of Finance, The reform program is based on four pillars. The first one is monetary adjustments through liberalization of exchange rate, strong fiscal consolidation to ensure the stability of public debt and monetary plan to contain inflation. The second pillar is to increase social safety measure in form of food or cash transfer subsidies. The third pillar is based on structural reforms to increase growth through encouraging investments. The last one is to close financing gaps.

As a result of liberalization of exchange rate, the currency was devalued significantly compared to US dollars [2]. Besides, inflation increased significantly to reach more than 30 per cent. The government imposed new taxes such as Value added tax (VAT), and new tariffs on roads and mines resulting in increase in raw material cost. Besides, the program includes removing any subsidies on energy supplies. New measures taken by Egyptian government led to increase in raw material costs and utilities costs which represent a business risk to the industrial sector.

1.2 Problem Statement

Under Egyptian economic circumstances, the Glass Tube factory decided to produce custom orders for customers other than Al-Araby lamps factory to maximize the utilization of available capacity. Accordingly, the factory will produce glass tubes using Make-To-Stock (MTS) and Make-To-Order (MTO) methods to minimize total cost. Production planning decision about glass pull rate and ratio of glass cullet in the batch are critical to minimize the cost. There are main limitations to glass tube production, which include:

- The furnace shall work continuously without any stoppage.
- Constant liquid glass level must be maintained inside the furnace.
- Space allocated for raw materials and final products warehouses is confined.
- Different glass tube products have different specifications.
- Make-to –Stock (MTS) demand must be satisfied.
- Glass pull rate and cullet ratio have specifications limits.
- Changes in glass pull rate and cullet ratio is limited.

1.3 Research Scope and Objectives

This research covers glass tube production processes including melting, glass tube formation, cutting and glazing, and storage. Besides, order fulfillment is included whether it is an order for MTS product or MTO product.

The research aims to develop a decision support tool to manage glass tube MTS and MTO products manufacturing. Simulation model is developed to simulated glass manufacturing and decisions for production. Simulation-based optimization is used to optimize policy parameters and production parameters to minimize cost.

1.4 Research Significance

This research develops a policy that helps the management to make production decisions. It develops an easy-to-use simulation model to evaluate policy parameters. The model takes into account variability inherent in glass tube demand.

Optimized production policy minimizes cost for producing glass tubes. This will help glass tubes to survive in current market conditions and competition with new developed lighting technologies. This policy assists in better utilization for current equipment. This increases the ability to produce variety of glass products.

1.5 Thesis layout

Thesis is organized in nine chapters. The first chapter is the introduction. The second chapter includes literature review for MTS/MTO planning problem and simulation using discrete event simulation. The third chapter includes problem description. Chapter four represents simulation model developed. Verification and validation for simulation model are presented in chapter five. Simulation-based optimization algorithm is developed through chapter six, where sensitivity analysis for solutions obtained from optimization algorithm is developed in chapter seven. Chapter eight concludes the work done and findings. References are listed in the last chapter.

Chapter Two
Literature Review

This research proposes a production policy to control the production of hybrid glass tube manufacturing systems. It uses simulation to simulate proposed policy parameters. Literature outlines similar problems in different situations. Literature review includes different sections which are MTS and MTO hybrid production systems, discrete event simulation applications in manufacturing, continuous flow simulation using discrete event simulation and other methods used for hybrid systems optimization.

2.1 MTS/MTO hybrid production strategy

Tsubone et al (2002) [3] designed a production planning system that combines both modes of production: MTS and MTO. The main objective is to shorten the manufacturing time of MTO products. The study takes into consideration order quantity routing, unit processing time and buffer capacity. The study doesn't include setup time between different products. The objective didn't consider minimizing cost.

Soman et al (2006) [4] developed a framework to manage an environment which uses both production strategies: make-to-stock and make-to-order. The study considers applying this framework for production planning and inventory control for a food processing factory which produces more than 230 products. The framework includes applying at first demand variability to select orders with low variability and high volume. This is followed by medium-term capacity planning through applying economic lot scheduling problem (ELSP). Finally, detailed schedule of MTO products along with MTS products. The research lacks analytical tool to support decision making process.

Kalautari, et al (2010) [5] presented a decision support system which assists in order acceptance/rejection decision. The system consists of five steps. The first step is to prioritize customers using a fuzzy TOPSIS method. This is followed by estimating the rough-cut capacity and rough-cut inventory based on capacity and material availability. At the third step, prices and delivery time is estimated using MILP model. The following step includes a set of proposed guidelines to help the organization to negotiate with customer over prices and due dates. If the order is accepted detailed scheduling is prepared at the fifth step. Research lacks providing analytical tools to support decision making process.

Zhang et al (2013) [6] developed analytical model to minimize the total cost of hybrid MTS/MTO production facility by selecting the inventory and capacity parameters. The facility consists of multiple machines which can be partially loaded by MTS or MTO products. The model is based on multi server queuing model where there is dynamic switch between MTS and MTO production via congestion switching policy. The setup time due to switch between products is negligible. The study proved that the hybrid system gives better results when there is low demand for products. The research considers discrete production where some machines can switch between MTS product and MTO product which is not the case for glass tube manufacturing.

Chen et al (2014) [7] developed a model which considers the co-optimization of inventory policy and prices of products of a facility which produces two of products which are MTS and MTO products. The main objective of the model is to maximize the discounted profit of the facility over infinite planning time horizon. The model was formulated based on Markovian decision analysis. The study neglects any setup time due to switching from one product to another.

Khakdaman et al (2014) [8] developed a robust optimization for multi-product multi-period production planning for a combined MTS-MTO production modes. The study takes into consideration uncertainties related to suppliers, operations and customers. This includes raw material costs, exchange rate, production cost, inventory holding costs and customer demand. The study develops linear deterministic model, and then it transforms the model into robust optimization model.

2.2 DES Application in Manufacturing

Pidd et al (1987) [9] developed a simulation model for automated food plant which can be used for small batch manufacturing facility and for continuous production facility. The model showed that simulation can be used for existing manufacturing plants and help in design new plant. The paper didn't show how to handle continuous/discrete hybrid system of producing food.

Fiorini et al (2005) [10] developed a simulation model to assess the investment plan for expanding production in CST factory. CST produces steel slabs and many other semi products made of steel. The factory utilizes two blast furnace, two converters and continuous casting machines. Expansion plan involved increasing production capacity to 7.5 Mt/y of slabs. Besides, expansion involves adding new equipment such as a third blast furnace, third converter, third continuous casting machine, coke oven battery, etc. the model was made realistic that it included machine failure, maintenance, schedules, etc.

Sharda et al (2008) [11] developed discrete event simulation model for reliability modeling of a chemical plant. The model identifies the impact of certain policies to enhance the reliability of equipment in the plant. The model could assist in determining the effectiveness of changing policies in terms of installing new equipment or changing inventory control policies. The plant produces 15 different products through 40 different subsystems. The production processes are continuous and discrete, and they are raw product loading, raw product mixing, reaction, raw product washing, drying, blending, storage and final packaging. The model was developed using ExtendSim. Paerto chart is developed then to show the most influential factor on plant reliability.

Park et al (2008) [12] developed simulation based planning and scheduling system for LCDs at one of Samsung factories in Korea, and it is called DPS system. DPS system is developed for daily planning and scheduling of LCD manufacturing due to continuous production of LCD. It encompasses filtering capacity, simulating operations, obtaining detailed loading scheduling and analyzing KPIs regarding the operations. The system didn't include long-term business risks. It focuses on daily or weekly planning and scheduling.

Liong et al (2016) [13] developed a model simulating the manufacturing of chili sauce using Arena software. The model was to compare current production processes with suggested new scenarios for improvement. The model considers only the operations of the factory. It doesn't include the inventory control of the factory. The model shows the utilization of each resource deployed in the process for each scenario. It also shows the average waiting time, processing time for each process.

2.3 Continuous Flow Process Simulation Using DES

Simulation techniques were implemented extensively in manufacturing field. Many chemical and fast moving consumers' goods (FMCG) are continuous flow process. There are different approaches were developed to model continuous flow. Continuous flow was approximated using discrete event simulation which makes the computation work much easier.

Lefrancois et al (1991) [14] developed a model to optimize the annealing operations of rolling mill facility. A simulation model is based on discrete event simulation which allows subroutine integration to optimize job scheduling and sequencing of various products produced by the rolling mill. Multi-objective model to optimize the annealing operations is constructed and it considers inventory holding costs, overall annealing operations and the overall efficiency of annealing furnaces.

Semenzato et al (1995) [15] developed a discrete event simulation model for sugar cane harvesting operations. The model includes a sequence of discrete processing units and considers the failure of allocated resources. The model is beneficial in determining the minimum resources for harvesting operations.

Also, Watson Edward (1997) [16] developed a simulation model for batch process in chemical plant. The model is based on discrete event simulation where continuous processes were approximated by discrete event modeling. The model was developed to assess new design implemented on decreasing cost and increasing throughput. The model gives feedback about design and operational parameters such as quality, customer satisfaction and flexibility to respond to quick order.

Arer et al (1999) [17] used simulation model to compare between different capacity expansion and sequencing alternatives for a sheet metal factory. The case study considers a subsystem of the factory which considers continuous sheet casting, cold rolling and annealing. The subsystem is a combined discrete and continuous system; therefore, two different models are developed: continuous model and discrete model. The continuous model is developed to find processing times and setup times. The discrete model is responsible for capacity analysis and studying the effect of sequencing. The model takes into considerations the product mix which is the result of changing the thickness of the sheet. Therefore, setup times are taken into consideration in the model.

Barton et al (2000) [18] proposed a new approach to discretize continuous simulation which is called discrete quantity approach (DQA). Conventionally, continuous system is approximated to discrete system with respect to time. DQA suggest discretizing the continuous system with respect to quantity instead. This approach is very useful in the case of having varying flow rate.

Kuo et al (2001) [19] built a model which simulates continuous flow of chemical plant products, storage in silos and discharging to trucks using discrete-event simulation. It is proposed to discretize the flow into fixed volumetric units that occurs between fixed time intervals. The model considers that the rate of flow is constant throughout operations.

Schlultz, Scott (2006) [20] developed simulation model for a glass float production line. The float line starts with a continuous process of liquid glass flowing out from furnace to cooled conveyor in shape of continuous ribbon of glass. After that, glass ribbon is cut into individual stream of products according to cutting algorithm; this process is pure discrete. The first obstacle in modeling is the combined continuous-discrete nature of the process. It was proposed to neglect the furnace modeling because glass furnace works without any shutdown. Therefore, the model focuses on the conveyor system. The model can be used for different applications such as cutting schedule analysis, sequencing algorithms comparison, cost study and scrap study.

Fioroni et al (2007) [21] proposed a technique to model continuous process using discrete event modeling. Continuous flow can be approximated by larger volume flow with larger inter-arrival time. In other words, volumes vary by steps of time not continuously. This approach is applied to Brazilian Steelmaking Company to verify that discrete approximation is effective. The study was implemented using Arena software.

Melouk et al (2013) [22] developed a real application simulation-based optimization model for steelmaking industry using Arena software. There is a need in steel manufacturing field to reduce costs due to increase in raw material prices and increase in global competition. The model investigates changes in design and operations of steelmaking facility to reduce cost and monitor inventory levels to reduce associated costs. The study involves experimentation used to optimize work-in-progress inventory only in order to reduce costs. The study provides a sensitivity analysis of the holding cost inventory and the daily total cost of operations. The study didn't cover the hybrid production systems for steel manufacturing.

Bursi et al (2015) [23] proposed an approach to model continuous flow using discrete event simulation (DES) through discrete event system specification (DEVS). The proposed model is to model is to simplify the continuous flow using discrete model which describes three main behavior of the system: failure and repairs, working speed and accumulation and throughput time base unit model for continuous flow is work centers which operate continuously with maximum speed and without buffer, and conveyor units with zero accumulation. This case doesn't apply for glass production systems as there is no shutdown for the furnace.

Asbjornsson et al (2016) [24] developed a simulation model for performance evaluation of crushing plant. Crushing production units are subject to frequent wear and failure due to harsh operating conditions. The model integrates discrete event simulation and continuous time simulation. The model develops a discrete event simulation for downtime of production units which will be the input to continuous time simulation. Mathematical models were developed for each production unit such as crushing. These models describe the changes in material flow and changes in particle sizes throughout the plant. Stochastic optimization model by genetic algorithm is formulated to find optimum operating conditions.

2.4 Other Methods for Continuous Process Optimization

Almada-Lobo, et al (2008) [25] developed also an optimization model considering production planning and scheduling problems of colored glass containers manufacturing. Changing the color of containers causes a lot of setup time to prepare for required ingredients suitable for the new color. The objective of this study is to minimize average inventory level, setup time and number of stock out. The model considers different variables which consider the duration of specific color batch inside the furnace, sequence of batches and inventory. Near optimum solution for weighted objective function was achieved using a variable neighborhood search technique (VNS). The developed model didn't consider having hybrid manufacturing of glass containers.

M. Faragallah and A. Elimam (2017) [26] developed an integrated optimization model for glass tube & florescent lamps at el-araby group. The model comprises all production steps from raw material mixing, continuous flow of glass furnace and inventory. Considering raw material mixing, the model optimizes each raw material composition in the batch while considering required quality of glass produced such as density and thermal expansion. The second part of the model deals with continuous flow glass furnace as it optimizes the inventory and crushed glass tube costs while considering inventory balance, safety stock of glass tubes and acceptable ranges of the glass pull rate, glass tube thickness and length. The third part of the model deals with end forming and fluorescent lamps discrete production. Total production and inventory cost of end formed tubes is minimized while meeting the requirement of inventory balance and safety stock. The model was formulated initially as nonlinear model and using separable programming the model as linearized. The model didn't take into consideration the variability of demand or customization of products. The model didn't handle the problem for hybrid glass tube manufacturing systems.

In this thesis, production policy for glass manufacturing using hybrid production system MTS and MTO is proposed, and it takes into account the uncertainty in demand. This is different from research developed by M. Faragallah and A. Elimam (2017). They considered the production for MTS products only with deterministic demand. Besides, this research approach is different from approaches developed by Soman et al (2006) or Kalautari, et al (2010). They developed hierarchical framework for hybrid production systems which lack analytical decisions aids. However, this research provides computational work to support decisions-making process. Besides, this research represents easy to use simulation model that provides simulation-based optimized policy parameters to management to use. On the other side, different algorithms developed such as linear deterministic programming model by M. Faragallah and A. Elimam (2017) and by Khadaman et al (2014), and variable neighborhood search technique (VNS) by Almada-Lobo, et al (2008) are complicated models which requires deeper knowledge of programming. This research consider modeling of continuous flow of glass as discrete where larger quantities of glass flow between fixed time interval similar to approach developed by Kue at al (2001); however, Kue et al (2001) considered a case of silos used for storing chemical material, and then discharging this material when needed. This is different from our approach where charging and discharging of the furnace can happen simultaneously that the glass level inside the furnace remains constant. The modeling of the furnace is neglected similar to the approach used by Schlultz, Scott (2006). Moreover, Faragallah and A. Elimam (2017) considered the effect of cullet ratio on energy consumption only where this research considers the effect of glass pull rate and cullet ratio on energy consumption used for melting.

In conclusion, this research aims to develop easy to use production policy which considers hybrid production glass tube manufacturing system. The tool shall provide analytical results, and consider uncertainties in demand.

Chapter Three
Problem Description and Methodology

3.1 Problem Description

This research considers the production planning decisions for hybrid glass tube manufacturing systems at Al-Araby glass factory. Al –Araby group, an Egyptian joint-stock family enterprise established in 1964, is a main producer for fluorescent lamps in Egypt. Originally, the factory was designed with a capacity to produce glass tubes using MTS production system that suits the demand of fluorescent lamps factory. Due to advances in lighting technology and governmental campaigns for energy savings, the demand for glass tubes has declined. Decline in glass tube demand leads to lower capacity utilization as manufacturers tend to lower the production rate to the minimum. To overcome new market conditions, glass tube manufacturers decided to diversify products using MTS and MTO hybrid manufacturing systems.

The capacity of the factory is governed by the capacity of the furnace which can produce between 550 to 800 kg/hr. of glass. There is no plan to change manufacturing capacity to match current demand. The furnace must work on a fixed level of material which is 90 tons. Therefore, raw material $B_{i,t}$ flows continuously inside the furnace. There is no stoppage allowed for glass tube manufacturing as stoppage will cause break down of the furnace. The planning horizon (T) for this research is one month. This time horizon is divided into smaller units of time (t) which is hour.

The factory can produce different products (i): a set of MTS products P_s and a set of MTO products P_o. Each product (i) has different specification: length l_i, diameter d_i, thickness s_i, and mass m_i. Each of the previous parameters has upper specification limit and lower specification limit. For example for the length, the limits are LSL_i^l, and USL_i^l.

For product $i \in P_s$, demand quantity D_i^s is fitted into a normal distribution N ($\mu_{s,i}$, $\sigma^2_{s,i}$). Based on the production schedule of fluorescent lamps factory, the production schedule is developed for MTS products P_s. The factory supplies MTS products Q_i^s to fluorescent lamps factory according to agreed production schedule.

For product $i \in P_o$, demand quantity D_i^o is defined by normal distribution N ($\mu_{o,i}$, $\sigma^2_{o,i}$). The factory receives the orders in the beginning of the month in order to schedule for the production of the required product. The factory can supply the required demand in different quantities Q_i^o, and delivery is done once per month. Setup time is neglected when change is done to the type of product. There is no safety stock for MTO products P_o.

The factory can control the production rate by controlling glass pull rate at any given time ($GPR_{i,t}$) and glass cullet ratio in the batch ($MG_{i,t}$). Glass pull rate is the amount of glass that are produced form the furnace per unit time and it is normally distributed N ($\mu_{gpr(i,t)}$, $\sigma^2_{gpr(i,t)}$). Glass cullet is the amount of recycled glass which is used for the production of glass. Change in Glass Pull Rate and cullet ratio affect the level of energy consumed during production as shown in Fig. 3.1 [27].

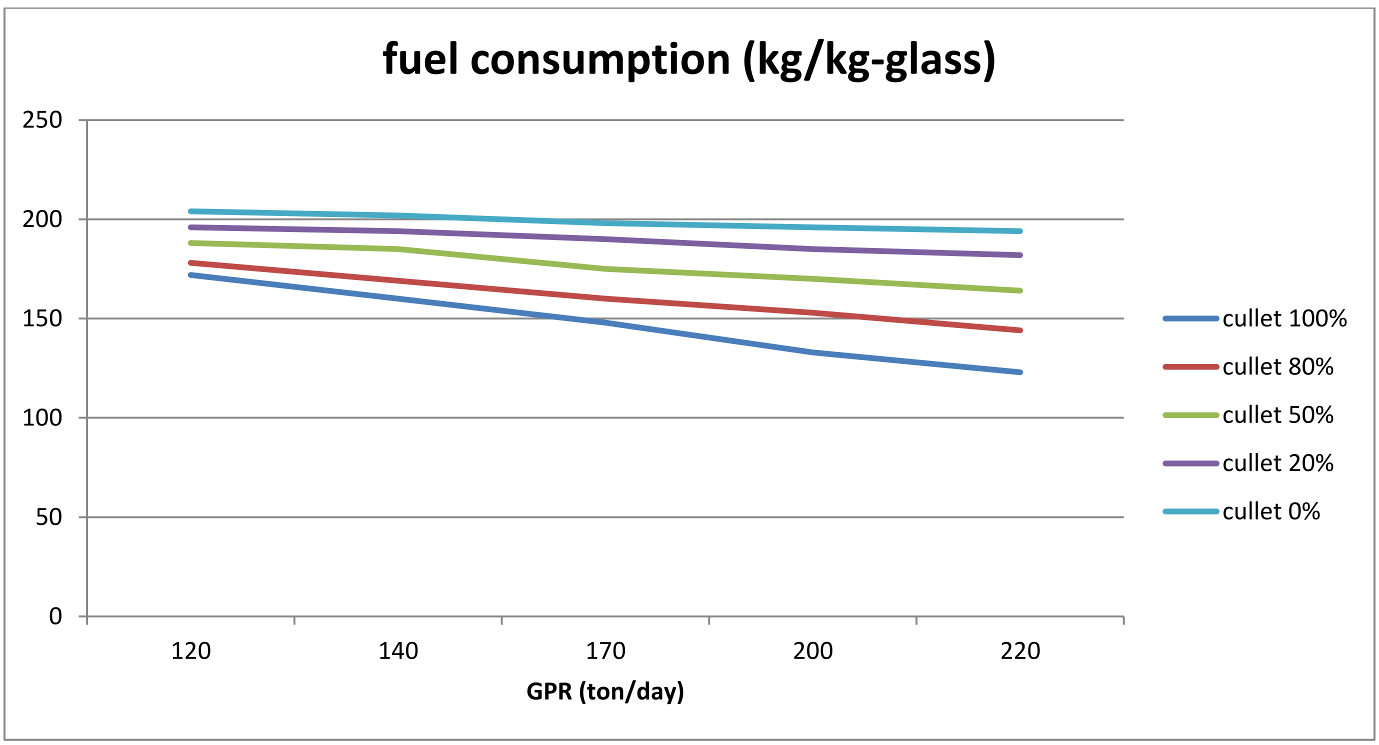

Figure 3.1: Fuel Consumption, Pull Rate and Cullet Ratio Relation [27]

There is limitation to change in glass pull rate and glass cullet ratio. Glass Pull Rate can vary between two values which are practically accepted at the factory GPR_l and GPR_h. Besides, Glass pull rate at a given time $(t+1)$ is allowed to change by a certain amount (ΔGPR) from the value at time (t). The amount of GPR change (ΔGPR) depends on whether it is increase or decrease. In the case of decrease, ΔGPR is limited by amount ΔGPR_l, and in the case of increase it is limited to ΔGPR_h. During changing glass pull rate, all products, produced form the furnace, are crushed for setup time φ.

Cullet ratio change is limited. Theoretically, cullet ratio can be used from 0% to 100% in glass making. Cullet ratio is limited due to technology used in the factory. Therefore, cullet ratio can range between two values MG_l and MG_h. Glass cullet is generated from different resources which are cut losses $CG_{i,t}^c$, defective products $CG_{i,t}^d$ and planned crushing $CG_{i,t}^p$. Defective products crushed quantity is random, and differs from one product one product to another.

The objective is to minimize total cost by controlling production policy parameters, glass pull rate and glass cullet ratio. The model takes into consideration the inventory cost $IC,$ raw material cost $RC,$ cost of energy EC consumed, crushing cost CC and added value lost cost AVC.

3.2 Methodology

Through several visits to Al-Araby factory, deep knowledge about glass tube manufacturing systems was obtained. With the assistance of many batch and production engineers, practical limits for production parameters such as glass pull rate (GPR) and cullet ratio were obtained. Also, knowledge was transferred about different raw material used and how to form raw material mix (batch) to meet certain oxides level to assure the quality for glass tube products. Then, mathematical model was developed, and it was nonlinear mixed integer model with stochastic parameters such as product demand. Therefore, simulation model was developed then to model proposed production policy and glass tube manufacturing system. Besides, simulation model is easier tool to represent dynamic and stochastic systems. This step is followed by verification and validation step to assure the accuracy of the developed model. After that, optimization is applied to minimize total cost by changing policy and production parameters. At the end, sensitivity analysis is performed to test the effect of parameters which has higher effect on total cost.

Chapter Four
Simulation Model

4.1 Production Proposed Policy

The policy controls glass tube manufacturing using two variables which are glass pull rate $GPR_{i,t}$ and percentage of glass used in batch $MG_{i,t}$ on daily basis. The policy prioritizes which product to be produced in the factory. The highest priority is given to crushing glass output in case of having shortage of cullet glass which is used for production. After which, the priority is given to producing MTS products because demand for MTS products is on a daily basis. Finally, if the factory satisfied conditions for higher priority items, MTO can be produced.

The policy proposes that there are a lower and upper levels for glass cullet inventory (z, Z). if the current inventory of glass cullet reaches the lower level z, the produced glass is crushed to make cullet inventory reaches the upper level Z. the time allocated for this operation can be also allocated for the weekly and monthly maintenance time. The policy also considers that there are lower and upper levels for MTS inventory (s, S). if the current inventory of glass cullet reaches the upper level Z and MTS inventory reaches s, the factory will produce MTS product till its inventory reaches S. after which the MTO product can be produced. the policy can be summarized as follows in the flow chart shown in Fig. 4.1.

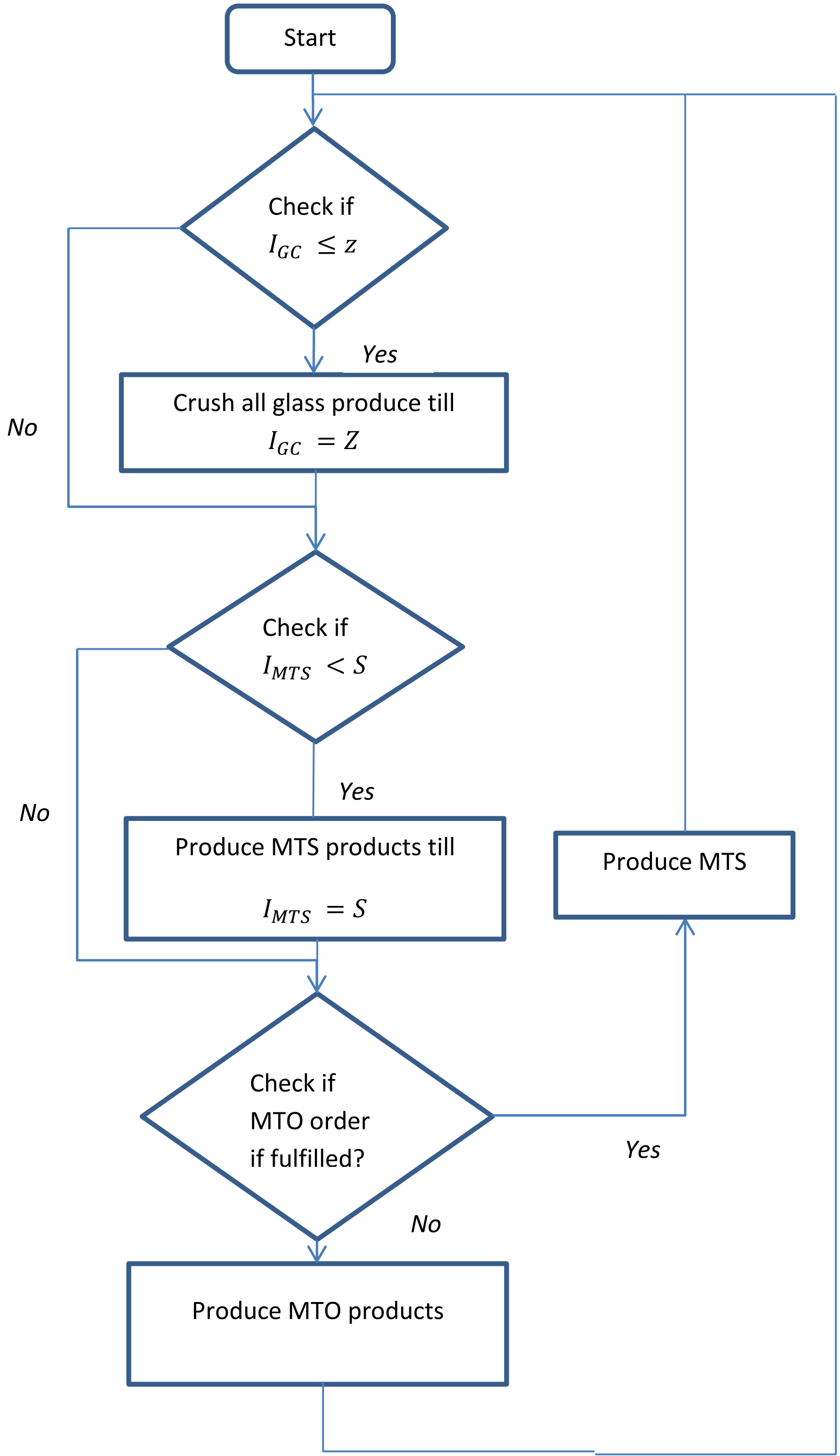

Figure 4.1: Proposed Production Policy

4.2 Simulation Model Assumptions

There are several assumptions are made:

1- Glass pull rate (GPR) and cullet ratio changes once a day.
2- Prices are fixed to products and are not sensitive to the demand.
3- Setup time, to change from one product to another, is negligible.
4- Raw material inventory is not considered in the model because it is assumed that no change in primary materials used in glass making.
5- Delivery of MTO order is done only once during planning horizon.
6- No change in capacity according to customers' demand.
7- Equipment reliability is not considered in the model.

4.3 Simulation Model for proposed production policy

Simulation model is used to test the effectiveness of a certain policy to cost reduction. Hybrid production environment for MTS and MTO products imposes difficulty for production planning. Developed simulation model is composed of three modules: decision, production and order fulfillment. The model is divided to three modules to add flexibility for changes in any of them. Decision module considers the application of the proposed policy adopted by the management. The production module depicts the processes in the production in simplified way. The third module is responsible for handling customer orders.

Simulation model is used to represent the dynamic behavior of hybrid MTS/MTO manufacturing systems as simulation can depict more details than analytical methods. That increases the accuracy of results from simulation model. It is an easy tool to represent stochastic nature for product demand, customer orders acceptance and fulfillment. Simulation has the ability to capture the system behavior over time horizon such as inventory and warehouse. Besides, it is impossible to conduct experiments to change production parameters in glass manufacturing systems because glass manufacturing is continuous process.

4.3.1 Software

Simulation model is done using Rockwell simulation software ARENA to simulate the production policy and its effect on the cost. ARENA is Visio-compatible flowcharting tool where entities are generated and follows the flow chart to execute predefined actions. ARENA contains different modules (blocks) and each one is used for certain task. The used modules in simulation are create, assign, decision, delay, read-write and dispose modules.

4.3.2 Input data

Different parameters are input for simulation model. These parameters are demand for MTS and MTO demand, quality, and raw material consumption and production parameters. Several interviews with production managers were conducted to collect useful data about glass production. Besides, Historical data were analyzed by input analyzer tool in ARENA.

4.3.2.1 MTS and MTO products demand

The demand for MTS products is not deterministic during the whole month. It was found that the demand for MTS product is stochastic and follows beta distribution as the following expression:

$$MTS\ daily\ demand = 1.87e + 004\ *\ BETA(0.89, 0.361)\ kg$$

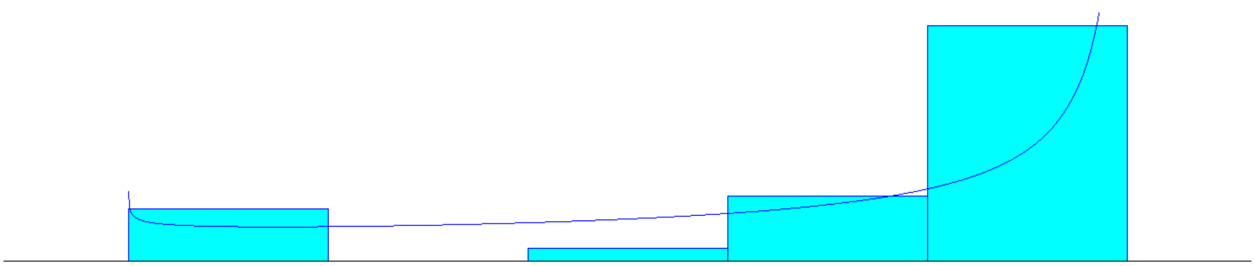

Figure 4.2: MTS demand Variability

Whereas, the monthly demand of MTO product is based on customer demand which is deterministic as MTO demand arrives once per month

$$MTO\ monthly\ demand =\ 19806.7\ kg$$

Table 4.1: MTS & MTO Demand

Product	Distribution	Expression	Square error
MTS	Beta	$1.87e + 004\ *\ BETA(0.89, 0.361)$	0.051303
MTO	deterministic	19806.7	---

4.3.2.2 MTS and MTO Product Quality

The quality rates for MTS and MTO product were analyzed. MTS quality rate was found to follow beta distribution through the following expression

$$MTS\ quality = 0.78 + 0.22 * BETA(8.08, 0.642)$$

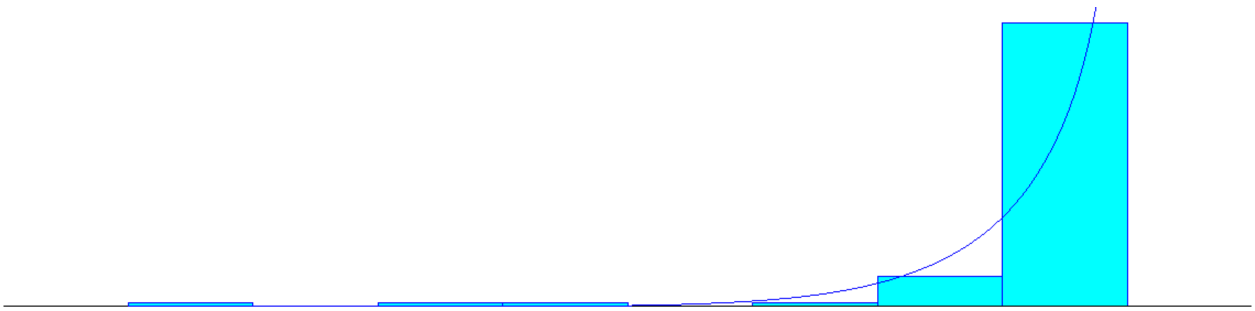

Figure 4.3: MTS Quality Variability

MTO quality follows beta distribution through the following expression

$$MTO\ quality = 0.86 + 0.14 * BETA(1.78, 0.468)$$

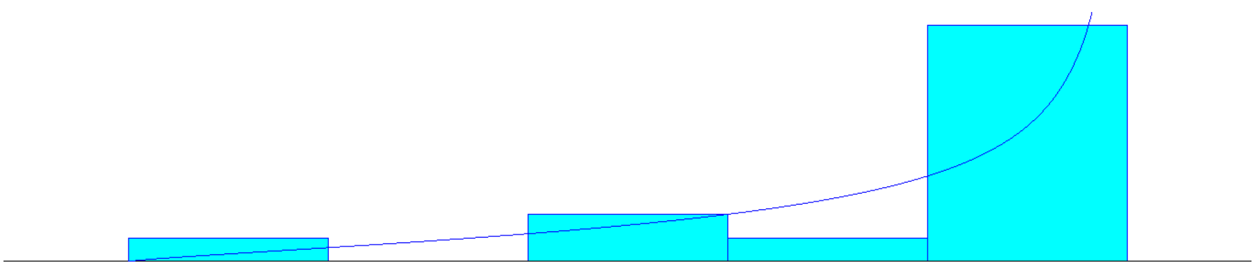

Figure 4.4: MTO Quality Variability

Table 4.2: MTS & MTO Quality

	Distribution	Expression	Square error
MTS quality	Beta	0.78 + 0.22 * BETA(8.08, 0.642)	0.004618
MTO quality	Beta	0.86 + 0.14 * BETA(1.78, 0.468)	0.031830

4.3.2.3 Batch Raw Material Composition

Historical data was analyzed to get distribution of raw material percentage of total batch weight without cullet because cullet ratio is a decision variable.

$$raw\ material\ percentage\ \% = \frac{raw\ material\ weight}{batch\ weight - cullet\ weight}$$

Table 4.3 summarizes the distribution of raw material percentage:

Table 4.3: Raw Material Percentage in Batch

raw material	distribution	expression	square error
borax	lognormal	LOGN(0.00788, 7.03e-005)	0.003029
carbon	Erlang	ERLA(6.3e-006, 25)	0
dolomite	normal	NORM(0.132, 0.00181)	0.01391
feldspar	Triangular	TRIA(0.08, 0.0845, 0.11)	0.138111
limestone	Weibull	0.01 + WEIB(0.0129, 9.74)	0.008623
silica sand	Weibull	0.49 + WEIB(0.0346, 6.71)	0.116359
soda ash	Lognormal	0.21 + LOGN(0.0112, 0.00113)	0.04285
sulphate	Normal	NORM(0.00249, 1.96e-005)	0.045077

4.3.2.4 Production Parameters

Interview with glass manufacturing experts showed that glass pull rate (GPR) may vary between 550 and 800 kg/hr for 90 ton furnace. Also, it was found that cullet ratio used in the batch ranges from 25 % to 40%. GRP change is limited to 5 Kg per hour.

4.3.3 Simulation Model

The model considers different types of glass tubes i that can be produced by Al-Araby factory. Each product has certain dimensions: density ρ_i, outer diameter d_i, thickness s_i and length l_i. Dimensions have specific upper and lower limits according to the type of the product as follows:

$$LSL^{d_i} \leq d_i \leq USL^{d_i} \qquad (4.1)$$

$$LSL^{l_i} \leq L_i \leq USL^{l_i} \qquad (4.2)$$

$$LSL^{s_i} \leq s_i \leq USL^{s_i} \qquad (4.3)$$

The total mass of glass tube m_i can be defined as follows

$$m_i - \left[\rho_i \times \pi \times \left((d_i \times s_i) - s_i^2\right) \times l_i\right] = 0 \qquad (4.4)$$

Masses of tubes are input to the model according to specifications deployed in factory.

4.3.3.1 Decision Module

This module is responsible for making decision of what to produce. Time of making decisions is random with exponential time of mean one hour. The policy parameters are glass cullet inventory limits (z, Z), MTS inventory limits (s, S), glass pull rate $GPR_{i,t}$ and percentage of glass used in batch $MG_{i,t}$. Whether the module chooses MTS, MTO or cullet to produce, the module set a value for glass pull rate and amount of cullet to use in glass making.

Glass Pull Rate (GPR)

The factory control the production rate by controlling the glass pull rate from the furnace $GPR_{i,t}$. Glass pull rate is limited to the capacity of the furnace and it has lower and upper limit.

$$GPR_l \leq GPR_{i,t} \leq GPR_h \qquad (4.5)$$

Glass pull rate can be changed to meet current demand. Change is limited by a certain amount ΔGPR which has a value while increasing glass pull rate ΔGPR_h, and has a different value while decreasing ΔGPR_l. During changing the glass pull rate, glass is crushed for 0.5 hr.

$$GPR_{i,t+1} = GPR_{i,t} + \Delta\text{GPR} \qquad (4.6)$$

Production selection of MTS, MTO and Cullet

The factory makes the decision to produce MTS or MTO products to reach the objective of decreasing the cost. At any time, the factory will decide to produce quantity of MTS product $q_{i,t}^s$ or to produce MTO product $q_{i,t}^o$. There are losses in form of crushed glass defined as $CG_{i,t}$.

$$GPR_{i,t} = \left(Y_{i,t}^s \times q_{i,t}^s\right) + \left(Y_{i,t}^o \times q_{i,t}^o\right) + CG_{i,t} \qquad (4.7)$$

Where,

$$Y_{i,t}^s = \begin{cases} 1, & q_{i,t}^s > 0 \\ 0, & otherwise \end{cases}$$

$$Y_{i,t}^o = \begin{cases} 1, & q_{i,t}^o > 0 \\ 0, & otherwise \end{cases}$$

These binary variables are defined as follows

$$q_{i,t}^s \leq M \times Y_{i,t}^s \qquad (4.8)$$

$$q_{i,t}^s \geq \delta \times Y_{i,t}^s \qquad (4.9)$$

$$q_{i,t}^o \leq M \times Y_{i,t}^o \qquad (4.10)$$

$$q_{i,t}^o \geq \delta \times Y_{i,t}^o \qquad (4.11)$$

Binary variables are defined for selection whether to produce MTS or MTO and the summation of the two variables must equal to one as it is not allowed to produce two different products at the same time.

$$\sum_i \left(Y_{i,t}^s + Y_{i,t}^o\right) = 1 \qquad (4.12)$$

The quantity delivered to the customer is the summation of all produced quantities $q_{i,t}^s$ and $q_{i,t}^o$during the planning horizon

$$Q_i^s = \sum_t q_{i,t}^s / m_i \qquad (4.13)$$

$$Q_i^o = \sum_t q_{i,t}^o / m_i \qquad (4.14)$$

The factory produces crushed glass $CG_{i,t}$ which is used regularly in the batch formulation. Crushed glass is produced due to cut losses from production $CG_{i,t}^c$, defective products $CG_{i,t}^d$, and crushing due to planning $CG_{i,t}^p$.

$$CG_{i,t} = CG_{i,t}^c + CG_{i,t}^d + C_{i,t}^p \quad (4.15)$$

The module decides (Fig. 4.5) to produce MTS whenever cullet inventory is higher lower limit (z) or MTO order is fulfilled. MTO product is produced whenever cullet inventory is higher than low limit (z) and MTS inventory is higher than high MTS inventory limit (S). Cullet is produced whenever cullet inventory is less than low cullet limit (z) till the inventory reaches high limit (Z). The model decides to produce MTS product whenever all previously mentioned conditions are satisfied.

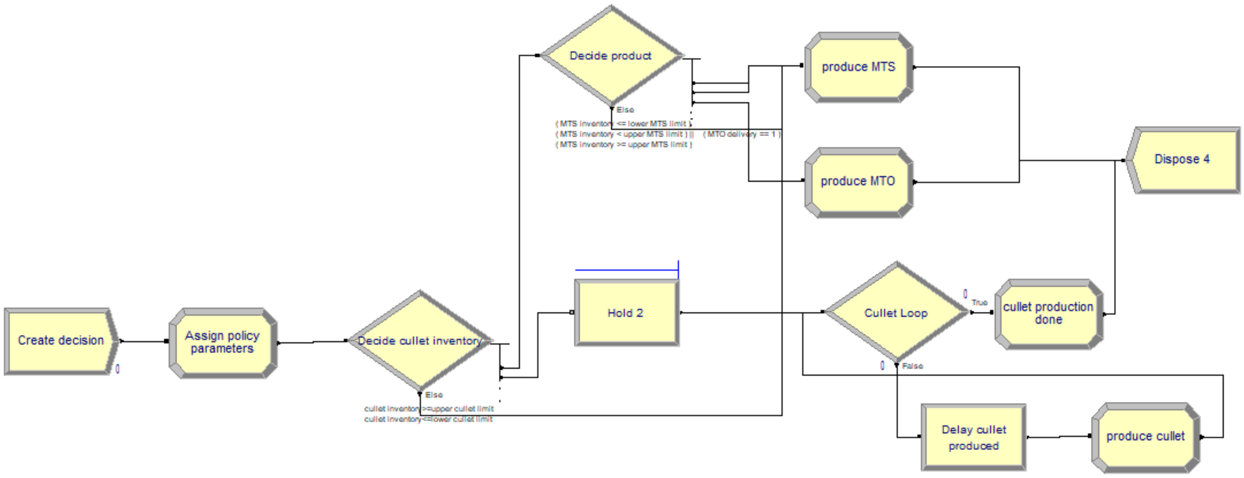

Figure 4.5: Decision Module

4.3.3.2 Production Module

Glass production is continuous during the whole year. Due to the fact that the molten glass level is maintained at constant level, glass pull from the furnace will not impact the level as it is compensated directly by feeding raw material. Therefore, the change of molten glass level inside the furnace can be neglected. As a result, continuous production can be discretized.

A decision about what the product the factory will produced is based on the output of decision model as shown in Fig. 4.6. Cut losses and defects rate are taken into consideration and the amount of cullet produced are added to cullet inventory. MTS and MTO Inventory levels will be updated according to decision made. Production costs are calculated in this module which includes raw material cost, energy costs and inventory costs.

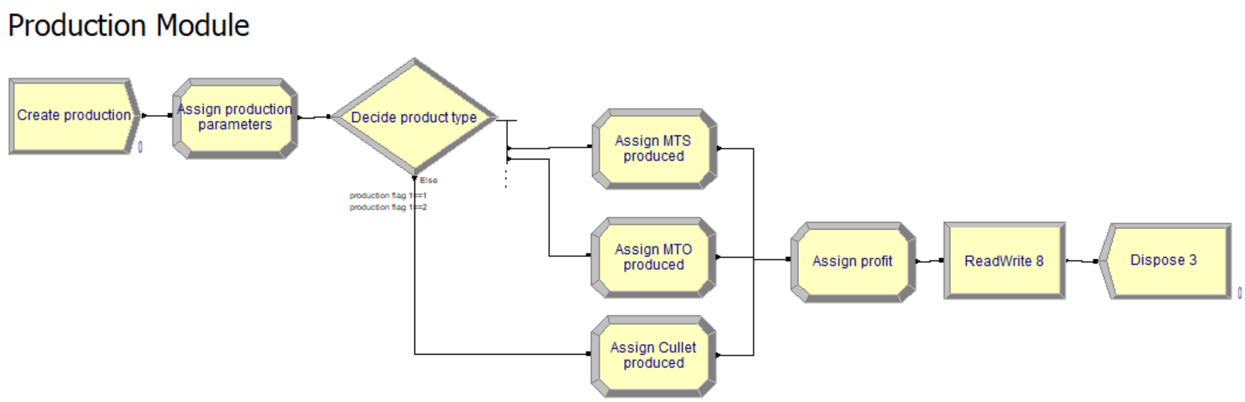

Figure 4.6: Production Module

Raw Material Consumption

For producing glass, raw material flows continuously into the furnace with batch rate $B_{i,t}$. Batch weight is the summation of all raw material rates $B_{i,t}^{rm}$ and the glass cullet rate used in glass making $B_{i,t}^{GC}$.

$$B_{i,t} = \sum_{rm} \left(B_{i,t}^{rm}\right) + B_{i,t}^{GC} \qquad (4.16)$$

Batch rate $B_{i,t}$ is proportional the glass pull rate $GPR_{i,t}$. Batch rate is larger in quantity to compensate for losses during melting process inside the furnace. Compensation factory is denoted by η_b.

$$B_{i,t} = (1 + \eta_b) \times GPR_{i,t} \qquad (4.17)$$

Amount of crushed glass used in batch $B_{i,t}^{GC}$ is proportional to the total batch weight by factor $MG_{i,t}$.

$$B_{i,t}^{GC} = MG_{i,t} \times (1 + \eta_b) \times GPR_{i,t} \qquad (4.18)$$

The amount of raw material rate $B_{i,t}^{rm}$ consumed to produce glass is defined as proportional of batch weight.

$$B_{i,t}^{rm} = \eta_{i,rm} \times (B_{i,t} - B_{i,t}^{GC}) \qquad (4.19)$$

Energy Consumption

Specific energy consumption decreases with the increase of glass pull rate and cullet ratio as shown in Fig. 2. Data was derived from the graph and tabulated in the table 4.4.

Table 4.4: Empirical Data for Energy Consumption versus GPR and Cullet Ratio

cullet ratio	GPR	Specific Consumption (kg/kg-glass)	Fuel consumption (m^3)
1	120	172	10939.2
1	140	160	11872
1	170	148	13334.8
1	200	133	14098
1	220	123	14341.8
0.8	120	178	11320.8
0.8	140	169	12539.8
0.8	170	160	14416
0.8	200	135	14310
0.8	220	144	16790.4
0.5	120	188	11956.8
0.5	140	185	13727
0.5	170	175	15767.5
0.5	200	170	18020
0.5	220	164	19122.4
0.2	120	196	12465.6
0.2	140	194	14394.8
0.2	170	190	17119
0.2	200	185	19610
0.2	220	182	21221.2
0	120	204	12974.4
0	140	202	14988.4
0	170	198	17839.8
0	200	196	20776
0	220	194	22620.4

Quantity of gas consumed $G_{i,t}$ defined by linear regression to correlate the consumption of fuel with glass pull rate and glass cullet ratio.

$$G_{i,t} = 6155.626 - (4813.02 \times MG_{i,t}) + \left(69.35206 \times GPR_{i,t}\left(\frac{ton}{day}\right)\right) \qquad (4.20)$$

Analysis of variance (ANOVA) shows that both variables (glass pull rate and cullet ratio) are significant as shown in table 4.5.

Table 4.5: ANOVA for Energy Consumption

	df	SS	MS	F	Significance F
Regression	2	2.42E+08	1.21E+08	149.8974	1.53E-13
Residual	22	17780218	808191.7		
Total	24	2.6E+08			

Regression equation for energy consumption is as shown in table 4.6.

Table 4.6: Energy Consumption Regression Equation

	Coefficients	Standard Error	t Stat	P-value
Intercept	6155.626	882.4492	6.975615	5.31E-07
MG	-4813.02	487.5484	-9.87189	1.53E-09
GPR	69.35206	4.875484	14.22465	1.42E-12

Normal probability plot shows that data is normal, so regression is valid as shown in Fig.4.7.

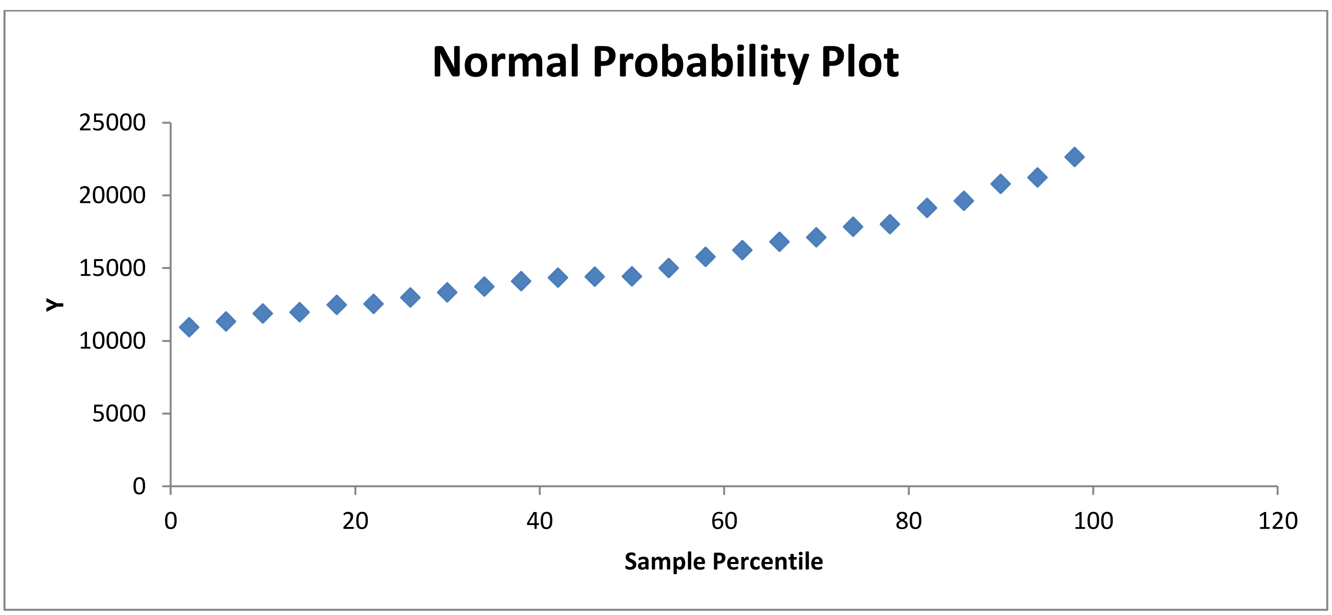

Figure 4.7: Normal Probability Plot

Finished Product Inventory

Inventory of MTS products $I_{i,t}^{s}$ increases when there is increase in the quantity produced for MTS $q_{i,t}^{s}$, and it decreased when order is met by Q_{i}^{s}.

$$I_{i,t}^{s} - I_{i,t-1}^{s} - q_{i,t}^{s} + Q_{i}^{s} = 0 \qquad (4.21)$$

For MTO product, inventory $I_{i,t}^{o}$ increases when there is increase in the quantity produced for MTO $q_{i,t}^{o}$, and it decreased when order is met by Q_{i}^{o}. Safety stock for MTO products are not kept in the warehouse.

$$I_{i,t}^{o} - I_{i,t-1}^{o} - q_{i,t}^{o} + Q_{i}^{o} = 0 \qquad (4.22)$$

Inventory of finished products has limitation which is the capacity of warehouse W, where the summation of MTS and MTO inventory at any time t should be less than or equal to warehouse capcity.

$$W \geq \sum_{i} (\mathrm{I}_{i,t}^{s} + I_{i,t}^{o}) \qquad (4.23)$$

Raw Material and Crushed Glass Inventory

Inventory level of raw material $I_{i,t}^{rm}$ depends on the rate of consumption of raw material $B_{i,t}^{rm}$ and raw material order delivery to the factory $RM_{i,t}$.

$$I_{i,t}^{rm} = I_{i,t-1}^{rm} + RM_{i,t} - B_{i,t}^{rm} \quad (4.24)$$

Crushed glass inventory $I_{i,t}^{GC}$ depends on the amount of crushed glass produced in the factory $CG_{i,t}$ and amount of crushed glass consumed in batch formulation $B_{i,t}^{GC}$.

$$I_{i,t}^{GC} = I_{i,t-1}^{GC} + CG_{i,t} - B_{i,t}^{GC} \quad (4.25)$$

Costs

Total direct cost for production and storage is denoted by TC. It is the summation of raw material cost , energy cost EC, inventory cost IC and penalty cost PC.

$$TC = RC + EC + IC + CC + AVC$$

Raw material cost RC is the summation of all costs of all raw material used in batch formulation by multiplying the unit cost of raw material c_{rm} by consumed quantity at any time $B_{i,t}^{rm}$.

$$RC = \sum_t \sum_i \left(c_{rm} \times B_{i,t}^{rm}\right) \qquad (4.26)$$

Energy cost EC is computed as follows

$$EC = \sum_i \sum_t c_g \times G_{i,t} \qquad (4.27)$$

Inventory costs is the multiplication of holding cost per unit C_h and inventory level of product (i) at time (t) denoted as $I_{i,t}^{o}$ and $I_{i,t}^{s}$.

$$IC = \sum_i \sum_t C_h \times (I_{i,t}^{o} + I_{i,t}^{s}) \qquad (4.28)$$

Crushed Cost CC is the cost resulted from crushing activity of the glass tubes. Crushing cost is the multiplication of crushing cost per unit C_{cr} and the quantity to be crushed $Q_{cr,t}$.

$$CC = \sum_i \sum_t C_{cr} \times (\,Q_{cr,t}) \qquad (4.29)$$

As a result of crushing of glass, added value to get glass is lost. Added value is the summation of raw material and energy consumed to produce unit glass multiplied to the quantity to be crushed. Added value cost AVC can be defined as follows

$$AVC = \frac{\sum_i \sum_t (c_g \times G_{i,t}) \;\; + \sum_t \sum_i \left(c_{rm} \times B_{i,t}^{rm}\right)}{\sum_i \sum_t (\,G_{i,t} + B_{i,t}^{rm})} \qquad (4.30)$$

4.3.3.3 Order Fulfillment Module

The factory receives MTS and MTO orders before the start of the new month. The simulation model deals with accepted orders; it doesn't include acceptance/rejection order problem. The input variables for the model are order demand and order due date. The model deals with order quantities as masses not number of tubes. The model considers MTS as a daily demand where MTO is a monthly demand. The model doesn't fulfill the order until the inventory of the product is higher than or equal to order quantity. If the order is released, revenues are calculated. After the MTO order is fulfilled, the remaining products kept in stock are crushed and added to cullet inventory. Also, amount of MTS product crushed is the difference between the MTS inventory and MTS low limit (s) as shown in Fig. 4.8.

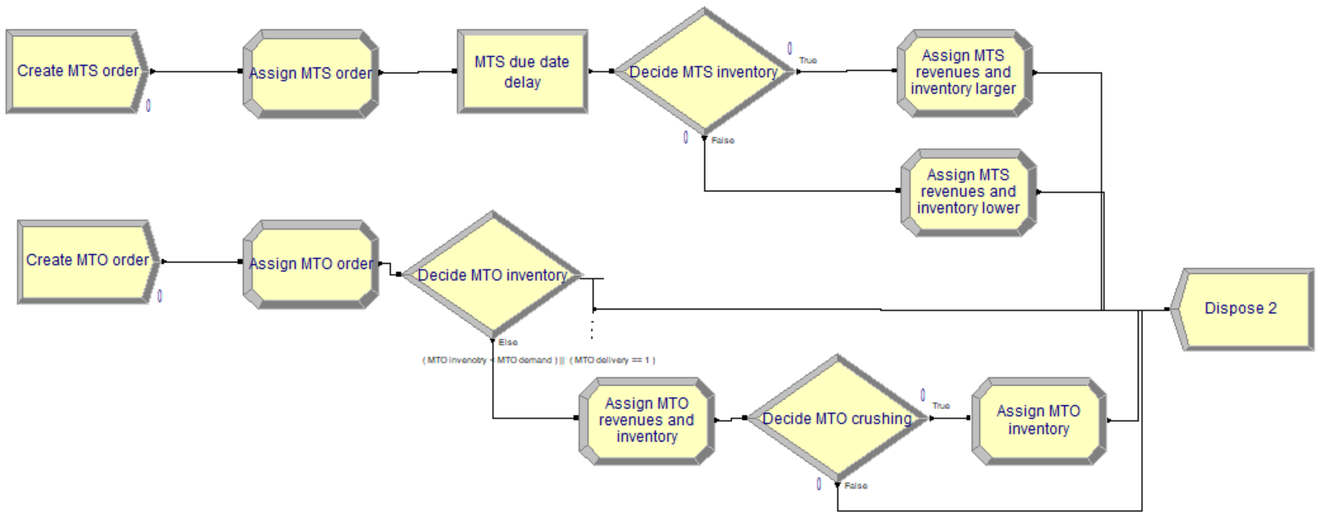

Figure 4.8: Order Fulfillment Module

Total revenue the factory is making during the time horizon of this study is denoted by R. Total revenue R is the summation of all orders' revenue either it is MTS or MTO product. Each order is assumed to include one product only.

$$R = \sum_i (R_i^s + R_i^o)$$

, where the revenue of an order is the product sum of all product prices p_i the quantity produced and delivered to customer.

$$R_i^s = p_i \times Q_i^s \qquad (4.31)$$

$$R_i^o = p_i \times Q_i^o \qquad (4.32)$$

For MTS order, delivered quantities should be less than or equal to the demand D_i^s.

$$Q_i^s \leq D_i^s \qquad (4.33)$$

In the case of MTO order, delivered quantity should be less than or equal to required demand D_i^o as shown in Fig. 4.8.

$$Q_i^o \leq D_i^o \qquad (4.34)$$

Chapter Five
Verification and Validation

5.1 Verification

The developed simulation model was initially verified using visual test through running with animation on Arena Simulation to keep track of generated entities and how the model corresponded to different entities. Besides, Arena doesn't create report unless there is no error in debugging and terminating entities. A report was generated for running the model for one replicate only as shown (appendix C).

Another way to verify the model is by estimating the arrival rate for an entity. Arrival rate theoretically is 1 per hour. The output value is 1.02 per hour. This calculated value is very close to initial value for arrival rate. In conclusion, verification tests prove that the model works correctly.

5.2 Number of Replications and Warm-up Period

In order to guarantee high accuracy of simulated results, there is a need to assure that results are collect at steady state condition of the system. Therefore, it is required to calculate warm-up period. Besides, there must be enough number of replicates to assure narrow confidence interval which ensures high precision for results.

5.2.1 Number of Replications

To guarantee high precision of simulation output, certain number of replications has to be specified. Most practitioners either use two little or too many number of replications. Little number of replications makes the output to be inaccurate where too many replications require high level of computation.

There are many approaches to determine the number of replications to guarantee high precision [28]. The first approach is to determine precision by defining the probability $1-\propto$. The second approach is graphical method where cumulative mean is plotted against the number of replications. The user can select the number of replications when the plot becomes steady. The third approach is to use confidence interval method. It depends on constructing confidence interval with changing number of replications as well as variable output. This thesis used the third method to define the number of replications because this approach defines variability as well. Different variable outputs were used which are MTS inventory and MTO inventory (see appendix A). It was found that required replication number is 15 replications as shown in Fig. 4.9&4.10.

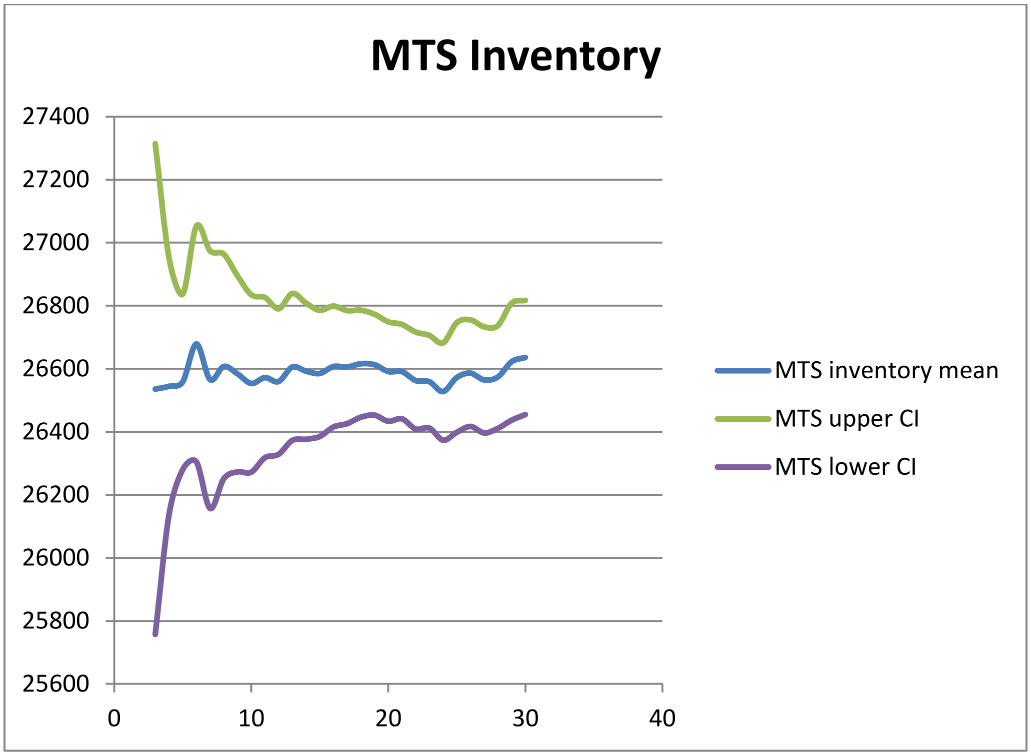

Figure 5.1: Replication Number Using MTS Inventory

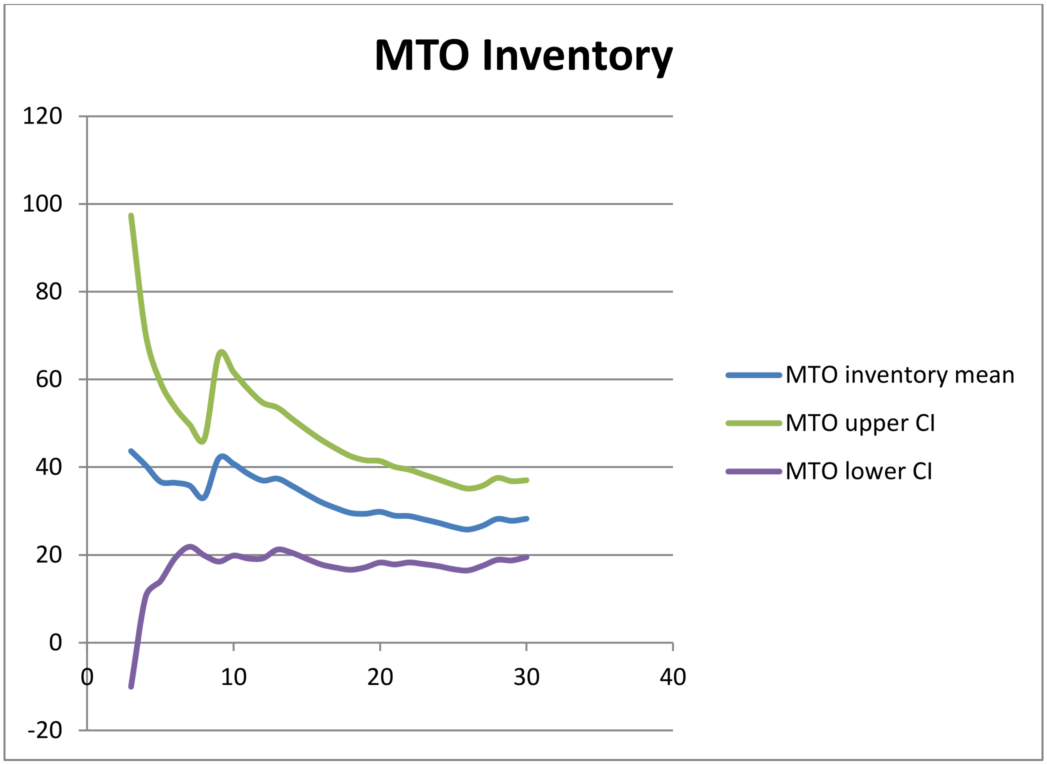

Figure 5.2: Replication Number using MTO Inventory

5.2.2 Warm-up Period

The model was tested for 3000 days to determine warm-up period. The model was run for 15 times to estimate the inventory of MTS product during 3000 days (see appendix B). After that, an average estimate for MTS inventory is calculated for each day. The last step is to calculate the moving average and plotting them against time as shown in the Fig. 4.11.

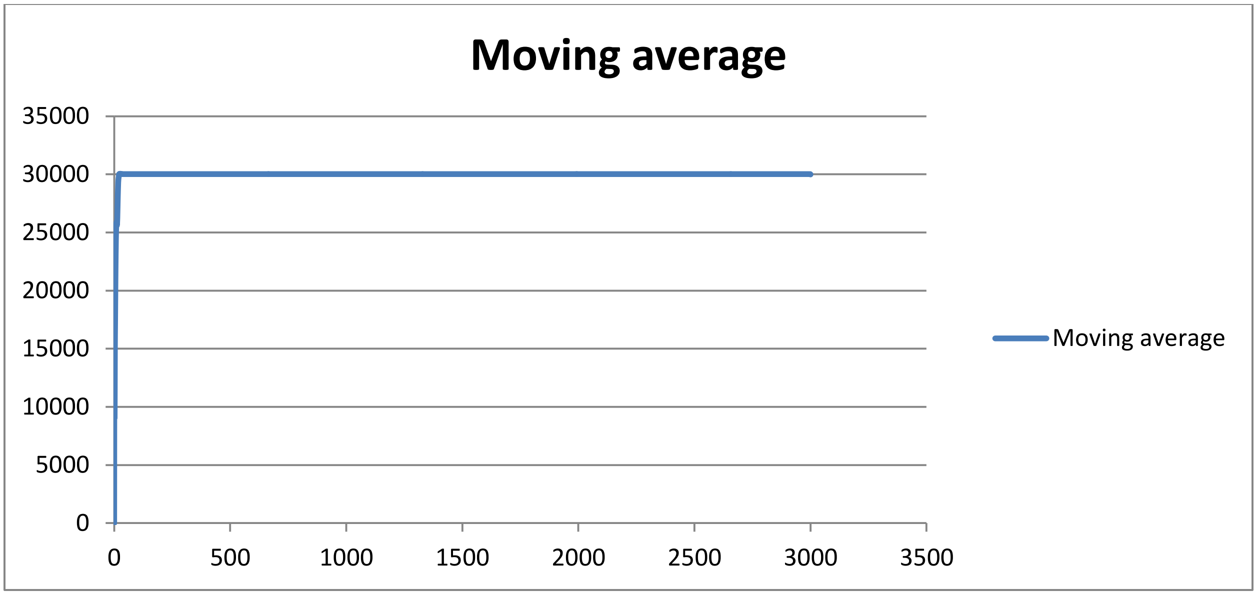

Figure 5.3: Warm-up Period (3000 days)

It was found that warm-up period can be estimated to be 21 days as shown in Fig. 4.12.

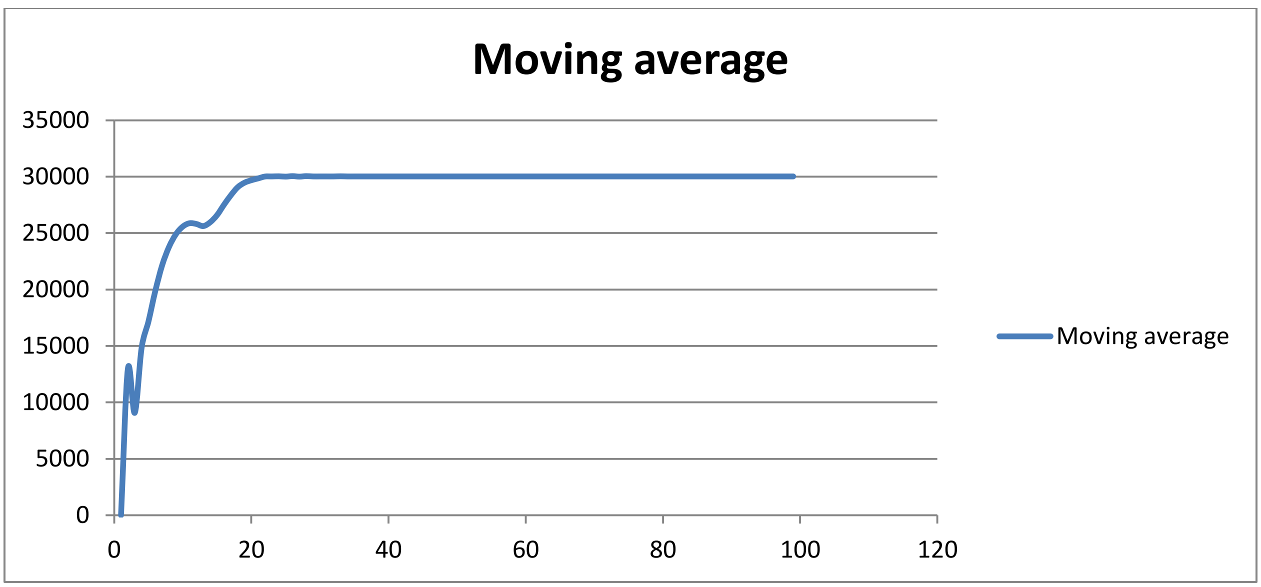

Figure 5.4: Warm-up Period (100 days)

5.3 Validation

The model was validated through different cases. The first case was formulated to force the whole glass production is crushed during the simulation run. In the second case, parameters were adjusted to produce only MTS products. The third case was simulated versus actual data provided by Al-Araby Glass factory.

5.3.1 The First Case

The first case assumes that the current inventory of crushed glass is equal to zero, where the policy control limit for crushing glass (z, Z) are 2668 and 4871 respectively. According to previous condition the production is forced to crush all glass output to reach the upper level of crushed glass inventory (Z). To make sure that only crushing will occur during simulation model, GPR was assumed to be very low number (1 kg/hr) if the model chooses to crush glass. All the assumptions used to test first case are summarized in table 5.1.

Table 5.1: Parameters Settings for The First Case

z (kg)	2668	$I_{i,t}^{GC}$	0
Z (kg)	4871	$I_{i,t}^{s}$	1000
s (kg)	18272	$I_{i,t}^{o}$	0
S (kg)	27838	GPR	1
$MG_{i,t}$	0.36		

The model was run for 30 days. The results showed that the model decided under these conditions to crush glass output and not to produce products either MTS or MTO. As shown in below graph, initial inventory was 1000, and then this quantity was released when an order arrives. After that, MTS product was not produced as there is no enough cullet stock to produce glass as shown in Fig. 5.5.

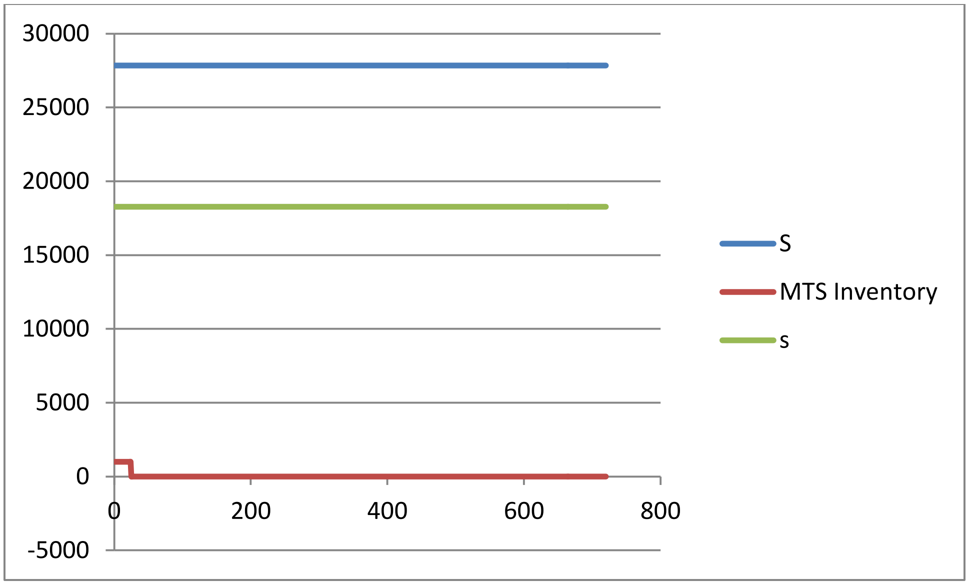

Figure 5.5: First Case MTS Inventory

On the other hand, the whole production was crushed to increase the level of cullet inventory as shown in Fig. 5.6. As glass pull rate was assumed to be very low, the cullet inventory didn't reach the level (Z) to start producing products during the whole simulation time.

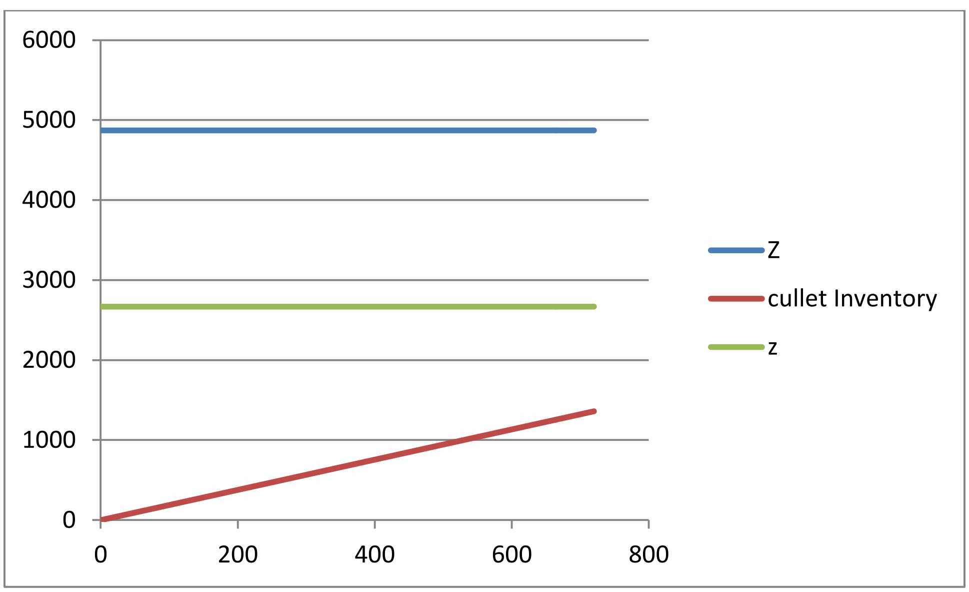

Figure 5.6: First Case Cullet Inventory

According to the first case, the costs which should have values are energy costs, MTS inventory costs and raw material costs. Revenue stream come from selling the initial inventory level of MTS inventory. There is no further revenue the factory makes.

5.3.2 The Second Case

The second case is to test whether the model will choose to produce MTS product or not. In this case, some assumptions are made to make it logical to produce MTS according to the developed policy. One assumption is to guarantee that inventory level of crushed glass is higher than the lower level (z). Also, the inventory level of MTS and MTO are low, so the model will choose to produce either one of them. All the assumptions used to test second case are summarized in table 5.2.

Table 5.2: Parameters Settings for The Second Case

z (kg)	2668	$I_{i,t0}^{GC}$	100000
Z (kg)	4871	$I_{i,t0}^{S}$	0
s (kg)	18272	$I_{i,t0}^{O}$	20000
S (kg)	27838	GPR	758
$MG_{i,t}$	0.36		

Initial level for cullet inventory was set to high number (40000) therefore the cullet inventory can cover the whole month cullet consumption. Consequently, the model has to produce either MTS or MTO. To force the model to produce MTS, the initial level for MTS inventory was set to Zero. Besides, MTO inventory was set to be higher than MTO order quantity that there is no need to produce MTO.

Results show that it is effective as it produced only MTS product. Fig. 5.7 shows that MTS inventory is increasing over the simulation run length where MTO inventory is kept at its initial level till an order arrives and goes to zero. Every day MTS order arrives and MTS inventory is updated.

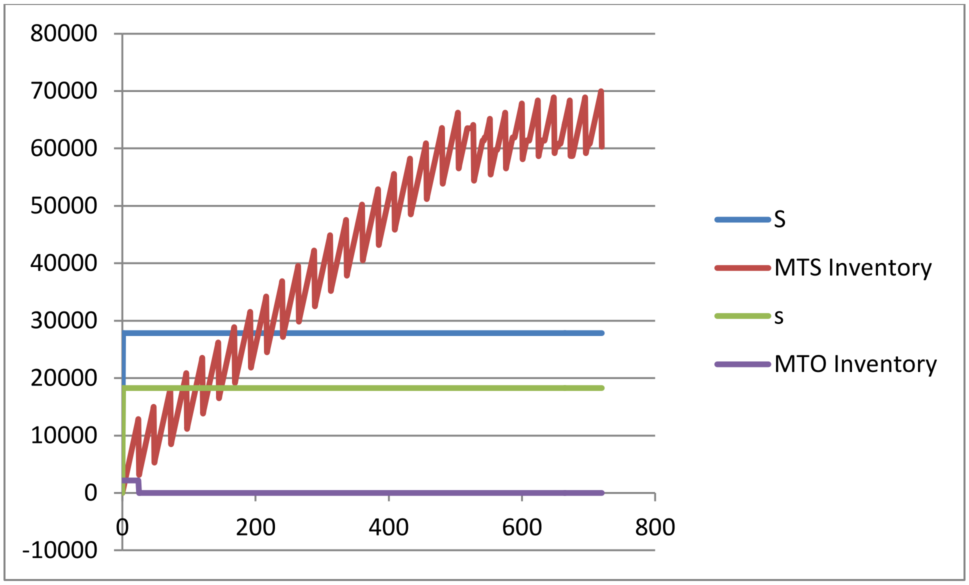

Figure 5.7: Second Case MTS & MTO Inventory

Cullet is not produced as it is produced during production from crushing excess MTS as shown in Fig.5.8. Once cullet inventory reaches lower control limit (z), cullet is produced till it reaches upper limit (Z).

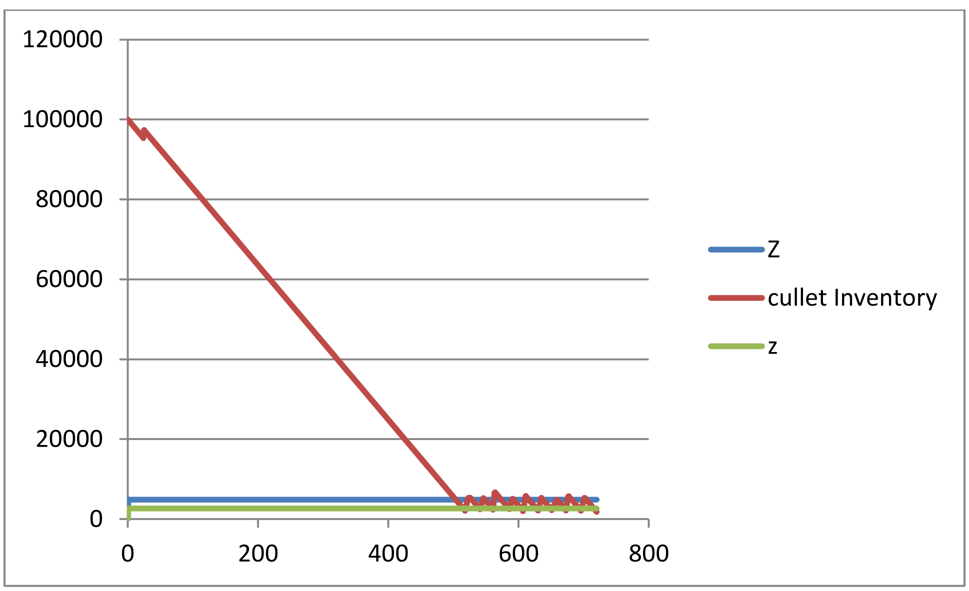

Figure 5.8: Second Case Cullet Inventory

5.3.3 The Third Case

In this section the model was validated using the same production policy used in the factory. The production policy entails producing MTS whenever MTS inventory levels reaches below the safety stock level. MTO product is produced when MTS inventory level is higher than the safety stock. MTS safety stock is maintained to hold MTS products in stock to compensate for failure and regular maintenance. The simulation model was run and the results are as shown in table 5.3:

Table 5.3: Third Case Results

	Simulation Mean	Half width	upper confidence interval	lower confidence interval	real data
MTS produced (kg)	370800.29	22979.84	393780.13	347820.45	388364.4
MTO produced (kg)	20665.09	7689.38	28354.47	12975.71	19494.92

It is concluded from the three cases that the model was verified successfully and works efficiently. It was found that real quantities for MTS and MTO produced fall within the range of confidence interval.

Chapter Six

Simulation-based Optimization

Near-optimum values for policy parameters can be obtained by applying simulation-based optimization using OptQuest tool in Arena software. The main objective of the simulation is to minimize the total cost the factory making during the simulation run length. Decision variables are glass pull rate, cullet ratio, MTS product limit (s, S), cullet limits (z, Z). Simulation run length is one month as MTO orders arrive once a month and production planning for glass manufacturing is prepared for one month.

OptQuest software, developed by F. Glover, J.P. Kelly and M. Laguna, has several optimization engines; however, the main optimization engine is scatter search methodology coupled with tabu search strategies. Scatter search methodology can handle continuous or discrete variable with one or multiple objective functions. Using OptQuest requires defined a set of controls, responses and constraints and objective function (s). Controls are the decision variables. They are policy parameters which are upper and lower cullet limits (z, Z), and upper and lower limits for MTS product limits (s, S). Also, production parameters, glass pull rate and cullet ratio, are controls. Where response defined is total cost, MTS inventory level, MTS produced quantity and MTO produced quantity. The objective defined is to minimize total cost. There are several constraints added to optimization model to guarantee logical outputs from the model. These constraints are as follows:

1- Production Capacity: the maximum capacity of the factory during the month is 483840 kg assuming there are no defects in products, and cut losses are assumed to be 10% of total production. The month is assumed to be 30 days.

$$maximum\ production\ capacity = 28 \times 24 \times (1 - 0.1) \times 800 = 483840$$

2- Production capacity may vary between two values which are 550 and 800 kg/hr. Amount of cullet ratio of the batch may vary between 25% and 40%. These values are practical values to guarantee the quality of the product. Beyond these values, there is no proven evidence on the quality of the products.

3- Due to the continuous production of glass tubes, it is better to define a range for produced quantities for MTS and MTO products because it is difficult to define an exact estimate to products quantities and the operations cannot be stopped.

$$MTS\ demand\ \leq MTS\ produced \leq MTS\ demand \times \emptyset$$

$$MTO\ demand\ \leq MTO\ produced \leq MTSO\ demand \times \emptyset$$

$$\emptyset > 1$$

Through this way, the computation time required to reach optimum solution will be less.

4- The fourth constraint is related to policy parameters. It is used to force the optimization to choose S with higher value than s and the same scenario applies for cullet limit (Z,z).

$$S \geq s$$

$$Z \geq z$$

There are several factors while choosing OptQuest to solve optimization problem. The first factor is the number of simulations. Number of simulations depends on number of controls. If the number of controls exceeds 100 controls, results might deteriorate. As we have only six controls, there is no problem regarding the accuracy of results. It was decided to have 1500 simulation runs to have better results despite the fact that number of simulations required is 100 simulations [29].

6.1 Optimization Case Study

Simulation-based optimization is applied to a real life case study at al-Araby glass factory to compare the effectiveness of the new approach proposed. The demand for MTS and MTO product for February is as shown in table 6.1:

Table 6.1: Optimization Case Study MTS and MTO Data

	MTS product	MTO product
average mass (kg)	0.164	0.085
total MTS produced (kg)	372372.2	19494.92
conformity %	98.8	92.6

Where glass pull rate was 780 kg/hr and cullet ratio was 27.5%.

Accordingly, constraints will be as follows:

Constraint (1) $MTS\ produced + MTO\ produced\ <\ 483840$

Constraint (2) $390000 \leq MTS\ produced \leq 420000$

Constraint (3) $19500 \leq MTO\ produced \leq 22000$

Constraint (4) $S \geq s$

Constraint (5) $Z \geq z$

Constraint (6) $GPR_{i,t+1} - GPR_{i,t} \leq 5$

6.2 Optimization Results

The optimum value for glass pull rate was 800 kg/hr to be used for all 28 days with no change from day to another. Production policy parameters were optimized as shown in table 6.2:

Table 6.2: Optimized Production Parameters

s	15000	z	6000
S	35000	Z	15000

On the other side, cullet ratio changes from day to another as shown in table 6.3.

Table 6.3: Optimized Cullet Ratio

Day	cullet ratio (MG)	Day	cullet ratio (MG)
1	0.289	15	0.398
2	0.400	16	0.260
3	0.400	17	0.400
4	0.274	18	0.290
5	0.398	19	0.400
6	0.400	20	0.287
7	0.250	21	0.254
8	0.287	22	0.400
9	0.400	23	0.260
10	0.302	24	0.400
11	0.400	25	0.389
12	0.399	26	0.379
13	0.400	27	0.270
14	0.280	28	0.400

The average cullet ratio for the whole month is 34.5%. Therefore, Cost was minimized to be 863058 EGP. Optimization results were applied to the previous case to validate the results with 15 replications to test the effect of optimized values on the profit the factory is making.

6.2.1 MTS and Cullet Inventory

For MTS inventory, it was found that the mean MTS inventory is 25553.12 kg with standard deviation equals to 4087 kg. The average hourly MTS inventory lies between lower and upper MTS production level as shown in Fig. 6.1.

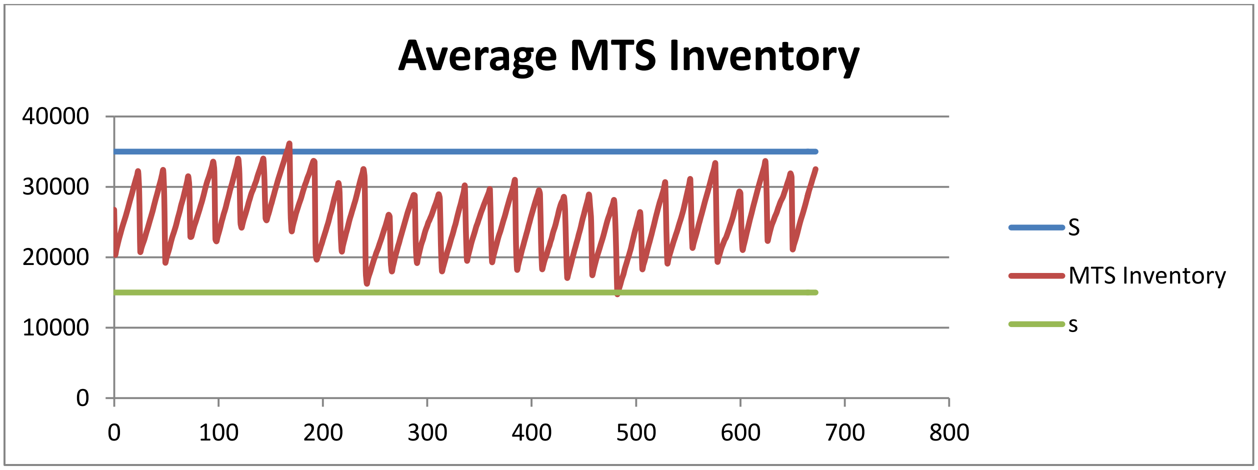

Figure 6.1: Average MTS Inventory

For the case of cullet inventory, it was found that average hourly cullet inventory fall between upper and lower control level (z,Z) as shown in Fig. 6.2. Cullet inventory average level is 9966.2 kg with standard deviation 813 kg.

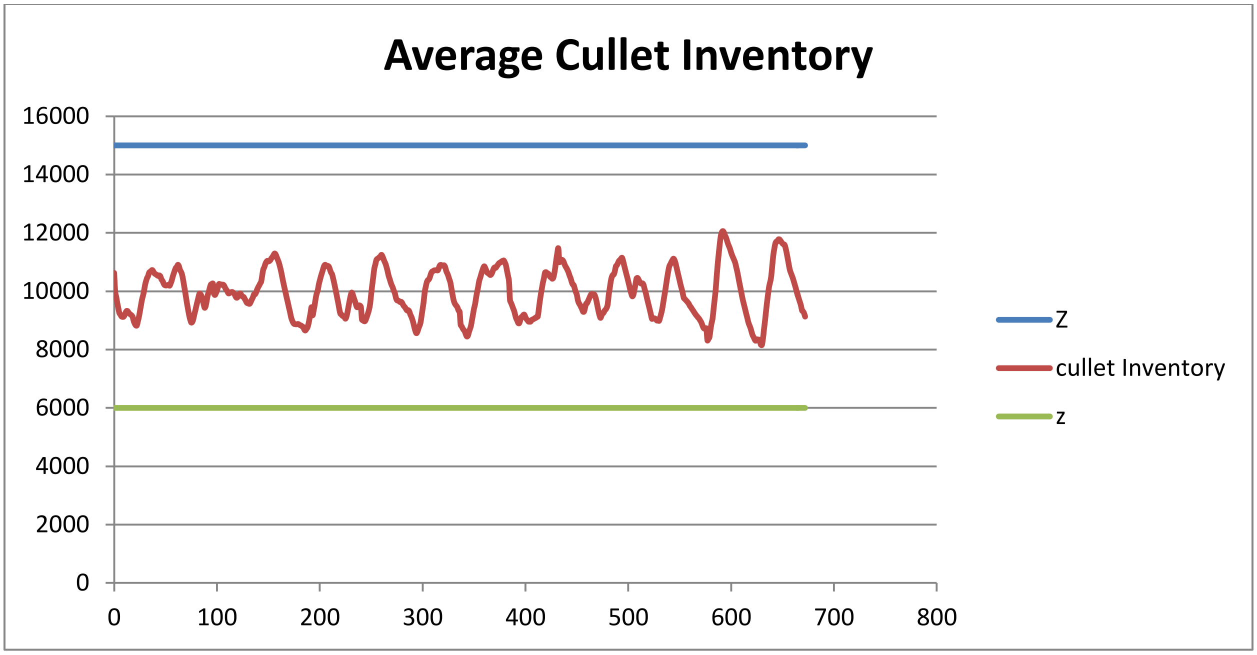

Figure 6.2: Average Cullet Inventory

6.2.2 MTS and MTO Production Quantity

For MTS and MTO production, the average MTS quantity produced for the whole month is 371770.8 kg with standard deviation of 10205.6 kg. While the average MTO quantity produced is 18455.6 kg with standard deviation 4696.9 kg as shown in table 6.4.

Table 6.4: MTS and MTO Produced Quantities

run	Total MTS produced	Total MTO produced	run	Total MTS produced	Total MTO produced
1	369799.9194	22243.35665	8	359895.1673	9754.663285
2	377408.2324	22215.81574	9	378838.8491	7043.682575
3	383336.3893	20167.26458	10	364490.3558	21638.18507
4	381864.7551	21724.20064	11	362231.4684	20244.92079
5	364638.2534	20276.15567	12	387582.197	20786.84354
6	381071.7713	20280.11255	13	362633.9047	20290.50009
7	354430.846	19394.79182	14	380035.7143	10423.71812
			15	368304.645	20349.47125

It was found that the total MTS produced quantity was 371770.8 kg where simulation results show that the total MTS produced quantity can vary between 402387.7 Kg, and 341153.9

kg. Therefore, actual quantity produced falls in confident interval. Confidence interval was constructed as follows

$$confidence\ interval = mean\ \pm (3 * standard\ deviation)$$

For MTO production, simulation results show that total MTO produced quantity falls between 33365.2 kg and 3546 kg. Therefore, actual MTO produced quantity falls in constructed confidence interval.

6.2.3 Raw Material Consumption

Considering raw material, it was found that raw material increased due to the increase in glass pull rate from 780 kg/hr to 800 kg/hr. However, total raw material without considering glass cullet decreased as culet ratio increased from 27.5% to 34.5%. Actual raw material consumption without considering glass cullet is 458596.5 kg, where the optimized raw material consumption is 457141.84 kg. The cost for raw material is increased by 857.1 EGP, and this is attributed to increase in feldspar consumption as shown in Table 6.5.

Table 6.5: Optimized Raw Material Consumption

	Actual consumption (Kg)	optimized consumption (kg)	cost per kg	Cost difference (EGP)
borax	3602.60	3602.83	5.05	1.2
dolomite	61245.40	60356.43	0.15	-133.35
feldspar	39204.8	41849.4	0.675	1785.1
carbon	72.25	71.84	22	-9
silica sand	241818.8	238813.77	0.15	-450.8
soda ash	101279.8	101139.48	2.25	-315.7
limestone	10236.32	10169.46	0.345	-23.1
sulphate	1136.5	1138.65	1.3	2.8
total	458596.47	457141.84		857.1

6.2.4 Crushing and Added Value Cost

This increase in cullet ratio increases the crushing cost of glass to make cullet as shown in table 6.6. The average crushing cost is 96085.5 EGP as shown in Table 6.6. As the cost of crushing equals to 2 EGP/kg, the total crushed quantity is 48042.8 kg that results in consuming 60.05 hr monthly to produce cullet. Therefore, the required crushing time is 2.1 hr per day. The actual crushing time was 2.1 hr/day. The actual total crushed quantity is 85436 kg, and that makes the actual crushed cost is 170872 EGP.

Table 6.6: Crushing Quantity and Cost

run	crushing cost (EGP)	Crushed quantity (kg)
1	93916.2	46958.1
2	85942.5	42971.3
3	81160.5	40580.3
4	81287.34	40643.7
5	101269.4	50634.7
6	82873.4	41436.7
7	113600	56800
8	120000	60000
9	100800	50400
10	101188	50594
11	105238	52619.1
12	76180	38090.1
13	104483.8	52241.9
14	96000	48000
15	97342.8	48671.4
total	96085.5	48042.8

Due to crushing, added value presented in raw material and energy is lost. Added value cost due to raw material and energy is summarized in table 6.7. The total lost added value is 140906.6 EGP.

Table 6.7: Added Value Cost Summary

run	Added value cost (EGP)	run	Added value cost (EGP)
1	137784.2	9	148275.6
2	125995.1	10	147407.7
3	119101.3	11	154220.5
4	118849.3	12	110946
5	148625.8	13	153245.2
6	121631.3	14	141089.8
7	167070	15	142787.7
8	176570		

6.2.5 Inventory Cost

Inventory holding costs for cullet is assumed to be the same of MTS product. Table 6.8 shows that MTS inventory cost has higher impact on inventory cost. The total inventory cost equals 70741.9 EGP on average.

Table 6.8: Inventory Costs

run	MTS inventory costs (EGP)	MTO inventory costs (EGP)	cullet inventory costs (EGP)	TOTAL INVENTORY COST (EGP)
1	40876.6	105.1	20357.3	61339.0
2	44951.0	101.8	20410.1	65462.9
3	54140.3	109.1	19333.0	73582.5
4	45454.8	95.1	19715.4	65265.4
5	79035.1	102.2	21548.2	100685.5
6	41309.4	98.1	20726.6	62134.1
7	37923.3	105.1	19764.0	57792.4
8	34836.9	52.8	19940.9	54830.6
9	31023.0	34.5	20340.9	51398.4
10	105730.2	110.0	20416.4	126256.6
11	69731.7	105.9	19497.5	89335.1
12	47780.5	108.7	19524.9	67414.1
13	40493.6	106.1	20304.4	60904.1
14	35448.0	56.4	20214.5	55719.0
15	49264.2	110.1	19634.2	69008.5
			average	70741.9

6.2.6 Energy Consumption

Energy consumption was decreased due to the fact that increasing cullet ratio of batch decreases the value of energy consumption as shown in table 6.9. It was found that energy consumption has decrease over the month period by 59793.65 m3. That leads to decrease in energy cost by 84309 EGP. Total energy cost reached 229872.8 EGP.

Table 19: Optimized Energy Consumption

DAY	Optimized Energy Consumption (m^3)	Actual Values (m^3)	Consumption Savings (m^3)	Energy Cost Savings (EGP)	Total Cost (EGP)
1	5818.5	6588.0	769.5	1085.0	8204.0
2	5563.7	7929.0	2365.3	3335.1	7844.8
3	6631.9	8211.0	1579.1	2226.5	9351.0
4	5571.5	8470.0	2898.5	4086.9	7855.8
5	5570.0	7601.0	2031.0	2863.7	7853.7
6	6282.9	7523.0	1240.1	1748.5	8858.9
7	6102.8	7091.0	988.2	1393.3	8605.0
8	5565.9	7025.0	1459.1	2057.3	7847.9
9	6029.7	6886.0	856.3	1207.4	8501.9
10	5562.0	7140.0	1578.0	2225.0	7842.4
11	5566.8	7954.0	2387.2	3366.0	7849.1
12	5562.0	8263.0	2701.0	3808.4	7842.4
13	5575.3	8262.0	2686.7	3788.3	7861.2
14	6232.1	8246.0	2013.9	2839.7	8787.2
15	5564.9	7665.0	2100.1	2961.1	7846.5
16	6082.6	7707.0	1624.4	2290.4	8576.4
17	5566.4	8395.0	2828.6	3988.3	7848.6
18	6084.1	8362.0	2277.9	3211.9	8578.5
19	5565.0	8427.0	2862.0	4035.4	7846.6
20	6107.2	8489.0	2381.8	3358.4	8611.1
21	6262.7	8440.0	2177.3	3070.0	8830.4
22	5575.1	8226.0	2650.9	3737.8	7860.9
23	6228.3	8258.0	2029.7	2861.9	8781.9
24	5562.1	8400.0	2837.9	4001.4	7842.6
25	5615.3	8350.0	2734.7	3855.9	7917.6
26	5668.9	8408.0	2739.1	3862.2	7993.1
27	6182.5	8336.0	2153.5	3036.5	8717.3
28	5330.2	8172.0	2841.8	4006.9	7515.6

6.2.7 Optimization Summary

Optimization results are shown in the following table 6.10.

Table 6.10: Optimization Results

S (kg)	15000
S (kg)	35000
z (kg)	6000
Z(kg)	15000
Average cullet ratio	34.5%
GPR (kg/hr)	800
Raw material cost (EGP)	325451.2
Energy costs (EGP)	229872.8
Inventory cost(EGP)	70741.9
Crushing cost (EGP)	96085.5
Lost added value (EGP)	140906.6
Total cost(EGP)	863058

Chapter Seven

Sensitivity Analysis

Pareto analysis was performed and it was found that more than 80 % of the cost depends on raw material, energy and added value cost as shown in table 7.1. Added value cost is the value of energy and raw material lost in crushing glass to make cullet. Therefore, raw material and energy are the most dominant factors for total costs.

Table 7.1: Pareto Analysis for Cost

	cost (EGP)	Percentage (%)	Cumulative Percentage (%)
Raw material cost	325451.1581	38%	38%
Energy costs	229872.7958	27%	64%
Added value cost	140906.6341	16%	81%
Inventory cost	96085.49274	11%	92%
Crushing cost	70741.87643	8%	100%

7.1 Raw Material Costs

Pareto analysis is performed on raw material. It was found that soda ash and sand silica are dominant raw materials in changing raw material costs as shown in table 7.2.

Table 7.2: Raw Material Cost Pareto Analysis

	total cost (EGP)	percentage	cumulative percentage
soda ash	225755.4284	70%	70%
silica sand	35536.85434	11%	81%
feldspar	28022.13906	8%	90%
borax	18049.39416	6%	95%
dolomite	8981.254098	3%	98%
limestone	3480.607404	1%	99%
carbon	1568.756213	0%	100%
sulphate	1468.45997	0%	100%

Table 7.3 shows raw material cost change from year 2013 to 2017 [30].

Table 7.3: Raw Material Costs

Raw Material	cost / ton (EGP)				
	2013	2014	2015	2016	2017
Silica Sand	130	150	165	150	170
Soda Ash	1728	2250	2300	2250	6000
Dolomite	172	240	150	150	560
K-feldspar	522	675	675	675	675
Borax	3991	5050	5200	5050	6950
Limestone	240	345	345	345	458.6
Sodium Sulphate	1095	1300	1300	1300	8500
Carbon	22000	22000	22000	30000	22000

7.1.1 Raw Material Cost Forecast

Raw material costs increased significantly in year 2017 due to economic regulations made by the government. From year 2013 till year 2017, Raw material prices show increasing trend. For example, sand silica price increases from 2013 till 2015 and decreased in 2016 and then increased in 2017 as shown in Fig. 7.1. These data are based on actual data available at the glass tube factory [30].

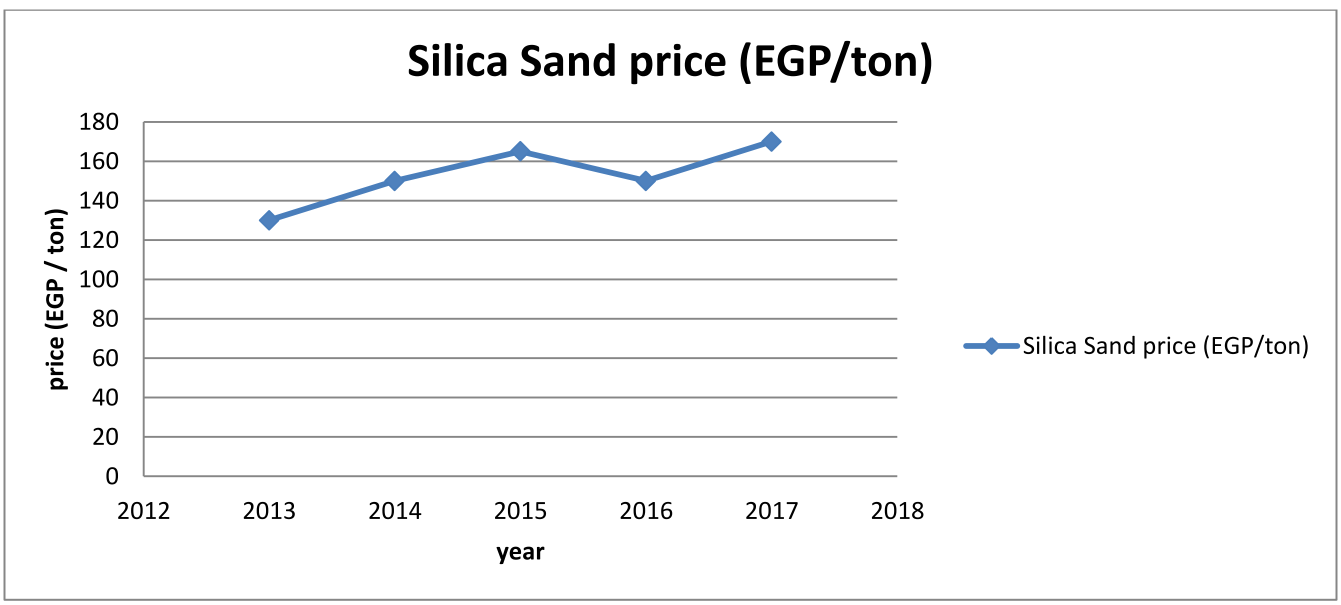

Figure 7.1: Silica Sand Prices from 2013 to 2017

Also, soda ash prices increased drastically through year 2017 where trend show steady prices before 2016 as shown in Fig. 7.2 [30].

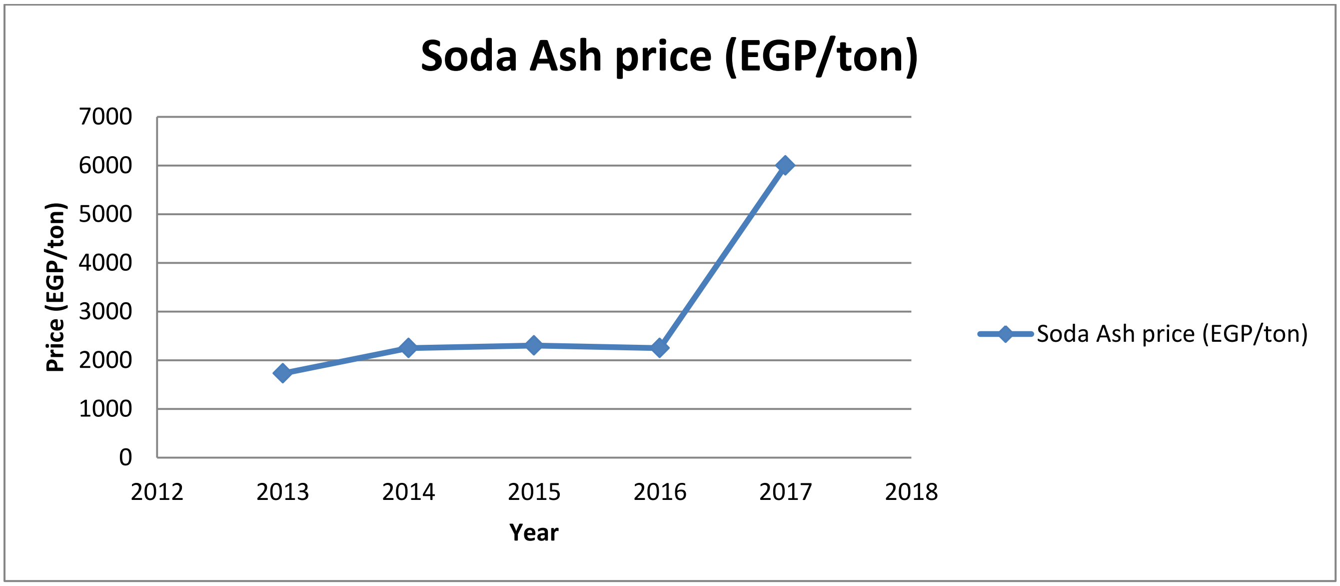

Figure 7.2: Soda Ash Price from 2013 to 2017

7.1.1.1 Silica Sand Price Forecast

Silica sand prices forecast was done using different methods based on historical data as shown in table 7.4.

Table 7.4: Silica Sand Price Forecast Using Different Methods

year	Silica Sand price (EGP/ton)	moving average (2)	moving average (3)	exponential smoothing (0.9)	exponential smoothing (0.8)	exponential smoothing (0.7)	regression
2013	130	--	--	--	--	--	137
2014	150	140	--	130	130	130	145
2015	165	157.5	148.333	132	134	136	153
2016	150	157.5	155	135.3	140.2	144.7	161
2017	170	160	161.667	136.77	142.16	146.29	169

It was found that regression has lowest mean sum of error as shown in table 7.5. Therefore, regression is best method to deploy to get forecast at 2018.

Table 7.5: MSE of Different Forecasting Methods

Method	MSE
moving average (2)	78.125
moving average (3)	93.05556
exponential smoothing (0.9)	702.3307
exponential smoothing (0.8)	6162.126
exponential smoothing (0.7)	457.8135
regression	72.75

Silica sand price will be 177 EGP/ton as per developed linear regression forecast for 2018.

7.1.1.2 Soda Ash Cost Forecast

Different forecasting methods are used to determine new prices as shown in table 25.

Table 7.6: Soda Ash Price Forecasting Using Different Methods

year	Soda ash price (EGP/ton)	moving average (2)	moving average (3)	exponential smoothing (0.9)	exponential smoothing (0.8)	exponential smoothing (0.7)	regressio n
2013	1728	--	--	--	--	--	1196.8
2014	2250	1989	--	1728	1728	1728	2051.2
2015	2300	2275	2092.667	1780.2	1832.4	1884.6	2905.6
2016	2250	2275	2266.667	1832.18	1925.92	2009.22	3760
2017	6000	4125	3516.667	1873.962	1990.736	2081.454	4614.4

It was found that forecast error is very high as shown in table 7.7.

Table 7.7: MSE for Different Forecasting Methods

Method	MSE
moving average (2)	896249
moving average (3)	1552552
exponential smoothing (0.9)	4435360
exponential smoothing (0.8)	7886183
exponential smoothing (0.7)	3964505
regression	1151565

Industry experts expect the increase of soda ash prices in 2018 by 20%, so soda ash price will be 7200 EGP/ton.

7.1.2 Raw Material Optimization results

Optimization was run for expected cost for new raw material prices. The results show increase in cullet ratio that the average cullet ratio used 39.9% as shown in table 7.8.

Table 7.8: Cullet ratio for raw material cost change

Day	cullet ratio (MG)	Day	cullet ratio (MG)
1	0.400	15	0.400
2	0.400	16	0.400
3	0.400	17	0.400
4	0.382	18	0.400
5	0.400	19	0.400
6	0.400	20	0.400
7	0.400	21	0.400
8	0.400	22	0.400
9	0.400	23	0.400
10	0.400	24	0.400
11	0.400	25	0.400
12	0.400	26	0.400
13	0.400	27	0.400
14	0.400	28	0.400

Glass pull rate is set to 800 kg/hr. it was found that production policy limits weren't changed as shown in table 7.9.

Table 7.9: New production and policy Parameters for New Raw Material Prices

	New values
upper MTS limit (S)	35000
lower MTS limit (s)	15000
Upper Culler limit (Z)	15000
lower Cullet limit (z)	6000
Average GPR (kg/hr)	800
Average Cullet Ratio	0.399
Optimized Cost	1318396

It was found that glass pull rate didn't change due to increase in raw material prices as shown in table 7.9. On the other hand, cullet ratio increased from 34.5% to 39.9%. Increasing cullet ratio decreases the amount of raw material required to be 430333.86 kg and decrease energy consumption used and it became 156309.97 m^3. Accordingly, energy cost decreases to be 220397.1 EGP, but raw material cost increases due to increase in prices and became 781922.629 EGP. Added value cost didn't change as increase in raw material cost is balanced by the decrease in energy cost. Crushing cost increased as there is increase in cullet ratio used in the batch which required increase in crushing activity. The total required crushing quantity as a result for increase in raw material prices is 54304.93 kg. Inventory cost decreased as the average inventory level for MTS product has decreased to be 22898.39 kg with standard deviation of 4261.148 kg. Also, the average inventory level for cullet inventory is 16234.17 kg with standard deviation of 8122.413 kg. Besides, the average total produced quantity for MTO product is 16234.17 kg with standard deviation of 8112.413 kg.

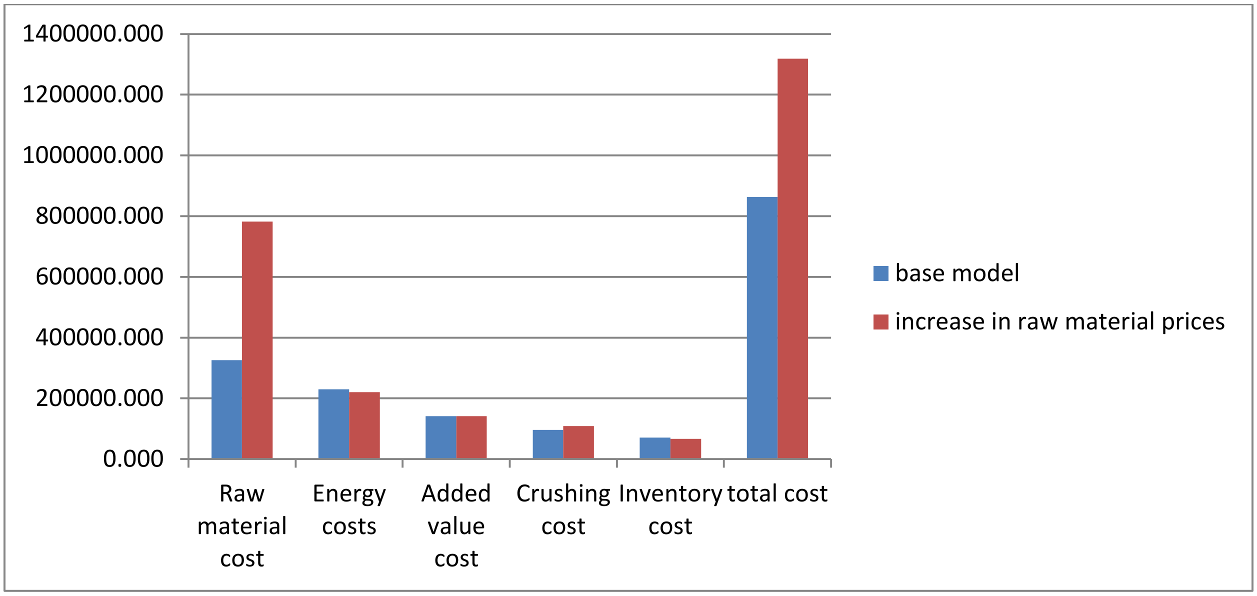

Figure 7.3: Comparison between Base Model and Increase in Raw Material Prices

In conclusion, increase in raw material prices cause increase in cullet ratio, increase in raw material cost and crushing cost, and decrease in energy cost and inventory cost. This increase didn't have impact on policy parameter, GPR or added value cost.

7.2 Energy Costs

Natural gas prices increased through years due to economic regulation in Egypt. In 2014, natural gas price reached 1.32 EGP/m^3 where it was 1.41 EGP/m^3 for 2015 and 2016 [30]. In 2017, natural gas price increased drastically to reach 3.2 EGP/m^3 as shown in Fig. 7.4.

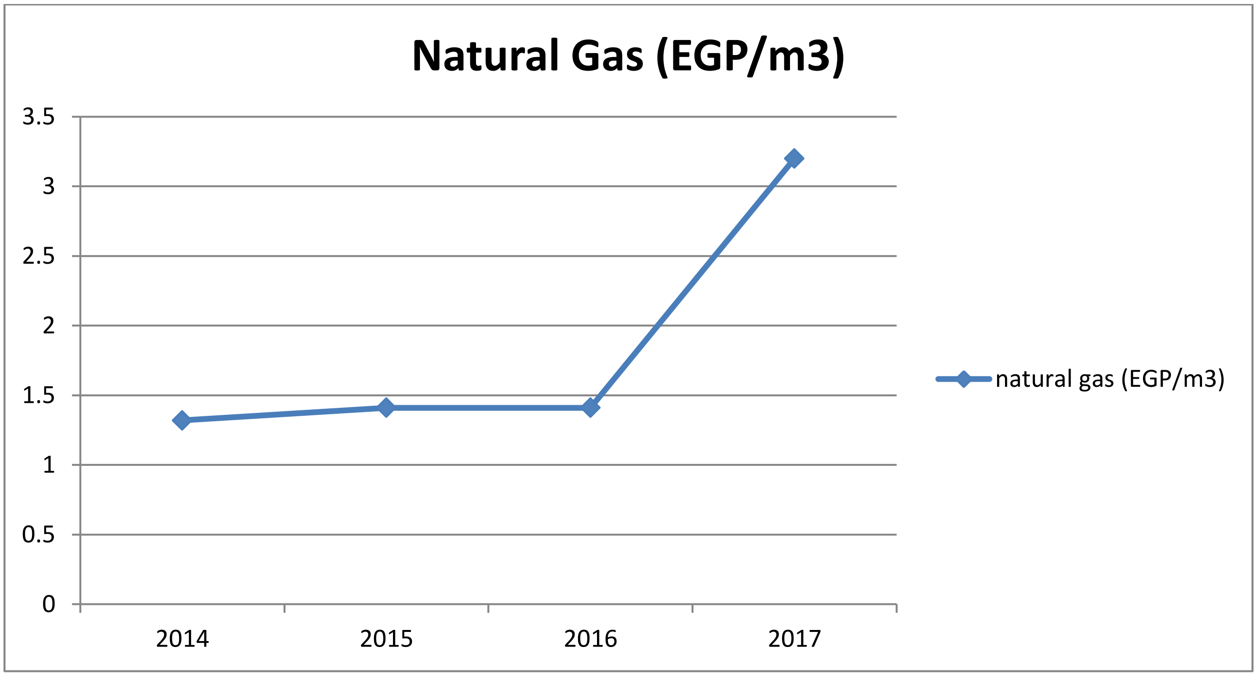

Figure 7.4: Natural Gas Prices from 2014 to 2017

7.2.1 Energy Price Forecast

Forecast was performed using different methods as shown in table 7.10.

Table 7.10: Natural Gas Forecasting using Different Methods

	natural gas (EGP/m3)	moving average (2)	moving average (3)	exponential smoothing (0.9)	exponential smoothing (0.8)	regressio n
2014	1.32	--	--	--	--	0.989
2015	1.41	1.365	--	1.32	1.32	1.553
2016	1.41	1.41	1.38	1.329	1.338	2.117
2017	3.2	2.305	2.01	1.3371	1.352	2.681

It was found that mean sum of squares using linear regression is the least one as shown in table 7.11.

Table 7.11: MSE of Different Forecasting Methods

moving average (2)	0.201
moving average (3)	0.356
exponential smoothing (0.9)	0.871
exponential smoothing (0.8)	0.856
regression	0.157

Using linear regression, the expected natural gas price for 2018 is 3.245 EGP/m^3.

7.2.2 Energy Optimization Results

Optimum solution changed with changing natural gas prices. Optimum cullet ratio is 38% for expected new price. Optimum glass pull remains 800 kg/hr. production parameters are as shown in table 7.12. It is clear that parameters changed due to change in energy prices.

Table 7.12: Production and Policy Parameters Summary for New Energy Prices

	New values
upper MTS limit (S)	35000
lower MTS limit (s)	9024
Upper Culler limit (Z)	15000
lower Cullet limit (z)	4335
Average GPR (kg/hr)	800
Average Cullet Ratio	0.38
Optimized Cost	1197621

Raw material cost decreased due to increase in cullet ratio which means less raw material quantity is used for glass batch. Inventory cost decreased due to decrease in average inventory level for MTS product and Cullet. Average inventory level for MTS product is 23040.4 kg with standard deviation of 4179.244 kg, and the average inventory level for glass cullet is 9074.635 kg with standard deviation 790.616 kg. Crushing cost increased slightly due to increase in cullet ratio required for making batch. The average total crushed quantity is 50347.435 kg. Besides, lost added value increased due to increase in energy prices. Energy cost increases due increase in the prices of energy therefore total cost increased as shown in Fig. 7.5.

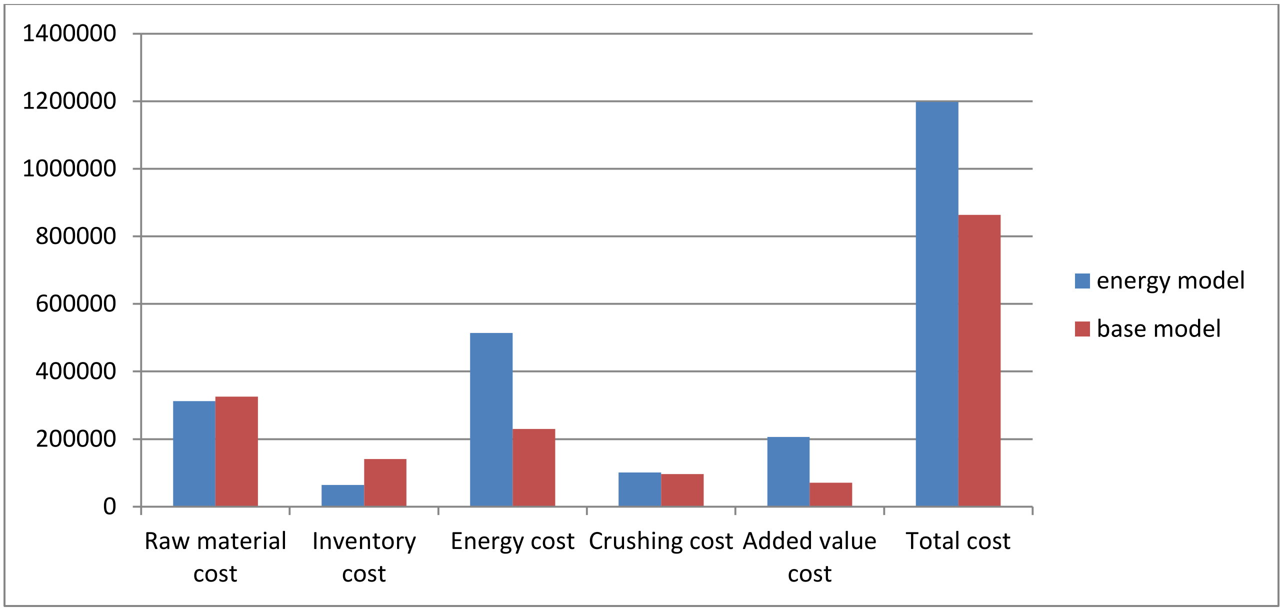

Figure 7.5: Comparison Between Base Model and New Energy Prices

In conclusion, increase in energy prices will increase cullet ratio, energy cost, crushing cost and added value cost. However, it will reduce raw material cost and inventory cost. In total, the total cost will increase. For policy parameters, upper control limits for producing MTS product and cullet will not change as a result to increase in energy prices where the lower control limits for both decreased.

Chapter Eight

Conclusion and Recommendations

This thesis developed an optimized production policy for MTS/MTO hybrid production system for continuous flow production of glass tube. Integrating MTS and MTO strategies will make full use of current capacity of glass manufacturing factory. Defining production rate and cullet ratio is important for better planning for glass manufacturing.

The developed production Policy is shown to be effective in minimizing total cost by controlling glass pull rate, cullet ratio, MTS production limits (S, s) and cullet production limits (Z, z). Through simulation based optimization, variability of demand, product quality was considered to find near -optimum solution to minimize total cost. This research considered costs for raw material, energy, inventory, crushing, and added value cost for crushing.

Discrete event simulation model was developed to represent production, order fulfillment and decision made in the factory using Rockwell Arena software. Continuous flow was discretized as the molten glass level inside the furnace is almost constant. The smaller the time interval is, the more accurate the discretization is. The number of replications and the warm-up period are checked to assure the precision of the results. The model was validated trough different cases. Simulation-based optimization using OptQuest tool in Arena was applied to optimize the parameters of the proposed policy. Proposed production policy is easy tool to aid decision making process as it can minimize total cost by controlling six variables which are production parameters and policy parameters.

Developed simulation model has several advantages. The model is divided into three modules, and this division adds great flexibility for users to change in the policy parameters easily. Simulation model will save a lot of money and effort associated with conducting experiments in factories. Besides, simulation model can have animations which make communication and exchanging ideas more effectively. Simulation model can handle uncertainty in customer demand and order fulfillment.

Results showed that the increase in raw material prices will lead to change in production parameters; however, policy parameter will not change. Therefore, there will be increase in total cost, raw material cost, crushing cost and decrease in energy cost. Increase in natural gas prices will have effect on production and policy parameters.

There are different issues can be taken into consideration for future research:

- Having multiple delivery times to fulfill MTO order.
- Price discounts according to product demand.
- Expanding the model to consider more than one customer for MTO products.
- Including penalty cost when the delivery time for MTO order exceeds predefined dates.

Chapter Nine
References

[1]Ministry of Electricity and and Renewable Energy, “Annual Report,” Arab Republic of Egypt, rep., 2014-2015.

[2]International Monetary Fund, "IMF Executive Board Approves US$12 billion Extended Arrangement under the Extended Fund Facility for Egypt", 2016.

[3] H. Tsubone and Y. Kobayashi, “Production seat booking system for the combination of make-to-order and make-to-stock products,” *Production Planning & Control*, vol. 13, no. 4, pp. 394–400, 2002.

[4] C. Soman, D. V. Donk, and G. Gaalman, “Capacitated planning and scheduling for combined make-to-order and make-to-stock production in the food industry: An illustrative case study,” *International Journal of Production Economics*, vol. 108, no. 1-2, pp. 191–199, 2006.

[5]M. Kalantari, M. Rabbani, and M. Ebadian, “A decision support system for order acceptance/rejection in hybrid MTS/MTO production systems,” *Applied Mathematical Modelling*, vol. 35, no. 3, pp. 1363–1377, 2010.

[6] Z. G. Zhang, I. Kim, M. Springer, G. (G. Cai, and Y. Yu, “Dynamic pooling of make-to-stock and make-to-order operations,” *International Journal of Production Economics*, vol. 144, no. 1, pp. 44–56, 2013.

[7] X. Chen, A. H. Tai, and Y. Yang, “Optimal production and pricing policies in a combined make-to-order/make-to-stock system,” *International Journal of Production Research*, vol. 52, no. 23, pp. 7027–7045, Nov. 2014.

[8] M. Khakdaman, K. Y. Wong, B. Zohoori, M. K. Tiwari, and R. Merkert, “Tactical production planning in a hybrid Make-to-Stock–Make-to-Order environment under supply, process and demand uncertainties: a robust optimisation model,” *International Journal of Production Research*, vol. 53, no. 5, pp. 1358–1386, 2014.

[9] M. Pidd, “Simulating Automated Food Plants,” *The Journal of the Operational Research Society*, vol. 38, no. 8, pp. 683–692, 1987.

[10] M. Fioroni, L. Franzese, E. Harano, B. Costhek, J. Mendes, J. Cuzzuol, J. D. S. Lima, R. Santos, R. Coelho, A. Silva, and O. Kimsr, “Simulation Based Decision for Steelmaking Operations Challenges,” *Proceedings of the Winter Simulation Conference, 2005.*, pp. 2657–2662, 2005.

[11] B. Sharda and S. J. Bury, “A discrete event simulation model for reliability modeling of a chemical plant,” *2008 Winter Simulation Conference*, pp. 1736–1740, 2008.

[12] B. C. Park, E. S. Park, B. K. Choi, B. H. Kim, and J. H. Lee, “Simulation based planning and scheduling system for TFT-LCD Fab,” *2008 Winter Simulation Conference*, 2008.

[13] C.-Y. Liong, S. H. A. Hamid, and I. M. Ibrahim, “Improving the performance of chili sauce manufacturing process using simulation approach,” *American Institute of Physics*, 2016.

[14] P. Lefrancois, P. L'esperance, and M. Turmel, “Batching annealing operations to optimize queueing times and furnace efficiency: a simulation model,” *1991 Winter Simulation Conference Proceedings.*, pp. 270–279, 1991.

[15] R. Semenzato, S. Lozano, and R. Valero, “A Discrete Event Simulation of Sugar Cane Harvesting Operations,” *Journal of the Operational Research Society*, vol. 46, no. 9, pp. 1073–1078, Sep. 1995.

[16] E. F. Watson, “An Application of Discrete-Event Simulation for Batch-Process Chemical-Plant Design,” *Interfaces*, vol. 27, no. 6, pp. 35–50, 1997.

[17] M. M. Arer and N. E. Ozdemirel, “Simulation of capacity expansion and sequencing alternatives for a sheet metal producer,” *Journal of the Operational Research Society*, vol. 50, no. 6, pp. 596–607, 1999.

[18] P. M. Barton and A. M. Tobias, “Discrete Quantity Approach to Continuous Simulation Modelling,” *The Journal of the Operational Research Society*, vol. 51, no. 4, p. 485, 2000.

[19] S. Kuo, E. Chen, P. Selikson, and Y. Lee, “Modeling continuous flow with discrete-event simulation,” *Proceeding of the 2001 Winter Simulation Conference.* , pp. 1099–1103.

[20] S. Schultz, “A Glass Float Line Simulation: Modeling Methodology and Applications,” *Proceedings of the 2006 Winter Simulation Conference*, pp. 688–693, 2006.

[21] M. M. Fioroni, J. Furia, P. Tecnologia, and C. Paulista, “Simulation of continuous behavior using discrete tools: Ore conveyor transport,” *2007 Winter Simulation Conference*, pp. 1655–1662, 2007.

[22] S. H. Melouk, N. K. Freeman, D. Miller, and M. Dunning, “Simulation optimization-based decision support tool for steel manufacturing,” *International Journal of Production Economics*, vol. 141, no. 1, pp. 269–276, 2013.

[23] F. Bursi, A. Ferrara, A. Grassi, and C. Ronzoni, “Simulating Continuous Time Production Flows in Food Industry by Means of Discrete Event Simulation,” *International Journal of Food Engineering*, vol. 11, no. 1, pp. 139–150, Jan. 2015.

[24] G. Asbjörnsson, M. Bengtsson, E. Hulthén, and M. Evertsson, “Modelling of discrete downtime in continuous crushing operation,” *Minerals Engineering*, vol. 98, pp. 22–29, 2016.

[25]Almada-Lobo, Bernardo, José F. Oliveira, and Maria Antónia Carravilla. "Production planning and scheduling in the glass container industry: A VNS approach." *International Journal of Production Economics* 114.1 (2008): 363-375.

[26] M. Faragallah and A. A. Elimam, “Optimization of Integrated Batch Mixing and Continuous Flow in Glass Tube & Fluorescent Lamp,” *Proceedings of the 6th International Conference on Operations Research and Enterprise Systems*, 2017.

[27] *Handy Manual – Output of a seminar on Energy conservation in Glass Industry*, united nations industrial development organization (UNIDO) and Ministry of International Trade and Industry (MITI) Japan, 1993.

[28] K. Hoad, S. Robinson, and R. Davies, “Automated selection of the number of replications for a discrete-event simulation,” *Journal of the Operational Research Society*, vol. 61, no. 11, pp. 1632–1644, 2009.

[29] OptQuest® for Arena, USER’S GUIDE, Rockwell Automation, PUBLICATION ARENAO-UM001H-EN-P, USA, January 2012 .

[30] Data was collected by contacting production manager at Al-araby glass factory.

Appendices

APPENDIX A

Table A.1 Number of Replications

replication number	MTS inventory mean	MTS half width	MTS upper CI	MTS lower CI	MTO inventory mean	MTO half width
3	26535.54	778.3	27313.84	25757.24	43.6596	53.71
4	26544.17	407.9	26952.07	26136.27	40.4197	29.92
5	26558.24	278.39	26836.63	26279.85	36.6948	22.71
6	26678.48	374.03	27052.51	26304.45	36.4339	17.19
7	26565.48	408.64	26974.12	26156.84	35.7782	13.92
8	26607.4	356.11	26963.51	26251.29	33.1147	13.24
9	26583.85	311.01	26894.86	26272.84	42.0736	23.59
10	26553.33	281.46	26834.79	26271.87	40.7492	20.91
11	26571.94	254.16	26826.1	26317.78	38.4823	19.3
12	26559.58	230.82	26790.4	26328.76	36.9554	17.73
13	26605.79	233.07	26838.86	26372.72	37.3872	16.17
14	26592.31	215.87	26808.18	26376.44	35.7277	15.27
15	26585.19	200.15	26785.34	26385.04	33.7994	14.71
16	26607.1	191.77	26798.87	26415.33	31.9983	14.2
17	26605.26	179.25	26784.51	26426.01	30.6574	13.57
18	26616.03	169.73	26785.76	26446.3	29.5579	12.94
19	26612.76	160.1	26772.86	26452.66	29.3735	12.2
20	26591.19	157.82	26749.01	26433.37	29.8249	11.57
21	26590.86	149.61	26740.47	26441.25	28.9427	11.12
22	26562.6	153.91	26716.51	26408.69	28.8422	10.57
23	26558.82	146.85	26705.67	26411.97	28.084	10.19
24	26527.75	154.29	26682.04	26373.46	27.3011	9.87
25	26572.24	173.87	26746.11	26398.37	26.3796	9.63
26	26586.08	169.14	26755.22	26416.94	25.7847	9.32
27	26564.61	168.33	26732.94	26396.28	26.6373	9.12
28	26574.06	163.06	26737.12	26411	28.1973	9.34
29	26622.38	185.6	26807.98	26436.78	27.7734	9.03
30	26635.87	181.15	26817.02	26454.72	28.244	8.77

APPENDIX B

Table B.1 Warm up period

time	Rep. 1	Rep. 2	Rep. 3	Rep. 4	Rep. 5	Rep. 6	Rep. 7	Rep. 8	Rep.9
0	0	0	0	0	0	0	0	0	0
1	14685	15353	14685	14685	4538	4538	12683	13350	15353
2	13883	5738	19890	17220	7740	7740	14550	14550	19223
3	17085	8273	21758	20423	12278	9608	15750	18420	23093
4	22958	10140	24960	24293	12810	10808	16950	20955	25628
5	24825	11340	29498	28163	14678	12675	20153	22155	27495
6	24690	15878	28285	28028	17213	17880	23355	24690	28028
7	27893	17745	28150	28560	17745	17745	23888	25223	28560
8	30428	18272	28015	30287	18272	18272	26423	28425	28952
9	28952	18272	27880	28285	18137	18137	28290	28952	29620
10	28285	18137	29080	28150	18002	18002	28823	30287	28285
11	28150	18272	28285	28015	17867	17867	28952	28952	28150
12	28682	18137	28150	27880	17732	17732	28285	28285	28015
13	28952	18002	32020	28412	18265	18272	28150	28150	27880
14	28285	17867	34292	32950	18272	18137	28015	27347	31082
15	31487	18272	34292	33625	18272	18272	29882	28547	33625
16	34960	18272	34292	34960	18272	18272	30955	34292	33625
17	33625	18272	34292	34292	18272	18272	28285	34292	34960
18	34960	18272	34292	33625	18272	18272	28150	34292	33625
19	33625	18272	34292	34960	18272	18272	32687	34292	34960
20	34960	18272	34292	34292	18272	18272	34292	34292	33625
21	33625	18272	34292	34292	18272	18272	34292	34292	34960
22	34960	18272	34292	34292	18272	18272	33625	34292	33625
23	34292	18272	34292	34292	18272	18272	34960	34292	34960
24	33625	18272	34292	34292	18272	18272	33625	34292	34292
25	34960	18272	34292	34292	18272	18272	34960	34292	34292
26	34292	18272	34292	34292	18272	18272	33625	34292	34292
27	34292	18272	34292	34292	18272	18272	34960	34292	34292
28	34292	18272	34292	34292	18272	18272	34292	34292	34292
29	34292	18272	34292	34292	18272	18272	33625	34292	34292
30	34292	18272	34292	34292	18272	18272	34960	34292	34292
31	34292	18272	34292	34292	18272	18272	34292	34292	34292
32	34292	18272	34292	34292	18272	18272	34292	34292	34292
33	34292	18272	34292	34292	18272	18272	34292	34292	34292
34	34292	18272	34292	34292	18272	18272	34292	34292	34292
35	34292	18272	34292	34292	18272	18272	34292	34292	34292
36	34292	18272	34292	34292	18272	18272	34292	34292	34292

37	34292	18272	34292	34292	18272	18272	34292	34292	34292
38	34292	18272	34292	34292	18272	18272	34292	34292	34292
39	34292	18272	34292	34292	18272	18272	34292	34292	34292
40	34292	18272	34292	34292	18272	18272	34292	34292	34292
41	34292	18272	34292	34292	18272	18272	34292	34292	34292
42	34292	18272	34292	34292	18272	18272	34292	34292	34292

APPENDIX C

4:18:59PM **Category Overview** March 2, 2018

Values Across All Replications

Unnamed Project

Replications: 15 Time Units: Hours

User Specified

Time Persistent

Variable	Average	Half Width	Minimum Average	Maximum Average	Minimum Value	Maximum Value
batch pull ratio	1.2000	0.00	1.2000	1.2000	1.2000	1.2000
borax consumption	3134.40	0.54	3132.58	3136.36	2668.18	3627.13
carbon consumption	62.5394	0.35	61.4924	63.5800	52.5000	73.2225
cullet inventory	9880.86	199.97	9279.83	10410.79	3974.95	18106.96
Cullet overstock	41.0282	4.42	24.5743	56.9003	21.0000	59.0000
cullet production hours	104.11	5.24	91.7381	121.99	75.0000	133.00
cullet stockout	21.4232	1.71	16.2363	26.4514	14.0000	30.0000
cut losses percentage	0.1000	0.00	0.1000	0.1000	0.1000	0.1000
decision arrival time	583.77	19.17	546.87	676.67	463.00	757.00
defect rate	0.00	0.00	0.00	0.00	0.00	0.00
dolomite consumption	52514.10	13.69	52441.31	52546.33	44661.09	60770.93
energy consumption	146837.47	13.70	146797.37	146873.78	125269.17	169290.74
energy cost per kg	1.4100	0.00	1.4100	1.4100	1.4100	1.4100
energy costs	207040.63	19.32	206984.29	207092.03	176629.53	238699.95
GPR1	800.00	0.00	800.00	800.00	800.00	800.00
GPR2	800.00	0.00	800.00	800.00	800.00	800.00
GPR3	800.00	0.00	800.00	800.00	800.00	800.00
holding cost per unit	0.00046000	0.00	0.00046000	0.00046000	0.00046000	0.00046000
limestone consumption	8845.64	14.40	8800.96	8889.74	7486.53	10287.87
lower cullet limit	4765.00	0.00	4765.00	4765.00	4765.00	4765.00
lower MTS limit	15000.00	0.00	15000.00	15000.00	15000.00	15000.00
MG1	0.3021	0.00	0.3021	0.3021	0.2510	0.4000
MG2	0.00	0.00	0.00	0.00	0.00	0.00
MG3	0.00	0.00	0.00	0.00	0.00	0.00
MTO crushed	492.28	306.28	0.00	1815.64	0.00	1815.64
MTO delivery	0.6667	0.27	0.00	1.0000	0.00	1.0000
MTO delivery time	0.00	0.00	0.00	0.00	0.00	0.00
MTO demand	19806.70	0.00	19806.70	19806.70	19806.70	19806.70
MTO invenotry	2831.73	3,010.43	0.00	18535.63	0.00	19011.66
MTO inventory cost	15.2766	16.27	0.00	100.25	0.00	102.89
MTO price per unit	1000.00	0.00	1000.00	1000.00	1000.00	1000.00
MTO produced	16526.47	3,885.77	1840.83	22307.11	0.00	22307.11
MTO production hours	23.7123	5.58	2.6786	32.0000	0.00	32.0000
MTO revenue	13204467	5,352,653.68	0.00	19806700	0.00	19806700
MTS arrival time	25.0000	0.00	25.0000	25.0000	21.0000	29.0000
MTS demand	13471.12	900.74	10712.50	16127.40	186.52	18695.97
MTS inventory	36878.36	11,523.67	19413.55	80890.62	3391.87	93918.80

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Figure C.1: Simulation Output Report